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## **INTRODUCTION**

The production company has a variable working mode. There are many factors, including random ones, that determine the way production lines operate. In practice, the production line is said to be "alive". It is therefore necessary to constantly observe the environment and conditions that may affect the safety at work, especially that carried out during production processes. The concept of conceptual and corrective ergonomics has been known for many years. The awareness of enterprises in the area of proper designing and organization of the work environment is increasingly noticeable. Preventive actions and the effects of these actions are measurable, manifesting in, inter alia, minimizing awkward situations and their effects (such as sickness absence, physical indisposition, accidents at work) or maximizing work efficiency (measured e.g. as the number of operations performed in a given time).

Many regulations, requirements, and guidelines must be met by companies, which means that the best practice rules within work ergonomics can be pushed to the background.

However, there is no doubt about the scope of the employer's obligations towards the employee in the context of ensuring safe and healthy working conditions. In Poland, such activities in enterprises are carried out by OHS services. The analysis of legislation and internet offers of companies specializing in providing OHS services shows that there are no clearly defined guidelines for the assessment of ergonomic conditions in workplaces.

The most frequently appearing rules in the scope of works of services that can be interpreted as those related to ergonomics are:

- initiating and developing various forms of popularizing OSH and ergonomics issues in the workplace,
- adaptation of work conditions and processes to the employee's abilities, in particular by appropriate design and organization of work stations, selection of machines and other technical devices as well as work tools as well as

production and work methods (Rozporządzenie Ministra Pracy i Polityki Socjalnej, 1997)

- the need to protect the health, that is to minimize hazards to the health and life of employees in the work environment, and to investigate these threats
- preventive actions consisting of checking the safety status and compliance with regulations by employers and employees,
- inspecting work processes and their organization in terms of the technical condition of rooms, installations, machinery and equipment, the use of personal protective equipment, lighting, assessment of the protection of employees against the action of hazardous or harmful materials,
- occupational risk assessment at work stations.

There are also no applicable legal provisions in Poland requiring an obligation on the entrepreneur to apply specific principles of preventive ergonomics at the stage of planning business activities and related processes. Only recommendations and good practice principles will appear. There are also no recommendations regarding the methods and tools that should be used when assessing working conditions. However, you can find papers or statistical data closely related to the analysis of working conditions, which means that the topic is important and constantly developed (Bartnicka and Kabiesz, 2019, Bartnicka and Kabiesz, 2018, Bartuzi and Roman-Liu, 2007; Bartnicka, 2015; Lowe et. al., 2017). According to data provided by the European Agency for Safety and Health at Work, 87% of Polish peoples feel comfortable with working conditions. Statistical data (ESENER, 2019) also shows that 93.1% of Polish manufacturing companies regularly assess occupational risk, with large companies (employing over 250 employees) doing this in 99.6%. This is probably the result of legal requirements. These values are higher compared to data on an EU scale. At the same time, 21% of the surveyed working people believe that their health or safety is at risk due to their work. It is highly probable that this awareness results from the knowledge of the risk assessment presented by the employer.

Many managers try to improve working conditions by using free available methods and tools. Some larger international companies have separated specialists or entire organizational units dealing with ergonomics. They use dedicated or commercial tools, because in large workplaces, employing a large number of employees and caring for high management standards, care for work ergonomics is becoming a standard. This study shows an example of verification of working conditions in an automotive company based on a comparative analysis of conceptual ergonomics and the real state.

## **METHODOLOGY OF RESEARCH**

This study was based on a planned research process, including 4 basic stages:

Stage 1: Recognition of the state of knowledge

Stage 2: Obtaining data from the conceptual work of the company

Stage 3: Real state analysis

#### Stage 4: Comparative analysis

The topics covered in the study were supported by the recognition of the state of knowledge about the rights and obligations of employers/entrepreneurs/investors in the field of work ergonomics. The duties and tasks of health and safety services in workplaces were reviewed. The research was carried out by analyzing the content of source documents, such as:

- Labour Code,
- Regulation of the Minister of Labour and Social Policy on general health and safety regulations,
- Ordinance of the Council of Ministers regarding the list of arduous, dangerous or harmful work to pregnant women and breastfeeding women,
- Regulation of the Minister of Labour and Social Policy on health and safety at work during manual transport works.
- Regulation of the Minister of Economy on the essential requirements for personal protective equipment
- Regulation of the Minister of Economy and Labor on training in the field of occupational health and safety
- Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location.
- Regulation of the Minister of Labor and Social Policy on the highest allowable concentrations and intensities of factors harmful to health in the work environment
- Ordinance of the Minister of Economy on occupational health and safety during the operation of machines and other technical devices for the earth, construction and road works

