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Productivity improvement through a work study with ergonomic risk assessment: A case study of a high-voltage line distribution operation

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Abstract

The operation of a high-voltage distribution system is risky to workers in many respects, as it involves long hours of work and the need for postures that affect employees' health, causing performance degradation. The aim of this research is to improve these aspects by studying the tasks, time required, and postures. This is combined with an ergonomic risk assessment in which we use rapid entire body assessment (REBA) to analyze the risk arising from employees' postures when working with high-voltage distribution lines with mobile elevating work platforms (MEWPs). We examine 10 processes with the aim of increasing productivity and reducing the ergonomic impact on employee health. The results indicate that problems are caused by the equipment used and the work methods, which cause delays. In addition, most of the postures also involved ergonomic risk at the high to medium level. We therefore introduced improvements by modifying and designing equipment to make it suitable for operation according to the ECRS principles, established postures that posed the least risk, and verified that this improvement did not cause further impact. Following this, the Digital Human Model (DHM) was used with the CATIA V5 program to improve the working methods. After the improvement, the overall working time was reduced by 16.00%, a maximum efficiency increase of 31.85% was found, and the ergonomic risk at the very high to high level was reduced by 87.24%.

Keywords: Productivity improvement, Ergonomics, DHM, Lineman

1. Introduction

In 2020, demand for electricity in the industrial, government, and household sectors of Thailand was 187,047 GWh [1]. The stability and security of the electric power distribution system are essential to ensure that all sectors can use electricity without interruption, and hence the overseeing agencies must respond to these needs promptly. Thailand has a unit called the Metropolitan Electricity Authority (MEA), which is responsible for overseeing the electrical distribution system under the supervision of the government, and manages the electrical distribution system covering three provinces in the capital and neighboring provinces. The Provincial Electricity Authority (PEA) oversees the power distribution system covering 74 provinces. Both agencies need to prepare their personnel, and use tools and work methods that are standardized and rapid.

Due to the expansion of business and industry, electricity demand has increased [1]. In special economic zones such as the Eastern Economic Corridor (EEC) special development zone in the east of Thailand [2], there is a constant need for electricity, meaning that the supply cannot be turned off for maintenance of the distribution system. High-voltage workers perform maintenance without turning off the electric current by using mobile elevating work platforms (MEWPs) and rubber gloves, which can cause them to suffer injury or death. It can also involve awkward postures, which can lead to work-related musculoskeletal disorders (WMSDs) [3, 4]. In the past, it was found that Thai employees had a rate of WMSDs as high as 80.80% arising from occupational conditions [5], which could affect their work, for example through absenteeism and increased need for medical care, and could cause disability [6]. These can be considered significant ergonomic problems arising from work that leads to the occurrence of WMSDs.

The ergonomic problems experienced by high-voltage workers result in WMSDs arising from the postures, time periods, and work methods involved, including repetitive work positions [7] such as raising the arms above the shoulders, twisting the torso, or exerting muscles to lift overly heavy objects [8, 9]. In addition, the wearing of safety belts and harnesses causes lordosis and disc protrusion [10]. Long working periods [11], working ages, and frequency increase the risk of WMSDs [12], resulting in decreased performance [13]. Hence, working methods should be improved, taking into consideration efficiency and the health effects on workers [14].

Productivity improvements must be based on ergonomic risk assessment tools that are appropriate for the job type and which consider all types of risk that can occur. Rapid entire body assessment (REBA) is an observation and assessment tool that is used to

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assess both dynamic and statistical work postures for workers at risk of WMSDs [15], and specifically considers unpredictable working postures [16]. It is suitable for assessing the angle of movement of muscles, measuring workload or exertion, repetition and movement frequency [17], focusing on a posture assessment of the torso, legs, neck, shoulders, arms, and wrists, as well as the degree of object gripping [18]. This means that REBA is a precision tool for the assessment of posture [19]. In 2019, Gumasing and Sasot assessed the behavior of garbage collectors using the REBA tool and NIOSH's lifting formulae, together with an employee fatigue assessment [11]. Wichai and Chaiklieng assessed the working behavior of 70 industrial employees who were moving materials using REBA tools and the NIOSH lifting formulae [20]. From a study of the ergonomic problems experienced by high-voltage workers, it was found that the patterns and postures of this group were dynamic in terms of both upper and lower limb movements. The REBA tool was therefore used to assess the risk of the work postures involved.

