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Original Article

Toward the Implementation of Digital Twin for Assessing the Ergonomic Aspects on Manufacturing Process

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Abstract *- Repetitive motion, awkward movement, and other factors can contribute to Musculoskeletal Disorders (MSDs) among operators. According to the Indonesian Health Ministry, approximately 11.9% of Indonesians have been diagnosed with musculoskeletal diseases and roughly 24.7% exhibit symptoms of MSDs. One of the divisions that have a similar problem is the shipping division of a shoe manufacturer, PT. XYZ, which requires a bent position during their shift. This study aims to address the prevalence and symptoms of MSDs in the operators' posture, such as picking, putting and organizing the shoes. By employing a digital twin approach using Tecnomatix Jack software, the real-time conditions of operators were simulated to assess ergonomic aspects using the OWAS, LBA and NIOSH methods. To support the analysis, the Nordic Musculoskeletal Questionnaire was administered by collecting data directly from 35 operators. As input data for the ergonomic assessment, eight movements were studied to demonstrate a major hazard to the operator's musculoskeletal system due to the movements. All of the movements in the real-time situation get 3 as the OWAS scores, 1284-1743 N for the LBA score, and 0-0.220 for LI in the NIOSH assessment. Both simulation results and direct interviews underscore the importance of implementing improvements, such as workplace design, integration of additional tools, and motion studies. As part of the proposed improvement, the implementation of ergonomic tables and workspace relayout was undertaken.*

Keywords *- Digital twin, Ergonomic tables, Musculoskeletal disorder, Tecnomatix jack, Relayout.*

1. Introduction

Repetitive motion, unnatural movement and other issues can drive the operators to suffer from musculoskeletal disorders (MSDs). MSDs can affect the nerves, tendons, muscles and supporting structures of the body. This kind of disorder can be called an ergonomic injury and illness [1]. World Health Organization reported that approximately 1.71 billion people worldwide have musculoskeletal conditions in 2019 [2]. Furthermore, the Indonesian Health Ministry stated that over 7.30% of Indonesians within the age of more than 15 years old is diagnosed with musculoskeletal disorder in term of joint problems. National Basic Health Research 2018 declared that among 7.6% to 37% of Indonesians have low back pain problems [3], and approximately 11.9% of Indonesians have been diagnosed with the prevalence of musculoskeletal diseases, and roughly 24.7% have the symptoms of MSDs. Based on the detailed movements, a study proved that repetitive motion, labour-intensive and standing position leads to high-risk MSDs and body pain in the area of lower back, thigh and foot [4]. Working in a standing position has some effects. Particularly, the result of standing position while working is musculoskeletal injuries such as on the part of the right hand, lower back, left wrist, right shoulder, left biceps, and right wrist of the workers [5]. Ergonomics refers to the design and arrangement of tools, equipment, and workspaces to improve efficiency, comfort, and safety while reducing physical strain and potential health issues like lumbar or joint problems in the upper limbs [6]. An inappropriate layout can drive less efficiency on the production line, whether it can cause a high level of anxiety or can be a serious threat to long-term effects. The advanced facility layout decreases comprehensive risk level and rapid upper limb assessment score; this also has an increase in efficiency and productivity compared to the existing design [7]. In terms of evaluating proper layout, it needs some trial and error. Nowadays, advanced technology, such as digital twins, is applied in the Industry 4.0 approach. A digital twin is described by many meanings; thus, it can be simply defined as the uncomplicated integration of data between real-time and

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virtual machines in one and the other direction [8]. The simulation will be generated in real/near-real time or as post-process. Based on the research by Wagner et al. [9], simulations with a digital production twin with an integrated digital product twin allow early estimations even before the actual ramp-up of the product. Tecnomatix Jack software can assist in building the trial and error easier by building and simulating the model, creating the production processes and building the logistic system. Based on research, Tecnomatix software contains more features rather than others, is easy to use, user-friendly and has a commendable interface. These advantages help new users to build the simulation more easily. From the industrial point of view, digital twin applications that are integrated into the factory are able to improve production time effectiveness, reduce cost, and build the system faster, more flexible and more efficiently [10]. In 2020, research was conducted on the production line to assess the ergonomic aspects such as OWAS, NIOSH, OCRA and force by using digital twin and initiating the changing the workstation layout and modified angle screwdriver [11]. In the pursuit of enhancing factory efficiency and operators' awareness of ergonomic aspects, PT XYZ, a shoe factory, diligently engages in continuous innovation. Among these initiatives are the implementation of a pilot line integrated with automation tools, the development of smart tools and jigs, the organization of kaizen events, and various other measures. Regrettably, despite these efforts, PT. XYZ frequently fails to address preexisting ergonomic concerns adequately. This study is concerned with the process in the sample room. There are six steps involved, including cutting, preparation, processing, stitching, assembly, and finishing. After the completion of all these processes, the shoes are transferred to the packing room and managed by the shipping division. One of the steps in the shipping process is the putting shoes into boxes. This task is predominantly performed by operators in a standing position to enhance their mobility. Regrettably, the operators frequently neglect the potential implications for their future musculoskeletal well-being while carrying out their duties. Particularly in the shipping division, the process of inputting shoes into boxes is not executed in the appropriate manner. Figure 1 and Figure 2 provide visual representations of the operators' working flow and the posture adopted by an operator while putting shoes into the box, respectively.

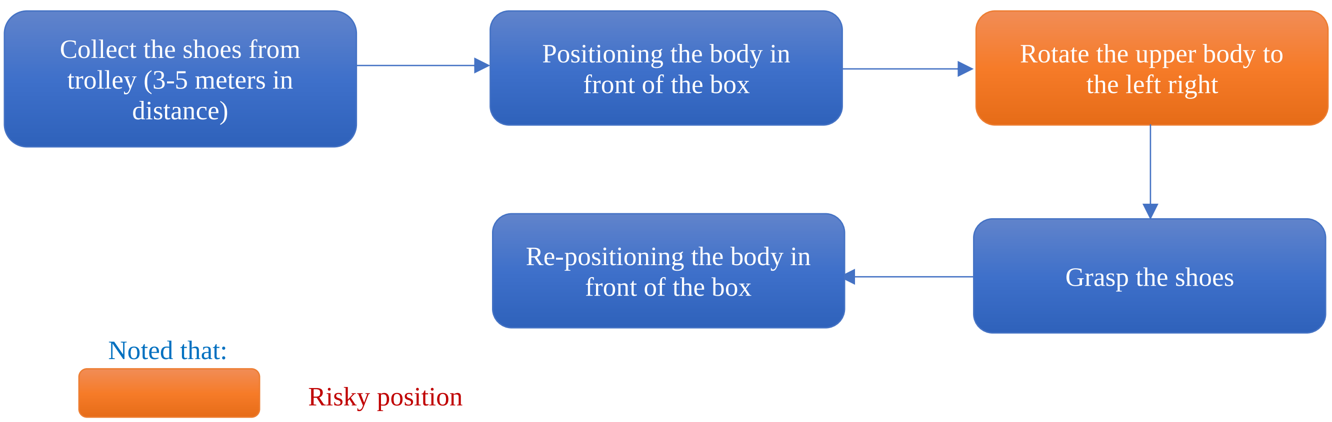


Fig. 1 Operators' working flow

Fig. 2 Operator while putting shoes into the box

To optimize the outcomes and minimize the costs of the process in the sample room, a scientific investigation can be undertaken through the implementation of a digital twin simulation model. An additional critical objective is to mitigate the impact of non-ergonomic motions on the production line. Employing data simulation tools, facilitating real-time or near-real-time simulations, as well as post-process simulations, can achieve comprehensive insights to optimize the system. The objective of this study is to enhance the ergonomic posture of sample room operators by employing a digital twin to simulate improvement without necessitating any alterations of MSDs in various occupational settings. Also, helps decision-makers make informed choices regarding layout design and understand the potential positive outcomes, including increased productivity, improved efficiency, cost reduction, enhanced employee well-being, and long-term sustainability.

