SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2022
ORGANIZATION AND MANAGEMENT SERIES NO. 164

MANAGEMENT OF ERGONOMIC INTERVENTIONS IN INDUSTRY 4.0

Kamil WRÓBEL

Poznan University of Technology; kamil.wrobel@put.poznan.pl, ORCID: 0000-0002-5883-5567

Purpose: The cognitive goal of the article is to quantify various states of variables influencing the worker's burden in the assembly process. On the other hand, the utilitarian goal is to assess the significance of variables for the application of artificial neural networks methods in supporting IE management.

Design/methodology/approach: The article deals with the management of ergonomic interventions in industry 4.0. The main tasks during the assembly process were defined on the example of the window production analysis. The application of the method of registering human load indicators to manage the states of variables in the chain of operation of the assembly process was justified. The study analyzed 16 states of variables such as noise, work pace, forced body position, movement, and the location of information and control elements of the IT system. During the bench tests, postural load, heart rate and NASA-TLX assessment were performed. In the preliminary and final studies, metric data was collected, cognitive-motor skills and work fatigue were assessed. The obtained results were quantified using a quantitative comparative method.

Findings: The article verifies the approach of measuring the individual workload of an employee for shaping working conditions in the context of assembly works. For the examined example, the weights of the system variables for the inference of artificial intelligence were determined in detail.

Research limitations/implications: The main limitation of the study is the research sample. Although the concept departs from statistical research, from the point of view of science, it is reasonable to look for the correlation of the burden on individual user groups, e.g. the elderly, people with disabilities. It is also important to further measure the synergy of individual variables.

Originality/value: The novelty of the article is the idea of EI management in the aspect of industry 4.0 through operational shaping and tactical state variables affecting the individual workload of an employee with the use of methods of artificial neural networks. For this purpose, a conceptual method of determining the workload of an employee was presented. The work is addressed to theorists and practitioners responsible for designing and organizing working conditions.

Keywords: human resources management, ergonomic interventions, industry 4.0, fuzzy cognitive maps, measuring employee workload.

Category of the paper: Research paper.

1. Introduction

1.1. Ergonomic interventions in Industry 4.0

Ergonomic interventions (EI) in industry 4.0 (P4.0) are activities and solutions aimed at increasing the quality of human-machine-environment interaction (HME) and consisting in (Wróbel, Hoffmann, Czarnecki, 2020):

1. improving a specific product, organizational operation, IT system or service within the defined ranges of changes – which allows a slight increase in the overall quality of the solution, service, interactions, etc.,
2. innovation, i.e. a new product, service, or application, that results from the innovative combination of the existing elements; as well as EI are also an interdisciplinary approach to search for new ideas and concepts, based on the knowledge from the applied/development researches from the anthropocentric, social, biotic and technical point of view (Dewicka, 2016); they synergistically increase the overall quality of the solution, or
3. inventions - substantially defining a new quality level for a given solution.

The ergonomic innovations, constituting the innovations in general, are one of the main factors enabling the comparative and/or competitive advantage. Nevertheless, such innovations may become a decisive factor for the survival on the market (Grabowski, Muraszkiewicz, 2017). EI within the I 4.0 are the response to the posed paradigms i. e. Panetto et al., (2019), Pacholski and Kałkowska (2019) and Tan et al. (2019) indicating the integration on the i.e. management, production, logistics and analysis level of organization, whereas their implementation enables i.e. unlocking creativity of the employees (Taylor et al., 2020), the ergonomics improvement for the HME interaction (Wróbel, 2020b), as well as professional stimulation of people with resource deficits (Butlewski, 2018).

1.2. EI management in industry 4.0

The 4.0 Industry (I 4.0) has capabilities of qualitative improvements on operational level, as it is based on proven solutions arising from the Industry 3.0 and implements many new solutions. In this context, the I 4.0 solutions have the capabilities of ergonomic interventions (EI) (as long as their selection increases the quality of HME interaction, also referred to as the HME), with consideration to the fact that focus in the I 4.0 is made on a human being, who is referred to as the 4.0 Operator (O 4.0). The O 4.0 in smart factories constitutes the element of operation, with respect to which the remaining elements of the organization make self-improvements towards diversified skills, capabilities and preferences of the O 4.0 (Kaasinen et al., 2020; Fletcher et al., 2020), and technological processes (TP) are simultaneously implemented on a previously unprecedented perfection level, with a dynamic reaction to the changes in the organization and its environment.