Also, an inventory of legislative documents related to broadly understood ergonomics was made. The European Agency for Safety and Health at Work has published a list of implemented EU directives on actions related to the protection of health and safety at work:

- Framework directive on safety and health at work.
- Directive 2009/104/EC – use of work equipment.
- Directive 99/92/EC – risks from explosive atmospheres.
- Directive 92/58/EEC – safety and/or health signs.
- Directive 89/656/EEC – use of personal protective equipment.
- Directive 89/654/EEC – workplace requirements.
- Others OSH related aspects.

As part of the second stage, the company's source materials developed at the planning stage of the production line work were collected, organized and analyzed. These activities took place in 2016-2018. The collected material included data from the workplace integration process, among others: list of planned operations, simulations and analyzes of the so-called ergonomic points obtained from ergonomic tests based on UAS and EAWS methods. The next

stage of work was the analysis of the real state that followed the launch of the production line in 2018. The research was carried out to identify the organization of work (including recognition of operations carried out on the production line, analysis of the manner of performing activities, organization of working time, quantitative research – simulations and measurements of ergonomic points). The last stage was a comparative analysis of the designed working conditions with real conditions occurring after starting the assembly line. An analysis of the company's improvement activities was also carried out in terms of work ergonomics related to the operation of the line.

The methods and tools used in the research were:

- TiCon (tool based on MTM, UAS, EAWS methods),
- explicit, direct and non-participating observations,
- free interviews,
- photographic and video registration.

## RESULTS AND DISCUSSION

### Ergonomic score analysis

By the principle of conceptual ergonomics, it is effective to shape working conditions at the design stage. Then there is the greatest possibility of preventive actions, which is associated with many possibilities of choosing solutions. These types of analyzes start up to 2 years before the production line is launched. A way of assessing ergonomic conditions among physically-working employees is to analyze the load on the musculoskeletal system during activities. There are many methods and tools dedicated to this issue. These are commercial and free methods and tools (indicator methods e.g. OCRA, JSI, KIM, REBA, RULA, NIOSH, OWAS, EAWS, biomechanics based methods, e.g. 3DSSPP, goniometric methods, etc.).

TiCON software was used during research work carried out on the company's premises, one of which modules is MTMErgonomics® based on the European Assembly Work-Sheet (EAWS) method. EAWS through the biomechanical ergonomics assessment sheet is an ergonomic tool that takes into account body posture, action force, manual weight manipulation, and upper limb loading during cyclical activities.

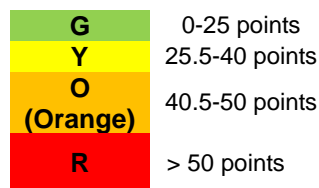
The assessment is provided in the form of traffic lights (Figure 1) by the Machinery Directive 2006/42/EC (Schaub et al., 2012).

0-25 points	<b>G (Green)</b>	No risk or low risk – recommended. No action is needed.
> 25-50 points	<b>Y (Yellow)</b>	Possible risk – not recommended. It is recommended to look at the problem to check and reduce risk.
> 50 points	<b>R (Red)</b>	High risk – should be avoided. Action should be taken to reduce the risk.

Fig. 1 Ergo points by EAWS sheets

Quantitative data (Ergo points) was obtained during the research, however, it is confidential data, so in the further part of the work only the colors were used. It is worth noting that for the rapid monitoring and predicting ergonomic hazards, the company has introduced an additional point interval, which has a warning character.

To visualize the results of each numerical value obtained from the enterprise belonging to a particular operation, the appropriate color was assigned, in accordance with the intervals located at the ergonomic points, based on the scale according to the Figure 2.



**Fig. 2 Ergo points scale used by enterprise**

As a result, the results obtained are presented in the form of tables (see Figure 3). The tables use numerical identification of individual operations, where 1 operation = 1 workstation. The comparative analysis of the results obtained was divided into 4 stages due to the different phases in which the production line was located in the years 2016-2019.

The table presents summary data regarding:

- operations and simulations performed in 2016, 2017 and 2018,
- analysis of the launched production line from 2018
- analysis of the production line carried out after increasing production in 2019.

