

Katarzyna ŁYP-WROŃSKA*, Arkadiusz WOLSKI, Marzanna KSIĄŻEK

AGH University of Science and Technology, Cracow, Poland

* Corresponding author: klyp@agh.edu.pl

ANALYSIS OF THE WORKING TIME OF ASSEMBLY RAILWAY PANTOGRAPH

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Key words: optimalization, Methods Time Measurement (MTM), Lean Management, labour efficiency.

Abstract: Every single company seeks to ensure good quality products in parallel to the the most effective production processes in its manufacturing plant. To achieve those goals, the organization of the workplace is very important. It shall be maximally adapted to the production of a given product, thereby increasing employee productivity which provides an added value through saved time.

Thanks to the study of work processes time, it is possible to determine the workload of individual activities and its continuity. It could be realized by using the basic methods of working time analysis, e.g., time study, activity study, comparisons and estimations, and methods of time measurement (MTM).

The objective of the work was to analyse the assembly work time of selected subassemblies of the half-asymmetric railway pantograph and the proposal to reorganize the workplace and production technology. Every activity during subassemblies production steps were recorded on video. Then, all elementary movements were described through Methods Time Measurement (MTM) and the reorganization of the workplace was proposed.

Knowing the course of the process steps of each subassembly and by analysing all obtained results, the organization of the workplace could be modified to minimize the process time as much as possible.

Analiza czasu pracy montażu pantografu kolejowego

Słowa kluczowe: optymalizacja, Methods Time Measurement (MTM), Lean Management, wydajność pracy.

Streszczenie: Każda firma produkcyjna dąży do zapewnienia produktów najlepszej jakości równoległe z najbardziej efektywnymi procesami produkcyjnymi. Aby osiągnąć te cele, firma powinna zwrócić szczególną uwagę na organizację miejsca pracy. Miejsce to powinno być maksymalnie dostosowane do procesu produkcji danego produktu, zwiększając tym samym produktywność pracowników. Zaoszczędzony czas zapewnia wartość dodaną dla firmy.

Dzięki badaniu czasu pracy możliwe jest określenie nakładu pracy poszczególnych działań i ich ciągłości. Można to zrealizować przy użyciu podstawowych metod analizy czasu pracy takich jak: badanie czasu, badanie aktywności, porównanie i estymacja, a także metody pomiaru czasu (MTM).

Celem zrealizowanych badań była analiza czasu pracy wybranych podzespołów półsymetrycznego pantografu kolejowego oraz propozycja reorganizacji miejsca pracy i technologii produkcji. Każda czynność procesu produkcji podzespołów została zarejestrowana na filmie. Opisano wszystkie ruchy elementarne za pomocą metody pomiaru czasu (MTM) i zaproponowano reorganizację miejsca pracy.

Znając przebieg etapów procesu dla poszczególnych podzespołów, a także analizując wszystkie uzyskane wyniki, organizacja miejsca pracy może zostać zmodyfikowana w taki sposób, aby maksymalnie skrócić czas procesu, co może przynieść ograniczenie strat, czyli zysk dla firmy.

Introduction

The main purpose of the production process is to manufacture the product in a way providing an economic effect which will be greater than the expenditure incurred, and therefore to generate a profit. It is connected with

the quality of management and broadly understood optimization of the work time. Well-organized work, i.e. the production technology and the work station, allow using full advantage of the employee's work. A poorly-organized job leads to inefficient use of the employee's working time and can cause him or her to be overwork, incommensurately with the activities performed.

Due to the fact that, during designing work processes, it is often not taken into account or does not realize that in on-going work processes there are some inconveniences and disturbances in its course which are going to lead to breaks and wasted time; therefore, it is necessary to carry out testing and measuring the time of a given work process. In this way, it is possible to locate at which stage of the process disturbances occur and how to eliminate them, leading to its optimization and increased work efficiency. Thanks to the study of the work process time, it is also possible to determine the workload for individual activities and its continuity.

