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Article

Practical Implementation of Lean Management Techniques and Ergonomic Consideration to Improve Manual Assembly Process During the COVID-19 Crisis

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Abstract. This research focused on the cycle time reduction of the automotive audio monitor base frame assembly process in a small electronic parts manufacturing company through the application of the Lean and ergonomics approaches. In recent years, the company has faced the problem of not being able to assemble products to meet customers' orders due to the need to lay off some skilled workers to survive during the COVID-19 crisis. This resulted in a severe loss in customer goodwill and confidence. The improvement process began with a review of the current assembly workflow as well as the detailed hand and arm movements of workers. Then, to determine the as-is operational procedure and average cycle time of the assembly process, a series of videos were recorded and playback in slow motion. Lean management techniques, such as 7 wastes and 5 Whys, were employed to identify the potential root causes of the problems. In addition, the ECRS (eliminate, combine, rearrange and simplify) techniques of Lean management in combination with the ergonomics principles were applied to modify the operational procedure and the postures and movements of the workers. The workspace and environmental conditions were also adjusted to enable more efficient workers' operations. The result demonstrated that such an approach could help reduce the cycle time of the assembly process to achieve the predefined target.

Keywords: Productivity improvement, manual assembly process, Lean management, ergonomics consideration, COVID-19.

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1. Introduction

In recent years, due to the COVID-19 pandemic, most manufacturing industries have gone through an economic crisis, especially manufacturers of automotive and electronic parts. As a result, they are inevitably striving to improve their production performance to meet ever-changing customer demands better product quality, higher productivity and lower costs. These key performance indicators, i.e. quality, time-to-market and cost, reflect the competitive advantages of the company over its rivals both locally and globally. Consequently, well-performing companies always leverage these indicators to drive their production plan and invest heavily in equipping their employees, who are their most valuable assets, with the necessary tools and techniques to respond effectively to changes in the production environment.

The case study company is a small manufacturer specialising in the assembly of base frames for audio monitors for the automotive industry to supply second-tier suppliers of well-known Japanese car manufacturers. The crisis of COVID-19 directly affects the company's performance and leads to a sharp decline in sales volume. In order to survive, to reduce overhead costs, the company has to lay off some workers and hire only as needed. As a result of this policy, some skilled workers with high wages also decide to join this scheme to take early retirement benefits from the company. However, this policy has a negative impact on the efficiency of the assembly process, as inadequately trained workers are hired to replace those skilled ones. As a result, the planned output has not been achieved since then, leading to backorders, delayed shipments, high complaint rates and lacking credibility in the eyes of customers.

The key processes of the automotive audio monitor base frame assembly line consist of (1) pasting tape and spacer to the base frame (Top) and (2) automatic visual inspection. The company uses the following parameters to estimate the monthly output of the assembly process, i.e. 5 workers; 65-second takt time; 1 8-hour shift (28,800 seconds) per day; and 26 working days per month. With such operational conditions, in May 2022, the customer order of 60,000 units could have been easily fulfilled with a few hours of overtime, but in reality, as shown in Fig. 1, the company could only produce about 51,000 units. Looking at the average cycle times of the two main processes, it is found that the process of pasting tape and spacer to the base frame (73 seconds) was unable to meet the specified takt time (65 seconds), while the automatic visual inspection managed to do so (Table 1). Therefore, the focus of this study is on improving the efficiency of the tape and spacer pasting to the base frame process.

Since the factory is small with about 50 workers after downsizing and most of the workers have only a high school diploma, the management agrees with the researchers that the approaches to process improvement must not be too complex, must be easy to implement and must have a high probability of success. Therefore, to achieve quick success and serve as a prototype for other processes in the future, the Lean management concept is applied to reduce the cycle time of the tape and spacer pasting to the base frame process. In addition to various techniques offered by the Lean management concepts (i.e. 7 wastes, motion and time study, cause and effect diagram, 5 Whys, 5W1H and ECRS), some ergonomic techniques are also used to improve the workers' fatigue.

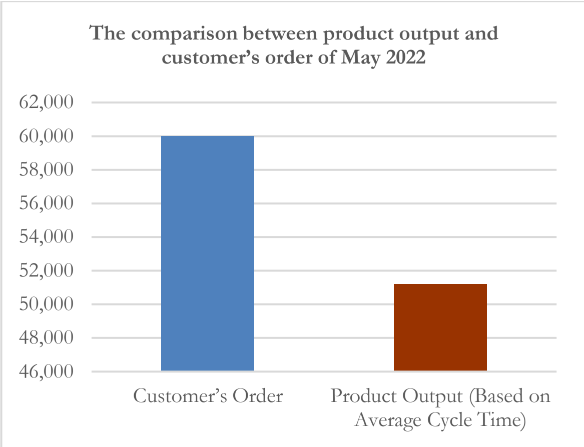

Fig. 1. Comparison of product output and customer order of May 2022.

Table 1. Average cycle time in each process.

Process	Average Cycle Time (second)	Takt Time (second)
Paste tape & spacer to base frame (Top)	73	65
Automatic visual inspection	65	65

Because this project is a prototype project and the tools used are basic tools that are easy to understand, the goal set by the management in consultation with the researchers is to improve the cycle time of the tape and spacer pasting to the base frame process by at least 5 per cent so that they can fulfil customer orders with overtime as usual. Moreover, if possible, better working environmental conditions are to be created according to the principle of ergonomics to reduce health problems caused by working in unsuitable postures.

The contributions of this research are as follows. The research contributes to the academic literature dealing with multi-objective optimisation of the manufacturing process in the field of industrial engineering. In addition, the method of studies and observations can provide a better understanding of most of the problems in the factory for each worker on the practical assembly line. Thus, the methodology of this research can suggest strategies to increase the efficiency of the workers and improve the overall productivity of the company. The 7-waste, 5W1H and ECRS principles as well as practical ergonomic concepts can be adapted to eliminate unnecessary movements in the work instruction and develop a new manuscript of the work instruction that is best suited for a particular situation.

The presentation sequence of the remaining Sections is as follows. Section 2 presents relevant literature on the Lean management concept, motion and time study technique, and basic ergonomics principles related to working conditions. Section 3 explains the methodology applied in this research. The implementation of the proposed concepts is illustrated in Section 4. Finally, Section 5 summarises the contribution of this research and provides a suggestion for further work.