Based on the previous studies that utilized digital twin technology, there hasn't been an application specifically designed to assess the risk of musculoskeletal disorders among shipping division operators, particularly in the realm of shoe manufacturing using Tecnomatix Jack Software. Prior research using digital twin technology has primarily focused on other manufacturing sectors, with limited observation or implementation within the shipping division's context.

2. Related Works

Indeed, numerous scientific investigations have been conducted to evaluate the ergonomic aspects related to musculoskeletal problems in the manufacturing sector. Previous research has encompassed a wide range of methodologies, incorporating both conventional and technological assessment techniques. Among the most frequently employed methods are RULA (Rapid Upper Limb Assessment), REBA (Rapid Entire Body Assessment), and OWAS (Ovako Working Posture Analysis System) [12]. These methods allow for the categorization of risk levels into low, medium, and high based on the outcomes of the assessments.

In 2018, a study conducted in Portugal discussed how the metallurgical industry would practice a continuous improvement assessment of the integrated condition toward lean implementations, ergonomics, and safety. Within various products to produce the company has about 12 production areas. The research is done by using ErgoSafeCI as the tool. There are about 9 sections containing about 72 questions; those are the yes or no questions. Nine sections of this research involve efficiency, continuous improvement, safety, standard, visual management, process and operation, material flow, zero defects, ergonomics and discipline. By the result, the researchers found out that the factory will get a high score from an excellent interaction among the lean, ergonomic, and safety [12]. Another study discussed an ergonomics risk on the U-shaped assembly line. The research was done using a two-stage framework. In the first one, the researchers divided the level of ergonomic risks (NIOSH, EAWS, OCRA, REBA and JSI) into easy, normal and hard classes. The level of risk was identified by using the method of best worst and ELECTRE TRI. The second stage of this research was building the mathematical model. In this research, the proportional distribution in the dispersion of each class through the station was tried to confirm. [13]. A hand tool redesign was proposed as a result of an ergonomic assessment of the furniture industry in India. During the working time, many activities involved the risk of Musculoskeletal Disorders (MSDs). Nordic questionnaire was chosen as the method to collect the data. The research subject is 70 random workers in the furniture industry located in Kota, India. As a result of the assessment, the study found that the highest part of workers' body that usually got MSDs issues is the shoulders (75.14%) and the knees (54.28%). Motion study is also conducted to reduce the ergonomic risk in the factory [14].

Research that compares Three methods, which are Ovako Working Posture Analysis System (OWAS), Rapid Upper Limb Assessment (RULA), and Rapid Entire Body Assessment (REBA), resulting that Rapid Upper Limb Assessment (RULA) is the best method for assessing the musculoskeletal disorder risk [15]. While the study on the clothing sector was done in Turkey, comparing the proper methodology to assess the performance of workers in the clothing sector, to determine the workers' posture, and to classify the stress factor of musculoskeletal problems.

Rapid Entire Body Assessment (REBA), Ovako Working Posture Analysing System (OWAS) and PLIBEL are used as the research methodology. This study showed that REBA and OWAS methods are preferably used to assess musculoskeletal problems in the clothing sector rather than PLIBEL due to the PLIBEL method's lack of providing numerical data [16].

Another research addressed ergonomics and facility design in the sewing division. e Rapid Upper Limb Assessment (RULA), fuzzy predictive model and Relevant Ergonomic Standards were applied in this research as tools to propose solutions [17].

Inappropriate layout while the operator is conducting the job guides the wrong work posture, as presented in research at Aluminium SMEs in Indonesia, which was done using the method of Nordic Body Map analysis and Rapid Upper Limb Assessment (RULA) analysis [18]. The final score for RULA is 7, which means the work systems need to change immediately. As an improvement, the researchers designed an ergonomic table and chair and, resulting in a reduction in the RULA score to 3.

In Italy, the research was conducted to avoid Ergonomic Postural Risk (EPR) by performing two approaches such as high-level monitoring and the operators' training. The researchers were using the Microsoft Kineth® V2 sensor as an innovative tool. The software provides semiautomatic Ergonomic Postural Risk (EPR) calculation called as K2RULA tool. The calculation was based on the Rapid Limb Assessment metrics (RULA) method.

Two sections did RULA calculation. The first section, or A section, includes the upper arm, lower arm and wrist, while the B section includes the neck, trunk and legs. The result of this research is the successful design of the Ergosentinel tool. The tool is used in the agri-food industry, specifically on their factory shopfloor [19]. A study in Italy proved that there was an easier way to modify the workplace. First, in this research, the researchers conducted the analysis of the assembly line layout, made the Standard Operating Procedures (SOP), estimated the time, and designed a preliminary workplace. Then, EAWSdigital® software has a role as the tool to complete the data on the EAWS checklist.

The design was built by the analysis of the whole body and upper limb. The product and workplace design was done by Digital Twin. The research proved that the used of digital twins made no change in the "zero cost" [20]. While in Peru, specifically in the accessory sector of clothing.

The objective was to address the lack of studies on musculoskeletal disorders (MSDs) in this industry. To reduce the percentage of MSDs, the researchers redesigned workstations and implemented combined ergonomic and Lean tools. The results were promising, showing a significant 71.85% decrease in MSDs in the sewing and cutting area. Additionally, there was a 20.73% reduction in absenteeism and an annual cost saving of S /. 505.72 (Peruvian soles). These outcomes highlight the potential benefits of integrating ergonomic and Lean methodologies in the textile industry to improve worker health and overall efficiency [21].

A study on the manufacturing process proposed to assist in the identification of ergonomic performances, especially in terms of monitoring and decision-making. There were seven steps in this research. As a result, the researchers stated that DT could minimize the time and cost of the trial, which is a new improvement; the assessment by the software was faster and more detailed [10]. Also, studies on the upper limb sitting position have been conducted, and little attention has been given to the lower limb. To address the gap, the paper introduces the Autonomous Height Adjustment System (AHAS) for IoT-based Smart Office Chairs.

The AHAS aims to adjust the height of office chairs based on the user's body weight. To implement this system, load cell sensors and linear motors are added as actuators to standard office chairs. The collected data is then stored on a cloud server using IoT concepts with the HTTP protocol, allowing real-time monitoring. The development of the system involves several stages, including mechanical, electrical, and software design, subject selection, data acquisition, and implementation. The presented results demonstrate that the proposed system works effectively, offering a solution for autonomous seat height adjustment [22].

Based on the previous research above, the researcher conducted a study about the digital twin approach in terms of ergonomic assessment. This research was conducted to simulate the manufacturing process, especially for the operators who are working on the process of arranging the shoes on the box. This research specifically focuses on the ergonomic aspects of a sample room for the footwear industry named PT. XYZ. The ergonomic assessments are done using the Tecnomatix Jack Simulate software by Siemens. The ergonomic aspects analyzed in this research are OWAS (Ovako Work Analysis System), LBA (Lower Back Analysis) and NIOSH (National Institute for Occupational Safety and Health).