1. Literature review

Definitions explaining the workplace can be found in many publications. One of them says that the job station is the smallest indivisible and organizational unit where human work takes place, realizing a specific part of the varied work process. At the same time, it is an essential element of the company's organizational structure, understood as a system of organizational units and their cooperative relations [1].

The basic principles regarding the organization of the work station are as follows [2]:

- Tools and materials shall be placed on a strictly defined and dedicated place.
- To bring the materials to the place of its application, containers and trays, which use gravity force shall be applied.
- Discharging products from the workplace should take place using gravity force wherever possible.
- Tools, materials, and measuring instruments should be placed as close as possible and in front of the employee.
- Good lighting of the work station shall be provided.
- The height of the bench and the seat should allow comfortable work in a sitting and standing position.
- Tools and materials should be arranged to ensure the best possible order of movement.
- The design and height of the seat should ensure the maintenance of the correct position of the body at work.

There are many methods of studying the work, depending on the type of the work performed and the purposefulness of the operations distributions to different degrees of integration [3]. Below, some of the most commonly used methods are given:

- Timing is the method of measuring repetitive operations or their elements (operation, activity, work movement) in order to determine, on the basis of a given number of measurements, the proper duration, and rational execution at a normal work rate [4]. To effectively perform the measurement of time consumption in the assembly process, using the timing method, qualified employees are required,

equipped with the appropriate equipment, such as clocks with second measurements, self-measuring instruments, photo equipment, automatic apparatus for time testing work, and automatic control devices [5].

- Working day photography – it is a continuous observation and measurement of time consumed at the workplace, taking into account working time and breaks throughout the entire observation. It usually includes one work shift or part of it. The aim of the working day photography is to determine the extent of use of the working time and its actual consumption to develop norms, dividing them into activities related to the preparation and completion of the production task entrusted to the employee, direct performance of activities and service of the workplace, and satisfying the physiological needs of the employee [6].
- Snapshots consist in determining the frequency of predetermined types of the mileage of one or more types of the work systems by means of randomly short-term observations. Observations of people and means of labour can be made [7]. The method of snapshot observation is based on the probability theory. No time measurements are made. The percentage share of the duration of a given element in the working time of the entire observation period is determined, assuming that it is the ratio of the number of observations of this element to the number of all observations.
- Comparison and estimation is the list of objects or activities to determine differences or compliance. The purpose of the comparison is to determine the course that is closest to the considered route. On the other hand, estimation is based on an approximate determination of the quantitative data. The estimated data can always be measured later. In the estimation, the normative time of the task of the mileage is determined from the memory or experience [7].
- Methods Time Measurement (MTM) allows on to analyse each manual work (the working method) on the basic elements of work (working movements) and giving, for each of them, normative execution time, being the function of traffic characteristics and conditions in which it is performed [2, 8].

2. Research method

The MTM was developed by H.B. Maynard, I.L. Schwab and G.J. Stegemerten – employees of the “Methods Engineering Council” office in Pittsburgh (Pennsylvania). Works on the method began in 1940, and its full description was published in 1948. To determine the value of times of elementary movements, the film technique was first used, but some movements were also

measured using a chronometer. Approximately 40,000 meters of film tape were analysed for the development of the final version of MTM [2].

The Elementary motion is the smallest element of a specific work movement [9]. On the other hand, the work movement is described in the literature as a component of activities performed by a human because of the tasks that lead to the intended purpose of the activity being analysed [9]. The authors of the method, based on many years of research on the elementary movements performed during manual assembling processes, determined the normative times for each. The value of this time depends on, among others, on the shape of the movement being carried out, its length, the difficulty encountered in making the movement, and sometimes on the weight of the object manipulated during the movement [10].

According to the definition of the MTM, it can be used only for manual work, to the extent that the duration of work depends only on an employee. Therefore, it must not be applied to works whose duration is limited and from the point of view of an employee independent of him (welding, soldering, painting, all kinds of machine work elements).