This concept is achieved with means of the solutions based on artificial intelligence (AI). On the one hand, such solutions adapt the TP to the changes at higher levels of organization's operation, with a simultaneous consideration to interaction between the HME and the TP. On the other hand, such solutions improve the manufacturing organization management (Longo, Nicoletti, Padovano, 2017). In terms of ensuring the proper quality of HME interaction, there are measures for the replacement or strengthening the O 4.0. Moreover, organization management (OM) should focus on the social engineering aspects through resource relationships at all levels of management (Jantsch, 1972). However, there is a lack of methodology and guidelines for transforming ideas into the practice of applying knowledge about the human factor in organization management (Peruzzini, Pellicciari, 2017). Organizations should focus on assessing employee activities, perceived comfort and quality of work from a physical and cognitive point of view (Chen, Khoo, Chen, 2015). Including, assessing human-machine interaction (Witten-Berg, 2016) and the dynamics of resource states through adaptive and proactive actions (Griffin, Neal, Parker, 2007).

1.3. Criteria and decision barriers in EI management in industry 4.0

The criteria for determining the scope of EI include economic, organizational, methods of organization and performance of work (Pacholski and Kałkowska, 2019), operational (Sparrow, 2020), as well as ergonomic criteria (e.g. Jasiak, Misztal, 2004) (cognitive, sociological, physiological, physical, anthropometric, motor, cultural, etc. requirements).

In the management and implementation of EI in terms of P4.0, the barriers are very often the costs related to the automation of assembly processes and quality control. This contributes to a certain exclusion of these processes from development towards P4.0. The solution to this problem is the use of individual multi-indicator monitoring of employee loads and the use of AI methods. The article presents this type of approach to the stage of quantification of the variable states affecting human load on the example of the window production process.

1.4. Purpose of the article

The cognitive goal of the article is the quantification of various states of operational and tactical variables influencing the workload of the employee in the process of window assembly. The utilitarian goal is to assess the significance of variables for the application of artificial neural network methods in supporting EI management for partially and non-automated assembly processes in the aspect of industry 4.0.

2. Variables in EI management in window production

2.1. The technological process of window production in the aspect of industry 4.0

The work system of any organization consists of resources and the relationship between these resources. The description of the dynamic phenomena accompanying the aforementioned relations of organization resources are chains of action (CA) (Slawinska, Wrobel, 2021). These are the characteristics of the systems of three elements: human, interface and technical device (Sławińska, 2016). The CA in the production of windows is presented in Table 1 – CA odpowiadają charakterystyczne zadania przedstawione w procedurze badań (rozdział 3.1).

Table 1.
Strategic and tactical stages of the CA for window production (selected scope)