For the first 3 years, the production line consists of 32 operations. Each year is a different stage of research that was carried out in the company. During this time, improvements were made to increase work comfort and raise productivity, which is described later.

### **Data analysis – 2016**

In 2016, the so-called "Zero Loop" also called Zero Step. There was no detailed information about the production line at the time. Initial concepts of assembly line management were only created. It was assumed that the line will consist of 32 operations. No specific times could be assumed due to the lack of detailed information. It was not known what technological solutions would be used. At this stage, the first illustrative simulations were carried out, although it was not possible to assign them times or points, so the column 'Data based on simulation – 2016' is almost filled with blue.

Empty fields next to operations No. 10, 15, 19, and 27 mean that there was a lack of knowledge about positions at this stage.

The next stage was the implementation of the workplace integration process. It consisted of collecting all the most detailed information from various organizational units, i.e. logistics, work analysis, quality, health and safety to be able to create certain assumptions. All these sectors shared their data as well as the necessary guidelines to start the process. The data was entered into the program, where 90% of the simulations were performed before the proper layout of the production line, and work stations were decided. Interviews with ergonomists show that it was a long and arduous process, and before choosing the final version, they had to perform hundreds of different simulations of given jobs, as well as adjust the positions of employees so that it was as ergonomic as possible. It should be emphasized that each simulation consisted of creating an illustrative workplace, i.e. it was necessary to position each element, take into account all the necessary tools, select the appropriate height at which they were to be, up to creating a visualization of movements that should be performed by a person in a specific position.

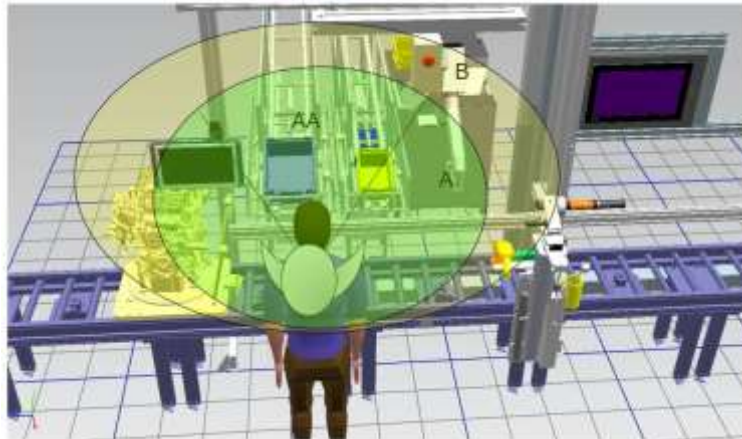
Work Operation	Data based on simulation			Data based on real production line working		Work operation
	2016	2017	2018	2018	2019	
1	B	G	G	G	G	1
2	B	Y	G	R	O	2
3	B	G	O	G	Y	3
4	B	G	Y	Y	Y	4
5	B	O	Y	Y	Y	5
6	B	G	G	G	G	6a
7	B	Y	G	G	G	6b
8	B	G	R	Y	G	7a
9	B	G	G	G	G	7b
10			G	G	Y	8
11	B	G	G	Y	G	9a
12	B	G	G	G	G	9b
13	B	G	O	O	Y	10a
14	B	G	G	G	G	10b
15			G	Y	Y	11a
16	B	G	G	Y	G	11b
17	B	G	G	G	G	12a
18	B	O	G	G	G	12b
19			Y	G	Y	13
20	B	G	G	G	G	14
21	B	G	G	G	G	15
22	B	Y	G	Y	G	16a
23	B	Y	Y	Y	Y	16b
24	B	Y	Y	Y	G	17a
25	B	G	G	G	G	17b
26	B	Y	G	G	G	18a
27			R	G	G	18b
28	B	R	G	G	G	19a
29	B	G	G	O	G	19b
30	B	G	G	O	G	20a
31	B	R	Y	Y	G	20b
32	B	G	G	Y	G	21
				G	G	22a
				G	G	22b
				G	G	23a
				Y	Y	23b
				Y	Y	24
				G	G	25a
				Y	Y	25b
				G	G	26a
				G	G	26b
				G	G	27a
				G	G	27b
				G	G	28a
				G	G	28b
				G	G	29a
				Y	Y	29b
				G	G	30a
				Y	Y	30b
				Y	Y	31a
				Y	Y	31b
				G	G	32
				G	G	33
				Y	Y	34

Fig. 3 Summary of ergonomic analysis results



Employee-related results were obtained by entering data into the TiCon program. Every, even the smallest factor influencing the obtained results was introduced – the employee's movement, his attitude during the performance of activities, the environment and working conditions, which then made up the entire work cycle at a specific position, i.e. operation. As a result, more detailed information on individual positions began to be received.