Methods Time Measurement has three variations, the use of which depends on the degree of the merge of elements and the type of production as follows [10]:

- MTM-1 (interchangeably with the name MTM) – for the mass and high-volume production, where the operation time ranges from 0.1 to 0.5 min;
- MTM-2 – for the medium & small-volume production, where the operation time ranges from 0.5 to 3.0 min; and,
- MTM-3 – for the unit production and for specific works, where the operation time ranges from 3.0 to 30.0 min.

This split results from the economical aspect of the profitability of applying a given method, depending on the degree of elements merge as well as how much we want to “divide” the process into components and on their basis determine the norms of times for individual operations.

In the MTM, the movements are split into three main groups. These are hand movements, eye movements, and movements of the legs and body. Each of them is divided into elementary movements, respectively, Groups 1 for 9 movements of hands, Group 2 for 2 elementary movements of eyes, and Group 3 for 15 movements of legs and the body. The MTM is used mainly in areas of researching and improving working time, designing methods of the performing work and organizing of workplaces, examining construction solutions of machines and devices from the point of view of production technology, and a service during operation, setting time standards, preparing time norms, and the development of objective measures of the work efficiency in positions [9]. The main advantage of this method includes the fact that it is a uniform basis for

dimensioning work. In addition, it is characterized by a simple construction, high accuracy, and uniformity of the use of time standards. Compared with other methods, it eliminates the cumbersome assessment of the pace of work and allows one to draw up norms of time with any degree of integration [9]. On the other hand, the use of this method has its drawbacks. One of them is the fact that, in order to use this method properly, a lot of practically experienced employees in its use is required, as well as the fact that the time needed to compile the results is disproportionately large (usually counts 1 hour per 1 minute's operation) [10]. MTM requires intensive training and extensive time studies and is quite complicated; so many companies avoid using MTM [11].

The MTM has its own unit of the time – TMU (Time Measurement Unit). This is due to the fact that, during the development of the method, a film was recorded, where the recording speed was 16 frames per second, which in terms of one frame gives a value of 0.0625 seconds. The use of such a unit of measure was uncomfortable, so it was decided to create the TMU unit. The time value for one TMU at the film speed of 16 frames per second is 1.736 TMU. The following calculations result from that:

$$1 \text{ TMU} = 0.0001 \text{ h} \quad (1.1)$$

$$1 \text{ TMU} = 0.0006 \text{ min} \quad (1.2)$$

$$1 \text{ TMU} = 0.036 \text{ sec} \quad (1.3)$$

In MTM-1, there are two general notions about movements – covered and covering movement. These are short names are to describe movements of one or two limbs simultaneously.

Covered movement, which is motion performed at the same time along with another move, has a lower value of time.

Covering movement, which is motion performed at the same time along with another move, has a greater value of time.

From the point of view of the total time of the operation, only longer time is significant – covering movement. Therefore, these movements are also called deterministic movements [2].

Analysis of elementary movements can be part of larger programs. All of these activities are aimed at optimizing and reducing costs. There are many different methods to achieve this purpose, for example, by implementing World Class Manufacturing or Lean Management. It is related to the application of various methods and tools for each type of activity, including the organization of a workplace, which brings measurable financial benefits [12, 13]. The Methods Time Measurement can be used in combination with other methods, e.g., DFA (Design for Assembly). The analysis of the motion study reduces production costs. It is best to design the analysis before building a workplace to avoid wrong decisions about standards [14]. This gives the possibility of, for example, creating a procedure, a manual, and a dictionary, as done in the automotive

industry [15]. It can be also compared different methods and to choose the most favourable for a given company [16].

3. Case study

The aim of the work was to analyse the assembly work time of the half-asymmetrical rail pantograph (see Fig. 1) and the proposal to reorganize the work station and

the production technology. The assembly process of the entire pantograph was recorded, and then 2 components were selected in order to perform the examination of the assembly operation time of these components. This article presents one assembly element – the Drive-Module Assembly (DMA). A comparative analysis of assembly operations according to the Methods Time Measurement and Timing was assumed. The scope of the tests covered the period from September 1 to November 15 of the same year.

