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Indicative Method of Human Failure in Sustainable Chain of Custody Management

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Abstract:

Purpose: *The purpose is for the action chain (AC) of sustainable management (SM) by monitoring the failure rates of the operator of technical devices and presentation of the results of selected validation of the developed method.*
Design/Methodology/Approach: *The presented method focuses on the monitoring and assessment of the organization's state, diagnosis of the causes of deviations from the operator's desired state and modeling the state of the system as a result of the planned implementation of ergonomic interventions (IE). Measuring the operator's reaction creates knowledge about the interaction and possibilities of modifying the system thanks to objective data.*
Findings: *The presented method allows to characterize the working environment (including employee workload) with the values of variables which constitute fuzzy cognitive maps (FCM) concepts. The state of the interaction process is determined by potential distractors, which include, inter alia, factors of the work environment, conditions of cognitive and decision-making processes, conditions of manual activities and personality traits.*
Practical Implications: *The implementation of the indicator method enables the assessment of the potential of IE, which may prove to be a threat to safety, task efficiency and convenience.*
Originality/Value: *The use of monitoring techniques and the analysis of operator loads and reliability in Industry 4.0 (I4.0) is possible in real time, when registering psychophysiological indicators for the so-called User experience (UX).*

Keywords: *Human factor, work safety, ergonomic intervention, industry 4.0, fuzzy cognitive maps.*

JEL codes: *M2, Q01.*

Paper Type: *Paper article.*

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1. Introduction

Industry 4.0 (I4.0) transforms organizations in terms of interaction in the digital workspace (DW) (Lorenz, Rüßmann, Strack, Lueth, and Bolle, 2015). This is related to the adoption of advanced digital technologies in the area of work performance management, modifying workload, as well as in the area of improving communication processes with internal and external clients (Peruzzini, Grandi, and Pellicciari, 2020).

The work system of any organization consists of resources and the relationship between these resources. The description of the dynamic phenomena accompanying the abovementioned relations are chains of action (CA). These are the characteristics of the systems of three elements, human, interface and technical device (Sławińska, 2016). Due to his nature, man is the weakest element of the system, but he can also be a key one. Recording the course of tasks and the state of the employee's body with the use of psychophysical indicators can be treated as a critical test of the functioning of the entire organization.

Real-time monitoring of the employee's condition and recording of AC enables the diagnosis of causes of changes in the work situation. 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). In modeling the work system, the authors of the article used artificial intelligence techniques, i.e., fuzzy cognitive maps (FCM). As each organization has its own specifics and different environmental conditions, it was assumed that FCM requires map adjustment to the organization.

The aim of the article is to present the theoretical framework of action chain of sustainable management (SM) by monitoring the failure rates of the operator of technical devices and presentation of the results of selected validation of the developed method. The validation of the human-machine-environment (H-M-E) system interaction assessment and modeling of ergonomic interventions in the system are presented.

2. Methodology of Digital Workspace Operator Loads

The method of sustainable SM management presented in the article by means of monitoring the DW operator's failure rates takes into account the validation of supporting decision-making processes in SM of the organization. In terms of validation, the impact of environmental conditions on operator stress and modeling of the impact of ergonomic interventions (EI) on the quality of the work system were included. For SM, it is important to consider the situation of transition between the system states in AC, and for the replenishment of human resources, it is interesting to change the operator's state - especially stress (Sławińska and Więcek-Janka, 2017).

The states of the system, i.e., difficult, unusual, and surprising situations, indicate the causes of failure and resilience of system components. The research emphasized the nature of the DW operator's work, which means that the employee has no direct contact with the subject of work. Through the cyber-physical system (CPS), it obtains information about the state of the work system. At the same time, the signals generated by the system affect the state of the entire system. Without individual bench tests, it is impossible to determine which of the variables at a given moment have a significant impact on the interactions in the system. For this purpose, individual system modeling, contextual processing and fine-tuning of information in individual organizations are necessary.

Early recognition of abnormal states enables corrective actions to be taken, therefore monitoring of load and human failure rates must be carried out in real time. Analyzing the work of operators from a physical and mental point of view is key to defining effective ways of working, optimizing tasks, and adapting the workplace to employees and the requirements of the work process (Romero *et al.*, 2016). The analysis of the operators' work provides an excellent opportunity for SM in all three dimensions of development (Stock and Seliger, 2016).

In the context of Industry 3.0, the measurement of the workload and reliability of a person at work is based on data derived from observation or records of all kinds of stumbles, omissions and faults in human behavior. There are several measurement approaches (Ratajczak, 1988). 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, and Pellicciari, 2020).