An example of simulations made in the TiCon program is shown in the Figure 4.



**Fig. 4 Example of simulations made in the TiCon**

#### ***Data analysis – 2017***

In 2017, works were continued to rely solely on the simulations and visualizations of each station, but the components on which they wanted to work were already known, and it was known where the sensor assemblies would be located. It was possible to enter approximate data into the software because the general technological outline was also known and some ergonomics were created. On this basis, a visualization of the assembly was created. Four positions that were not yet known were still being struggled. Preliminary simulations can be qualified as successful, but a whole team of specialists worked for a long time to achieve this state – especially since they were based on the simulations and assumptions alone.

#### ***Data analysis – Simulations 2018***

The first thing observed was to maintain the concept of 32 operations and eliminate white fields. The reason for changing colors, e.g. from green to yellow or from red to green, was the fact that four operations were developed that affect the results of the entire production line.

Significant progress can be observed in the 2018 simulation phase, as many as 4 workstations have changed to the most desirable green color, and white fields have disappeared. However, yellow and orange were added for one position.

#### **Data analysis – 2018 – Launched assembly line**

The data presented during this period are no longer simulation data. The production line of the drive system components was launched, which turned into

real results of ergonomics tests at workplaces. The concept of 32 workplaces has been maintained. After analysis, it can be seen that there has been an apparent deterioration in the color analysis. As a result, a much smaller number of green workstation and a much larger number of yellow were obtained, compared to the simulations from 2018. Red at the second workplace appeared due to a change in the measurement method – the instrumentation at this station was changed. This was the basis for seeking new solutions to improve the process. These activities were combined with a factor related to increasing production.

#### **Data analysis – 2019** – current state

The last analysis was carried out in 2019. This is the representation of the current state. The engine production line has been expanded to increase production. But for this to happen, it was necessary to increase the number of workstations – operations. In this way, a total of 54 operations were created out of 32 operations. It was decided to split positions, i.e. the employee performs fewer tasks in one position, but faster.

Comparative analysis showed that at this stage complete reduction of red fields and reduction of orange fields to one position was achieved. To sum up, the entire production line is based, with a significant advantage in green and several yellow fields.

#### **Simulation vs reality**

Following the principle of continuous improvement and Deming cycle methods (PDCA – Plan, Do, Check, Act), before the creation of the production line, the planning stage takes place. Simulations and calculations are made – risk assessment and analysis of ergonomic factors during the product / process development phase. The following risk factors were assessed before design:

- action speed,
- duration of force,
- organization of work,
- duration of the activities.

In the case of the examined company, ergonomics planning focused on attitude analysis. When creating a Human model, reference points are marked on the simulation (head, shoulders, arms, hands, legs), in this way you can see what position the employee takes when performing a specific task.

The Figure 5 shows a screenshot of the windows available in the TiCon EAWS section.

Each movement performed by an employee while working on a specific position is modeled during the simulation process. It does not matter if it is a preliminary visualization (Plan), final simulations, and implementation (Do) or control of real conditions (Check). Modeling concerns, among others, the range of hand movement, distance, and the time of staying in the modeled body position.