Table 1. shows about the summary of related works in this study:

Table 1. Summary of related works

Ref No	Business Sector	Research Method	Software
12	Metallurgical industry	Lean, safety and ergonomics	ErgosafeCI
13	Samental furniture industry	NIOSH, OCRA, EAWS, and COPSOQ indexes.	ELECTRE TRI
14	Furniture industry	Nordic Musculoskeletal Questionnaire	CAD for redesign hand tool
15	Automotive	OWAS, RULA and REBA	-
16	Clothing	PLIBEL, REBA and OWAS methods	-
17	Sewing division	RULA, Fuzzy Predictive Model, Relevant Ergonomic Standard	-
18	Aluminum industry	Nordic Body Map Analysis and RULA	-
19	Agri-food industry	RULA	K2RUKA
20	Automotive	EAWS	EAWSdigital ®
21	Clothing accessory	RULA, REBA and NIOSH	The Delmia V5
22	Any business related to sitting posture	Internet of Things (IoT)	Smart Office Chairs

As the validation of the ergonomic aspect assessment generated by the simulation software, the Nordic Musculoskeletal questionnaire was distributed to 35 operators to determine the operators' body parts that contain the pain and potentially cause the symptoms of musculoskeletal disorder.

3. Research Methodology

The research used the simulation method for the digital twin approach. The use of research flow is to simplify the understanding of research steps. Based on Greco et al.'s ergonomic analysis, the research has to follow several steps [11]. Figure 3.1 below shows about the following steps of the research:

According to the research flowchart diagram adapted from the previous study by Greco et al. (2020), the framework of this research is to determine the ergonomic issues of the task of manual work in a manufacturing scenario.

During the research, there were seven steps to determine the ergonomic issues:

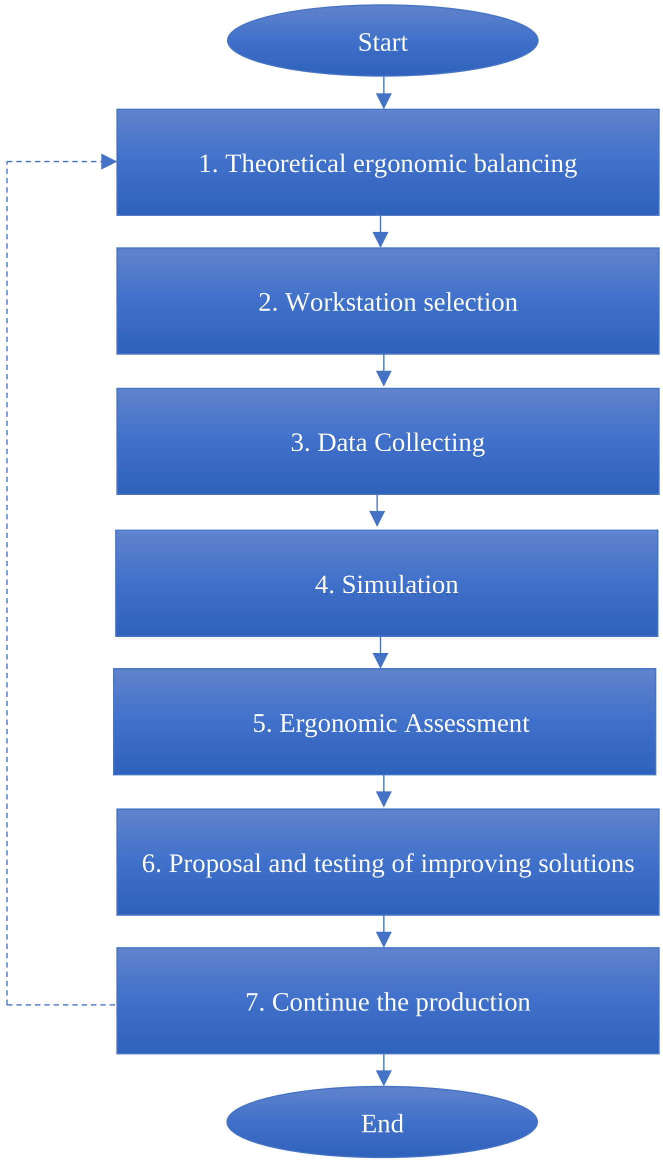


Fig. 3 Research flow

3.1. Theoretical Ergonomic Balancing

This step was defined along the design and engineering phase toward the focused production line to select the workstation.

3.2. Workstation Selection

While the selected workstation is confirmed.

3.3. Data Collection

This step was conducted by using direct observation, interview and documentation.

3.4. Simulation

After the data was collected, all of the data were transferred to the software.

3.5. Ergonomic Assessment

Based on the simulation that was proposed to generate the ergonomic aspects assessment.

3.6. Proposal and Testing of Improving Solution

Based on points #4 and #5, it can be summarized on what motion and what kind of improvement solution can solve the problem.

3.7. Continue the Production

After all of the problems are solved, this end step of the research can be continued to the 1st step of this research.

The research framework was built to present a clear explanation of the research objectives. The research framework simply defines the problems, research tasks, methods and improvement action.

The working conditions here include repetitive motion, horizontal and vertical movement, the angle while the worker twists their body and other fatalistic conditions while the operators conduct their job. The MSDs are the independent variable where the problem details are injuries of repetitive strain or sudden injuries that usually appear in the workplace [22]. Ergonomic Assessment is the basic method to determine the risk level of musculoskeletal disorder.

The assessments adopted three methods: the Ovako Work Analysis System (OWAS), Lower Back Analysis (LBA) and National Institute for Occupational Safety and Health (NIOSH) generated by the simulation within the digital twin approach. While Nordic Musculoskeletal Questionnaire data are gained by distributing the questionnaire to the workers.

Based on Saquib et al., dependent variables in their study are three factors that affect the musculoskeletal disorder force of extreme activity; working in a static posture and extreme vibration that usually comes from the tools can reduce blood flow, breaking the nerves and strengthening the muscle fatigue [22].

Simulation is used to avoid the trial-and-error processes that are high-cost and highly time-consuming. The simulation software that was used was Tecnomatix® Jack software. The use of software in this research aims to simulate and modeling the human-performed task in the manufacturing area toward its ergonomic analysis.

Specifically, the use of the simulation is to simulate the tasks of manual material handling on a plant first, while the second is to predict the workers' performance to prevent injury and optimize the layout of the work area. Generally, the steps of Process Simulate Human are: set up the virtual scenario, set the real-time layout, create digital human, create human operation and analyze human performance.