2. Literature Review

Up to the present, a lot of research literature has been published on improving the efficiency and productivity of assembly line processes in various manufacturing industries both domestic and overseas through the application of motion and time study, as well as some popular diagrams, charts and tools involving in the industrial engineering field. The research works of Biswas et al. [1] proposed the process of study techniques for motion and time study to be recorded in a specific job. Athikulrat [2] improved productivity in the electronic parts assembly line by integrating the fundamental of hand motions with a micro-motion study analysis sheet to separate or eliminate worker hand movements in the processes. In addition, the two-handed process chart was conducted to study the waste movements and optimise the workflows for the case study of Sejpal [3], which addressed the assembly of a downlighter. This helped reduce worker fatigue and ultimately led to higher production output. Wankhede et al. [4] applied the motion study with the concept of MUDAS to eliminate waste in the assembly of canopy lamps. This was one of the Kaizen methods involved in the Lean management process. Gujar and Shahare [5] developed new jigs design to eliminate drawbacks and created new working procedures for the sheet metal manufacturing industry. The new design of methods significantly improved the quality of industry standards.

Suhardi et al. [6] highlighted the principles, concepts, methods, procedures and tools used for Lean manufacturing and the implementation of Value Stream Mapping (VSM), where the model could help identify wastes by separating value-added and non-value-added activities in the production process. Likewise, Sawassalung and Chutima [7] also analysed the process by comparing the ratio of value-added activities in all operations, which was indicated as the design standard time ratio (DSTR). The factor that affected the most was the operations that used labour rather than machining.

Chutima and Suphapruksapongse [8] presented a practical method for assembly line balancing using the algorithms, COMSOAL, for simulation analysis of the monitor assembly line. The simulation provided an in-depth computerised model of a real proposed system which gave a better understanding of the essential characteristics and behaviour of such a system for a given set of conditions. This could lead to more efficient analysis results.

Pertiwi and Astuti [9] explained how efficient ECRS methods can increase the balancing line of assembly production. In addition, Choojan and Chutima [10] designed a new working flow using the Lean concept and ECRS technique to improve the supplement parts on the assembly line in an automotive manufacturing company. Moktadir et al. [11] applied the working performance rating of each worker to establish a new effective process for leather product operations. The applied theories enabled guidance with tools such as a questionnaire technique of 5W1H came to analyse the problem rationally with the ECRS principle to develop new working procedures under principles of motion economy as well as line balancing conditions.

Rawangwong et al. [12] have introduced and revealed how ergonomic working methods and areas, as well as environmental conditions, affected worker fatigue during long-time repetitive work in production processes. Malashree et al. [13] described that worker fatigue could sufficiently affect worker efficiency. Therefore, the study of ergonomic theories such as working posture using Rapid Entire Body Assessment (REBA) was a method that investigated the whole-body system and helped indicate better posture for a particular task. In addition, Yusuff and Abdullah [14] conducted a case study on the application of the Lean 6S ergonomic principle, which correlates Lean with safety and identified risk factors using the Rapid Upper Limb Assessment (RULA). The assessment factor from RULA analysis can provide a rapid assessment of the musculoskeletal system based on the working posture to reduce the risk of injury to the worker.

From various methods and techniques to improve the efficiency and productivity of assembly line processes discussed in previous literature, strategies with complex data based on the man-machine interactions on assembly lines were employed. In contrast, this study focused on the manual assembly process, which was performed solely by man. In this respect, this research could be considered a new study that combined practical Lean management with simple ergonomic principles to create a new vision of the method structure. Not only could this study create a new work environment structure but also considered the efficiency of individual workers as well. Of course, this could be a prototype for helping small manufacturers that were seriously affected by the COVID-19 pandemic to survive and achieve their goals over a period of time.

3. Methodology

The approach to reducing the cycle time begins with studying the workflow of the base frame (Top) assembly process as shown in Fig. 2. The average cycle time of the process is determined by direct time measurement [15]. The current work instruction used in the assembly process is carefully reviewed and then modified to reduce unnecessary and inappropriate motions of workers. Moreover, the work behaviour of workers (e.g. hand movement, picking and placing components on the base frame) is also observed to find ways to improve the ergonomics and environment of the workspace. The work instruction used in explaining in detail how to paste tape and spacer properly to the base frame (Top) consists of 13 steps as shown in Table 2. It is noticeable that each step consumes different operations times, depending on the activities inside.

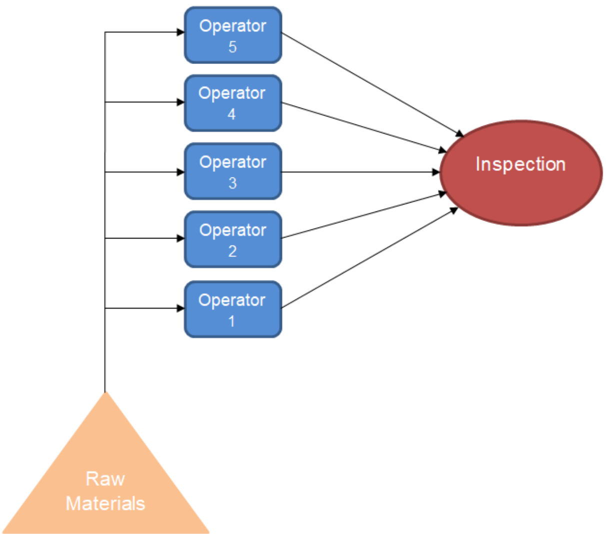

Fig. 2. Flow diagram of the production process.

Table 2. Work instruction of the tape and spacer pasting to the base frame (Top) assembly process.

Description of the work instruction	Average CT
1. Hold and touch the 3M sheet 2 times, then pick up the base frame (Top) from the base frame package and put it on the jig.	7.57
2. Peel off the tape from the base sheet.	2.69
3. Paste the tape on the base frame (Top). After that, press on the release liner of tape 2 times upwards with the rubber and peel off the release liner of tape.	10.76
4. Peel off the release liner of tape and paste it onto the base counting sheet.	6.24
5. Peel off the spacer from the base sheet.	2.41
6. Paste the spacer from the base frame (Top) upwards. While pasting the spacer, use the finger to press on the release liner of the spacer 1 time.	8.58
7. Peel off the spacer from the base sheet.	2.48
8. Paste the spacer from the base frame (Top) upwards. While pasting the spacer, use the finger to press on the release liner of the spacer 1 time.	8.58
9. Pick up the pusher jig and put it on the product. After that, press on the pusher jig on all 2 sides 2 times by the roller.	7.92
10. Take off the pusher jig from the product.	2.70
11. Pick up the plate overlay and place it on the product to check the complete 3 positions.	4.52
12. Pick up the plate from the product. After that, pre-peel by tilting the spacer 45° to check that the spacer is firmly connected to the base frame (Top).	5.83
13. Pick up the base frame (Top) from the jig and put the product on the base frame bar.	2.85