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. Heart monitoring is one of the most common methods used in medicine. This is now available thanks to the simplicity of measurement and inexpensive sensors. In particular, the measurement concerns HR and HRV, which correlate correlated with physical and mental workload (Mulder, De Waard, and Brookhuis, 2004).

Currently, research into the use of eye tracking technology is also widespread (Sharma and Gedeon, 2012). Other indicators are also specified, i.e., analysis of electroconductivity activity, electroencephalography, electromyography and the use of accelerometers and gyroscopes, e.g., in smart watches and smartphones (Moschetti, Fiorini, Esposito, Dario, and Cavallo, 2016). Complementing the information on operator workloads is the measurement of individual cognitive load and situational awareness (Endsley, 1995). For this, behavioral and cognitive methods are used.

One of the most common methods is the NASA Task Load Index (NASA-TLX) (Hart and Staveland, 1988). Another example is the technologies of the digital human model (DHM) and virtual reality (VR). These technologies offer great opportunities, e.g., in the assessment of postural loads, but the preparation of reliable simulations is complicated and time-consuming (Chaffin, 2007).

Moreover, the postural burden of the DW operator is relatively low. On the other hand, VR, although it supports qualitative assessment based on direct observation, interviews and is an accurate method of predicting human factors at the design stage, it is devoid of a structured assessment and measurement procedure (Peruzzini, Grandi, and Pellicciari, 2020).

The method of sustainable SC management presented in the article by means of monitoring the CPP operator's failure rates considers the validation of supporting decision-making processes in sustainable management (ZZ) of the organization. In terms of validation, the impact of environmental conditions on operator stress and modeling of the impact of ergonomic interventions (IE) on the quality of the work system were included. For ZZ, it is important to consider the situation of transition between the system states in LD, and for the replenishment of human resources, it is interesting to change the operator's state - especially stress (Sławińska and Więcek-Janka, 2017). The states of the system, i.e., difficult, unusual, and surprising situations, indicate the causes of failure and resilience of system components.

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Moreover, the postural burden of the CPP operator is relatively low. On the other hand, VR, although it supports qualitative assessment based on direct observation, interviews and is an accurate method of predicting human factors at the design stage, it is devoid of a structured assessment and measurement procedure (Peruzzini, Grandi, and Pellicciari, 2020).

3. Application of Fuzzy Cognitive Maps

Artificial intelligence (AI) methods and techniques enable the physical implementation of inference through algorithmic application implementation - expert systems (Wróbel, 2020). Methods, techniques, and approaches are selected considering the knowledge of the modeled system. FCM is a type of neural network that is simple and effective to use, including simulating the relationship between the states of an organization's resources. In FCM, knowledge about the system takes the form of a graph based on an element relationship matrix. The vertices of the graph represent the elements of the system in the form of the so-called concepts. The edges of the graph show the relationships between the concepts in the interval [-1,1]. FCM uses fuzzy logic, with the rule base defined by a graph (Wróbel and Hoffmann, 2019).

The implementation of FCM requires the definition of nodes, edges, and their weights as well as the size of the variables reflecting the actual state of the factor under study. The next stage is determining the value and function of membership for the nodes - the falsification stage. Then the inference is performed. This process ends with defuzzification. If the output values meet the assumptions, and their further recalculation does not change their values, the algorithm is finished (Wróbel and Hoffmann, 2019). Supervised and unsupervised learning is used in FCM application. Unattended learning works in such a way as to obtain the desired system state in the next iteration.

Supervised and unsupervised learning improves networks by introducing examples, i.e., input X and output data Y. Based on the data X and Y, the network will tune and consolidate the appropriate rules, generating the right results. There are 21 inference approaches in unsupported FCM learning (Papageorgiou, 2012).

4. Sustainable Management of Action Chain

SM of organization 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 and 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, and Chen, 2015).