No	Operation level (all)	Tactical level (selected range)
1.	Cutting PVC posts to size	1.1. Pick up the bars; 1.2. Loading the posts into the PVC saw; 1.3. Taking the posts out of the Saw; 1.4. Loading the posts on the mobile rack; 1.5. Transporting the posts on the rack to the next position
2.	Preparation of posts - installation of PVC posts with metal profiles	2.1. Pick up the bars; 2.2. Get the connector; 2.3. Twisting of posts and profiles; 2.4. Putting the connected elements back on the shelf; 2.5. Transporting the posts on the rack to the next position
3.	CNC processing of window frame profiles	3.1. Taking twisted posts and profiles from the rack; 3.2. Verification of dimensions; 3.3. Scanning an item; 3.4. Loading of elements into the NCN machining machine; 3.5. Twisting and milling of elements loaded into the machine; 3.6. Receipt of items; 3.7. Machine operation verification; 3.8. Labeling elements with labels; 3.9. Putting the processed elements on the shelf; 3.10. The elements are transported on the rack to the next station
4.	Welding of PVC profiles	4.1. Checking the order in the IT system; 4.2. Taking a few profiles from the rack; 4.3. Verification of the downloaded items with the order; 4.4. Entering data into the IT system; 4.5. Setting the collected elements in the PVC welding machine; 4.6. Switching on the welding machine; 4.7. Welding and processing of the window frame or sashes by the device; 4.8. Moving the welded elements to the next station by the device
5.	Forging window frames	5.1. Collection of door frames and leaves by an employee; 5.2. Completion of assembled and tethered elements; 5.3. Twisting selected elements, e.g. hinges; 5.4. Forging selected elements; 5.5. Scanning frames (stickers) and identification with the order; 5.6. Putting the forged elements on the shelf; 5.7. The elements are transported on the rack to the next station
6.	Folding frames and window sashes	6.1. Taking the frame from the rack; 6.2. Frame codes check; 6.3. Get the right wings; 6.4. Placing the wings in the frome; 6.5. Verification of the performance of previous tasks - quality control; 6.6. The combination of wings and Frome; 6.7. Re-quality control - window functionality; 6.8. Window scanning - verification with the order and window description; 6.9. Putting the connected elements back on the shelf; 6.10. The elements are transported on the rack to the next station
7.	Glazing of windows	7.1. Collection of the combined frame and window sashes; 7.2. Scanning and verification with the order; 7.3. Taking the glass and placing it in the sash; 7.4. Getting the shims; 7.5. Placing the washers under the glass; 7.6. Securing the glass position; 7.7. Quality control - window functionality; 7.8. Transporting the window for quality control - offset with a roller conveyor
8.	Quality control	8.1. Comprehensive window control and verification with the order;
9.	Securing the window for transport	9.1. Downloading the window from the transmitter; 9.2. Positioning the window on the palette; 9.3. Securing the window for transport; 9.4. Transport of the pallet to the warehouse

Real-time monitoring of the employee's condition and recording of CA enables the diagnosis of causes of changes in the work situation (Slawinska, Wrobel, 2021). The diagnosis of the causes of changes becomes the basis for the optimization of work processes, it is important for improving productivity and reducing the costs of modifying the work system in improving safety and ergonomics (Butlewski et al., 2020).

a) b) c) d)

Figure 1. Examples of work stations: a) post cutting station (PVC saw); b) post preparation station; c) CNC processing station; d) PVC profiles welding station.

Source: https://www.youtube.com/watch?v=UOodLJof7Y0.

For this purpose, significant technical and organizational variables affecting the workload of the employee should be identified. Based on the analysis of window production processes (example in Fig. 1), the frequent states of the variables were determined, which are described in Table 3.

2.2. Worker Workload in IE Management

Analyzing the work and load (tab. 2) of operators from a physical and mental point of view is key to defining effective ways of working and optimizing tasks (Romero et al., 2016). The use of monitoring and analysis techniques of loads and operator reliability in P4.0 is possible in real time, when recording psychophysiological indicators in terms of the so-called User experience (UX). Measuring the operator's reaction creates knowledge about the interaction and possibilities of modifying the system thanks to objective data (Peruzzini, Grandi, Pellicciari, 2020).

Table 2.
Types of employee workload

Lp.	Type of load	The essence of the load
1.	Sensory and cognitive	All the loads that arise during the reception, processing and transmission of information between elements of the environment, and above all, between people and computers
2.	Postural-physical	Loads related to the way work is performed, body posture, body characteristics (internal loads) and external loads
3.	Stress-emotional	All psychological burdens
4.	Motorized	Stress on eye-hand coordination, eye-foot coordination and coordination during locomotion

The main set of indicators used to measure UX are heart rate (HR), heart rate variability (HRV), respiratory rate, pupil dilation, gaze direction, and eye blinking. In particular, the measurement concerns HR and HRV, which correlate correlated with physical and mental workload (Mulder, De Waard, Brookhuis, 2004). Other indicators are also specified, i.e. analysis of electroconductivity activity, electroencephalography, electromyography and the use of accelerometers and gyroscopes (Moschetti, Fiorini, Esposito, Dario, Cavallo, 2016) and the measurement of individual cognitive load and situational awareness (for example: NASA Task Load Index (NASA-TLX) (Hart, Staveland, 1988; Endsley, 1995).

