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ANALYSIS OF THE WORKING TIME OF THE SELECTED TECHNOLOGICAL PROCESS

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Purpose: The purpose of this paper is to analyze the impact of process reorganization and the application of the MTM-1 method on the production efficiency of selected operations in the manufacturing of screws. The study aims to assess the changes in production time, reduction of non-standard activities, and improvements in motion economy and management
Design/methodology/approach: The objectives of this research are achieved through a combination of empirical investigation and the application of the MTM-1 method. The study encompasses an analysis of pre-existing production processes and their respective timings. The practical implementation of the MTM-1 technique is employed to reevaluate the process and derive optimized time values. The theoretical scope of the paper lies in process optimization and industrial engineering methodologies.
Findings: The research findings indicate a significant reduction in production time after the reorganization and the application of the MTM-1 method. The time required for individual operations decreased from an average of 12.88 minutes to 9.46 minutes, marking an efficiency gain of approximately 30%. Moreover, non-standard activities and unnecessary movements, such as excessive body, leg, and eye motions, were reduced by nearly 40%. The most time-consuming motions identified were walking and positioning. This study confirms the positive impact of process optimization on production efficiency and ergonomic improvements.
Research limitations/implications: While this research provides valuable insights into process optimization using the MTM-1 method, the study is limited to a specific production context. Further research could explore the application of similar methodologies in diverse manufacturing environments. Additionally, a broader range of metrics could be considered to comprehensively evaluate the impact of process changes.
Practical implications: The findings of this study hold practical implications for manufacturing industries. Implementing the identified process improvements and considering the principles of motion economy can lead to enhanced production efficiency and reduced ergonomic strain on workers. Companies can adopt the optimized practices and methods discussed in this paper to improve overall operational performance.
Social implications: The research's social implications revolve around the potential improvement in worker well-being and safety. By reducing non-standard activities and minimizing excessive motions, companies can contribute to improved workplace ergonomics and employee satisfaction. Additionally, the promotion of efficient production practices aligns with principles of sustainable manufacturing and responsible corporate behavior.

Originality/value: (mandatory) This paper contributes to the field of industrial engineering by showcasing the tangible benefits of applying the MTM-1 method in the context of screw production. The study's value lies in its practical insights into process optimization and the subsequent enhancement of production efficiency and worker comfort. This paper is relevant to researchers, practitioners, and professionals seeking to streamline manufacturing processes and improve workplace ergonomics.

Keywords: MTM-Method-Time Measurement, Lean Management, ergonomic improvements, production management, WCM.

Category of the paper: Case study.

1. Introduction

In the literature, there is no unequivocal term "process," which is often confused with concepts such as procedure, activity, or task. Every activity or set of activities can be presented as a process, during which, starting from an initial state or input, we obtain a result, i.e., an output enriched with added value that is meaningful to the customer. The definition of the process can be found in the PN-ISO technological standards, where a process is defined as: "a set of interrelated resources and activities that transform input into output" and produce a result that has value for the customer (Ossowski, 2012).

Production, on the other hand, involves manufacturing products from raw materials using various processes. It is a study of the processes required for manufacturing parts and assembling them in machines. A production process is one carried out in a facility to transform semi-finished products or raw materials into finished products. The art of transforming raw materials into finished products using various tools, machinery, production settings, and production processes is known as manufacturing (Singh, 2006).

Manufacturing is the creation of products from raw materials through various processing methods and equipment in operations organized according to a developed plan for the appropriate use of resources such as materials, energy, capital, and people. Products can be defined as all the results of human work, both tangible and intangible. Products can include various types of services, activities, organizations, and technological or organizational ideas. Production management is the execution and delivery of finished products or services. A manufacturing facility is a separate process that consists of one or several production systems. The process of producing products must take place in a specially designed, complex manufacturing process. This process is a component of all activities aimed at applying human thought to transform raw materials, materials, and semi-finished products into a product of the required quality. The production process also includes a series of research and development activities, as well as distribution and customer service. The manufacturing process includes operations such as (Kubiński, 2008):

1. Technological operations - assembly or disassembly of a product, involving a permanent change in the relative positions of the product's components.
2. Control or measurement operations - visual inspection, inspection, measurement, testing objects, and comparing the results with requirements.
3. Transportation operations - moving a product, material, or part from a warehouse or to a warehouse, as planned in the production process.
4. Storage and warehousing (storage) operations - during this operation, items are at rest and await further processing, inspection, or transport. This operation does not change the product's characteristics but requires a place for storage in a warehouse.

The model of the manufacturing process can be used to analyze the production process (Dwiliński, 2002) The structure of the system is the complexity of the relevant production factors. The criteria for this include the diversity of technological operations, such as levels of system efficiency (Gawlik, Plichta, Swić, 2013):

- Organizational level: The most important are the relationships between the company and the market. Factors affecting efficiency include the overall goals of the company, methods of measurement, and so on.
- Process level: The level of interdepartmental processes related to the development of new products, procurement, production, sales, etc.
- Job level: Where the processes are supervised by workers performing various tasks.

Process planning involves selecting production resources (machines, cutting tools, presses, devices, fixtures, measuring tools, etc.), determining the efficient sequence of operations, specifying changes in the form, dimensions, or finish of the machines, and defining operator actions. It also establishes an efficient sequence of production steps to minimize material handling, ensuring that work is done at minimal costs and maximum efficiency (Singh, 2006).

A good understanding of the principles of designing and implementing a technological process is fundamental to the success of any project. The main elements that make up a technological process are operations, procedures, and actions. An operation is the basic element of a process that aims to change the dimensions, shape, and properties of a given object. The operation is performed at a specific workstation by one worker or one crew without interruptions for other tasks. It also allows for the calculation of execution costs. We distinguish between simple operations, where the number of procedures is small and complex operations, which consist of several procedures. A procedure is a part of an operation that we perform without changing the work tools, without changing the processing parameters, or with a single setting and mounting. The division of operations into procedures is not always clear and necessary, for example, when conventional machines are used in the process, the division must be clear. However, if the technological process is designed for CNC machines or numerically controlled machine systems, this division is not always clear (Karpiński, 2004).

The structure of a technological process refers to individual operations that make up the discontinuity of the process and the gradual shaping. The discontinuity of the process involves using various methods and types of processing. To obtain a finished product with the correct dimensions, surface roughness, or properties, each operation must be carried out gradually, taking into account different processing methods. The following points illustrate the structure of a technological process (Bieniok, 2004).