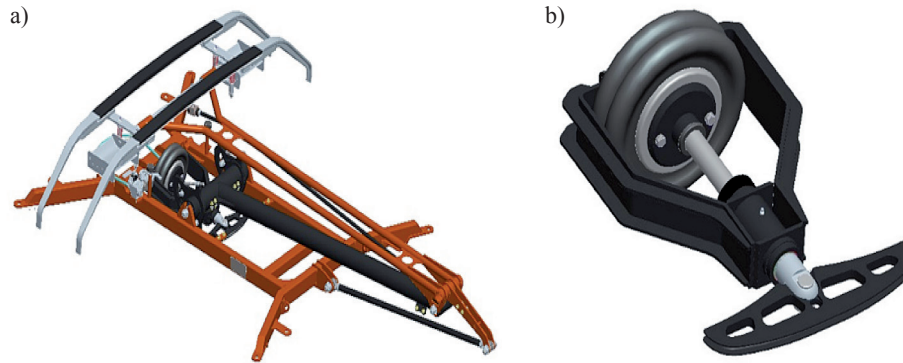


Fig. 1. a) Railway pantograph, b) Drive-Module Assembly (DMA)

Based on the recorded video, all activities performed by one employee during the assembly processes of the pantograph were registered. On the basis of the observations made in the previous period, during the recording, the employee performed work under normal conditions of the work environment and intensity of effort, and he had the appropriate level of the experience and skill in performing activities and worked according to the established method, according to literature recommendations [9]. On the basis of the film, the measured real time was recorded. All major materials and components were weighed. The distance covered by employee and the dimensions of the work stations were measured. Then, the film was repeatedly played; and based on the MTM method, according to the norms of this methodology, all elementary movements made by the employee were described and the appropriate codes and times were assigned in the TMU unit to them. Later on, the results were compared with the time of the timing method. Next, when analysing the obtained results, it was proposed to reorganize the workstation and assembly method. Then, for the reorganized work station and the method of assembly, the elementary movements and times were described and codes assigned.

4. Research results

This subsection will present the values of time during performed DMA assembly operations according

to norms of MTM elementary time, before proposed reorganization of working station and production technology as well as theoretical times that could be obtained after introducing changes in the organization of the assembly station and technology. The values given are values for covering movements, and covered movements were also included in the analysis but were omitted in the record, due to their shorter duration.

During the analysis, the assembly process was divided into 153 operations (see Table 1).

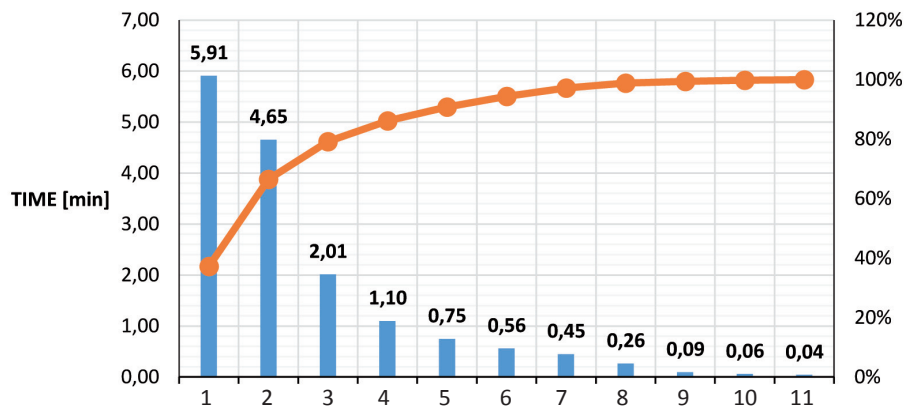
The chart below (see Fig. 2) presents a Pareto Diagram showing the percentage of movements in relation to the total value of time expressed in minutes. All elementary movements according to MTM are listed: motions of the upper limbs from Group 1, concise movements from Group 3 as *the body, leg, and eye* movements. The summary also contains the total time of movements from all three groups of elementary movements.