3. Research method and scope

3.1. Research procedure

The quantification of the variable states for the assembly process was preceded by a research procedure:

1. preliminary research, i.e. collecting metric data and assessing cognitive-motor skills (using the test (Wróbel, 2020)),
2. preceded by HR and NASA-TLX measurements (resting measurement), experimental tests involving the performance of 16 tasks (Table 3); each task was a work cycle covering: a) Approach to the position and information and control activities; b) approaching the "material pallet", picking up the material containers and transferring the material to the site; c) communication with the information and control device, verification of the correctness of the collected material, use of the assembly manual and assembly of the collected elements; d) dismantling the elements and putting them back in the containers; e) completing the NASA-TLX survey; f) reference of containers; g) Rest,
3. overall assessment of employee's work fatigue.

The total duration of the research was approximately 3 hours.

3.2. Scope, tools and research stand

The assessment was made taking into account 1 person. Such an approach is in line with the ergonomics' pursuit of "optimal" adaptation of working conditions to the employee, which is difficult due to the personal differentiation. During the research, the person was to perform 16 tasks chronologically, which were selected to define specific research goals (Table 3).

Table 3.
Tasks carried out during the research process

Task No.	Description of the task [variable state]
1	Free work without imposed working time; one position; manipulation space = work straight ahead; manipulation close to the body; info source at the height of the working plane next to the mounted object - on the left side; working plane height = 110 cm; distance between the post and the pallet equal to 3 meters
2	As in task 1 + travel distance 2x longer
3	As in the quest 1 + 2x faster
4	As in task 1 + stress factors: "negative assessment of the employee's work by the supervisor"
5	As in task 1 + manipulation space = 45 degrees to the right
6	As in task 5 + manipulation space 2x further (or max.); an info source next to the manipulation box
7	As in task 1 + manipulation space 2x further (or max.); an info source next to the manipulation box
8	As in task 1 + info source 50 cm higher and further
9	As in task 1 + info source 50 cm straight ahead
10	As in task 1 + info source moved 45 degrees to the leftand 50 cm further
11	As in task 1 + listening and comprehending a documentary = 40-60 db
12	As in task 1 + with industrial noise = 60-80 db
13	As in task 1 + work plane height = 90 cm
14	As in task 1 + work plane height = 130 cm
15	As in task 5 + work plane height = 130 cm
16	Move and manipulate an 8 kg object for 40 seconds

The research included indicators and research tools such as: 1) type of thoughts [positive/ negative] - signaled by person; 2) postural load index according to the RULA (ang. Rapid Upper Limb Assessment); 3) heart rate (HR) - measured with the Huawei GT2 Pro smartwatch; 4) NASA-TLX indicators.

A test stand was prepared for the research (Fig. 2).

Figure 2. Test stand.

Despite the fact that the production of windows is associated with heavy elements, the research used light elements in order to eliminate the impact of external physical loads on the collected and analyzed indicators, which, for example, could make it difficult to assess the level of stress in task 4. The assembled and disassembled elements were Lego blocks from set 42133 [lego.com] given to the 18th page of the manual (fig. 3).

Figure 3. Assembled and disassembled elements (lego.com).

Assessment of the impact of external physical forces, i.e. the force needed for movement and manipulation, was included in task no. 16 (Table 3), which consisted of moving and manipulating an object weighing 8 kg for 40 seconds.

4. Results

4.1. Results of preliminary and final tests

The examined person was a 23-year-old woman weighing 47 kg, height 170 cm and having an average resting heart rate of 69 HR. The declared fatigue after completing all tasks was assessed by the respondent as low (grade 3 on a 10-point scale, where 10 - extreme work exhaustion). The examined person did not have any deficits in terms of the functionality of the locomotor system. The average task completion time in the cognitive-motor skills assessment test, the average task completion time was 10 seconds (min. = 9; max. = 11) and the steering accuracy coefficient U was 21 (min. = 14; max. = 34).

4.2. Results of postural-physical stress

The most unfavorable states of the variables for the average and maximum postural load were forcing the torso twist by an angle of 45°, abducting and crossing the upper limbs, and using the extreme range of the grip (Table 4).

Table 4.
Average and maximum values of postural load according to RULA for the body position during communication with the information and control device, reaching elements from containers and assembly

Task No.	RULA rating [mean]	RULA rating [max.]	Task No.	RULA rating [mean]	RULA rating [max.]	Task No.	RULA rating [mean]	RULA rating [max.]	Task No.	RULA rating [mean]	RULA rating [max.]
1.	2,33	3	5.	4,33	5	9.	2,33	3	13.	3	4
2.	2,33	3	6.	4,33	5	10.	2,66	3	14.	2,33	3
3.	2,33	3	7.	3,66	5	11.	2,33	3	15.	4,33	5
4.	2,33	3	8.	2,66	3	12.	2,33	3			

Postural load was lowest when there was no forced position of the torso and upper limbs. Even in the case of forcing to look at the information and control device distant from the examined person (as in task 9).