1. Preliminary Operations - These include cutting of bar materials, straightening, and tapping.
2. Creating the machining base for further operations - This includes surface and hole machining. This base is prepared at the beginning of the process to machine all remaining surfaces later.
3. Performing rough and shaping operations - This involves removing damaged layers of material and shaping the object according to the engineering drawing.
4. Performing heat treatment or thermo-chemical treatment operations - This process involves obtaining changes in the properties of the surface layer of products subjected to treatment due to temperature, time, and the technological environment.
5. Performing finishing and precision machining operations - These methods include grinding, turning, milling, and milling.
6. Performing quality control operations - This operation may also occur during the process, after major machining operations.

In the machine industry, time standardization is the necessary amount of time required to complete a specific scope of work under the appropriate technical and organizational conditions of the plant, by a specified number of workers with designated qualifications. The issue of time standardization is related to optimizing the time required for individual tasks at a given workstation. The result of the proposed actions should be the selection of appropriate methods for standardizing work time to streamline the execution of specific tasks by employees.

Analytical measurement techniques allow for the determination of unit time and preparatory and finishing times for technological operations (Bieniok, 2004). Analytical measurement techniques include methods such as time study, workday photography, and video analysis, including snapshot operations.

Time study is a fundamental method for determining the main time or auxiliary time, which is a fundamental component of the unit time of a technological operation (Bieniok, 2004). This method involves measuring time using a stopwatch to record the duration and pace of the activities in the technological process. The purpose of this study is to measure the current duration of a given activity and determine the optimal duration of a specific operation to ensure the overall process is efficient (Jędrzejewski, Kocjan, 2021). The following elements are involved in conducting this study (Bieniok, 2004):

- Identifying the workplace and selecting the employee.
- Getting acquainted with management and workers, the methods used, the work environment, and the product.
- Breaking down the operation into elements.
- Determining the number of measurements.

During the observation of a particular operation, the duration of the operation is recorded. This activity should be repeated several times. Then, the arithmetic mean or weighted average is calculated. The result obtained determines the actual duration of a given operation cycle and forms the basis for the time standard. This method allows for the precise determination of the labor intensity of a specific stage in the technological process (Bieniok, 2004).

Workday photography is one of the oldest time measurement methods. Data from observations using this method illustrate various ways of performing tasks and are used to formulate the correct sequence of operations and the likelihood of irregularities in the process. Workday photography involves measuring times throughout an entire work shift for a specific employee. The duration of a particular activity is observed and later subjected to analysis. Based on this data, defects that occur at a particular workstation are identified, and possible solutions to the problem are suggested. A report is then prepared (Bartnicka, 2016). There are four types of workday photography (Bieniok, 2004):

1. Individual Workday Photography - In this case, the work of a single employee is assessed during a specific time frame.
2. Team Workday Photography - A team of workers who perform the same task is observed.
3. Route Photography - Several or dozens of workers performing tasks at a specific time of day on a specified route are observed.
4. Self-Photography - This method is the most time-consuming because the performer must document their workday photography over an extended period. It is primarily used for studying the time organization of managerial and office work.

Workday photography allows for the determination of elements such as task preparation and completion, the execution of simple tasks, and workstation operation. This method helps identify the causes of breaks and downtime and develops organizational and technical objectives to address them (Grabowska, Matela, 2021).

Video analysis involves recording images with a phone or camera. This method allows observers to see how a particular process or task is performed as if they were present at the production site.

Snapshot operation is one of the most popular methods for collecting information about the current state of a process. This technique belongs to statistical methods. To ensure reliable results that align with reality, as many attempts as possible should be made. In this method, numerous observations are made regarding the workforce, processes, and machines over a certain period. The goal of such work is to identify the structure of work and breaks for employees and machines (Mioduszewski, 2013). The application of snapshot operation methods requires meeting the following elements (Bieniok, 2004):

- Representativeness - Taking a sufficiently large sample of selected observations.
- Randomness - Randomly selecting observation moments.
- Causally Continuous - Making observations in situations considered routine.

The method of snapshot operations involves (Bieniok, 2004):

- Making random 2-second observations at appropriate times.
- Capturing observations within a specific work time frame.
- Recording the results of observations.
- Calculating the time utilization plan based on a predefined time classification.

The final results involve (Bieniok, 2004):

- Developing a time utilization plan expressed in percentages.
- Presenting the results in tables and diagrams.
- Confirming the credibility of the obtained results.
- Improving the specific element to minimize time losses.

The snapshot operation technique is one of the simpler methods of work time standardization. It allows for the simultaneous observation of several objects or dozens of them. The obtained results are representative when the correct research procedure is used.

Analytical and computational methods allow for the determination of execution time and preparatory-concluding time for a planned process (Katschenreiter-Praszkiewicz, 2015). Analytical-computational techniques are distinguished based on elementary movements and time standards. Time standards are understood as quantities of time needed to perform specific work operations the length of justified work breaks for an employee or the most favorable machine work conditions (Żukowski, Duczmal, 2007). The following standards are distinguished (Bieniok, 2004):

- Time standards establish the amount of time needed to complete a specific task.
- Efficiency standards specify the number of product units that must be produced in a specific time unit.
- Service standards set the number of machines allocated to an employee or an entire team working in a multi-station service system.
- Staffing standards determine the number of employees required to operate one or more machines.

Time standards are determined based on observations and measurements at individual workstations. This method involves developing separate time consumption categories, such as (Żukowski, Duczmal, 2007):

- Preparatory-concluding time standards (tpz).
- Main time standards (tg).
- Auxiliary time standards (tp).

- Technical and organizational service time standards (tto).
- Time standards for physiological breaks (tf).

The time standardization method aims to increase work efficiency and resource productivity. In manufacturing facilities, work standards have broad applications, and this research helps eliminate disruptions in the entire production process (Żukowski, Duczmal, 2007).

Method Time Measurement (MTM) is a tool for describing, structuring, configuring, and planning work systems through defined process modules, to be an efficient pattern for production systems. This method can be used wherever there is a need to plan, organize, and execute human tasks effectively. With this method, a planned process can be executed from start to finish without additional costs associated with process inefficiency (de Almeida, Ferreira, 2009).

The MTM methodology involves structuring sequences of movements into basic movements. Each basic movement is assigned a standard time value, which is determined as a function of factors influencing its composition. The MTM methodology can be applied to configure work methods and products (de Almeida, Ferreira, 2009). The assumptions of elementary movements are as follows (Ekonomika ruchów elementarnych…, 2021).

- Simultaneity of movements – performing work with both hands using general ergonomic principles.
- Simplifying movements – aiming to simplify elementary movements to make them as time-efficient as possible.

By applying these principles, the optimization process can yield increased work efficiency while reducing the burden of work. Considering these principles, a person can accomplish more work while becoming less fatigued.