3.1. Data Collection

The data related to the cycle time of the assembly process of the automobile audio monitor base frame (Top) were collected from 20 samples per worker during May 2022. At that time, five workers were hired to work in this process. The statistical analyses of data are computed by the Minitab software. The average cycle time of each worker is shown in Table 3. It is observed that the average cycle times of the workers are relatively varied, ranging from 67.58 to 78.66 seconds. Note that Worker1 and Worker5 are semi-skilled workers who have been working in this process for a few months, whereas the others are newly employed. It is obvious that all workers spent more operations time than the specified tack time (65 seconds). To examine whether there are statistical differences in the average values of the cycle times from different workers, the one-way analysis of variance (ANOVA) is applied to the set of collected data. Since the null hypothesis (Ho) is rejected, it is inferred that at least the average cycle time from one worker is different from the others at a 95% confidence interval [16]. After that, the Fisher Pairwise comparison based on the LSD method is further conducted to categorise workers with no significantly different average cycle times into the same groups. The result shows that individual workers complete the same assembly process with different average cycle times than the others (Fig. 3). Moreover, no workers statistically spend the amount of operations time close to the others, making it impossible to classify any of them into the same group.

Table 3. Worker grouping based on average cycle times.

No. Workers	N	Mean	Grouping
Worker4	20	78.66	A
Worker3	20	76.52	B
Worker2	20	74.43	C
Worker1	20	68.48	D
Worker5	20	67.58	E

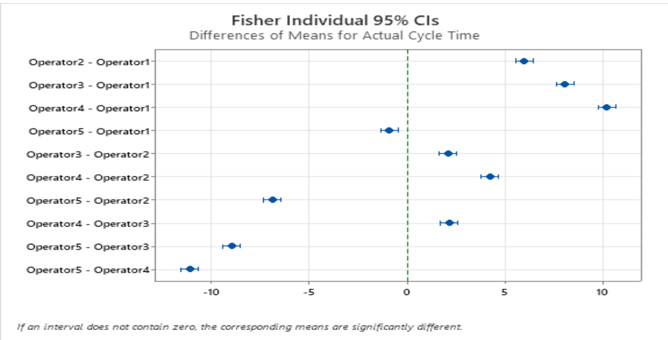

Fig. 3. Fisher pairwise comparisons on the average cycle times of workers.

3.2. Analysis and Discussion

As mentioned earlier that the average cycle time to complete one unit of the base frame (Top) assembly by any worker (i.e. Worker1 - Worker5) is statically different from the others. In addition, they all cannot complete the given assembly tasks within a specified takt time. However, the performance of these workers could be sorted in descending order of the average cycle times as follows: Worker4 > Worker3 > Worker2 > Worker1 > Worker5. Regardless of statistical consideration, the differences in the average cycle times can be simply classified into two groups based on the length of time working in the process, i.e. (1) high-value group (comprising Worker4, Worker3 and Worker2) in which the average cycle times of workers are greater than 70 seconds, and (2) the low-value group (comprising Worker1 and Worker5) in which the average cycle time of workers are between 70 and 65 seconds. Consequently, one worker from each group with the highest (Group 1) and lowest (Group 2) average cycle times is selected as a representative to investigate the root causes of the problem. From observing the assembly operations performed by the two representative workers over a long period through video recording playbacks, it is noticeable that the motion steps of the left and right hands of the workers are more or less the same during the assembly operations, as they follow the work instruction they have been trained before allowing them to work in the production line (as shown in Table 4).

Table 4. Two-handed process chart of the selected worker for the base frame (Top) assembly.

Product Assembly by Paste Tape and Spacer to Base Frame (Top)					
Left Hand			Right Hand		
No.	Description of the activities	Symbols	No.	Description of the activities	Symbols
		○ ⇨ D □ ▽			○ ⇨ D □ ▽
1.	Hold the 3M sheet 2 times		1.	Hold the 3M sheet 2 times	
2.	Touch the 3M sheet 2 times		2.	Touch the 3M sheet 2 times	
3.	Pick up the base frame		3.	Idle	
4.	Place the base frame onto the jig		4.	Hold the jig	
5.	Hold the jig		5.	Pick up the tweezer	
6.	Idle		6.	Peel off a tape from the base sheet	
7.	Hold the base frame		7.	Paste a tape onto the base frame	
8.	Press on the release liner of tape		8.	Idle/Hold the tweezer	
9.	Hold a tape/the base frame		9.	Press on the release liner of tape 2 times	
10.	Hold a tape/the base frame		10.	Peel the release liner of tape	
11.	Touch/Swipe the release liner of tape		11.	Hold the release liner of tape	
12.	Hold the sheet		12.	Paste the release liner of tape to the sheet	
13.	Idle		13.	Peel a spacer from the base sheet	
14.	Press on the release liner of spacer		14.	Paste a spacer onto the base frame (R)	
15.	Idle		15.	Peel a spacer from the base sheet	
16.	Press on the release liner of spacer		16.	Paste a spacer onto the base frame (L)	
17.	Idle		17.	Pick up the pusher jig	
18.	Idle		18.	Place the pusher jig onto the base frame	
19.	Idle		19.	Pick up the roller	
20.	Hold the jig		20.	Press the roller on the pusher jig (L) 2 times	
21.	Hold the jig		21.	Press the roller on the pusher jig (R) 2 times	
22.	Idle		22.	Take off the pusher jig from the product and put it on the tray	
23.	Idle		23.	Pick up the plate overlay	
24.	Hold the jig		24.	Put the plate overlay onto the product	
25.	Hold the product		25.	Point to 3 positions on the product to check on the overlay jig, spacer, tape	
26.	Hold the product		26.	Take off the overlay plate to the sheet	
27.	Hold the product		27.	Pre-peel the release liner of spacer (L)	
28.	Hold the product		28.	Pre-peel the release liner of spacer (R)	
29.	Pick up the base frame assembly from the jig		29.	Hold the tweezer	
30.	Idle		30.	Place the base frame assembly to the base frame bar	
31.	Idle		31.	Place the tweezer	

3.2.1. Root-causes Analysis

To solve the problem of the inability to work within a given cycle time and also to provide basic knowledge among workers, as promised to management, a team is formed consisting of researchers, workers and

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supervisors of the assembly process. To facilitate cooperation among team members and enable everyone to know what they are doing, the researchers train everyone in basic decision-making and Lean techniques. Then, several brainstorming sessions are conducted to identify the root causes of the problem. The 5 Whys in conjunction with the Cause and Effect diagram are applied to identify all root causes and sub-causes. The 4M1E technique (i.e. Man, Machine, Method, Material and Environment) is used as a starting point for establishing guidelines to identify the root causes of the problem within the cause-effect diagram. An example of the 5 Whys questions with the corresponding answers is exemplified in Table 5. The pictorial representation of the Cause and Effect diagram is depicted in Fig. 4.