4.3. Task load results according to heart rate measurement

The obtained results of the heart rate measurement showed that the heart rate at the beginning of the tests was the highest and it decreased with time (Table 5).

Table 5.
Average HR index for tasks - without taking into account the rest time

Task No.	HR [mean]	Task No.	HR [mean]	Task No.	HR [mean]	Task No.	HR [mean]
1.	84,91	5.	78,83	9.	75,33	13.	76,33
2.	85,83	6.	75,5	10.	76,33	14.	72,41
3.	80,83	7.	74,25	11.	76,16	15.	72,83
4.	82,5	8.	74,16	12.	76,33	16.	72,83

It was probably related to stress and anxiety, as the test person was not previously instructed about the scope and course of the research.

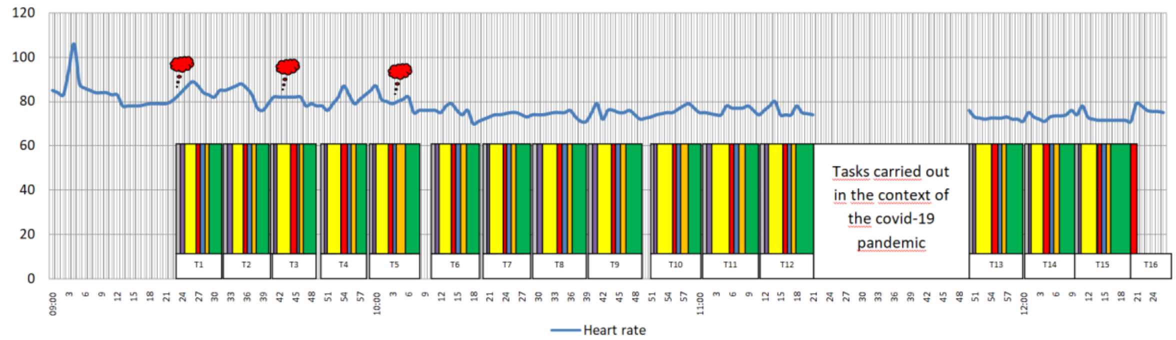

Figure 4. The course of the heart rate value during the tasks performed - description: 1) red clouds show the time of occurrence of negative thoughts in the examined person; 2) gray task flow - approach to the station and interaction with the info-control device; 3) purple task flow - approach the pallet with containers, pick them up and transport them to the workplace; 4) yellow task flow - assembly of the collected elements; 5) red course of the task - disassembly of elements; 6) blue task flow - completion of the NASA-TLX survey; 7) orange task flow - reference pallet containers; 8) green course of the task – rest.

4.4. Task (factor) load results according to NASA-TLX

The results of mental and physical stress are presented in Figure 5.

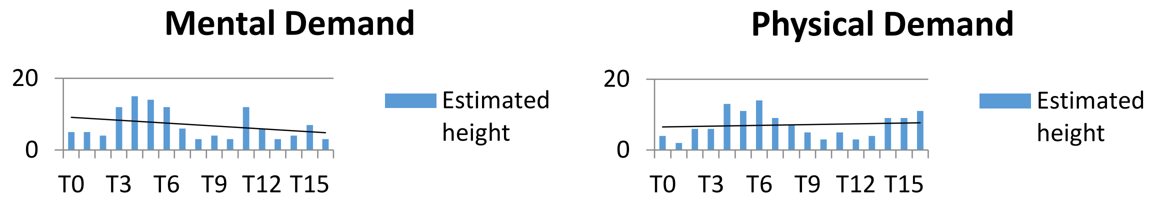

Figure 5. Task load related to mental and physical needs.

The results of the time and performance load are shown in Figure 6.

Figure 6. Task load related to the time demand and required capacity.

The results of the effort load and frustration are given in Figure 7.