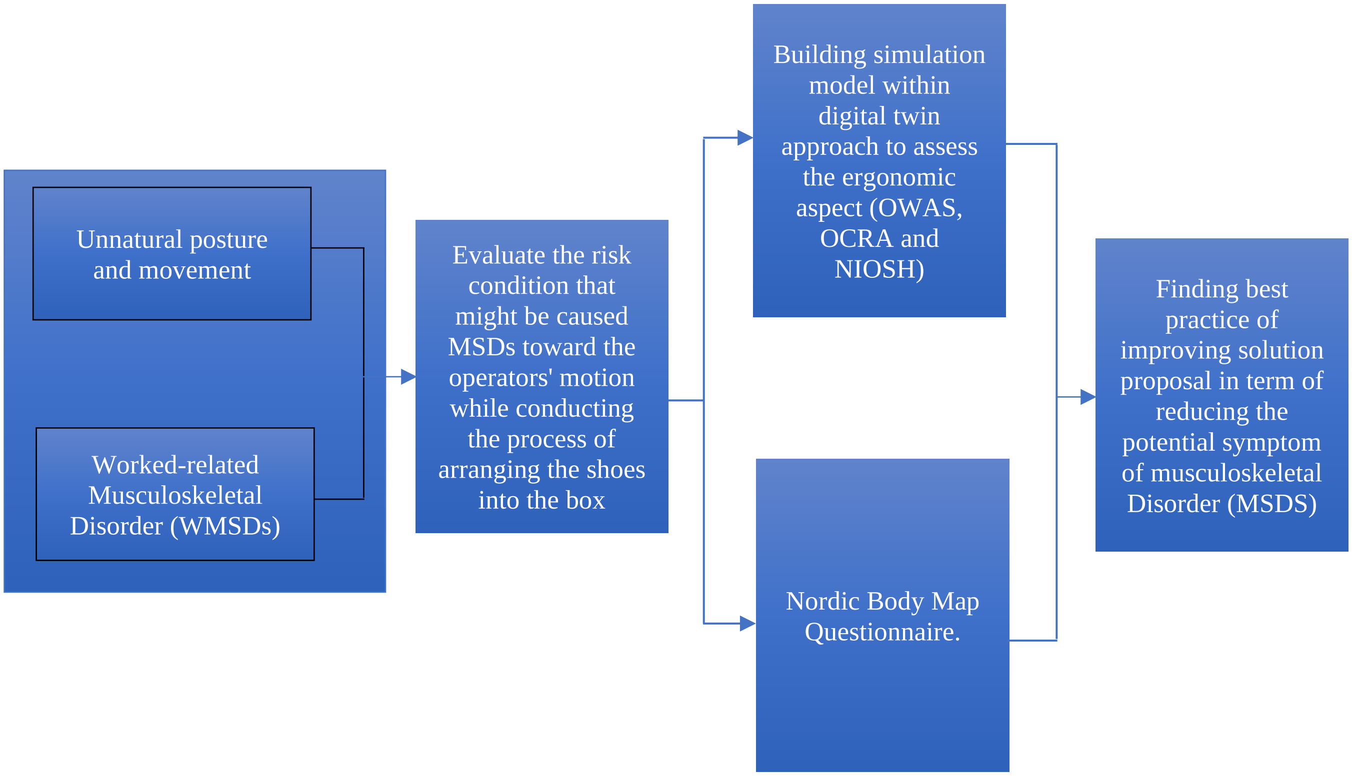


Fig. 4 Research framework

As the validation of simulation results for the overall ergonomic aspects, the Nordic Musculoskeletal Questionnaire was conducted to assess the muscle soreness of the 35 workers directly.

Before the model on the Tecnomatix was designed, it needed 1 operator as the object on the video taken directly in the sample room. That one operator will be worked based on the SOP to finish the process of arranging the shoes into the box.

The data are collected by direct observation, interview and documentation on the production line in PT XYZ, especially the operator who is working in the process of arranging the shoes into the box. Based on Schutt, there are different techniques for the analysis of qualitative data, such as data documentation and data collection process data of an organization [21]. Correlation among the conceptual data, corroboration and reporting of the finding. The analysis on the Nordic Musculoskeletal Questionnaire is determined by the symptoms on the Nordic Musculoskeletal Questionnaire that ask about the operators' conditions both before and after working conditions. The result of the questionnaire aims to identify the symptoms and validate the risk level assessment generated by simulation software. The critical issues analysis validated the MSD's symptoms by distributing the Nordic Musculoskeletal Questionnaire and Nordic Body Map questionnaire. The summary data of complaint grades are processed with Microsoft Excel. Subsequently, while the numerical simulation does the discussion and possible solution testing within the digital twin approach, the decision-making processes are required in furtherance of production process improvement.

4. Data Collection

4.1. Respondent Characteristics

The respondents in this research are the employees of the shipping division PT. XYZ. The shipping division is working on the process of putting the shoes into the box within the amount of 35 employees. Involved respondents are observed based on their age, working period, bedtime at home before working in the office, body height, body weight and other details on the Nordic Musculoskeletal Questionnaire. The basic determination is based on the consideration that MSDs can be caused by these things. The age characteristic is divided into three categories such as <30 years old, 30-40 years old and >40 years old. Based on the questionnaire result, most of the respondents are on the age of less than 30 years old, while the smallest categories are on the age of 30-40 years. Founded on the respondents' working period, it is divided into four categories such as less than 5 years, 5 until 10 years, and 11 until 15 years and greater than 15 years. Based on summary data, both the working periods 5-10 years and 11-15 years have the same value, such as 11 or 31.43% of respondents.

The respondent's height on the PT.XYZ are really varieties because they come from the difference in genders and ethnicities. The questionnaire result proved that the respondents' height is in the range of 152-178 cm. The highest height on the respondents' result is 161-165 within 9 or 25.71% of respondents. According to the weight result, the weight range is 45-75 kg. The highest weight on the respondents' response is 66-70kg, which has 9 respondents (25.71%), and the smallest number of respondents is in the 51-55 categories within 2 persons.

4.2. Operator's Postures

The initial posture observed in the video capture corresponds to the operator's initial motion while putting the shoes into the box, which is part A in Table 1.

It is evident that the operator's movement deviates from the typical or optimal human posture. The upper body, encompassing the neck, shoulders, and upper back, is noticeably flexed forward, causing a bending of the spine. This forward flexion is primarily aimed at reaching the shoes placed on the floor. As a result, the operator adopts this posture to accommodate the low height of the shoes and facilitate their retrieval.

Part B illustrates the operator's motion during the process of retrieving shoes. Notably, the waist adopts an angle ranging from 45 to 90 degrees relative to the alignment of the upper body and the legs. This extreme angle has significant implications for human physiology, as it is likely to induce discomfort and potentially give rise to pain sensations. It is crucial to prioritize ergonomic considerations and maintain proper body mechanics to minimize the risk of injury and promote long-term musculoskeletal health.

Shoe lifting position (picking process), representing the operator's posture, plays a significant role in influencing the balance of the human body. The ability to maintain balance is a highly intricate process that requires the coordination of multiple bodily systems, including the musculoskeletal, nervous, and vestibular systems. By understanding the intricate mechanisms involved in maintaining balance, the operator can appreciate the remarkable capabilities of the human body and the importance of optimal posture in promoting overall well-being.

Part D closely resembles the first and eighth figures, sharing similar characteristics except for the variation in the hand load. In this instance, the fourth figure portrays an individual assuming an unnatural posture while bearing a load between 0.5 and 1 kg in their hand. This depiction highlights the potential physical implications experienced by the operator due to the specific hand load. These physiological responses underscore the significance of considering ergonomic principles and proper lifting techniques when handling loads.

Putting shoes into the box 2 depicts the scenario where the operator is engaged in a bending motion while carrying a load ranging from 0.5 to 1 kg in both hands. The experience of the operator during such an activity can vary depending on several factors, including their individual strength, physical condition, and technique. Operators should consider seeking assistance or utilizing appropriate equipment if necessary.

On the part F such as organize shoes in a box, the operator takes a few seconds to arrange and tidy up the shoes inside the box. Repetitive bent postures can have various effects on the human body, particularly when maintained for prolonged periods of time. One of the most common consequences is the strain and discomfort experienced in the back and neck regions.

The body pressure exerted on the pre-finish work 1 is intricately linked to the process of transitioning from a bent position to standing upright. During this transition, the distribution of weight-bearing forces undergoes a significant shift.