Improving working methods through the principles of work-study and ECRS is a simple method that can reduce work time [21]. These authors analyzed the workflow by creating a value stream mapping (VSM), and studied the work tasks to reduce both waste and risk. In 2015, Chueprasert and Ongkunrak led an ECRS study to improve the process of pasteurized milk production by balancing the production line. The results showed that the production efficiency increased, with a cost reduction of 570,283 baht per year [22]. In 2019, Suhardi et al. used ECRS and value stream mapping principles to improve performance based on 30 samples. The results showed a 4.79% reduction in working time [23].

The digital human model (DHM) is a tool that simulates posture, and can be applied to a proposed improvement before it is put into practice to verify the improvement, and to check that the ergonomic risk is no greater than before. Numerous studies have employed a DHM to simulate or redesign workstations to anticipate and plan for a reduction in ergonomic risk [19], such as improvements in shipping crane cabin workstations [24], improving a pressing tool for removing wax from a workstation [25], and designing a crane control room workstation in a steel mill to reduce risk [24]. After these improvements, the redesigned workstations provided a clearer picture of the improvements and the predicted ergonomic risk. In addition, such tools can reduce the time required and increase the quality of the design process [26]. Examples of design programs include CATIA V5 [24, 25, 27] and ManneQuin Pro [28]. However, the use of DHM might differ from the assessment directly to the employee. Hence, the DHM should be used in conjunction with an ergonomic risk assessment to minimize these discrepancies [29].

Due to the increase in energy demand during the economic expansion, operators now have higher workloads on a daily basis, and employees have reported symptoms of fatigue caused by work which may result in WMSDs in future. A previous study was conducted on the operational effects of ergonomic risk and WMSDs for this group of practitioners. However, no researchers have focused on improving working methods for the same job description or work with similar characteristics [3, 8-10]. Hence, this research aims to increase work efficiency by improving methods, time, and work postures in conjunction with an ergonomic risk assessment of high-voltage workers in Rayong by improving working conditions when operating without power cuts using MEWPs. This is one province in EEC where there are many high-voltage workers. The objective was to increase the work efficiency and reduce the impact of ergonomic risk on the health of the workers due to the need to stand for long periods and raise their arms above their shoulders [8, 9], which causes WMSDs [30] and tremendous shoulder pain [31]. Furthermore, workers who climb poles wearing safety belts and harnesses may experience spinal problems [10]. The results of our work can be used as guidelines for developing similar working methods for the maximum benefit of agencies and workers. Moreover, they can be used to reduce the impact of the work on the operators, resulting in reductions in the chances of injury, the cost of medical care, and the time needed to recuperate due to abnormal working postures or fatigue from working for long periods.

2. Materials and methods

In this research, we studied high-voltage line distribution operations in which employees used work stations on MEWPs. Approval was granted by the Khon Kaen University Ethics Committee in Human Research. Workers using MEWPs were considered when undertaking 10 processes, which were prioritized with the analytic hierarchy process (AHP) with ergonomic risk as a factor for consideration. The study considered posture, working time, frequency of work, workload, and external threats. The results showed that the process with the highest priority was disconnecting and connecting high-voltage distribution using a double dead end pole and buck arm pole connected to a PG clamp or tube [32]. The procedure applied in the study is described below.

1. We studied all the steps in the work process using a flow process chart and considered the sequence of tasks occurring in the workflow. A total of 10 tasks were identified that consisted of 61 subtasks. The process began with the preparation of work, starting up the MEWPs, and coming down to collect equipment from the ground, as shown in Table 1.