Table 5. 5 Whys root causes analysis for the production exceeded the cycle time problem.

5 Whys		
	Why	**Reason**
Why 1	Why do the workers have a longer average actual cycle time than the standard time?	Because the workers are over-moving and the working performances are slowing down over time.
Why 2	Why are the workers over-moving and the working performances slowing down over time?	Because the workers get fatigued over a period.
Why 3	Why do the workers get fatigued over a period?	Because the workers lack enthusiasm and linger while working because of the prolonged adoption of unhealthy working posture.
Why 4	Why do the workers lack enthusiasm and linger while working because of the prolonged adoption of unhealthy working posture?	Because the workers lack motivation owing to different personality and behaviour.
Why 5	Why do the workers lack motivation owing to different personality and behaviour?	Because the workers lack training in working discipline and standard principles toward the company culture.

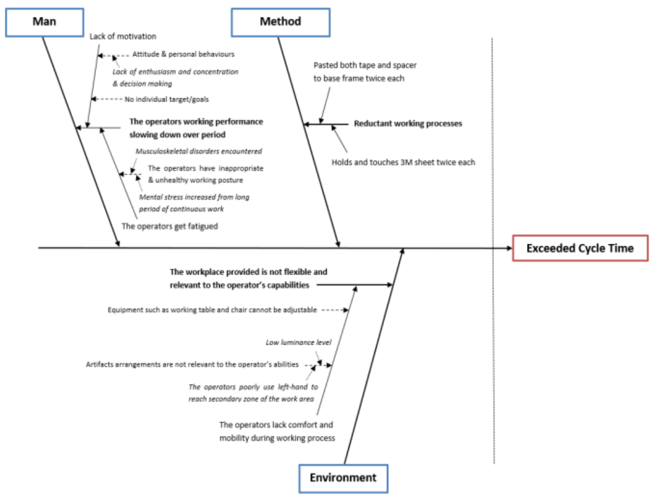

Fig. 4. Cause and Effect diagram for the production exceeded the cycle time problem.

According to the 5 whys and Cause and Effect diagram, the analysis of the possible outcomes was done in a prior discussion with the production team. The result was that the workers' performance decreased over time due to fatigue. Therefore, new appropriate work instructions and environment design were considered to reduce the workflow and the inconvenience of the workbench design.

It is obvious that most manufacturing industries in Thailand, including the company of interest, have been facing enormous difficulties since the COVID-19 pandemic. In order to survive economically, the company has to reduce the number of employees. Often, workers in the production line have to change their roles and jobs according to their competencies in order to finish the workpieces according to the product requirements. Such job rotation inevitably leads to lower yields and poorer product quality [17]. Under irregular working conditions, workers often need to be retrained from time to time. As a result, workers' work experience and skills may be lost when the job responsibilities change. Worse still, when urgent situations arise, such as a significant production backlog, new workers who may have no experience or have never been trained must be hired to fill the line. Because the work skills and experience of the newcomers are not adequate or equivalent to the trained ones, it causes the cycle time to exceed the standard time.

It is worth mentioning that the physical and mental health of the workers is another important factor to realise the achievement of the production target of the company, i.e. lowering the cycle time [18]. Since the quality and quantity of the assembly products are greatly dependent upon manual workers, they should be physically and mentally prepared. In reality, the performances of the workers could be undermined by their physical problems and/or psychological frustration. This could inadvertently affect the production efficiency of the company or cause excessive cycle time of the process [19]. Moreover, workers with good talent but lack commitment, dedication and concentration may not be able to support the achievement of the production goal as well.

3.2.2. Posture and Work Environment Analysis

Workspace and environmental conditions are essential factors for manufacturing high-quality products. Generally, a workspace should design to be comfortable and effective for performing long-time repetitive work [20]. In this factory, each workspace consists of a work table and a chair. Also, the related main equipment and tools are normally installed and located on the right-hand side of the work table or at suitable positions based on the design by the team of foreign engineers during the line setups.

The principles of motion and time study, as well as ergonomics, should be taken into account in workspace design. From observing the manual work in the assembly of base frames (Top), all workers face non-smoothed movements in picking up the base frame from the base frame package, located on the left-hand side of the work area, and putting it on the jig with the left hand at the first operational step (step No.1). Similarly, in the final step (step No.13), the workers have to pick up the complete base frame (Top) from the jig and taking it to put on the base frame bar, located on the right-hand side of the working area, using the right hand. Superficially, it seems like there is no problem, but in reality, they are working under unnatural postures or aptitudes. This could result in anxiety and stress for the workers [21]. A possible reason is that most of the workers in the factory are right-handed.

Considering work chairs for the workers to sit and work, the fatigue of the workers while sitting at work for a long time is another vital factor that brings about a decrement in production efficiency. It is noticed that work chairs used in the factory cannot be rotated and are unadjustable. In addition, they have a smooth sitting surface and a relatively small size. Therefore, the effect of an ergonomically improper design of the workspace also causes delays during the assembly of the products as feedback from the workers. Cleanness, air and noise pollution, temperature, lighting, overcrowding, etc. are also examples of the environmental conditions that are considered under the safety regulations and health standards of the factory.

From the observation, during the prolonged period of continuous work, the workers are found to adopt unhealthy sitting postures as shown in Fig. 5, leading to immobility and discomfort, health problems such as musculoskeletal disorders, respiratory problems and psychological stress. This information is obtained from the number of consultations that the workers visit with the factory's nurse. This problem could promote degenerate fatigue and loss of productivity. However, there is no ideal posture that works best for all situations. Nevertheless, some ergonomic principles can help prevent the permanent adoption of poor working postures by identifying suitable postures. For example, the boundary between the worker and the work area as well as the height of the desk and chair, must be set up appropriately as shown in Fig. 6. As a result, properly designed equipment that meets the working standard and requirements is brought in.

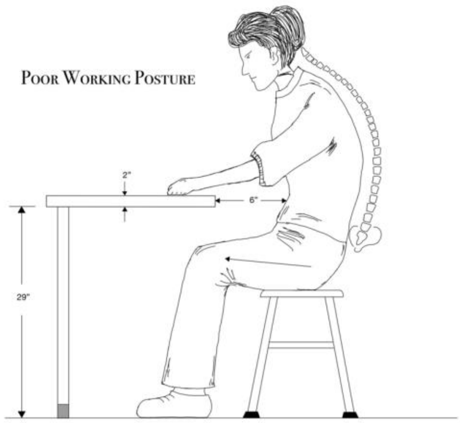

Fig. 5. Poor working posture of the worker.