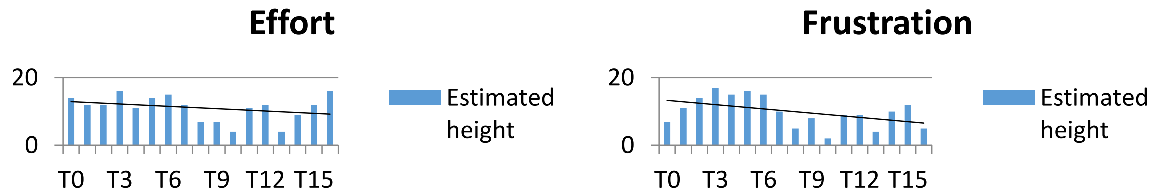

Figure 7. Task load related to the required effort and frustration.

The comparison of the heart rate trend (Table 6) with the trends of the NASA-TLX ratings (Fig. 5-7) shows the similarity of the direction of the trends (apart from the performance required trend), but their quality of fit is different.

5. Quantification of the significance of variables in supporting EI management

The quantification was performed by a quantitative comparative method. For EI and employee workload management, it is beneficial to separate the quantifications into postural load, heart rate, NASA-TLX ratings, NASA-TLX cumulative ratings, and all load indices cumulative. The individual quantifications should take into account the dispersion of the minimum and maximum marks (Table 6) in relation to the overall result of employee fatigue after work (chapter 4.1).

Table 6.
Values of load indices for the tested variable states *(table continued on page 11)*

No. task	Average RULA rating	Average HR indicator	NASA-TLX rating						min.	max.	mean
			Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration			
1	2,33	84,91	5	2	12	16	12	11	2	84,91	18,16
2	2,33	85,83	4	6	11	9	12	14	2,33	85,83	18,02
3	2,33	80,83	12	6	17	16	16	17	2,33	80,83	20,90
4	2,33	82,5	15	13	16	8	11	15	2,33	82,5	20,35
5	4,33	78,83	14	11	8	11	14	16	4,33	78,83	19,65
6	4,33	75,5	12	14	11	7	15	15	4,33	75,5	19,23
7	3,66	74,25	6	9	6	16	12	10	3,66	74,25	17,11
8	2,66	74,16	3	7	3	13	7	5	2,66	74,16	14,35
9	2,33	75,33	4	5	4	15	7	8	2,33	75,33	15,08
10	2,66	76,33	3	3	3	18	4	2	2	76,33	14,00
11	2,33	76,16	12	5	6	15	11	9	2,33	76,16	17,06
12	2,33	76,33	6	3	6	19	12	9	2,33	76,33	16,71
13	3	76,33	3	4	3	20	4	4	3	76,33	14,67
14	2,33	72,41	4	9	5	18	9	10	2,33	72,41	16,22
15	4,33	72,83	7	9	9	15	12	12	4,33	72,83	17,65
16	-	72,83	3	11	2	5	16	5	2	72,83	16,40
min.	2,33	72,41	3	2	2	5	4	2			
max.	4,33	85,83	15	14	17	20	16	17			
mean	2,91	77,21	7,06	7,31	7,63	13,81	10,88	10,13			

The developed quantifications were made for methods based on artificial neural networks, so the evaluation range is in the range from 0 to 1 (Tab. 7).

Table 7.
Quantifications according to the range of human load measurement

Overall assessment of fatigue after work	Quantification of postural load [according to RULA]		The quantification of the workload of the heart		Quantification of NASA-TLX ratings		Quantification of NASA-TLX Cumulative Ratings		Quantification of all load indicators cumulative	
	1.	2.	1.	2.	1.	2.	1.	2.	1.	2.
1	1	0.0	65-66	0.0	1	0.0	6-11	0.0	11	0.0
			68	0.05	2	0.05	12-17	0.05	12	0.05
2	2	0.2	70	0.1	3	0.1	18-23	0.1	13	0.1
			72	0.15	4	0.15	24-29	0.15	14	0.15
3	3	0.4	74	0.2	5	0.2	30-35	0.2	15	0.2
			76	0.25	6	0.25	36-41	0.25	16	0.25
4	4	0.5	78	0.3	7	0.3	42-47	0.3	17	0.3
			80	0.35	8	0.35	48-53	0.35	18	0.35
5	5	0.6	82	0.4	9	0.4	54-59	0.4	19	0.4
			84	0.45	10	0.45	60-65	0.45	20	0.45
6	6	0.8	86	0.5	11	0.5	66-71	0.5	21	0.5
			88	0.55	12	0.55	72-77	0.55	22	0.55

Cont. table 7.