Last but not least, pre-finish works 2 that present repetitive 90º bent postures can pose various risks to the human body, especially if maintained over extended periods. One major risk is musculoskeletal strain, as this posture can strain the muscles, tendons, and ligaments involved, leading to imbalances, fatigue, and discomfort in areas like the lower back, hips, knees, and ankles.

Table 2 provides a comprehensive overview of operator's postures, illustrating the various positions adopted by operators while performing their tasks. The table categorizes these postures into different types, each of which represents a specific configuration of the operator's body during work.

4.3. Nordic Musculoskeletal Questionnaire

In general, there are three questions with yes or no answers as follows;

A: Have you, at any time during the last 12 months, had trouble (ache, pain, discomfort, numbness) in?

B: Have you, at any time during the last 12 months, been prevented from doing your normal work (at home or away from home) because of the trouble?

C: Have you had trouble at any time during the last 7 days?

The detailed results of 35 respondents for each body part on the Nordic Musculoskeletal Questionnaire are explained in Table 3.

The questionnaire can be concluded based on the direct interview with the operators on the PT.XYZ. For the neck, 19 out of 35 respondents said that they have had a neck problem during the last 12 months, and 10 out of 35 had the problem anytime during the last 7 days.

Table 2.Operators' posture

Process Name	Video Capture (a)	Process Name	Video Capture (a)
(A) Starting position takes the shoes.		**(B) Shoe holding position (picking process)**	
(C) Shoe lifting position (picking process)		**(D) Putting shoes into the box 1**	
(E) Putting shoes into the box 2		**(F) Organize shoes in a box.**	
(G) Pre-finish work 1		**(H) Pre-finish work 2**	

Table 3. Nordic musculoskeletal questionnaire result

Body Part	A			B	C
	Left	Right	Both		
Neck	19			0	10
Shoulders	7	13	3	2	9
Elbows	2	6	3	0	8
Wrists/Hands	3	6	1	1	4
Upper Back	7			0	3
Lower Back	23			1	5
One or Both Hips/Thighs	7			2	1
One or Both Knee	22			1	10
One or Both Ankles/Feet	10			2	0

As for the body part that has hand movements, 23 respondents felt the problem during the last 12 months, 2 respondents were prevented from doing normal work, and 9 out of 35 respondents had trouble at any time during the last 7 days. Elbows are contained with the joint to control hand movements; 11 respondents had trouble during the last 12 months, and 8 respondents had trouble at any time during the last 7 days. Wrists or hands that work harder while doing hand movements have 10 respondents who had trouble during the last 12 months, 1 respondent was prevented from doing normal work, and 8 respondents had trouble at any time during the last 7 days. In the back body part, which is the upper back, 7 respondents felt trouble during the last 12 months, and 3 out of 35 respondents had trouble at any time during the last 7 days. Especially for the lower back area, more than half of respondents, specifically 23 out of 35, felt the trouble during the last 12 months, 1 respondent was prevented from doing normal work, and 5 had trouble at any time during the last 7 days. One or Both Hips/Thighs 7 respondents felt the trouble during the last 12 months, 2 respondents were prevented from doing normal work, and 1 respondent had trouble at any time during the last 7 days. For one or both knee, 22 respondents got trouble during the last 12 months, 1 were prevented from doing normal work, and 10 had trouble at any time during the last 7 days. As for the body part with the pedestal function, One or Both Ankles/Feet 10 felt the problem during the last 12 months, and 2 had trouble at any time during the last 7 days.

4.4. Simulation by using Tecnomatix Jack

In the shoe industry, anthropometric data is used to create virtual human models and conduct virtual environment testing. This data is also utilized to establish ergonomic design parameters for the proposed design configuration, which serves as the output of the research.

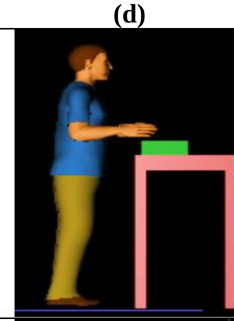
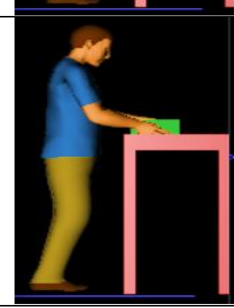
Regarding the anthropometric data, it will be utilized in this research as input data for creating virtual human models (mannequins) using Tecnomatix Jack 8.4 software. The data was inputted by Advance Human Scaling for the 25 body segments available in Tecnomatix Jack 8.4. This study simulates both real-time situations and improvement proposals.

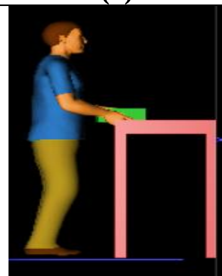
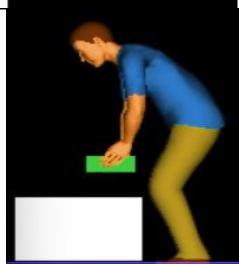
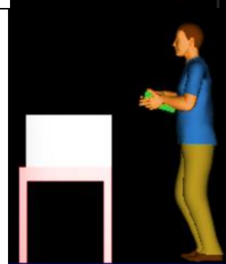
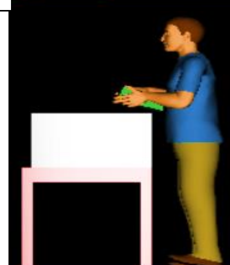
As improvement tools, the tables have been designed by considering ergonomic aspects. The size of the tables has been engineered based on anthropometry calculations, aiming for natural posture adaptation. The anthropometry dimensions adopted for the design are elbow height and hip height. Initially, in the current situation, when the operator puts on or takes off shoes, both heights are zero cm because the shoes' box is located at the bottom of the floor. The dimensions of the original box are 60 cm for the length, 50 cm for the width, and 35 cm for the height.

For the anthropometry data, this research used criteria encompassing all tribes in Indonesia, both genders (male and female), and ages ranging from 20 to 47 years old. Based on these criteria and using the 50th percentile, the elbow height and hip height were determined to be 101.7 cm and 95.11 cm, respectively. Related to the anthropometry issue, this research designs two tables as tools to prevent musculoskeletal issues. The detail dimension of the tables is explained in detail below, while the tolerance for both tables is ±2 cm.

Table 4. presents a comparison between real-time situations and improvement proposal simulations, offering insights into the effectiveness of suggested changes. By juxtaposing actual data with simulated outcomes, it allows for a comprehensive evaluation of the proposed solutions' potential impact on the observed scenarios.

Table 4. Comparison of real-time and improvement proposal

No	Real-Time Situation (c)	Improvement Proposal (d)
1		
2		

No	Real-Time Situation (c)	Improvement Proposal (d)
3		
4		
5		
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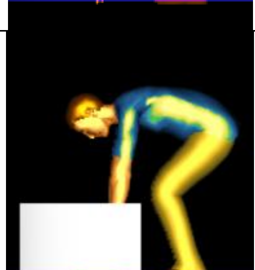
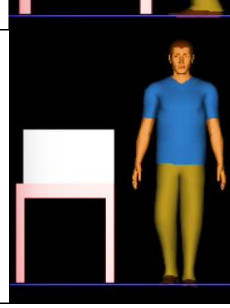
7		
8		

To achieve a natural posture, the first ergonomic table, which is represented in numbers 1 to 3 in Table 4, which serves as the place for the shoes before they are taken out by the operator, is designed with dimensions of 100 cm for the length, 50 cm for the width, and 95 cm for the height. The height of the table is customized according to the hip height on the anthropometry data, which was 95.11 cm; considering human hip height when designing a table is crucial for creating ergonomic and user-friendly furniture.