2. We studied the workflow using a flow process chart and considered the sequence of tasks in the workflow study (10 tasks with 61 subtasks). In all of the tasks, the 16 operators worked in pairs. Since this was high-risk work, it involved joint operations. Each pair of operators was trained to a skillful and expert level.

3. We studied working hours by recording a video of these operations, using drones to capture complete and clear details. Since the workstation was high above the ground, we used the direct time study method, which involved using a stopwatch for each working process and averaging the running time for each task to record the average times before improvement. The details are shown in Table 2.

Table 1 Process details

Task no.	Details
1	Workers went to lockers 1 and 2 to put on safety helmets and harnesses.
2	Workers went to the back of the truck to pick up traffic cones and place them around the working area.
3	Workers went to locker 3 to take the ground wire installation kit and set it up on the truck.
4	Workers went to locker 4 to prepare a tool bag.
5	Workers got onto the truck and climbed onto the platform to unplug the wires from the clamp, starting with phases A, B, and C.
6	Workers got onto the truck and climbed onto the platform to reconnect the wires, starting with phases C, B, and A.
7	Workers went to locker 4 to store the tool bag.
8	Workers went back to remove the ground wire and took it back to locker 3.
9	Workers collected the traffic cones and put them in the back of the truck.
10	Workers took off the safety helmet and harness and returned them to lockers 1 and 2.

Table 2 Working times before improvement

Task no.	Time (s)	Task no.	Time (s)
1	149.79	6	533.43
2	57.46	7	23.24
3	100.90	8	97.80
4	24.16	9	40.18
5	438.61	10	110.56

4. Work posture was studied by assessing the ergonomic risk at each step. A total of 16 operators were assessed using the REBA tool, which considered the posture of the neck, trunk, legs, arms, and wrists, including the force/load, hand-holding characteristics, and the activities performed. The criteria for the score were divided into five levels of risk: negligible, low, medium, high, and very high [16]. For example, the results of the ergonomic risk assessment for Task 1 showed that all 16 employees were at medium risk, while for Task 5, one employee was at medium risk, 14 were at high risk, and one was at very high risk, as shown in Figure 1.

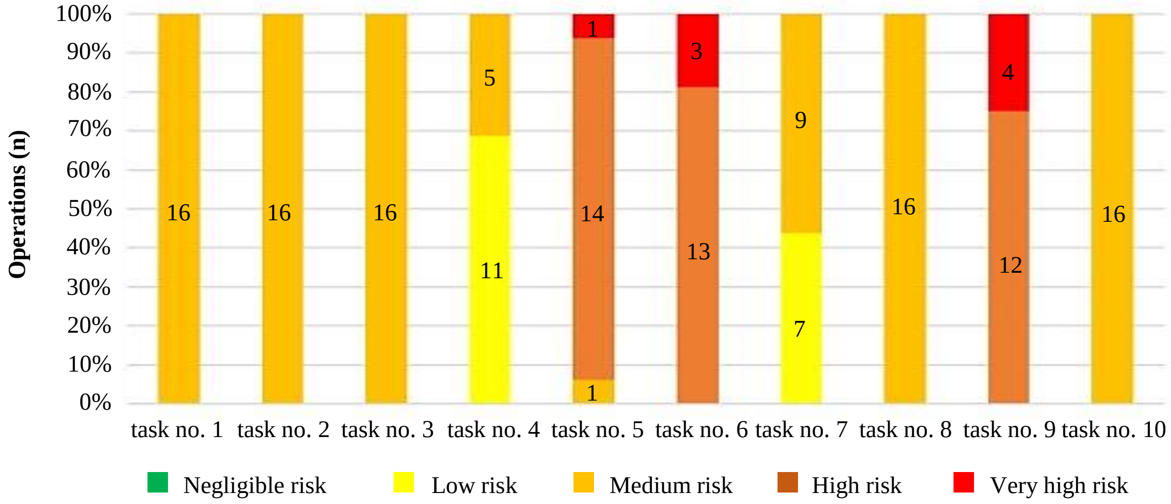


Figure 1 Ergonomic risk levels for each task before improvement

From Table 2 and Figure 1, we see that the working time for each task was between 23.24 and 533.43 s. Task 6 took the most time to complete and had the highest ergonomic risk, and overall had an ergonomic risk of highest to medium risk. Workflow improvements were identified by analyzing the cause of the problem with a cause and effect diagram to.