The MTM method was first applied in the 1940s. The method breaks down work into smaller units of motion. It includes 17 basic movements, of which typically 5 are used, each with assigned elementary times. These movements include reaching, grasping, carrying, assembling, and releasing. Individual movements are combined based on tables with normative times.

The advantages of using the MTM method include:

- Determining the time for a specific activity broken down into smaller elements, taking into account the prevailing conditions and parameters affecting work pace.
- The ability to design a specific operation before the entire technological process is started.
- Streamlining the work process easily through straightforward analysis.
- The ability to determine the detailed duration of a specific activity and its elements.
- Establishing optimal work process improvements.

The MTM method is used by technologists at various stages of product production, work organizers, and when selecting the most appropriate work execution variant. Its biggest advantage is the ability to standardize workstations and establish time standards needed to calculate the duration of a specific task or overall company costs (Ekonomika ruchów elementarnych…, 2021).

Summative, comparative, and estimation methods allow for the determination of unit time for the planned process. These methods require planning a catalog of benchmark jobs, which can be used to determine labor intensiveness by estimating the differences between the benchmark object or process and the one currently being executed (Kutschenreiter-Praszkiewicz, 2015).

This article aims the working time for the production of fasteners in a selected technological process in a fastener production company. The pressing process was used for the study as one of the processes in fastener production.

2. Methods

Methods of data acquisition:

- Direct interviews conducted with employees of the company.
- Observation of the manufacturing process within the company.
- Participation in tasks and teamwork within the company.
- Analysis of the company's materials and system documents.

The company's primary area of operation is the production of connectors and screws. The facility offers connectors manufactured according to national and European standards, as well as custom-sized components with enhanced mechanical properties. The company's product range includes metric screws with hexagonal heads, inch screws with hexagonal heads, screws for caterpillar tracks, screws with twelve-sided heads, double-sided screws, cylindrical screws with hexagonal sockets, cup-head screws with collars, standard and crown nuts, self-locking nuts, plugs, and hydraulic connectors, pins, and rivets. Additionally, the company provides services related to the thermal and surface treatment of entrusted components, such as heat improvement, galvanic zinc coating, zinc or manganese phosphate treatment, and oxidization (blackening). The company possesses its own Materials Research Laboratory. The products manufactured find applications in construction, energy, petrochemicals, automotive, machinery, and defense industries, as well as in oil and gas extraction. The facility exports its products to countries including Germany, Sweden, Finland, Lithuania, and Hungary. The company's products are utilized by globally recognized manufacturers of machinery, equipment, and vehicles. The description of the integrated management system in the company is presented in Figure 1.

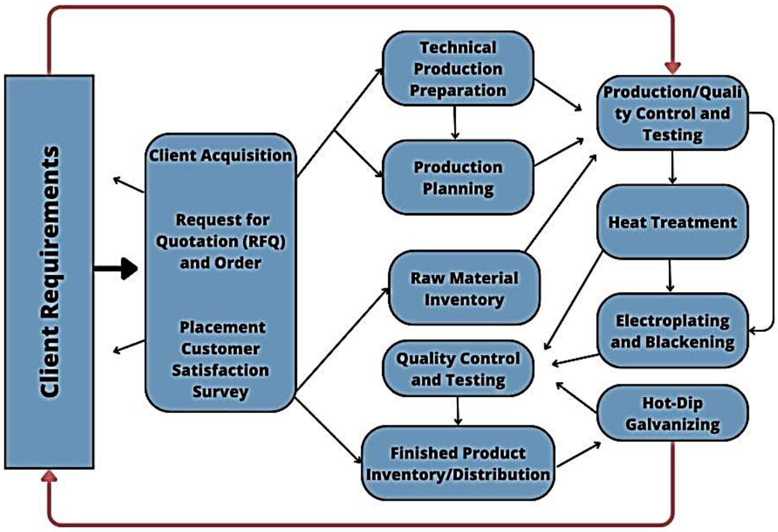

Figure 1. Diagram of the integrated management system in the company.

Source: Own elaboration (Company internal materials).

The process of fulfilling the entire order is crucial for the customer. It is important to keep it constantly moving in the supply chain management process, ensuring its efficiency. The relationship between a company and its interested customer is mutual consumption. The company acquires a customer through bidding interactions, followed by product orders, and finally conducts customer satisfaction surveys. When integrating into a company's production plan, their process can be divided into several stages. The implementation of the order includes elements such as: receiving an order from the customer, confirming the order, production planning, purchasing materials required for production, heat treatment or galvanization of products, conducting destructive or non-destructive testing, packaging finished products, assembling, and warehousing, and then transportation, which is the delivery of the order.

Screws and nuts are used in various applications, such as machinery construction, furniture production, hydraulics, and vehicles. Screws and nuts create a form of metric fasteners. Inside the nut is a thread that is placed on the screw, creating a reliable installation. The materials used for producing screws and nuts include stainless steel, carbon steel, chrome steel, or alloy steel; titanium, copper, and brass. Screws are made from very strong, thick wire or rod steel. After spending 30 hours in an oven, which softens the steel, enabling further processing, the wire is immersed in a tank of sulfuric acid, which removes rust. It is then rinsed with water and coated with zinc phosphate, a substance that acts as an anti-corrosive and lubricant, making screw forming easier. Screws are made by the cold forging method, shaping the steel using dies of various shapes. First, the machine straightens the wires and cuts them into sections slightly longer than the future screw. The excess is then transformed into the head. Each section is pressed into successive dies, which gradually shape the screw's head. The machine forges up to 300 heads per minute. The die forms a small flange. Then it is molded into a round head. Finally, it gives it a shape, such as a hexagon. The other end of the screw is shaped by another machine. A large header forms a so-called "shoulder", an oblique cut to facilitate the nut application. Each screw must have a thread, which is also created by the cold forging method. Special heads extrude it. Samples are taken from each production batch and subjected to quality control. Quality controllers use various tools such as micrometer screws to measure diameters, calipers, and ring gauges for threads. Nuts are hot-forged. The machine produces billets by cutting a steel rod, heated to 1200°C, into short sections for malleability. Then hydraulic hammers give the billets a hexagonal shape while the die punches a hole. Then the tap cuts the thread in the hole. Black oil is used here, lubricating the tap to minimize wear. Screws and nuts are placed in an oven heated to 870°C for an hour. This gives them the desired hardness. Rapid, five-minute cooling in oil stabilizes the metal's internal structure. The steel is hard but brittle. To give it proper strength, screws and nuts are heated in an oven for another hour. Quality controllers conduct random strength tests by measuring the force required to break the screw. If it is greater than or equal to the allowable force, the batch passes inspection, provided that the fracture occurred on the threaded, weakest section. Finally, the finished products are ready for packaging. Labels provide information about product sizes and grades. In Figure 2, the stages of the screw manufacturing process are presented.