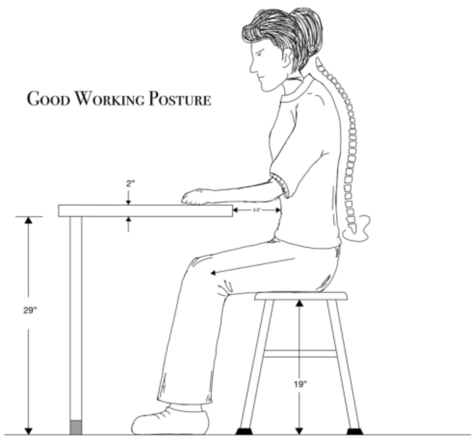

Fig. 6. Good working posture of the worker.

The level of brightness is considered in relation to the standards and assessed through a list of factors and worker's requirements based on the principle of ergonomics as follows [22]:

- Luminance should be appropriate for different types of work.
- Positioning of lights should prevent light reflection on the worker's eyes which can cause eye strain.
- Workers are right-handed, so light tubes should be placed in the opposite direction and at the opposite angle.

The general idea for the design and installation of the fluorescent tube at the workplace in the work area to provide a better performance is shown in Fig. 7.

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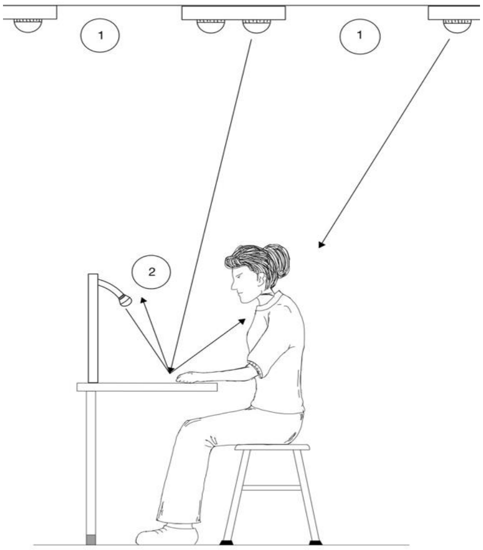

Fig. 7. General lights arrangement in the work area.

3.2.3. Analysis with 5W1H and ECRS Methods

The ECRS principle, one of the Lean management techniques for process improvement, consists of four actions: E (Eliminate) is the elimination of non-value added operations; C (Combine) is the combination of operations to be done by a single resource; R (Rearrange) is a reorder of operations in another more effective sequence; S (Simplify) is to simplify the operations with additional tools or supporting equipment [23]. This valuable technique can help the workers to enhance their performance and to modify their work instructions. In practice, the collection of answers obtained from the 5W1H analysis is necessary to support and supplement the ECRS technique to improve the process.

To effectively adjust the work instruction of the assembly process, the questionnaire technique; 7 wastes (i.e. unnecessary or improper movements), 5W1H (What, Who, Where, When, Why, and How); and the ECRS techniques are applied to consolidate and analyse the information about the problems encountered in order to modify and reduce the worker's movements while working as much as possible [24]. The detailed lists of each 5W1H question together with the descriptive answers, corresponding to each question, for steps No.1, No.2, No.3, No.9 and No.13 have been reported in Tables 6 - 10, respectively. Consolidation of the observation of the workers' movements and discussion with the production teams revealed that there was a reduction in work in steps No.1, No.3 and No.9. It was also found that working steps No.2 and No.13 could not be carried out smoothly for the workers as all the workers were right-handed. As a result, the modified work instruction is developed in place of the current one.

Table 6. Detailed lists of 5W1H questions with correspondingly descriptive answers and the results of ECRS analysis for step No.1.

5W1H	Questions	Answers
What	What is done in procedure No.1?	The worker holds the 3M sheet 2 times and touches the 3M sheet 2 times.
Why	Why is it needed to hold and touch the 3M sheet twice each?	Because it is a traditional practice used by workers.
Where	Where is the work done?	The working position has been placed in the arranged area in a clean room.
Why	Why should it be done here?	The work is performed according to the location and procedures of the factory layout.
Who	Who does the work?	The assembly process worker.
Why	Why does she do it, cannot use m/c?	In this procedure, the use of m/c doesn't need to require.
When	When is the work done?	At the beginning of the product assembly process.
Why	Why it must be done in this procedure, can it be done in another procedure?	It cannot be changed according to the working instructions.
How	How is the work done?	The worker holds and touches the 3M sheet before starting the assembly process.
Why	Why is it being done this way?	Help to remove dust and make sure that their gloves are not sticky before picking up the base frame.
Solution (Simplify)	Can this step be done with other way?	Reduce the number of times to hold and touch the 3M sheet to 1 time each.

The workers normally hold the 3M sheet 2 times and touched the 3M sheet 2 times to ensure the cleanliness of gloves before beginning the assembly process. However, in a clean room atmosphere, it is hardly found that dust or dirt can make the worker's gloves dirty. From the researchers' perspective along with the discussion with the company manager, it is found that in this regard, the workers have to spend more unnecessary movements and strain their hands more quickly resulting in workers' fatigue when they work for long periods of time. Therefore, to reduce the hand movements to as least as possible, the number of times to hold the 3M sheet and to touch the 3M sheet is reduced to 1 time each only.

Table 7. Detailed lists of 5W1H questions with correspondingly descriptive answers and the results of ECRS analysis for step No.2.

5W1H	Questions	Answers
What	What is done in procedure No.2?	After holding and touching the 3M sheet, the worker starts the assembly process by picking up the base frame from the base frame pack.
Why	Why is it being done this way?	Because it is a traditional practice used by workers.
Where	Where is the work done?	The working position has been placed in the arranged area in a clean room.
Why	Why should it be done here?	The work is performed according to the location and procedures of the factory layout.
Who	Who does the work?	The assembly process worker.
Why	Why does she do it, cannot use m/c?	In this procedure, the use of m/c doesn't need to require.
When	When is the work done?	The beginning of the assembly process.
Why	Why it must be done in this procedure, can it be done in another procedure?	According to the working instruction, it is the first step of the assembly process.
How	How is the work done?	The worker picks up the base frame and places the base frame onto the jig by using the left hand. Then, the worker picks up the tweezer using the right hand.
Why	Why is it being done this way?	The worker followed the working instruction from the customer order.
Solution (Rearrange)	Can this step be done with other way?	Change the working area by moving the base frame package to the right side and the base frame bar to the left side in order to start by picking up both the base frame and the tweezer using the right hand.