Movements from Group 3 represents *walk, steps, and rotating the corps* movements; therefore, those movements are combined and grouped into one collection named *walking*, and then referred to the total value of elementary movements times from Group 3.

To illustrate the distance the employee performs during the DMA assembly process, a Spaghetti Diagram (see Fig. 3) was made on the basis of the recorded film. All of the paths of the road that the employee overcomes in order to collect material (black line) and tools (green line and red line) have been marked on the layout of the production hall.

Table 1. Part of the time measurement results of the assembly operations of DMA according to the MTM

No.	Description	CODE	TIME [TMU]
1	Take a corps from the rack and rewrite it into the stage (1.5 m)	S	29.00
		R40A	11.30
		G1A	1.70
		M40B	16.90
		TB.C2	37.20
		WM	26.10
		M50B	19.73
		RL1	1.70
2	Walk to the bookshelf – 7 m	TB.C2	37.20
		WM	121.80
		TB.C2	37.20
3	Taking from the ring rack (nuts) and moving to the other hand	S	29.00
		R40C	16.80
		G4A	7.30
		M30A	12.70
		G3	5.60
...			
124	Taking the nut from the table – M16 A2	R20A	7.80
		G1B	3.50
		G2	5.60
		M30A	12.70
		M30C	15.10
		P1SSE	18.20
...			
153	Putting the subassembly down to the intermediate position	M60C	29.46
		RL1	1.70
SUM		[TMU]	26483.33
		[s]	953.40
		[min]	15.89
Real time assembly (according to timing)		[min]	16.02
Difference		[min]	0.13
		[%]	0.81



1 – locate 2 – move the body, legs and eyes, 3 – displace, 4 – non-normative activities, 5 – press, 6 – reach, 7 – grab, 8 – move the crank, 9 – turn, 10 – separate, 11 – leave

Fig. 2. Pareto Diagram with the participation of individual movements in the DMA assembly process

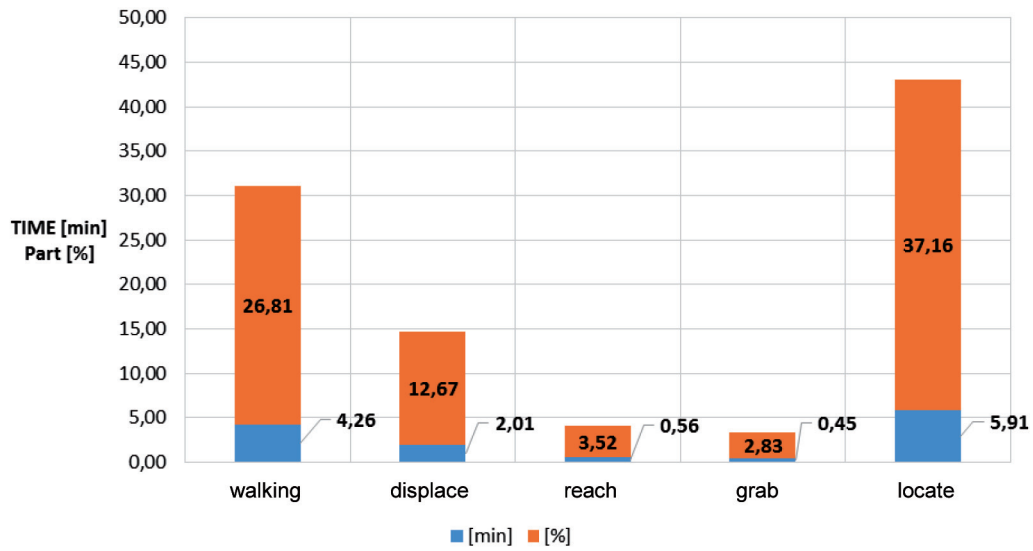


Fig. 4. The participation of the most important movements in the DMA assembly process

Table 2. Part of the time measurement results of the assembly operations of DMA According to the MTM after reorganization