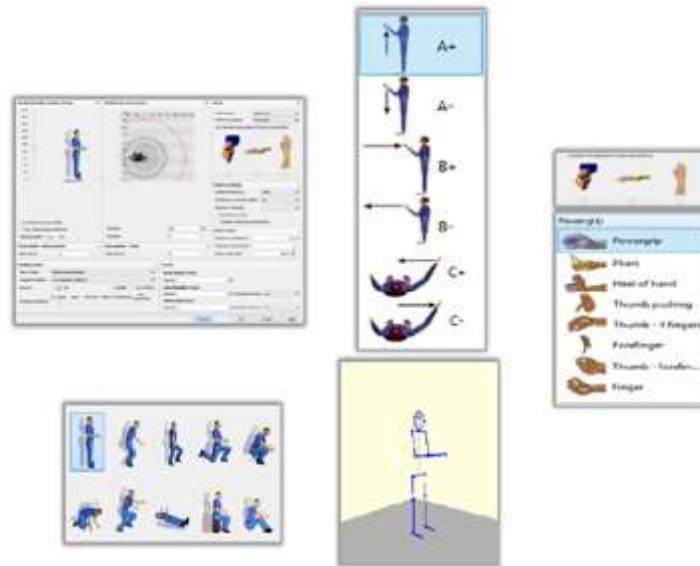


Fig. 5 Screenshot of the windows from EAWS section in the TiCon

The program includes the possibility of modeling individual body sections – position and rotation of e.g. hands, fingers, or feet. In addition, it is possible to select an item during an activity. During the risk assessment, all data related to not only the body position taken by the employee at the time of the activity but also the organization of working time, etc. are entered. The effect is to receive feedback related to maintaining ranges of movement and body position within the ranges of predefined norms. If the values are red, it is a signal to the need to introduce organizational changes (e.g. the way activities are performed or the workplace is reorganized).

The Figure 6 shows how to model work activities at individual workstations.

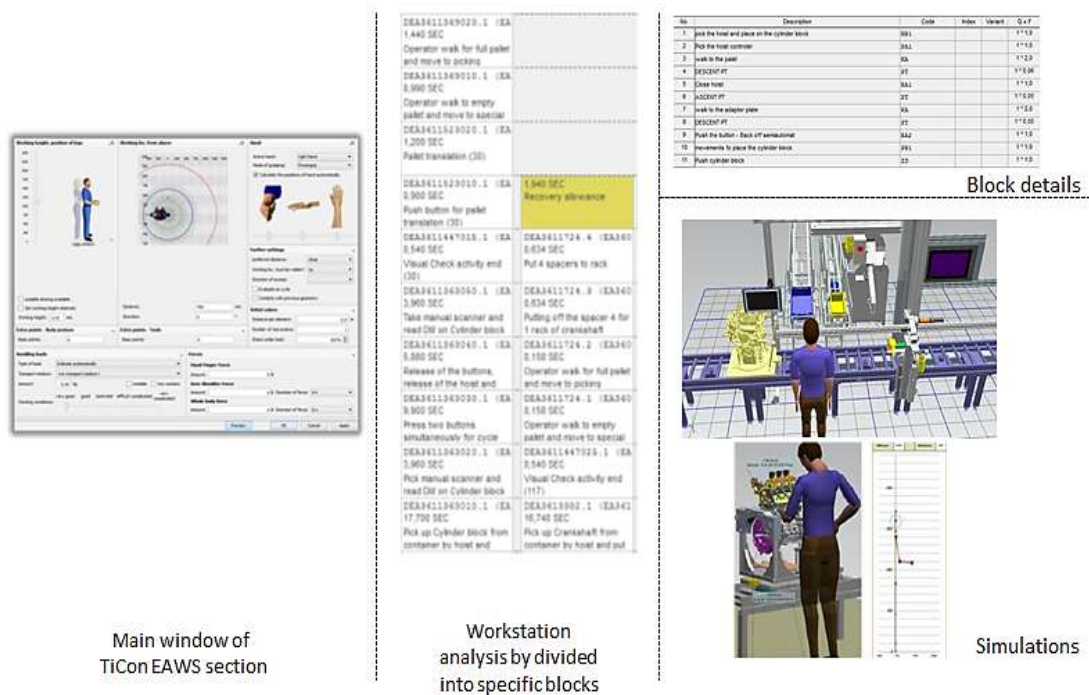
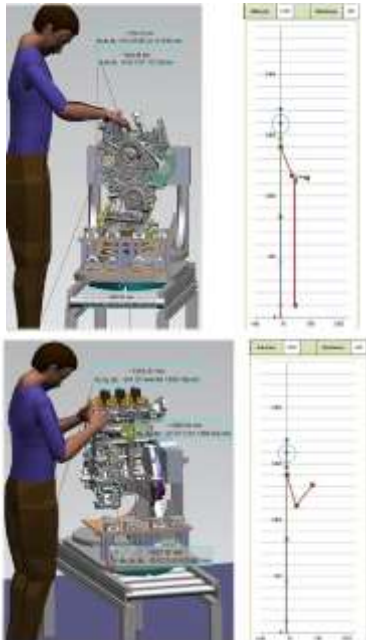


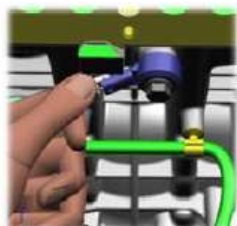
Fig. 6 Steps of modelling process in TiCon

In addition, the Figure 7 shows a comparison of the simulation with the real state after starting the production line.