5. We analyzed the problems with the work using a cause and effect diagram, as shown in Figure 2. We drew up improvement guidelines based on the ECRS and ergonomic principles, and then applied these guidelines to check the posture using a DHM implemented in the CATIA V5 program. The cause and effect diagram was used to identify the causes of problems using the 4M factors (man, machine, method and material). This approach can accurately represent the relationship between the problem and its causes, allowing us to find a suitable solution to the problem. It was found that the ergonomic risk was no greater than before the improvement. We therefore let the staff carry out the improvement in practice before collecting data.

6. We examined the data after improvement to analyze the working times and ergonomic risk. The data were then used to compare the performance before and after the improvement using a statistical paired samples T-test.

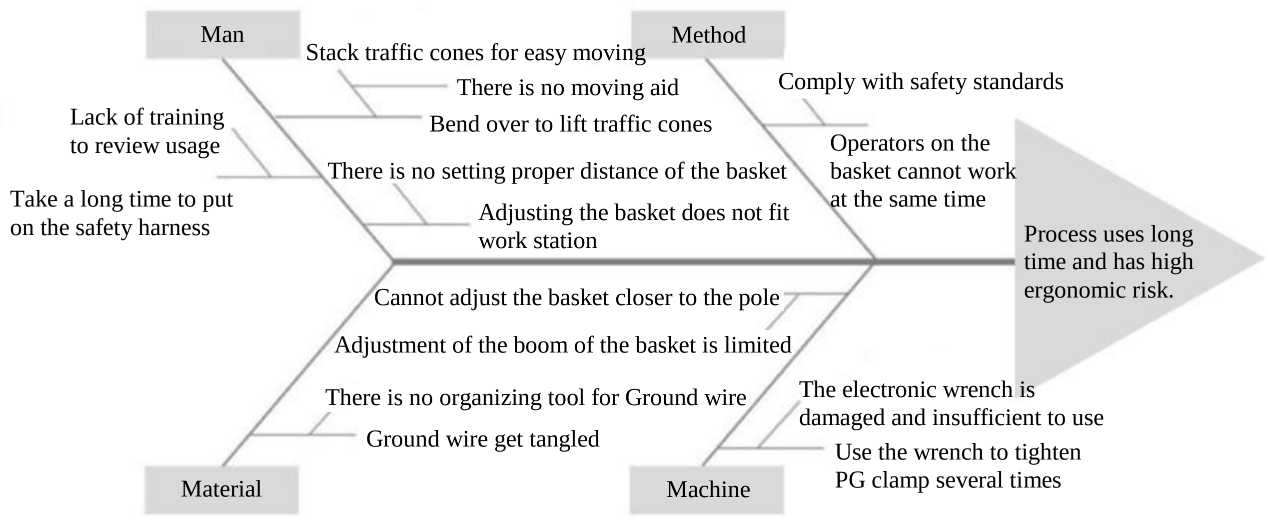


Figure 2 Cause and effect diagram

3. Results

After identifying the causes of the problems described above, a solution was introduced by brainstorming with experts in high-voltage operations and applying their recommendations in the design of equipment together with ergonomic principles to develop improvements. This process was also used to find ways to improve procedures so that operators could work with the correct posture to reduce the ergonomic risk. The work could be improved by simplifying it, by using devices that made it more accessible, and by setting the work posture according to the improved guidelines, as shown in Table 3.