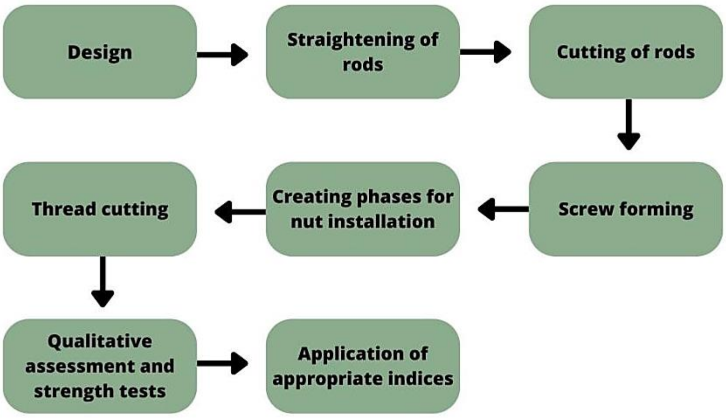

Figure 2. Stages of Screw Manufacturing Process.

Source: Own Compilation.

Throughout the entire process, the Method of Time Measurement (MTM) elemental motion analysis can be applied.

The choice of MTM variant depends on the level of integration of elements and the type of production. Three variants of the method are distinguished (Strzelecki, 1983):

- MTM-1 - for mass production and large-scale production, where operation times range from 0.1 to 0.5 minutes.
- MTM-2 - for medium and small-scale production, where operation times range from 0.5 to 3.0 minutes.
- MTM-3 - for custom production and specific tasks, where operation times range from 3.0 to 30.0 minutes.

In this work, an analysis of the working time of a selected production process was conducted using MTM-1.

The inventors of the MTM-1 method divided the motions performed by the worker in the assembly process into three groups. Each of the groups consists of several types of elementary movements (Drązkiewicz, 1972):

- Group 1 - Hand Movements.
- Group 2 - Eye Movements.
- Group 3 - Leg and Body Movements.

a) Group 1 consists of 9 elementary hand movements:

1. Reach (R).
2. Move (M).
3. Grasp (G).
4. Turn (T).
5. Position (P).
6. Apply Pressure (AP).
7. Disengage (D).
8. Release (RL).
9. Crank (C).

b) Group 2 consists of 2 elementary eye movements:

1. Eye Travel (ET).
2. Eye Focus (EF).

c) Group 3 consists of 15 elementary leg and body movements:

1. Foot Motion (FM).
2. Leg Motion (LM).
3. Walk (W).
4. Side Step (SS).
5. Turn Body (TB).
6. Stoop (B).
7. Return to Stoop (AB).
8. Stoop Down (S).
9. Return to Stoop Down (AS).
10. Kneel to One Knee (KK).
11. Return to Kneel to One Knee (AKK).
12. Kneel on Both Knees (KBK).
13. Return to Kneel on Both Knees (AKBK).
14. Sit (SIT).
15. Stand Up (STD).

In the original formulation of the MTM method, American units of length and weight were used, expressed in inches and pounds. In Europe, corresponding units of centimeters and kilograms were applied. However, when it comes to the unit of time in the MTM method, the situation is more complex. The standard recording speed was 16 frames per second, which translates to 0.0625 seconds per frame. Using such a time measurement unit would be cumbersome, so the authors decided to create a new unit of time called TMU (Time Measurement Unit). The time value for one TMU at a recording speed of 16 frames per second is 1.736 TMU. The formula for the MTM method unit looks as follows (Drązkiewicz, 1972):

$$1\ \text{TMU} = 0.036\ \text{seconds},\ 1\ \text{hour} = 100{,}000\ \text{TMU} \tag{1}$$

The characteristics of elementary hand movements (which account for approximately 80% of all movements) are as follows (Strzelecki, 1983):

1. Reach R: The purpose of the reaching movement is to move an empty hand or an object weighing up to a maximum of 1.25 kg to a specified location. It can be performed with the hand or fingers. The movement is characterized by execution conditions, length, types of movement, and movement difficulties. The notation for this movement consists of the letter R indicating the movement, a number indicating the length of the movement, and the letters A, B, C, D, or E indicating the execution conditions.
2. Move M: The purpose of the moving movement is to change the position of an object in space. It can be performed with the hand or fingers. The movement is characterized by execution conditions, length, types of movement, and the weight of the moved object. The notation for this movement consists of the letter M indicating the movement, a number indicating the length of the movement, the letters A, B, C, D, or E indicating the execution conditions, and a number indicating the weight of the moved object.
3. Grasp G: The purpose of the grasping movement is to gain control over an object (or objects) with fingers and/or the hand to enable the next work element. This movement is classified into 5 categories and several classes. The notation for this movement consists of the letter G indicating the movement, a number indicating the category of the movement, optionally the letters A, B, C, or the letters A, B, C, and a number 1, 2, or 3.
4. Release RL: The purpose of the releasing movement is to release one or more objects from hand control by opening the fingers or breaking contact.
5. Position P: The purpose of the positioning movement is to correctly place one object relative to another. It is performed with fingers or a hand. There are only two types of positioning - in-a-hole and linear. It is characterized by the type of fit and pressure, as well as by the degree of symmetry and the difficulty of manipulating objects. The notation for this movement consists of the letter P1, P2, or P3 indicating the movement depending on the fit, the letters S, SS, or NS depending on the degree of fit symmetry, the letters E or D depending on the difficulty of manipulating the object, and a number indicating the weight of the moved object.

6. Disengage D: The purpose of the disengaging movement is to overcome resistance when disconnecting objects. During the execution of the movement, there is an involuntary recoil of the hand. It is characterized by the type of fit, manipulation difficulty, and care. The notation for this movement consists of the letter D1, D2, or D3 indicating the movement depending on the fit, and the letters E or D indicating the difficulty of manipulating the object.
7. Turn T: The purpose of the turning movement is to rotate the empty hand or an object around the axis of the forearm. It is characterized by the angle of rotation of the hand and the weight of the object. The notation for this movement consists of the letter T indicating the movement, a number indicating the angle of rotation, and the letters S, M, or L depending on the weight of the object.
8. Apply Pressure AP: The purpose of applying pressure movement is to overcome resistance by exerting controlled force. It can be performed by any part of the body.
9. Crank C: The purpose of the cranking movement is to move an object in a circular path. It is characterized by the diameter of the path, the number of turns, and the execution conditions (whether the elbow remains nearly immobile during the movement or performs circular movements). The notation for this movement consists of the letter C indicating the movement, a number indicating the diameter of the path, the letters A or B depending on the elbow movement, and a number indicating the number of turns.