Simulation – before assembly  
line launched



Reality – line at work



**Fig. 7 Comparison of planned and actual working conditions**

On the left is the graphic area – simulation, profile model (Human), or zoom on the hand reflecting how it should be arranged at a given stage of production and a photo showing the actual state.

Observation shows that individual activities, in most cases, are carried out as intended, which confirms the correctness of planning activities. Additionally, detailed observation of how employees perform activities and the mapping of work movements in a computer program allows ergonomic analysis support improvement (Act).

Concerning the presented ergo point analyzes, examples of preventive and streamlining actions were presented:

- a) organizational changes in selected positions by introducing automated, mobile sagas with details. This solution results in the elimination of the awkward position of the body by not having to lean out to collect details. Sensors were used. When the product is in a certain place on the production line, the sensor registers it and gives a signal that the sag automatically ejects. If there are no elements in a given sag – it is enough for the employee to press the foot pedal placed on the floor under the production line tape, and the sag changes – another full basket will enter its place. The visualization of the solution is presented in the Figure 8.



**Fig. 8 Visualization of work condition improvement after organizational changes**

- b) Balancing the production line between operations. In case 40sec is obtained at one stage of the production line and is close to unfavorable limits, then the time can be reduced by e.g. 5sec. and add it to the next operation, which has a large margin. If several activities took a long time in the third position, one of them was moved to an adjacent position. Thanks to this, times are equalized and optimal results achieved in both positions.

The effects of the actions are noticed in the ergo points analysis, as shown in the Table. It contains values – ERGO points and times for three operations. You can see how the changes introduced – balancing the production line, positively affected the positions. Red was eliminated and in return, two green and one yellow were obtained.

	BEFORE			AFTER		
ERGO points	39.5	15.5	59	23.5	15.5	33.5
Time [sec]	18.1	21.8	20.3	17.2	19.8	17.9

- c) Workplace automation. By introducing complete automation in some workplaces, all manual activities were eliminated. Before the introduction of

automation, 60.5 ERGO points were obtained, which is definitely above the allowable values, and after automation, we get 0 ERGO points. In this way, the red color on the production line has been eliminated.

- d) Rotational work system – fatigue resulting from monotype work has been eliminated.
- e) Replacing hand tools with power tools. By using this type of solution, the load on the upper limbs (hands, fingers, wrists) was reduced and the time of surgery was shortened.

## CONCLUSION

Despite the lack of unambiguous guidelines and specified procedures in the scope of assessing work ergonomics, enterprises decide to take action in this area. The concept of continuous improvement based on four stages of the Deming cycle can be the basis for work quality management, including broadly understood management of working conditions in the context of ergonomics. Based on the analyzes carried out, it can be concluded that introductory actions, eliminating randomness of actions, and introducing thoughtful work organizations can translate into positive effects. However, it is important to treat these activities in a continuous, looping manner. Continuous improvement, through systematic control of factors affecting work ergonomics, their analysis, and attempts to verify with real conditions should be permanently inscribed in the processes of services dealing with occupational health and safety not only of industrial enterprises.

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**Abstract:** Analysis of working conditions in terms of ergonomics is an increasingly popular topic among industrial enterprises. This is primarily due to the development of departments responsible for maintaining safe and healthy working conditions, but also awareness of the impact of working conditions on maintaining safety and maintaining the rhythm of work. Care for working conditions translates into the possibility of maintaining the level of activities performed, which indirectly affects the quality of final products. Conducting activities in the field of shaping ergonomic working conditions in the context of continuous improvement based on the Deming cycle and the principles of conceptual ergonomics seem to be a key approach to care for work safety. Treating this process as a continuous and looped process gives you the ability to react quickly and predict adverse effects. However, constant control, observation, and analysis of the possibilities of implementing improvement solutions is important. The purpose of the article is to compare ergonomic working conditions at selected work stations with the assumptions and plans developed before launching the assembly line. The research included a comparative analysis of results in the form of ergonomic score obtained from TiCon software, based on MTM, UAS, and EAWS methods. The research was carried out at the turn of 2016-2020 in an automotive company dealing in the production of passenger car drive system components.

**Keywords:** ergonomics, working conditions, working conditions management