The second ergonomic table, which is represented in numbers 4 to 8 in Table 4, located below the box, is designed with dimensions of 65 cm for length, 55 cm for width, and 65 cm for height. The height of the second table is calculated with respect to the box height, ensuring a natural work posture for the operator. The height of the table and box is the total elbow height, which is 101.7 cm. The primary objective of ergonomic design is to create a comfortable and efficient workspace that minimizes the risk of musculoskeletal disorders and promotes overall well-being. The height of a table plays a significant role in achieving this goal. By aligning the height of a table with the average height of a person's elbow, it ensures that the user can maintain a natural and relaxed posture while working.

The software generates various scores, namely OWAS (Ovako Working Posture Analysis System) score, LBA (Lower Back Analysis) score, and NIOSH (National Institute for Occupational Safety and Health) score. These scores serve as quantitative indicators that allow for a comprehensive comparison of the different aspects of the workplace situation and the proposed solution. The proposed improvement tools were simulated using Tecnomatix Jack V 8.4 while in a standing position. The results are shown in Table 5.

The data presented in Table 4 provides valuable insights into the analysis of ergonomic parameters, specifically focusing on the OWAS, LBA, and NIOSH scores for various postures. Notably, the majority of OWAS scores demonstrated a substantial shift from 3 to 1, indicating significant improvements in ergonomic conditions across various postures. However, the sixth posture exhibited a less pronounced improvement, with the OWAS score changing only from 3 to 2, suggesting the need for further attention and intervention in this specific posture. Regarding the LBA score, the most noteworthy change occurred during the third posture, characterized by a substantial decrease from 1,743 N to 444 N. This significant reduction in load on the lumbosacral back region reflects an improved biomechanical profile and may contribute to a lowered risk of musculoskeletal issues in the workplace. Similarly, the NIOSH score also demonstrated its most remarkable change during the third posture, where the Load Index (LI) decreased by 0.05, transitioning from 0.170 to 0.120. This reduction in the LI denotes a substantial alleviation of overall body load, signifying enhanced ergonomic conditions for the workers.

Table 5. Comparison of the real-time situation and improvement proposal simulation result

No	Process Name	OWAS Score		LBA Score		NIOSH Score	
		c	d	c	d	c	d
1	Starting position takes the shoes	3	1	1284	394	0.000	0.000
2	Shoe holding position (picking process)	3	1	1627	558	0.220	0.080
3	Shoe lifting position (picking process)	3	1	1743	444	0.170	0.120
4	Putting shoes into the box 1	3	1	1416	485	0.130	0.130
5	Putting shoes into the box 2	3	1	1681	485	0.160	0.130
6	Organize shoes in a box	3	2	1651	1358	0.190	0.180
7	Pre-finish work 1	3	1	1696	810	0.000	0.000
8	Pre-finish work 2	3	1	1545	365	0.000	0.000

This reduction can be attributed to the change from a bent position, which places more strain on the body, to a more natural and ergonomic posture. This reduction indicates a substantial alleviation of the load placed on the body, mitigating the risks associated with the task. This reduction in the LBA score suggests a notable decrease in the physical stress and strain placed on the body during the motion. This indicates a positive effect on the ergonomic factors associated with this motion, leading to a lower risk of musculoskeletal strain or discomfort for the workers performing the task.

In summary, the data from the table demonstrates a substantial improvement in various metrics after the implementation of the improvement solution. The OWAS, LBA, and NIOSH scores all experienced significant positive changes, indicating a reduction in physical strain, force exertion, and discomfort. These improvements signify the effectiveness of the implemented solution in optimizing the motions and enhancing the overall ergonomics and worker experience.

4.5. Assessment Analysis

4.5.1. OWAS Analysis

The assessment protocol within the Ovako Working Posture Analysis System (OWAS) is contingent upon multiple ergonomic variables in the occupational milieu. These appraisals predominantly revolve around the meticulous evaluation and classification of laborers' bodily stances, encompassing facets like anatomical alignments, force application, recurrent gestures, and the temporal extent of these actions across diverse tasks. The overarching objective of this scrutiny is to discern potentially detrimental or taxing bodily postures assumed by personnel, which could precipitate musculoskeletal complications or impairments.

Based on the graph, the comparison between real-time condition and improvement proposal are positively changed. OWAS assessments serve to elucidate and enhance the ergonomic landscape within a workplace by delineating specific areas necessitating alterations or adaptations to cultivate improved and safer ergonomic practices conducive to the well-being of employees.

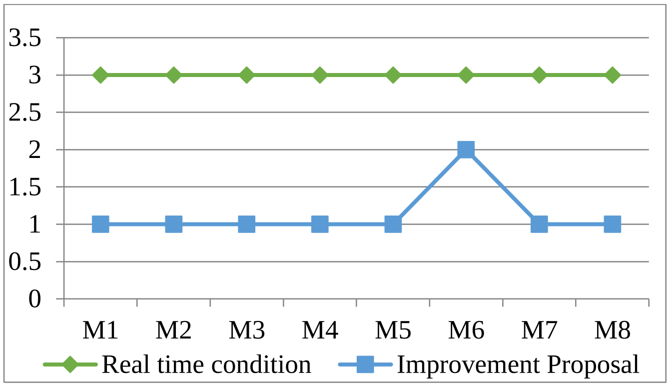


Fig. 5 OWAS results

4.5.2. LBA Analysis

The evaluation of lower back analysis is subject to a myriad of influencing factors, predominantly encompassing biomechanical parameters. These factors encompass the integrity of the lumbar structure, muscular strength, flexibility, and the individual's posture during the assessment. Additionally, variables such as load distribution, analytical methodologies employed, and any existing lower back conditions or injuries significantly impact the assessment. Environmental factors, including the surface characteristics of the analysis setting and the precision of equipment used for quantifying forces and pressure distribution, further contribute to the evaluation.

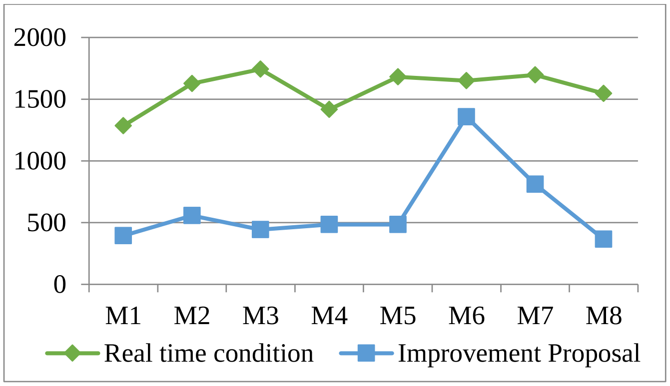


Fig. 6 LBA results

A comprehensive assessment necessitates a multifaceted approach, encompassing diverse facets to accurately interpret and comprehend the implications of lower back analysis under a substantial load of 3400 N. Significant change in this study caused by the additional ergonomic tools and layout rearrangement.