Table 3 Approaches to improving working methods

Cause of the problem	Approaches to improving working methods
A wrench is used to tighten the PG clamp nut several times	Allocate sufficient electric wrenches for use, establish this as a standard tool for work, and suggest correct postures for using these tools
The MEWP platform cannot be moved closer to the pole	Recommend a proper posture for working in areas where the MEWP platform cannot be adjusted close to the workstation (Table 4)
The ground wire becomes tangled during use and is stored in the box after use	Store the ground wire on a cable reel and suggest a correct posture for using tools
Workers take a long time to put on the safety harness	Train staff and review the guidelines and methods for putting on safety harnesses correctly and quickly (Table 4)
Workers are forced into awkward postures because they do not adjust the platform to fit the workstation	Set the platform distance so that the electrical cable is between the edge of the platform and the wire level is between the xiphoid process and the navel of the worker
Workers bend over to lift traffic cones and stack them on top of each other, causing increased load	Design traffic cone storage carts to reduce the load when moving them (Figure 3)

Figure 3 Traffic cone storage cart

As shown in Table 3, we considered improvements to the problematic workflows, starting with the use of an electric wrench rather than a hand wrench to tighten the PG clamp. The operator can hold an electric wrench more comfortably than a manual wrench, as the grip fits the operator's hand. Furthermore, equipment to reduce the energy expended by the worker was used, such as a traffic cone storage cart. This was ergonomically designed based on the average distance from the floor to the operator's hand, so that the operator could use it at a distance that was comfortable [33]. Moreover, wheels were installed to ease the movement of the cart, thus eliminating the need for operators to lift the traffic cones, as illustrated in Figure 3.

A cable reel was also used to help store ground wires, in order to reduce wire tangles and enable employees to perform their tasks faster. This also reduced the ergonomic risk arising from operators having to spread their arms to loosen the ground wire. There was also a training review on how to put on a safety harness properly, so that operators could work easily and could determine the distance of the platform adjustment to fit the workstation. This was determined in conjunction with a safe distance for working with electricity, to reduce the need to raise the arms, twist the torso, and bend the trunk. These improvements took into account the convenience and suitability of working conditions, in order to avoid increasing the burden on operators, such as the weight of the equipment, the durability of the device, and ease of movement.

The postures required by these improvements in the workflow were simulated with a DHM in CATIA V5, to ensure they had less (or no more) ergonomic risk than before. The improved postures did not tend to increase the ergonomic risk to a greater level than before. A 14-day trial was then conducted, including training on how to carry out Tasks 1-10 to reduce working time. Before the operators put them into practice, the improved guidelines were explained and demonstrated. During the 14-day trial, periodic observations were carried out to verify that the operators were performing the work correctly according to the guidelines. The results of posture simulation with DHM and the work postures after improvement are shown in Table 4.

The average time required was then calculated to allow us to compare the results before and after the improvement, as shown in Table 5. The results of the ergonomic risk assessment in the improved task, and a comparison of the results before and after the improvement, are shown in Figure 4.

Table 4 DHM Simulation results and work postures after improvement

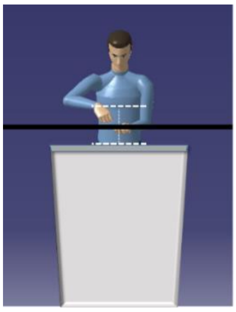
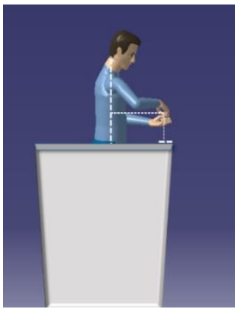
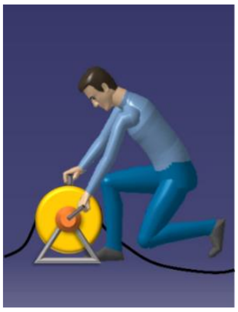
Details	Work posture before improvement	Posture simulation with DHM	Work posture after improvement
Tasks 2 and 9			
Task 3			
Task 5			
Tasks 2 and 9			
Task 3			