<table>
<tr><td rowspan="2">7</td><td rowspan="8">7</td><td rowspan="8">1.0</td><td>90</td><td>0.6</td><td>13</td><td>0.6</td><td>78-83</td><td>0.6</td><td>23</td><td>0.6</td></tr>
<tr><td>92</td><td>0.65</td><td>14</td><td>0.65</td><td>84-89</td><td>0.65</td><td>24</td><td>0.65</td></tr>
<tr><td rowspan="2">8</td><td>94</td><td>0.7</td><td>15</td><td>0.7</td><td>90-95</td><td>0.7</td><td>25</td><td>0.7</td></tr>
<tr><td>96</td><td>0.75</td><td>16</td><td>0.75</td><td>96-101</td><td>0.75</td><td>26</td><td>0.75</td></tr>
<tr><td rowspan="2">9</td><td>98</td><td>0.8</td><td>17</td><td>0.8</td><td>102-107</td><td>0.8</td><td>27</td><td>0.8</td></tr>
<tr><td>100</td><td>0.85</td><td>18</td><td>0.85</td><td>108-113</td><td>0.85</td><td>28</td><td>0.85</td></tr>
<tr><td rowspan="2">10</td><td>102</td><td>0.9</td><td>19</td><td>0.9</td><td>114-119</td><td>0.9</td><td>29</td><td>0.9</td></tr>
<tr><td>104</td><td>1.0</td><td>20</td><td>1.0</td><td>120</td><td>1.0</td><td>30</td><td>1.0</td></tr>
</table>

Note: *1. – The value of the indicator; 2. – The significance of the variable.*

6. Summary

The P4.0 concept includes 9 pillars, for example big data and artificial intelligence, standalone robots, simulations and information systems integration. At the same time, it is not specified what combination and scope of application of the P4.0 pillars determines the transition of the organization to the P4.0 level. This means that enterprises, taking into account their situation, can individually pursue their development. Manufacturing companies, which require human manipulation, may have problems with financing high-capital technologies that replace humans, and therefore should especially take into account the requirements of ergonomics. Therefore, the use of management support with the use of AI methods can be a solution. The concept of the solution should consist of automatic collection of data on human loads, individual quantification of variables affecting the employee's load, computer inference generating hints for the employee and his superiors, as well as statistical analysis and registration.

The research in the scope of the article allows you to check the presented concept against the need to determine the significance of the variables necessary to identify the parameters of inference of neural networks in order to use them to describe, model and predict real changes.

On the basis of bench tests, personalized results of the impact of variable states occurring in the window assembly process were obtained. The obtained results were subjected to deliberate quantifications, which were assigned to the IE management objective, e.g. the need to minimize the stress load at the expense of the physical load. The quantifications made will enable their use in the method of artificial neural networks in supporting IE management for partially and non-automated assembly processes in the aspect of industry 4.0.

Funding

This work was supported by the Faculty of Management Engineering at the Poznan University of Technology. This article was prepared as part of the project [grant number 0811/SBAD/1058].

References

1. Butlewski, M. (2018). *Projektowanie ergonomiczne wobec dynamiki deficytu zasobów ludzkich.* Wydawnictwo Politechniki Poznańskiej.
2. Dewicka, A. (2016). Charakterystyka instytucjonalnego programu wspierania innowacji techniczno-ergonomicznych w małych i średnich przedsiębiorstwach. *Zeszyty Naukowe Politechniki Poznańskiej. Organizacja i Zarządzanie*.
3. Endsley, M.R. (1995). A taxonomy of situation awareness errors. *Human factors in aviation operations*, *3*(2), pp.287-292.
4. Grabowski, S., Muraszkiewicz, M. (2017). Modelowanie ekosystemów informacyjnych dla innowacyjnych społeczności programistycznych. *Zagadnienia Informacji Naukowej-Studia Informacyjne*, *55*(2(110)), 30-45.
5. Griffin, M.A., Neal, A., Parker, S.K. (2007). A new model of work role performance: Positive behavior in uncertain and interdependent contexts. *Academy of management journal*, *50*(2), pp. 327-347.
6. Hart, S.G., Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in psychology, Vol. 52,* pp. 139-183. North-Holland.
7. Jantsch, E. (1972). Towards interdisciplinarity and transdisciplinarity in education and innovation. *Interdisciplinarity*.
8. Jasiak, A., Misztal, A. (2004). *Makroergonomia i projektowanie makroergonomiczne: materiały pomocnicze*. Wyd. Politechniki Poznańskiej.
9. Kaasinen, E., Schmalfuß, F., Özturk, C., Aromaa, S., Boubekeur, M., Heilala, J., ... Mehta, R. (2020). Empowering and engaging industrial workers with Operator 4.0 solutions. *Computers & Industrial Engineering*, *139,* 105678.
10. Lego.com, https://www.lego.com/cdn/product-assets/product.bi.core.pdf/6394257.pdf.
11. Longo, F., Nicoletti, L., Padovano, A. (2017). Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. *Computers & industrial engineering*, *113*, 144-159.