Due to the aptitude of the workers, most of them are indicated as right-handed. It is noticed that it is difficult and uncomfortable for the workers to pick up the base frame and place it onto the jig by using their left hand. With such conditions, uncomfortable levels and decelerate work motivation could be promoted. Therefore, a useful solution would be to address the needs of the workers by rearranging and allocating the artefacts in the workspace. This is accomplished by moving the base frame package to the right side and the base frame bar to the left side, and then starting to pick up both the tweezer and base frame with the right hand. Not only can this new procedure reduce work steps, but also a better work performance is achieved.

Table 8. Detailed lists of 5W1H questions with correspondingly descriptive answers and the results of ECRS analysis for step No.3.

5W1H	Questions	Answers
What	What is done in procedure No.3?	Paste a tape on the base frame. After that press on the release liner of tape 2 times upwards with the rubber and peel off the release liner of tape.
Why	Why is it needed to press on the release liner of tape 2 times?	Because it is a traditional practice used by workers.
Where	Where is the work done?	The working position has been placed in the arranged area in a clean room.
Why	Why should it be done here?	The work is performed according to the location and procedures of the factory layout.
Who	Who does the work?	The assembly process worker.
Why	Why does she do it, cannot use m/c?	The product is simple but does need hand-craft skills and the specific tool as the rubber tweezer. The use of machinery causes high production costs, so it might not be suitable for investment.
When	When is the work done?	In procedure #3 of the working process, which is the highest cycle time in the process.
Why	Why it must be done in this procedure, can it be done in another procedure?	It cannot be changed according to the working instructions.
How	How is the work done?	The worker presses on the release liner of tape 2 times upwards with the rubber tweezer.
Why	Why is it being done this way?	Make sure that the tape sticks to the base frame.
Solution (Simplify)	Can this step be done with other way?	Reduce the number of times to press the release liner of tape upwards to 1 time.

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In this step, the manager appraises that the workers usually waste their operations time by pressing the release liner of tape 2 times, in which the work instruction is only mentioned in such a way that the workers must ensure that the release liner tape is properly stuck to the base frame and does not cause defection to the product. As a result, the number of presses to the release liner of tape can be reduced to only 1 time.

Table 9. Detailed lists of 5W1H questions with correspondingly descriptive answers and the results of ECRS analysis for step No.9.

5W1H	Questions	Answers
What	What is done in procedure No.9?	Pick up the pusher jig and put it on the product. After that press on the pusher jig on all 2 sides 2 times by the roller for fixing the spacer to the base frame.
Why	Why is it needed to press on the pusher jig on both sides twice each side?	Because it is a traditional practice used by workers.
Where	Where is the work done?	The working position has been placed in the arranged area in a clean room.
Why	Why should it be done here?	The work is performed according to the location and procedures of the factory layout.
Who	Who does the work?	The assembly process worker.
Why	Why does she do it, cannot use m/c?	The product is simple but does need the specific tools such as the pusher jig and the roller. The use of machinery causes high production costs, so it might not be suitable for investment.
When	When is the work done?	In procedure #9 of the working process after pasting tape and spacer to the base frame completely.
Why	Why it must be done in this procedure, can it be done in another procedure?	It cannot be changed according to the customer's requirements.
How	How is the work done?	The worker presses on the pusher jig on all 2 sides 2 times by the roller for fixing the spacer to the base frame.
Why	Why is it being done this way?	Make sure that the spacer sticks to the base frame.
Solution (Simplify)	Can this step be done with other way?	Reduce the number of times to press the pusher jig on all 2 sides by the roller to 1 time on both sides.

Table 10. Detailed lists of 5W1H questions with correspondingly descriptive answers and the results of ECRS analysis for step No.13.

5W1H	Questions	Answers
What	What is done in procedure No.13?	Pick up the base frame from the jig and take the base frame to put on the base frame bar.
Why	Why is it needed to press on the pusher jig on both sides twice each side?	Because it is a traditional practice used by workers.
Where	Where is the work done?	The working position has been placed in the arranged area in a clean room.
Why	Why should it be done here?	The work is performed according to the location and procedures of the factory layout.
Who	Who does the work?	The assembly process worker.
Why	Why does she do it, cannot use m/c?	In this procedure, the use of m/c doesn't need to require.
When	When is the work done?	Procedure #13, which is the final procedure of the assembly process.
Why	Why it must be done in this procedure, can it be done in another procedure?	According to the working instruction, it is the last step of the assembly process.
How	How is the work done?	The worker picks up the base frame from the jig with the left hand while holding the tweezer in the right hand. After that, the worker puts the base frame to the base frame bar on the right side and then puts down the tweezer.
Why	Why is it being done this way?	The worker followed the working instruction from the customer's order.
Solution (Rearrange)	Can this step be done with other way?	Before picking up the base frame from the jig, first, the operator should put down the tweezer. After that, use both hands to pick up the base frame carefully and put the base frame into the base frame bar on the left side.

A similar approach is applied to reduce workers' hand movements as much as possible without neglecting the context of the standard working principle. The workers need to press on the pusher jig on all 2 sides 2 times using the roller to fix the spacer to the base frame.

However, no one can confirm whether rolling on the pusher jig multiple times will efficiently give better performance or not. After monitoring the work for a long period, it is decided that the number of times for rolling the pusher jig on all sides be reduced to 1 time each only.

In this procedure, the workers pick up the base frame from the jig using the left hand while holding the tweezer in the right hand. Then, the workers put the base frame to the base frame bar on the right side and put down the tweezer afterwards. It is found that it is impractical for the workers to work in this way using their left hand since an accident could occur leading to product fall and damage. Hence, picking up the base frame with both hands is a much safer procedure.

4. Results

Following the results of the analysis of the assembly process for the automobile audio monitor base frame (Top), some significant adjustments are made to the workspace and environmental conditions, as well as the work procedures, to improve the productivity of the company.

4.1. Workspace and Environmental Conditions

An overview of the workspace after adjusting the assembly of the automobile audio monitor base frame (Top) process can be displayed in Fig. 8. It is noticed that most essential materials, tools and equipment are located in more or less the same position as before. However, only the base frames (Top) before and after pasting tape and spacer are switched from left to right hand, and vice versa. Such a swap makes the workers' hand movements more efficient under new operating circumstances than in the original one, especially for tedious repetitive work. One possible reason for this is that almost all workers working in this factory are right-handed rather than left-handed. Thus, such an adapted workspace help reduce the cycle time for product assembly.