Table 5 Average times before and after improvement

Time (s)	Task 1	Task 2	Task 3	Task 4	Task 5
Before	149.79	57.46	100.90	24.16	438.61
After	112.23	67.21	68.77	24.16	467.99
Time (s)	**Task 6**	**Task 7**	**Task 8**	**Task 9**	**Task 10**
Before	533.43	23.24	97.80	40.18	110.56
After	479.28	23.24	82.68	65.27	90.72

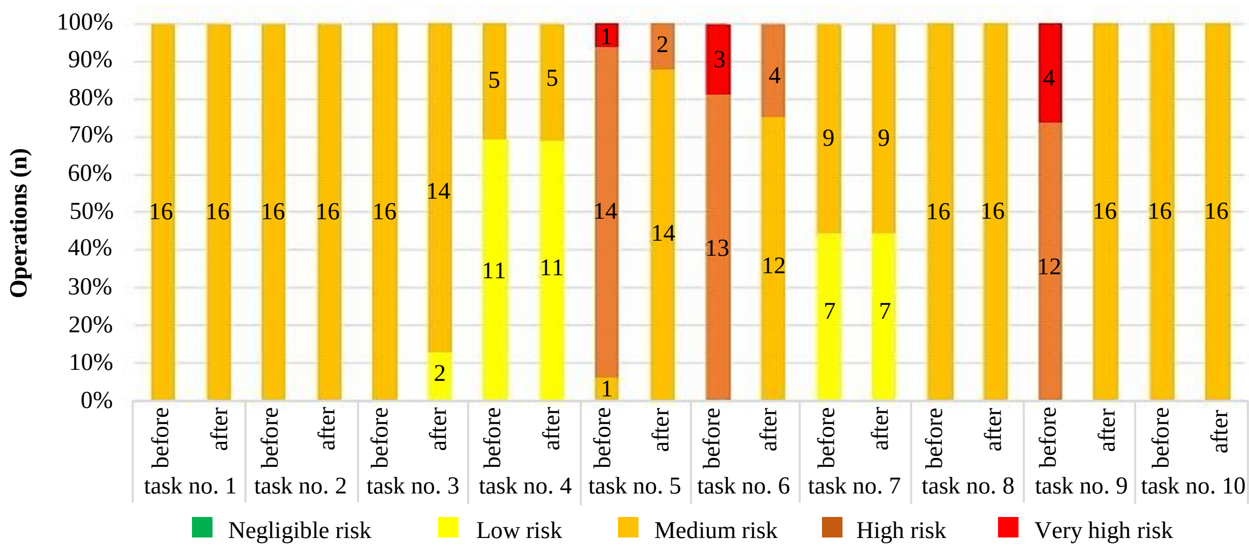


Figure 4 Ergonomic risk before and after improvement

Table 5 shows that after improvement, the time required for Tasks 1, 3, 5, 6, 8, and 10 was decreased. For Tasks 2 and 9, the time was increased due to the higher device handling times. Tasks 4 and 7 were not affected by the improvements, and the average times were unchanged. When comparing the working times after improvement, we see that the time for each task was reduced from 40.18-533.43 s to 65.27-479.28 s, and the time efficiency increased by between 10.15% and 31.85%. According to Figure 4, most of the improved tasks showed a reduced level of risk; there was a decrease in ergonomic risk at the very high and high levels, while the medium risk was increased. Overall, ergonomic risk was reduced from very high or high levels to medium or low levels.

The data before and after improvement were compared in order to find statistical differences with inferential statistics comparing the sample mean. In this study, there were eight samples from 16 operators, which were compared in two ways, as follows:

1) Comparison of working times before and after improvement using a statistical paired samples T-test at a 95% confidence interval. The two hypotheses were:

H_0: The working times before and after the improvement were no different.

H_1: The working time after the improvement was lower than before the improvement.

2) Comparison of the ergonomic risks of the work posture before and after improvement using a paired samples T-test at a 95% confidence interval. The hypotheses were as follows:

H_0: The ergonomic risks of the work posture before and after the improvement were no different.

H_1: The ergonomic risk of the work posture after the improvement was less than before the improvement.