12. Moschetti, A., Fiorini, L., Esposito, D., Dario, P., Cavallo, F. (2016). Recognition of daily gestures with wearable inertial rings and bracelets. *Sensors*, *16*(8), p. 1341.
13. Mulder, L.B.J., de Waard, D., Brookhuis, K.A. (2004). Estimating mental effort using heart rate and heart rate variability. In *Handbook of human factors and ergonomics methods* (pp. 227-236). CRC Press.
14. Pacholski, L., Kałkowska, J. (2019). Perspektywy zmienności paradygmatów ergonomii i organizacji przemysłowych procesów wytwarzania maszyn. In: L. Pacholski, J. Kałkowska, P. Kiełbasa, *Ergonomia wobec wyzwań masowości i globalizacji w produkcji*.
15. Panetto, H., Iung, B., Ivanov, D., Weichhart, G., Wang, X. (2019). Challenges for the cyber-physical manufacturing enterprises of the future. *Annual Reviews in Control*, *47*, 200-213.
16. Peruzzini, M., Pellicciari, M. (2018). User experience evaluation model for sustainable manufacturing. *International Journal of Computer Integrated Manufacturing*, *31*(6), pp. 494-512.
17. Peruzzini, M., Grandi, F., Pellicciari, M. (2020). Exploring the potential of Operator 4.0 interface and monitoring. *Computers & Industrial Engineering*, *139*, p. 105600.
18. Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, Å., Gorecky, D. (2016). *Towards an operator 4.0 typology: a human-centric perspective on the fourth industrial revolution technologies.* Proceedings of the international conference on computers and industrial engineering (CIE46). Tianjin, China, pp. 29-31.
19. Slawinska, M., Wrobel, K. (2021). Indicative Method of Human Failure in Sustainable Chain of Custody Management. *European Research Studies*, *24*(S5), 709-726.
20. Tan, Q., Tong, Y., Wu, S., Li, D. (2019). Anthropocentric Approach for Smart Assembly: Integration and Collaboration. *Journal of Robotics*.
21. Taylor, M.P., Boxall, P., Chen, J.J., Xu, X., Liew, A., Adeniji, A. (2020). Operator 4.0 or Maker 1.0? Exploring the implications of Industrie 4.0 for innovation, safety and quality of work in small economies and enterprises. *Computers & Industrial Engineering*, *139*, 105486.
22. Wróbel, K. (2020). *Metoda kształtowania ergonomiczności ręcznych elementów sterowniczych dla osób starszych, praca doktorska*. Wydział Inżynierii Zarządzania. Politechnika Poznańska, https://www.fem.put.poznan.pl/strona/sites/default/files/Doktor/15_Praca_doktorska_2019_Wrobel_Kamil_15_11_2019.pdf, 20.08.2020.
23. Wróbel, K., Hoffmann, T., Czarnecki, K. (2020). *Management of Ergonomic Interventions when Modeling The Technological Processes in The Industry 4.0.* Proceedings of the 36th International Business Information Management Association Conference (IBIMA), 4-5 November 2020, Granada, Spain. Sustainable Economic Development and Advancing Education Excellence in the era of Global Pandemic, pp. 3202-3211.
24. Youtube.com, https://www.youtube.com/watch?v=UOodLJof7Y0.