3. Results

The time analysis was conducted during the pressing operation using tools such as workday photography and video analysis. This operation is a machining method involving the repetitive introduction of material into a closed forming die, often its plasticization, followed by melting, hardening, or solidification, and then the removal of the object, in this case called a press-out, from the socket. It can be carried out on presses or without their assistance, but always with the use of a tool, which is the forming die with a forming socket.

Based on the data, the times for individual operations were calculated according to the standards of elementary motions in the MTM method. Table 2 includes selected operations according to the MTM-1 methodology.

Table 1.
Selected Activities Described Using the MTM Method

Description of Activities	Code	Explanation of the Code
An employee walking 6 meters to the shelf	TB.C2	Rotating the body with the movement of one leg and bringing the other forward
	WM	Normal walking for every 1 meter
	TB.C2	Rotating the body with the movement of one leg and bringing the other forward
Retrieving a matrix from the shelf	EF	Careful examination
	S	The object can be placed in infinitely many positions around an axis aligned with the folding direction - symmetrically
	R40A	Reaching for an object located at a distance of 40 cm in a specific place
	G1C1	Grasping a roughly cylindrical object
	M40C	Moving the object a distance of 40 cm to an exact location
Placing the screws in a container	M30C	Moving the object a distance of 30 cm to an exact location
	RL1	Releasing the object by opening the fingers

Source: Own work.

After analyzing the elementary motions, calculations were made for all elementary motions of the upper limbs, elementary eye movements, body movements, and leg movements. The movements from the 2nd and 3rd groups of elementary motions were detailed along with the elementary movements from the 1st group. This compilation is presented in Figure 3. The total time for elementary motions performed during this operation was 12.88 minutes. The compilation also includes non-standard activities, which are those not subject to norms.

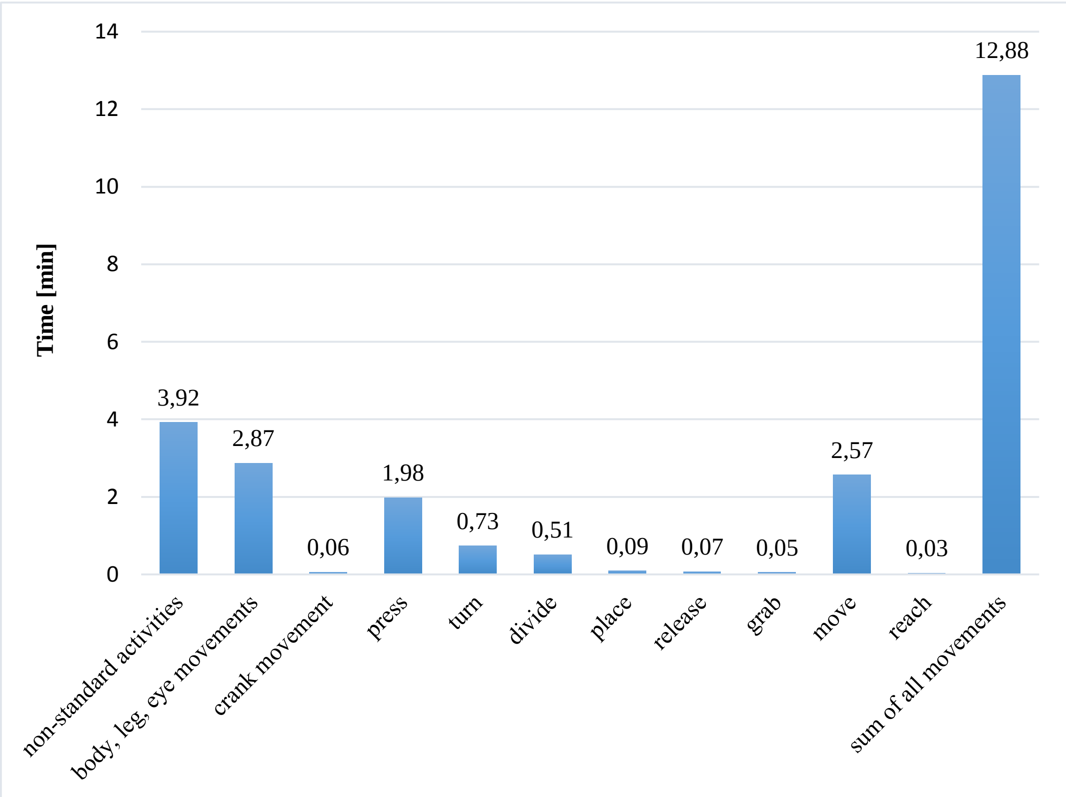

Figure 3. Values of time for individual movements performed during the pressing operation.

Next, the total time for movements from groups 2 and 3 was measured. Knowing that most of the movements in group 3 consist of walking, side steps, and turning the body, the total time for these specified movements was calculated and summed up. The results obtained are presented in Table 2.

Table 2.
Elementary movements from group 2. Comparison of the time of and group 3 during the pressing operation

Elementary movements from group 2	Elementary movements from group 3
27,30 TMU	4 989,1 TMU
0,99 s	179,6 s
0,02 min	2,99 min

Source: Own elaboration.

Figure 4 shows a Pareto Diagram, indicating the percentage contribution of movements about the total time expressed in minutes.