4.5.3. NIOSH Analysis

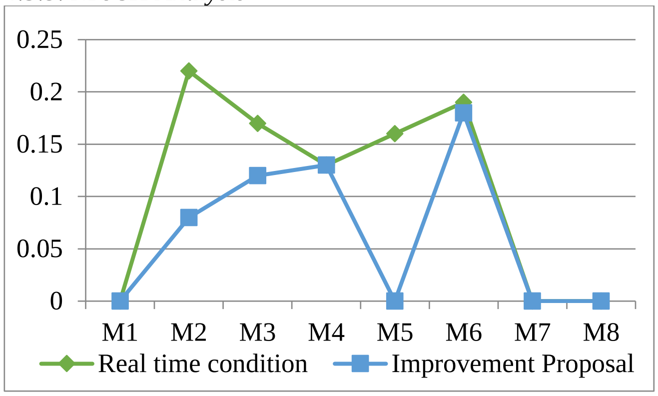


Fig 7. NIOSH results

Numerous determinants shape the evaluation criteria employed by the National Institute for Occupational Safety and Health (NIOSH). These criteria encompass a broad spectrum of factors, such as the characterization of occupational hazards, prevailing workplace conditions, levels of exposure, and the potential health risks confronted by workers. NIOSH assessments routinely integrate empirical evidence, meticulous data analysis, research discoveries, and established benchmarks within safety and health domains. Furthermore, regulatory conformity, adherence to endorsed safety protocols, technological innovations in occupational safety, and the efficacy of implemented risk mitigation strategies are integral facets guiding NIOSH's evaluation methodologies. Moreover, collaborative efforts involving industry experts and stakeholders, as well as continuous surveillance and appraisal of occupational health and safety initiatives, significantly contribute to shaping NIOSH's comprehensive evaluation framework.

4.6. Layout Proposal

When considering a layout change within the context of ergonomic issues, it is crucial to prioritize the well-being and comfort of employees. Ergonomics focuses on optimizing the workspace to reduce the risk of musculoskeletal disorders and promote overall health. Therefore, when planning a layout change, factors such as desk and chair heights, workstation design, lighting, and ventilation should be carefully considered. Ergonomically adjustable furniture, such as ergonomic chairs and height-adjustable desks, can be incorporated to accommodate different body types and promote proper posture. In this study, an improvement proposal with an additional 2 tables is adjusted. The layout should also facilitate easy access to frequently used items, minimizing the need for repetitive reaching or excessive twisting. Adequate lighting that reduces glare and eyestrain, as well as proper ventilation to maintain air quality, should also be taken into account. By incorporating these ergonomic considerations into the layout change, employers can create a workspace that supports employee well-being, reduces the risk of work-related injuries, and promotes overall productivity.

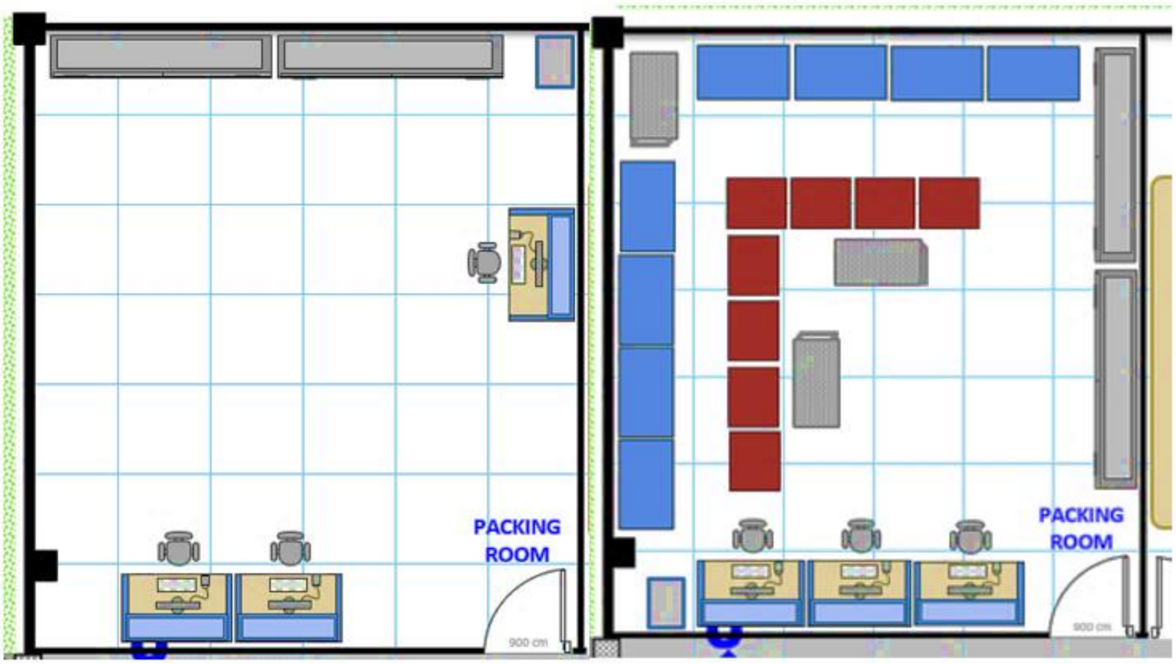


Fig. 8 Comparison of real-time layout and proposal layout

The layout proposal for the study aims to incorporate an additional set of tables to accommodate the need for expansion. The proposed layout includes the addition of eight tables, consisting of four tables designated as Table A and four tables designated as Table B. The existing packing room has dimensions measuring 6.5 meters in length and 5.5 meters in width. Presently, the room is equipped with three working tables, each measuring 1.2 meters in length and 0.7 meters in width. Additionally, there are three chairs, two storage cabinets with dimensions of 2.4 meters in length and 0.6 meters in width, as well as one cabinet measuring 0.55 meters in length and 0.4 meters in width. Subsequently, the unoccupied space within the central room is utilized for the purpose of conducting the shoe arrangement process, whereby shoes are systematically organized into their respective boxes. Subsequently, incorporating 8 tables of type A, 8 tables of type B, and 3 trolleys, the layout proposal was meticulously designed, taking various considerations into account. Figure 8 present schematic representations illustrating the current layout configuration employed at PT.

The implementation of additional tables and the rearrangement of the packing room will bring several advantages to the company from a scientific perspective. Firstly, this modification will significantly contribute to improving the well-being of the operators. By introducing additional tables, operators will have a more ergonomic and comfortable working environment. Properly designed workstations and adequate space allocation can reduce the physical strain on operators, minimizing the risk of musculoskeletal disorders and improving overall work satisfaction. Secondly, this change will have a positive impact on the productivity of the operators. With the availability of more tables, operators can organize their tasks more efficiently, ensuring easy access to materials and tools required for the packing process. By reducing the need to move around and search for items constantly, the time spent on each task can be optimized, leading to enhanced productivity.

Moreover, the reduced physical exertion and improved well-being resulting from the ergonomic setup will contribute to reducing fatigue and increasing operators' focus and concentration levels, further boosting productivity. Additionally, the incorporation of additional tables and a well-designed layout aims to improve line production efficiency. By streamlining the packing process and reducing unnecessary movement, the overall workflow will become more streamlined and synchronized. This can minimize bottlenecks and delays, ultimately resulting in smoother operations and faster output. The improved efficiency can have a cascading effect on other areas of the company, such as inventory management, customer satisfaction, and profitability. By considering ergonomic principles and optimizing workflow, the company can create a more conducive working environment, leading to happier and more efficient employees ultimately contributing to the overall success of the organization.