We compared the times and ergonomic risks of the work by analyzing the times required for the eight improved tasks carried out by 16 operators divided into eight pairs, using Microsoft Excel, and found that both were significantly lower than before improvement, with a significance value of less than 0.05, as shown in Table 6.

Table 6 Comparison of data before and after improvement with a paired samples T-test

Time			**Ergonomic risk**		
t-Test: paired two sample for means			**t-Test: paired two sample for means**		
	After	**Before**		**After**	**Before**
Mean	833.68	992.48	Mean	48.50	54.88
Variance	2657.34	1116.79	Variance	3.14	91.27
Observations	8	8	Observations	8	8
Pearson correlation	-0.378		Pearson correlation	0.679	
Hypothesized mean difference	0		Hypothesized mean difference	0	
df	7		df	7	
t Stat	-6.303		t Stat	-2.134	
P(T<=t) one-tail	0.000		P(T<=t) one-tail	0.035	
t Critical one-tail	1.895		t Critical one-tail	1.895	
PIT<=t) two-tail	0.000		PIT<=t) two-tail	0.070	
t Critical two-tail	2.365		t Critical two-tail	2.365	

4. Discussion

A time and motion study is a method of performance improvement that can increase productivity based on an analysis of tasks and activities, with the aim of addressing problematic processes. As in the study by Al-Saleh [34], performance improvements were made using a time and motion study in conjunction with an improvement simulation tool to determine the changes. Before the improvement, the processes used in the study consisted of 10 tasks, consisting of 61 subtasks, which took between 23.24 and 533.45 s. Each task was derived from the working separation of workers. The ergonomic risk to workers, which was assessed with REBA, was mostly at a high to medium level. This led to WMSDs from the use of working postures such as raising the arms, twisting the torso, and bending the trunk [8, 9]. Cause and effect diagrams were used to identify the main problems and to analyze the root causes of these problems. Then, ECRS was applied alongside ergonomics principles to improve the processes using assistive equipment. The ergonomic risks could be reduced and the work could be made easier [25] through the use of ergonomic guidelines for working and training to increase the understanding of ergonomic working postures [35]. Before these were implemented in practice, the posture of the improved approach was simulated using a DHM. It was found that each improvement showed a decrease in ergonomic risk. The times for the improved tasks were reduced to 65.27-479.28 s, with a 16.00% reduction in overall working time, and an increase in efficiency of 31.85%. At the very high to high level of ergonomic risk, we found a decrease of 87.24% in risk compared to before the improvement. The results of this study indicate that ECRS can increase productivity, especially in terms of time efficiency [23], and the use of ergonomics to improve working processes can reduce the ergonomic risk to workers [25]. The use of a DHM in the design process to verify the ergonomic risk of the improved approaches confirmed that the ergonomic risk was no greater than before the improvement [26]. In addition, it was found that by applying the work method improvement approach, i.e., by combining a work study with ergonomic principles, the result was a change for the better in terms of reduced working time and ergonomic risk. Tasks 6 and 9 posed the greatest problems, as they had the highest ergonomic risk and working times. The results showed that both procedures were more effective after improvement, which had a positive effect on both the tasks and the operators.

5. Conclusions

In this research, we used a time and motion study integrated with REBA. A DHM was used to simulate the posture used in the improved approach in order to determine the ergonomic risk before it was put into practice. We found that applying ECRS principles could reduce the waste that occurred. According to the study, the processes required long periods of time and posed high ergonomic risk. We applied ECRS to improve the work methods by making them simpler, by introducing assistive equipment, and by improving working postures according to ergonomic principles, which could reduce operator fatigue and allowed employees to work more conveniently. After improvement, the maximum efficiency of the procedures increased and the ergonomic risk was significantly reduced. This allowed operators to increase the number of day-to-day tasks carried out due to a 16.00% reduction in working time. This improvement process can be applied to other, similar tasks to increase productivity and reduce ergonomic risks in order to prevent WMSDs.

6. Acknowledgments

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