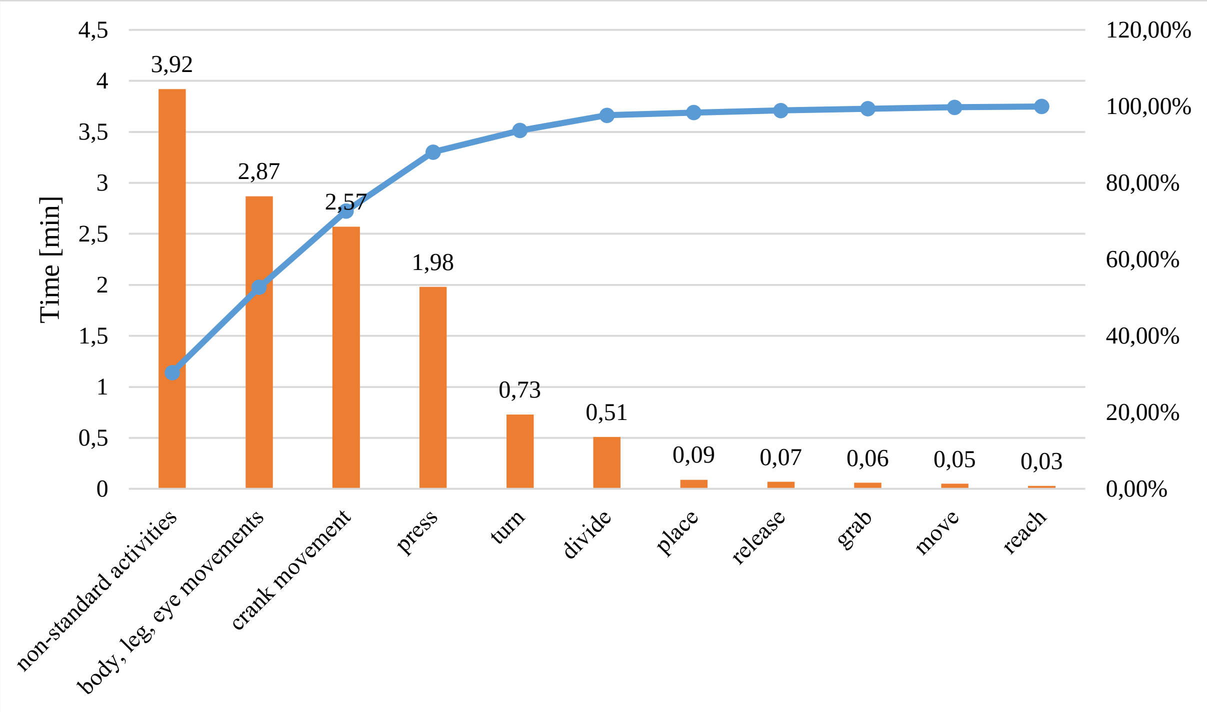

Figure 4. Pareto chart with the participation of individual movements during the pressing operation.

It can be observed that the most time-consuming activities are non-standard activities, body, leg, and eye movements, as well as the "bring" movement, which together account for slightly over 70% of the total operation time. Other moves such as place, release, grab, move and reach, while important, are a small part of the total.

Figure 5 presents the time (expressed in minutes) and the percentage contribution of elementary movements for which it was observed that their time values would change after the reorganization. By altering the organization of the workstation, a reduction in the time of elementary movements such as "reach," "grasp," and "move" was anticipated. Changing the sequence of these movements was expected to yield reliable results.

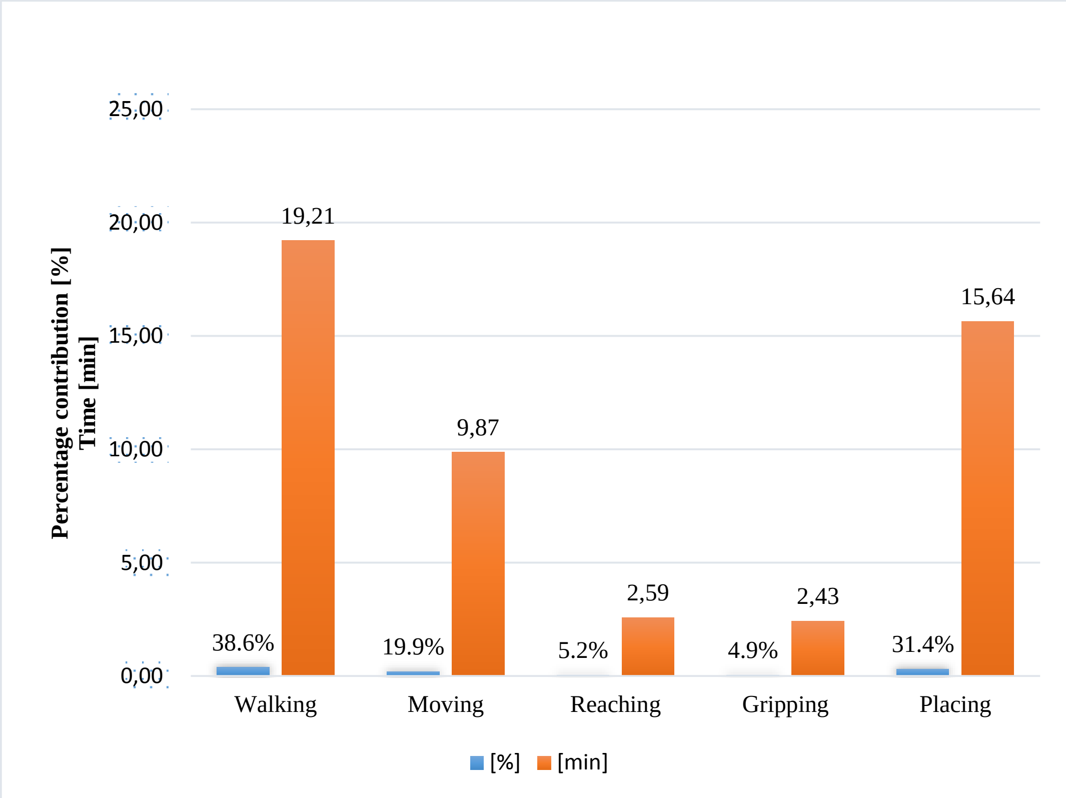

Figure 5. The participation of the most important movements during the pressing operation.

To reduce the operation time, after conducting the analysis, changes were proposed in the organization of the workplace and technology. It was assumed that each product produced would have its workstation. All materials needed for production should be placed on the production table within easy reach to avoid wasting a lot of time fetching them from the warehouse shelves.

After making changes in the workplace, a time analysis was conducted again using the MTM-1 method. Operations were recorded and assigned times. Based on this, individual elementary movements from group 1, group 2, and group 3, as well as non-standard activities, were recorded and presented in Figure 6.