No.	DESCRIPTION	CODE	TIME [TMU]
1	Take a corps from the rack and rewrite it into the stage (1.5 m)	S	29.00
		R20A	7.80
		G1A	1.70
		M20B	11.66
		AS	31.90
		TB.C2	74.40
		WM	26.10
		M30B	14.39
		RL1	1.70
2	Walk to the bookshelf – 7 m	TB.C2	37.20
		WM	121.80
		TB.C2	37.20
3	Picking the precision roller	EF	7.30
		S	29.00
		R50A	13.00
		G1C1	7.30
		M50B	18.64
		AS	31.90
...			
34	Putting the screw on the table	M30B	13.20
		RL1	1.70
...			
SUM		[TMU]	18133.33
		[s]	652.80
		[min]	10.88
Time according to MTM standards before reorganization		[min]	15.89
Difference		[min]	5.01
		[%]	31.71

The total results given in the table are the values of time that can be obtained by running the manufacturing process according to the proposed changes. Then all of the operations were rewritten, the elementary movements were described, and the times were assigned to them. Times remaining in the process of non-normative activities were recorded. Results of times of individual elementary movements from Group 1, the total time of movements from Groups 2 and 3 collected in group named movements of the *body*, *legs*, and *eyes* and the time of non-normative activities after reorganization.

From the Pareto Diagram (see Fig. 5) prepared for new time values, it is clear that still about 80% of the total assembly time consists of movements *to locate, displace and move the body, legs, and eyes*. This is due to the fact that the greatest time reduction was obtained for the set of movements from Groups 2 and 3.

After reorganization (orange line), the elementary movements of Group 1 represent 86.91% compared to 63.76% before the reorganization (blue line) (see Fig. 6).

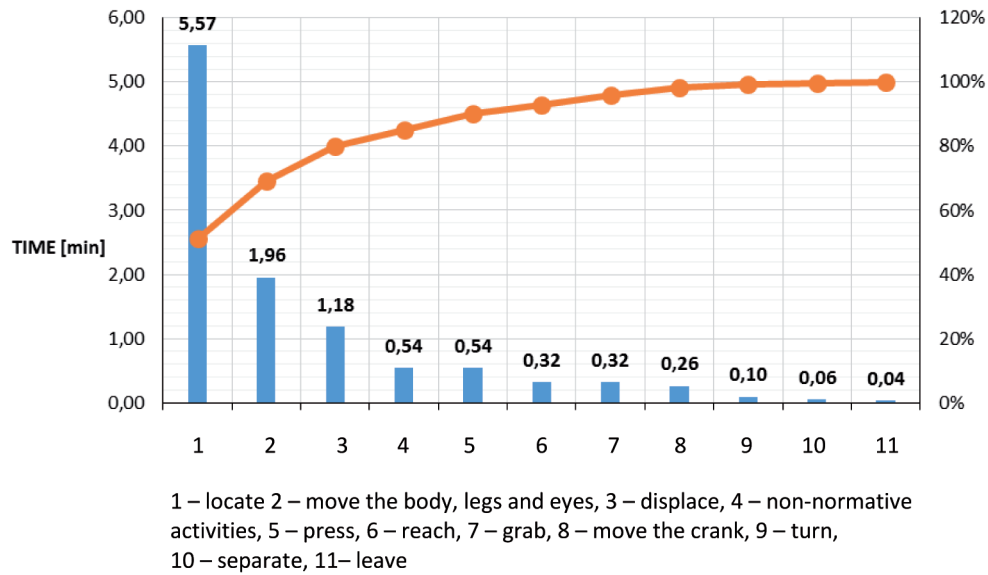


Fig. 5. Pareto Diagram with the participation of individual movements in the DMA assembly after reorganization