Since the environmental conditions in the factory, such as cleanliness, air and noise pollution, temperature, lighting, overcrowding, and so on, are based on health and safety standards, then not much issue needs to be worried about these matters. Nevertheless, the workers' fatigue, which is related to the non-ergonomic workspace, is one thing that should be sought out to enhance the performance of the workers. From the discussion with the manager on workers' feedback, it is found that the new design of the work chair should be used since it is more comfortable and effective for long-sitting work than the original one. This is due to no slipping when sitting, not being tired when working for a long time and relaxation of the muscles around the buttocks. In addition, with the new chair, the seat can also be rotated both clockwise and counterclockwise, which affects the adjustable height of the seats [25]. Observation has shown that workers can adjust the new chair to their height as well as the acknowledgement of good working posture in the training to better and constantly adapt to the proper working conditions. Therefore, a new design for the work chair is chosen as shown in Fig. 9. In addition, some works need more lighting than normal. It is obvious that the additional lights provide a better view for the workers and create an appropriate outlook due to the adequate brightness when assembling such a product. Therefore, the desk clamp magnifying lamp and fluorescent tube are also additionally installed as exhibited in Fig 10.

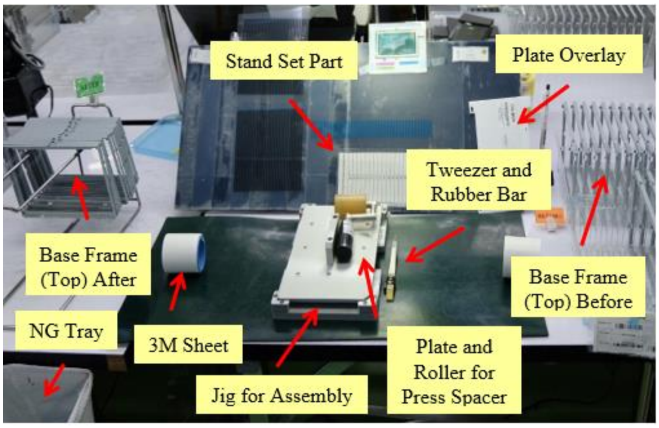

Fig. 8. Workspace for the base frame (Top) assembly after the adjustment.

Fig. 9. The comparison of a new design of the work chair and the original chair: (a) top view, (b) side view and (c) in service.

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(a) (b)

Fig. 10. More light at work provided by (a) new desk clamp magnifying lamp, and (b) fluorescent tube added up in the workspace layout.

4.2. Modified work instruction

Due to the impressive results demonstrated in the assembly process of the automobile audio monitor base frame (Top) arising from the application of Lean management tools and techniques, the analysed work steps are previously presented in Table 6 to Table 10. In general, the modified work instruction is quite similar to the original one, except for steps No.1, No.3, No.9 and No.13. The modified work instruction suggests switching from the left hand to the right hand when starting to pick up the base frame (Top) from the base frame package and putting it on the jig, and still using the right hand to pick up the tweezer, in step No.1, is achieved by adjusting the workspace (moving the base frame package to the right side and the base frame bar to the left side). However, holding and touching the 3M sheet in step No.1, pressing on the release liner of tape with the plastic edge tweezers in step No.3, and pressing on the pusher jig on all 2 sides by the roller in step No.9, respectively, are also carried out to reduce from 2 times to only 1 time. Moreover, in step No.13, the worker has to put down the tweezer in the right position of the table, before picking up the base frame from the jig. Then, he has to carefully pick up the base frame with both hands and put it into the base frame bar on the left side. Although such adjustments have a direct impact on the reduction of product assembly average cycle time, the quality of the product must also be verified after the assembly is completed to ensure customer satisfaction. The quality control of the base frame (Top) after pasting tape and spacer have to be examined by using both visual and automatic inspection as well as warning to prevent worker error and detect defects that may occur during processing before packaging and delivery. With this scheme, all poor quality and non-standard products are immediately rejected for rework, which means that there are no damaged product outputs. Hence, to confirm the effectiveness of this quality control scenario, the total quantity of finished products (100%) is continuously checked. Furthermore, it is also found that the average cycle time for such inspections is fairly constant and also corresponds to the given takt time.

Table 11. Modified work instruction of the paste tape and spacer to the base frame (Top) assembly.

Description of the Modified Work Instruction	Average CT
1. Hold and touch the 3M sheet 1 time, then pick up the base frame (Top) from the base frame package and put it on the jig.	6.90
2. Peel off the tape from the base sheet by picking from the right side to the left side so as not to damage the tape.	2.21
3. Paste the tape on the base frame (Top). After that, press on the release liner of tape 1 time upwards with the rubber and peel off the release liner of tape.	8.82
4. Peel off the release liner of tape and paste it onto the base counting sheet.	5.56
5. Peel off the spacer from the base sheet by picking from the right side to the left side so as not to damage the spacer.	2.31
6. Paste the spacer from the base frame (Top) upwards. While pasting the spacer, use the finger to press on the release liner of the spacer 1 time.	9.64
7. Peel off the spacer from the base sheet by picking from the right side to the left side so as not to damage the spacer.	2.68
8. Paste the spacer from the base frame (Top) upwards. While pasting the spacer, use the finger to press on the release liner of the spacer 1 time.	8.01
9. Pick up the pusher jig and put it on the product. After that, press on the pusher jig on all 2 sides 1 time by the roller.	5.72
10. Take off the pusher jig from the product.	1.88
11. Pick up the plate overlay and place it on the product to check the complete 3 positions.	6.18
12. Pick up the plate from the product. After that, pre-peel by tilting the spacer 45° to check that the spacer is firmly connected to the base frame (Top).	5.74
13. Pick up the base frame (Top) from the jig and put the product on the base frame bar.	2.49

4.3. Implementation Results

As mentioned earlier, the improvements in workflow, workspace and environment in the assembly of the audio monitor base frame (Top) are based on the application of the Lean management techniques. In order to verify whether these adjustments lead to a reduction in the average cycle time of the product without negatively affecting the quality of the product, a comparative study is carried out. Based on the results obtained before (May 2022) and after (October 2022) the improvements, the average cycle time of each worker (5 workers in total) is presented in Table 12 and Fig. 11. The determination of product output based on customer orders, takt time and average cycle time before and after the improvement is also shown in Fig. 12.

Table 12. Comparison of each worker's average cycle time before and after improvements.