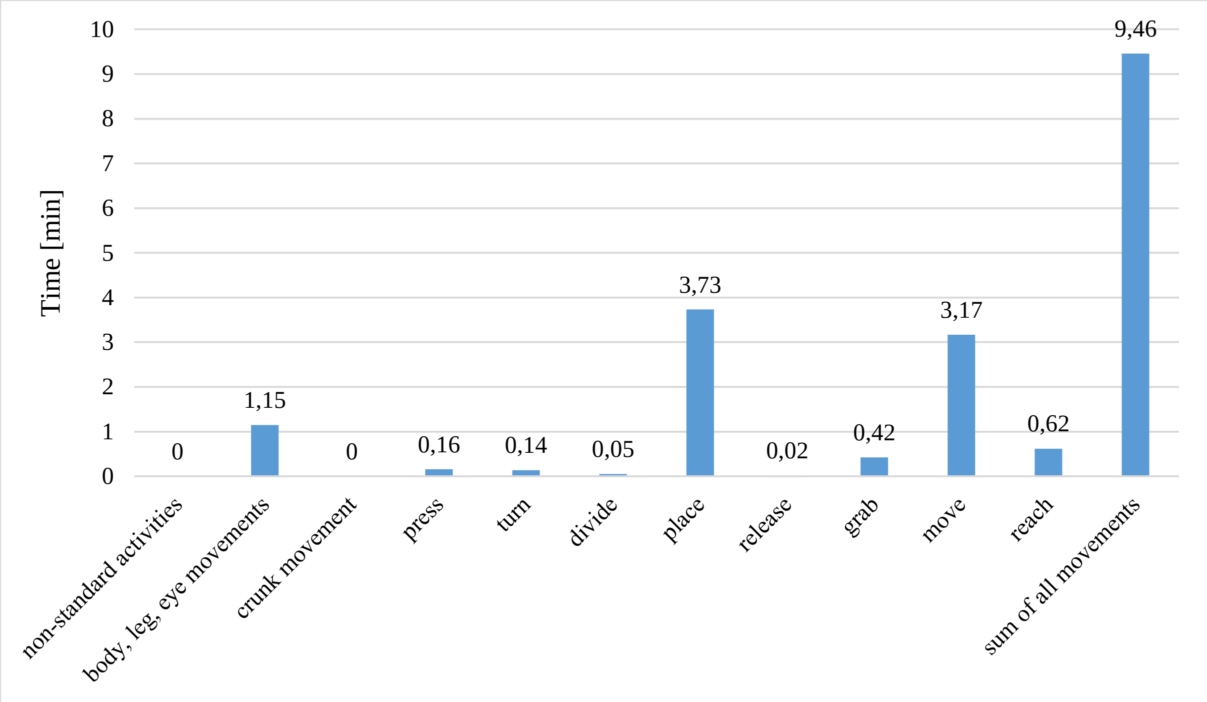

Figure 6. The time values of individual movements performed during the pressing operation are as follows.

When analyzing the cart, attention was drawn to the exceptional importance of certain movements, including: place (3,73 min), move (3,17 min) and body, leg, eye movements (1,15 min). The total time off all movements was 9,46 min.

The Pareto Diagram (Figure 7) created for the time values after the reorganization during the pressing operation shows that approximately 80% of all elementary movements are composed of elementary movements to position and transfer. Movements from group 1 constitute a significant majority compared to the values before the reorganization. Thanks to changes in technology, it was possible to eliminate movements referred to as non-standard activities.

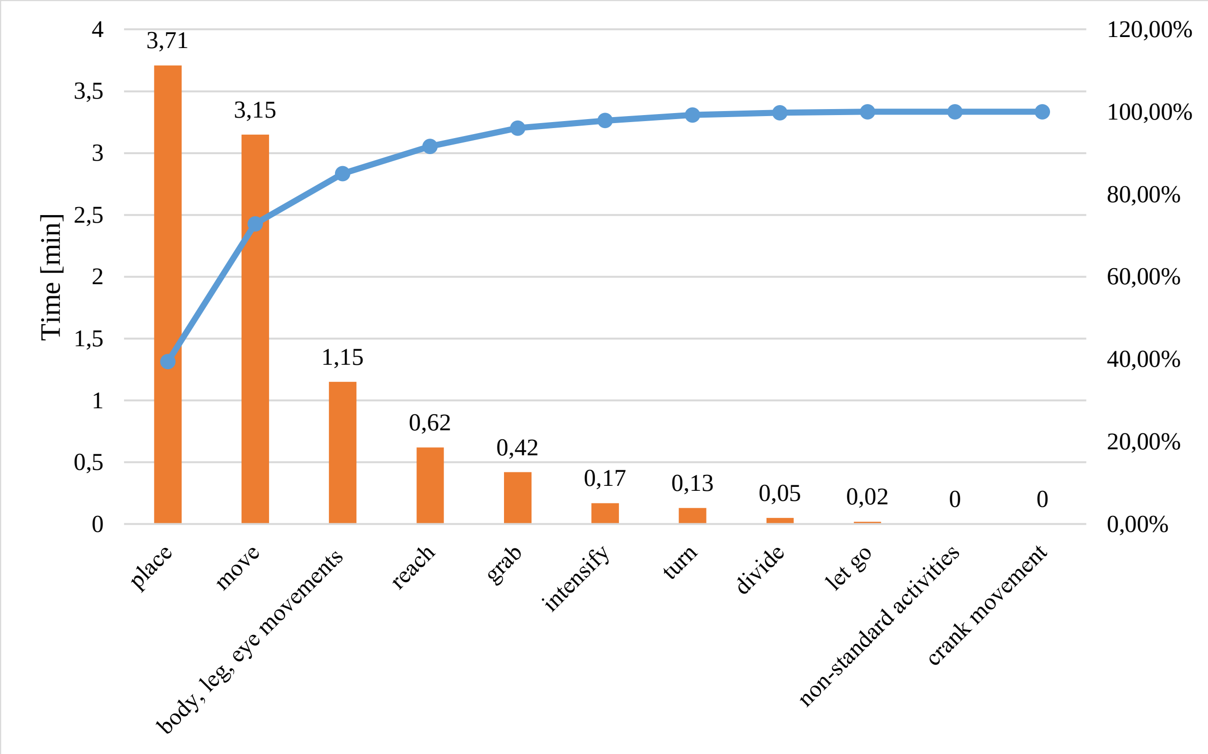

Figure 7. The Pareto Diagram depicting the participation of individual movements during the pressing operation after the workstation changes.

Of significant value are the movements: place, move and body, leg, eye movements. Non-standard activities and crank movement have been eliminated to zero.

When it comes to the movements of walking, moving, reaching, grasping, and positioning, it was possible to reduce their duration, as shown in Figure 8.