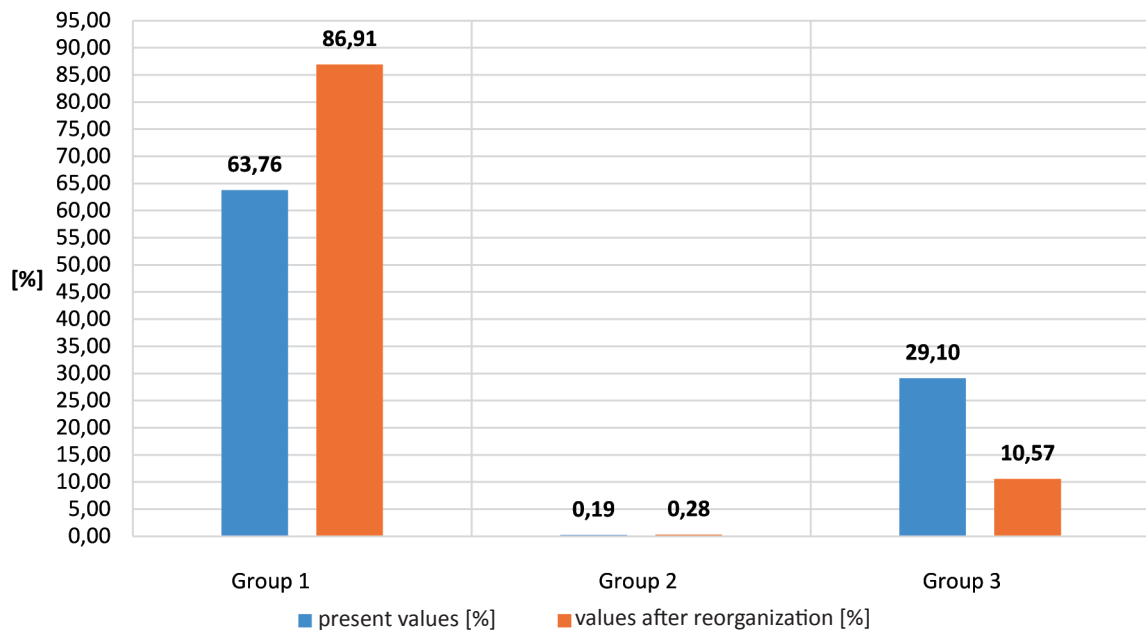


Fig. 6. Comparison of the percentage share of individual groups of elementary movements before and after the reorganization

The graph in Fig. 7 shows the share of movements from the walking group and the rest of elementary movements from Group 3 in relation to the total time of Group 3 movements after the process was reorganized.

A new Spaghetti diagram (see Fig. 8) showing the worker's movement during the assembly of the DMA after the changes was made – collecting material (black) and collecting tools (green).

Figure 9 presents a comparison of the percentage share of the most important elementary movements for which the value of time was expected to change.