5. Conclusion

In conclusion, while digital twin technology has shown significant promise in various manufacturing sectors, its specific application to assess the risk of musculoskeletal disorders among shipping division operators, particularly in shoe manufacturing using Tecnomatix Jack Software, remains largely unexplored. Prior studies have highlighted the potential and effectiveness of digital twins in enhancing operational efficiency and safety, yet there exists a gap in its utilization within this specific context. Thus, there is a pressing need for further research and development to harness the full potential of digital twin technology in addressing musculoskeletal disorder risks in the shipping division, paving the way for improved safety measures and optimized work environments for operators in the shoe manufacturing industry.The simulation-based risk assessment of the operators' motion and posture in the packing room indicated that the work postures impose a harmful level of stress on the musculoskeletal system, necessitating immediate corrective actions. While the low back compression force fell below the recommended limit for most healthy workers, the varying range of Lumbar Index values highlights the importance of implementing preventive measures to mitigate the risk of low back injuries. The findings from this assessment underscore the significance of maintaining a safe and ergonomic work environment to protect the health and safety of the operators.

Upon completion of the improvement proposal simulation, the assessment reveals compelling evidence of significant improvement changes in all three metrics: OWAS (Ovako Working Posture Analysis System), LBA (Lower Back Analysis), and NIOSH (National Institute for Occupational Safety and Health) scores. Specifically focusing on the OWAS score, it was observed that prior to the implementation of the improvement proposal, all motions in the real-time solution received a score of 3. As for the LBA and NIOSH assessments, all motions demonstrated a reduction in their scores, which signifies an overall enhancement in ergonomic considerations. These findings validate the effectiveness of the improvement proposal, which has successfully addressed and mitigated ergonomic risks, resulting in improved occupational safety and well-being for individuals performing the assessed motions.

The implementation of additional tables and rearranging the packing room will bring several advantages to the company from a scientific perspective. Firstly, it will improve the well-being of the operators by creating a more ergonomic and comfortable working environment. Secondly, the changes will positively impact operator productivity. This will reduce the time spent on each task and optimize productivity by minimizing the need for constant movement and item searching. Additionally, incorporating additional tables and a well-designed layout aims to improve line production efficiency. Streamlining the packing process and minimizing unnecessary movement will make the overall workflow more streamlined and synchronized. This will minimize bottlenecks and delays, resulting in smoother operations and faster output. The improved efficiency can have a positive impact on other areas of the company, such as inventory management, customer satisfaction, and profitability. By considering ergonomic principles and optimizing workflow, the company can create a more conducive working environment that leads to happier and more efficient employees. Ultimately, this will contribute to the overall success of the organization.

References

[1] Allina Abdullah et al., "Ergonomic Evaluation of Musculoskeletal Disorder Risk Associated with Working Posture in the Cable Support System Factory," *International Journal of Advance and Applied Sciences*, vol. 4, no. 12, pp. 193-198, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[2] Indonesian Health Ministry, Laporan Nasional Riskesdas 2018, Indonesian Health Ministry, Jakarta, 2019. [Online]. Availbale: https://repository.badankebijakan.kemkes.go.id/id/eprint/3514

[3] World Health Organization, Musculoskeletal health, 2022. [Online]. Availbale: https://www.who.int/news-room/fact-sheets/detail/musculoskeletal-conditions#:~:text=Musculoskeletal%20health%20refers%20to%20the,joints%20and%20adjacent%20connective%20tissues.

[4] Bhawana Rathore, Ashok Kumar Pundir, and Rauf Iqbal, "Ergonomic Risk Factors in Glass Artware Industries and Prevalence of Musculoskeletal Disorder," *International Journal of Industrial Ergonomics*, vol. 80, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[5] M. Saquib et al., "Factor Affecting Musculoskeletal Disorders and Cumulative Trauma Disorders in Workplace Design: A Review," *International Journal for Scientific Research and Development*, vol. 4, no. 1, pp. 313-316, 2016. [Publisher Link]

[6] Gouri Naik, and Mohammed Rajik Khan, "Prevalence of MSDs and Postural Risk Assessment in Floor Mopping Activity Through Subjective and Objective Measures," *Safety and Health at Work*, vol. 11, no. 1, pp. 80-87, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[7] Jocelyn D. Abad, "Ergonomics and Simulation-Based Approach in Improving Facility Layout," *Journal of Industrial Engineering International*, vol. 14, pp. 783-791, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[8] Maulshree Singh et al., "Applications of Digital Twin across Industries: A Review," *Applied Sciences*, vol. 12, no. 11, pp. 1-28, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[9] Raphael Wagner et al., "Challenges and Potentials of Digital Twins and Industry 4.0 in Product Design and Production for High Performance Products," *Procedia CIRP*, vol. 84, pp. 88-93, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[10] David Guerra-Zubiaga et al., "An Approach to Develop a Digital Twin for Industry 4.0 Systems: Manufacturing Automation Case Studies," *International Journal of Computer Integrated Manufacturing*, vol. 34, no. 9, pp. 933-949, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[11] Alessandro Greco et al., "Digital Twin for Monitoring Ergonomics during Manufacturing Production," *Applied Sciences*, vol. 10, no. 21, pp. 1-20, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Marlene Ferreira Brito et al., "A Continuous Improvement Assessment Tool, Considering Lean, Safety And Ergonomics," *International Journal of Lean Six Sigma*, vol. 11, no. 5, pp. 879-902, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Mahdi Mokhtarzadeh, Masoud Rabbani, and Neda Manavizadeh, "A Novel Two-Stage Framework for Reducing Ergonomic Risks of a Mixed-Model Parallel U-Shaped Assembly-Line," *Applied Mathematical Modelling*, vol. 93, pp. 597-617, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[14] Rahul Jain et al., "Ergonomic Assessment and Hand Tool Redesign for the Small Scale Furniture Industry," *Materialstoday : Proceedings*, vol. 44, pp. 4952-4955, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] Dohyung Kee, "Comparison of OWAS, RULA and REBA for Assessing Potential Work-Related Musculoskeletal Disorders," *International Journal of Industrial Ergonomics*, vol. 83, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[16] Meral Isler, Mehmet Küçük, and Mücella Guner, "Ergonomic Assessment of Working Postures in Clothing Sector with Scientific Observation Methods," *International Journal of Clothing Science and Technology*, vol. 30, no. 6, pp. 757-771, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[17] Jocelyn D. Abad, "Ergonomics and Simulation-Based Approach in Improving Facility Layout," *Journal of Industrial Engineering International*, vol. 14, pp. 783–791, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[18] Okka Adiyanto et al., "Application of Nordic Body Map and Rapid Upper Limb Assessment for Assessing Work-related Musculoskeletal Disorders: A Case Study in Small and Medium Enterprises," *International Journal of Integrated Engineering*, vol. 14, no. 4, pp. 10-19, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[19] Vito M. Manghisi et al., "Automatic Ergonomic Postural Risk Monitoring on the Factory Shopfloor – the Ergosentinel Tool," *Procedia Manufacturing*, vol. 42, pp. 97-103, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[20] F. Caputo et al., "Digital Twins to Enhance the Integration of Ergonomics in the Workplace Design," *International Journal of Industrial Ergonomics*, vol. 71, pp. 20-31, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[21] Thedy Yogasara and Chrisye FionaWenas, "The Application of the Revised NIOSH Lifting Equation and REBA Method in Manual Work Evaluation (A Case Study at PT. Caladi Lima Sembilan, Bandung)," *8th South East Asia Ergonomics Society Conference, 12th Indonesian Physiological Society Congress - 15th Scientific Seminar*, Denpasar, 2005. [Google Scholar] [Publisher Link]

[22] Roland Gauthy, Musculoskeletal Disorders. An Ill-Understood Pandemic, 2007. [Online]. Available: https://www.etui.org/publications/guides/musculoskeletal-disorders-an-ill-understood-pandemic