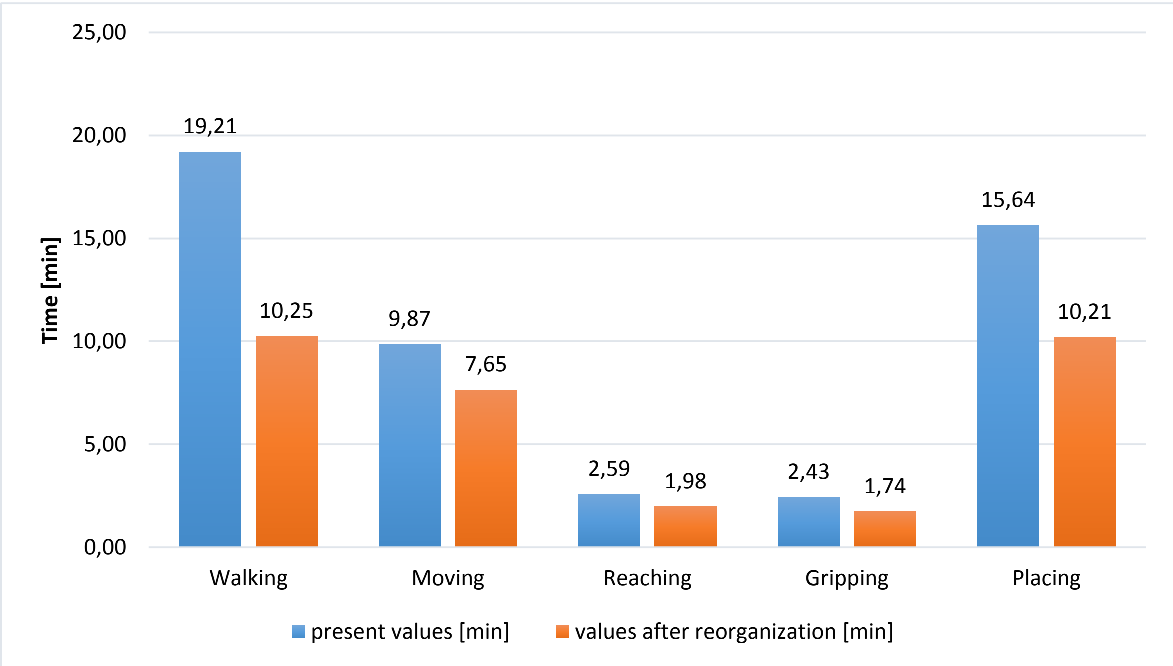

Figure 8. Comparison of the timeshare of the most important movements during the pressing operation before and after changes in the workstation organization and technology.

In each of the analyzed activities, a significant reduction in it's duration was achieved. The walking move was reduced to an impressive 10,25 minutes and the moving move to 7,65 minutes. The reaching move was reduced to just 1,98 minutes, and the gripping move was reduced to 1,74 minutes. Moreover, the placing time was reduced to 10,21 minutes. These significant achievements in time optimization of movements have significantly influenced the efficiency of the process.

The percentage share of the most important movements is presented in Figure 8. As can be observed, despite the shorter duration of individual movements, their percentage share has increased in most cases.

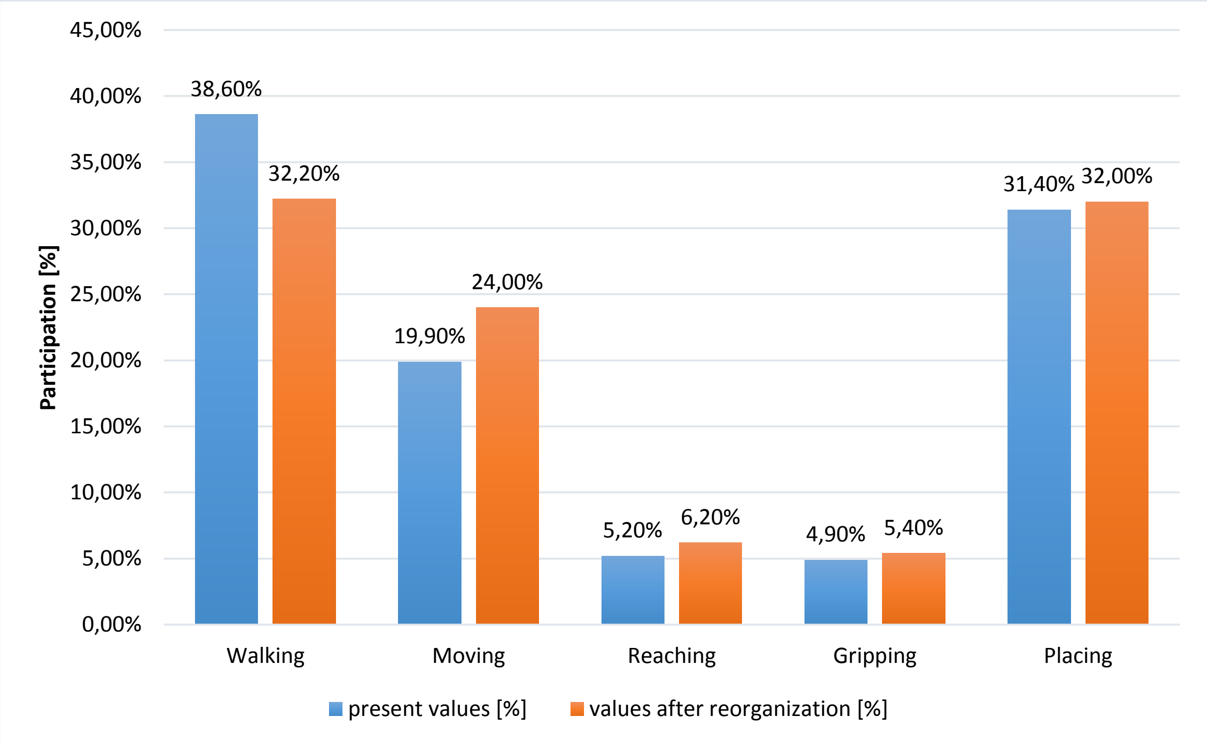

Figure 9. Comparison of the percentage share of the most important movements during the pressing operation before and after changes in workstation organization and technology.

The percentages showing the share of individual movements in the overall statement clearly reflect the changes made. Walking, which initially occupied a significant share, was effectively reduced to 32.2%. At the same time, other movements gained importance. Moving increased its share to 24%, which was a significant increase. The reaching traffic is currently 6.2%. Gripping now accounts for 5.4% of the total. On the other hand, placing traffic, despite a slight increase, remains at the level of 32%, still being an important part of the process. These changes in the percentage structure of movements are important for optimizing the process.

4. Summary

In screw production, the following technological operations are used: stamping, pressing, rolling, milling, and cutting. This article aimed to analyze the working time of manufacturing fasteners in a selected technological process in screw production.

Analyzing the research results, it can be observed that the time taken for individual operations in the process before the changes was 12.88 minutes. After the workstation reorganization and the application of the MTM-1 method, the time for performing all operations was reduced to 9.46 minutes. This represents a reduction in time by 3.42 minutes, which is nearly a 30% acceleration in production time at the given workstation. Non-standardized activities and the 'move' motion were significantly reduced. The time for body, leg, and eye movements was reduced by nearly 40%. The most time-consuming movements at the workstation are walking and positioning. The workstation should be designed so that all necessary materials are located at the workstation, and finished products do not need to be stored far away.

Through this analysis, the entire production process can be streamlined, and its optimal improvement can be determined, and this work also confirms it.

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