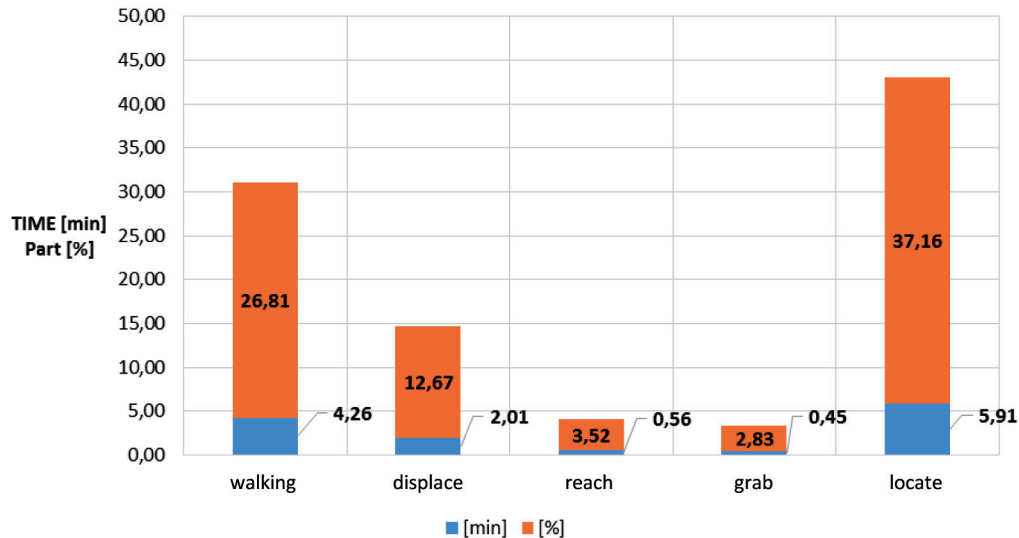


Fig. 9. Comparison of the percentage share of the most important movements in the DMA assembly process before and after reorganization

Discussion and conclusion

When analysing all obtained results, one can come to the conclusion that, for each subassembly assembled in the production process, the railway pantograph should create separate work stations adapted to the production of only one semi-product. Time measurements made it possible to identify unnecessary operations that generated unnecessary time consumption. Knowing the course of each of these assembly processes, it was possible to modify the organization of the workstation so as to minimize the process time.

The greatest reduction of time was achieved by transferring most of the materials needed for production from the storage rack to the cuvettes placed on the stage. First of all, it allowed reducing the time of elementary movements from Group 3. The employee did not have to move so much around the hall to collect materials during assembly operations. Most of them were at hand or near the work station, or on a shelf with painted elements, to which he was 3 meters away. The transfer of tools needed for assembly from a trolley located at the storage racks to one standing trolley on the right side of the stage

The chart contains the values of the times of the given movements before and after the reorganization.

Looking at this movement from the perspective of their percentage participation in the process after the reorganization, one can notice some larger changes in these values. Traffic share of *relocate* increased by 6.75%, *reach* by 1.83%, *grab* by 5.98%, and *locate* by 18.14%, among others, thanks to the reduction of the movement department, *walk*, *side steps*, and *rotate the body* with a total value of 16.49%.

also contributed to reducing the number of elementary movements from Group 3.

The assembly process was reduced by the time of movements from Group 3 by 3.47 minutes. Analysis of working time according to MTM also allowed us to identify activities performed during assembly, for which it was not possible to use it. These were activities related to the removal of materials and operations of applying glue to some combined elements. It is not advisable in the assembly processes that the worker would have to carry out a removal treatment. In the case of DMA it was only grinding the inner surface of the body sleeve to remove the layer of varnish and primer used during priming, thus to achieve the inner diameter of the sleeve allowing the placement of bearings within. These operations should be eliminated by securing the holes of painted elements before priming and painting with journals, and machining should be performed before the assembly operations, or it should be commissioned to another company on the basis of cooperation. It is possible to consider the option of purchasing rollers machined so that it can be easily place bearings on them without having to do any additional machining. Before

the changes, the elementary movements of Group 1, i.e. the movements of the upper limbs, constituted only 63.76%. The application of changes was reflected in the values of individual elementary movements, which is best seen in the percentage of movements from Groups 1, 2, and 3 – 86.91%, and their share was increased by 23.15%.

Thanks to all the changes from the original 15.89 min to 10.88 min. production time decreased by 31.38%. These changes have a positive reflection on the total unit cost of manufacturing the pantograph, with an average annual production of 250 pieces. This is a confirmation of the research contained in other articles [12,13].

It took about 48 man-hours to investigate and analyse the movements performed during the operation. Taking into account the sum of all assembly operations (before and after the reorganization amounting to 54.32 minutes), it turns out that it took 53.02 man-days to analyse the one minute assembly operation. This is consistent with data given in the literature [10]. However, despite such a long time needed to perform the analysis, choosing this method enabled the distribution of activities performed on elementary movements, the change of which was the basis for the reorganization of the work station and production technology.

In summary, the analysis gave the opportunity to optimize. However, from the perspective of this type of production, such analysis is very time-consuming. It is confirmed that MTM is best for mass production. In the future, for this company, it is more appropriate to use MTM-2 or MTM-3 with a greater degree of merge of movements.

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