No. Workers	Average Cycle Time (second), Before Improvement	Average Cycle Time (second), After Improvement	Time Diff. (second)
Worker1	68.48	64.32	4.16
Worker2	74.43	69.24	5.19
Worker3	76.52	70.25	6.27
Worker4	78.66	73.41	5.25
Worker5	67.58	63.47	4.11
Total	**73.13**	**68.14**	**4.99**

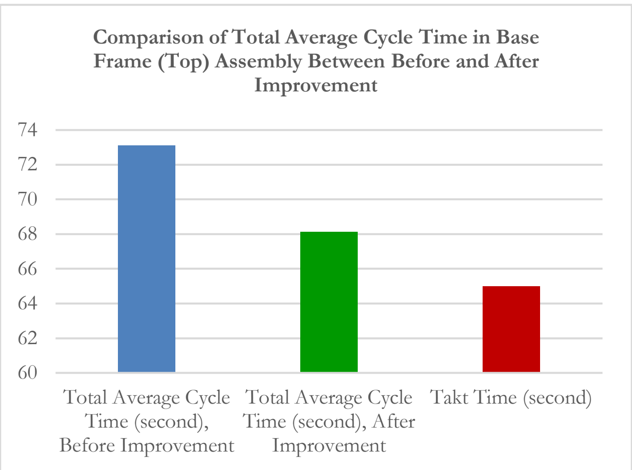

Fig. 11. Comparison of average cycle time to complete a unit of base frame (Top) assembly before and after improvements.

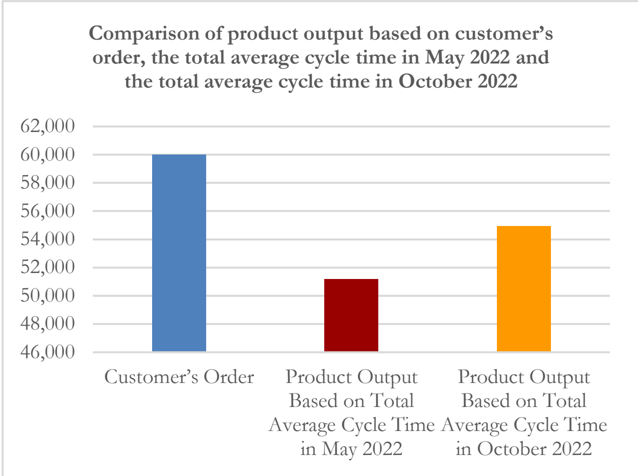

Fig. 12. Comparison of product output based on customer's order before and after improvements.

According to the results shown in Fig. 11, the average cycle time after the improvements is relatively lower than the original one. More specifically, the average cycle time decreases by about 6.82% from 73.13 seconds to 68.14 seconds, while the takt time is 65 seconds. Fig. 12 shows that production in October 2022 increases from 51,196 units/month to 54,945 units/month or an increase of 7.32% compared to May 2022. Although this quantity is still lower than the customer's order (60,000 units/month), this problem can be easily remedied by additional overtime.

It is obvious that the workers in the low-value group as classified in Section 3.2 (i.e. Worker1 and Worker5) can achieve the target of a cycle time of 65 seconds, while the workers in the high-value group (i.e. Worker2, Worker3 and Worker5) still complete the assembly job with exceeding takt time. Especially Worker4 (highest cycle time) has some difficulties with the new work instruction compared to Worker5 (lowest cycle time) due to least experience, unenthusiastic and mental condition (e.g. obsessive-compulsive disorder). However, the management and project team members expect that within one or two months after the implementation of the new work instruction, all workers, especially those in the high-value group, will perform significantly better than it is now because they will receive proper training under the new work instruction which is more effective. In addition, they will gain more work experience. As a result, the cycle time of the assembly process should soon be reduced to less than the specified task time (65 seconds). Even though the productivity of the improved assembly process does not seem to be completely successful at the moment, the productivity of the company looks much better and more satisfactory for the management and customers. The number of backorders and customer complaints reportedly reduces substantially. In addition, workers are more satisfied with their work, especially in terms of a better working environment and less fatigue from work.

In accordance with the long-term project monitoring plan, an interview was conducted with the management team on the continuous results process of the new design structure. After the implementation, the feedback was initially quite good, especially in terms of health, safety, comfort and job satisfaction. The improvements were positive and the workers have become accustomed to the new way of working. As a result, it was reported that the company achieved a productivity increase of 10% by the end of 2022.

5. Conclusions

The objective of this study is to improve productivity by reducing the cycle time in the company's assembly process through the implementation of the Lean and ergonomic concepts. The product under study is the base frame of an automotive audio monitor (Top), which is assembled manually in 13 steps using tape and spacers. In recent years, the factory has faced the problem of not being able to produce the quantity of product to meet customer orders, resulting in a loss of profit and customer confidence. To alleviate the problems, the research starts by studying the workflow and the hand and arm movements of the workers. The two-hand process chart is used to identify the improper movements of the workers during the assembly of the products. In addition, the workspace, including tables, chairs, paths for walking and moving the products, associated tools and equipment, and environmental conditions such as cleanliness, air and noise pollution, temperature, lighting, overcrowding, etc. during the assembly process are observed for further improvements. It is discovered that, under the 4M1E principle, lacking individual goals, musculoskeletal disorders encountered, a difference in body shapes and psychological stress from a long period of continuous work are the root causes of the Man. While, pasting tape and spacer to the base frame twice at a time, and holding and touching the 3M sheet twice at a time are the root causes of the Method. Lastly, the root cause of the Environment composes of non-adjustable work tables and chairs, low levels of brightness, and poorly used workers' left-hand to reach the secondary zone of the workspace. The 5W1H and ECRS techniques are applied to modify the work instruction and workspace. When considering the work chair, the ergonomic design is brought to reduce the workers' fatigue, i.e. able to be rotated and adjustable, not slipping while sitting, not being tired when working for a long time, and relaxing the stress of the muscles around the buttocks. Moreover, to increase the illuminance level, the desk clamp magnifying lamp and fluorescent tube are supplemented for extra utilisation as needed. After the improvement, it is found that the average cycle time decreases by approximately 6.82% from 73.13 seconds to 68.14 seconds. In terms of the product outputs, the amount is increased from 51,196 units/month to 54,945 units/month or a 7.32% improvement. Although the target customer's orders to be achieved is 60,000 units/month, this problem can be easily solved by adding overtime. It is worth mentioning that after the improvement, the satisfaction level of workers has improved remarkedly and the management is satisfied with the solution, especially in the situation where labour is scarce during the COVID-19 crisis. Moreover, as recommended by [26] and [27], when the market situation is back to what it used to be, introducing automation or robots into the assembly process is a way to increase production efficiency. Also, this option is less dependent on human labour.

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