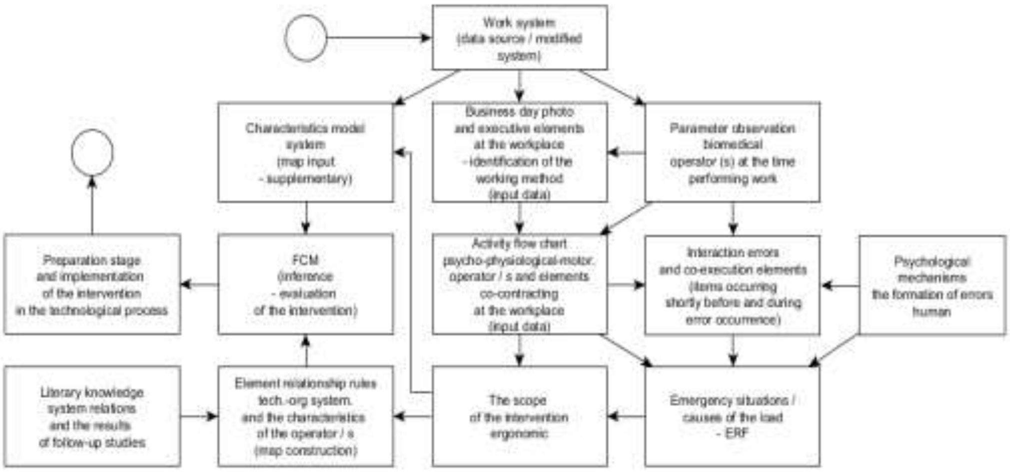
Including, assessing human-machine interaction (Witten-Berg, 2016) and the dynamics of resource states through adaptive and proactive actions (Griffin, Neal, and Parker, 2007). The presented method focuses on monitoring and assessment of the organization's condition, diagnosis of the reasons for deviations from the desired operator's condition and modeling the system condition because of the planned EI implementation.

The use of measuring devices of heart rate value in organizations comes down to low cost, non-invasiveness, and durability (Sharma and Gedeon, 2012), therefore, the monitoring method indicates the heart rate sensor (HR), and in the system assessment, the audit of the organization, including workstations, etc. human error mechanisms (Lindsay and Norman, 1984) and knowledge about AC were used in the diagnosis, and in FCM modeling.

Monitoring of operator unreliability indicators enables determining the causes of difficult situations. Knowledge about the psychological mechanisms of human error is the basis of EI and the justification for optimizing solutions with FCM. The application of the method is possible for a separate employee, workplace, and process, considering various situations. The individual steps, methods, and techniques of activities as well as decision links used in the method are presented in Figure 1.

The method presented by the authors allows to characterize the work environment with the values of the variables that constitute FCM concepts. The state of the interaction process is determined by potential distractors, which include groups of load factors such as the work environment and the nature of the workplace, factors related to functioning in the workplace, conditions of cognitive and decision-making processes, conditions of manual and locomotor activities, and personality traits (Sławińska, 2019). The use of FCM allows to reduce costs and shorten the simulation time compared to DHM, Motion Capture and VR technologies.

Figure 1. *Stages, methods, techniques of activities and method decision relationships*



Source: *Own study.*

5. Procedure and Scope of Validation

5.1 Ergonomic Validation of System Interactions

In the ergonomic validation of the H-M-E system interaction, the impact of environmental conditions on the operator's stress was measured. For this purpose, the HR measurement was used. HR measurement was used to validate the impact of environmental conditions on the operator's stress. The measurement and observation of the DW operator's work lasted from 08:00 to 19:10. The characteristics of variable working conditions in subsequent observations are presented in Table 1.

Table 1. *The scope of the variables of the validation process*

	Observation	Variables characteristics: Ligtning	Pace of work	Parallel tasks	Body position	Distance from the screen	Position of upper limbs	Noise	Observation time
Basic characteristics	1.	Good lightning	Fast pace of work	One task	Upright, propped	150 cm distance from the screen	Neutral propped; distance ab. 80 cm from the body	Moderate	17:45
Modified characteristics	2.	as in the input characteristics + poor lighting							17:24
	3.	as in the input characteristics + slow pace of work							18:05
	4.	as in the input characteristics + lying body position							18:12
	5.	as in the input characteristics + 300 cm distance from the screen - ergonomic							18:35
	6.	as in the input characteristics + position of the upper knot bent at the elbow joint unsupported; close to the body at the level of the solar plexus - comfortable position of the upper legs							18:42
	7.	as in the input characteristics + absolute silence							18:49
	8.	as in the input characteristics + two parallel tasks							19:04

Source: *Own study.*

The Polar Vantage V smartwatch was used to measure the heart rate.

5.2 Validation of the Modeling of the Impact of Ergonomic Interventions on the Work System

The validation of the modeling of the impact of EI on the quality of elements / variables of the work system was carried out with the use of FCM with algorithmic application implementation. An open-access application (github.com) was used, with added functionalities, such as loading maps from Excel sheets, saving data, improving the visualization of dialog boxes and maps. The validation was performed for the actual state of the work system variables and for the exemplary modified DW (Table 2).

In modeling the impact of variables on the system, two variants of the EI scenarios were taken into account for both variable state models (Table 2). The first variant concerns the reduction of the stress level (FCM variable state value range 0.1-0.2) while increasing the efficiency of the process implementation (0.9-1.0). The second variant assumes lowering the frequency of non-compliance (0.0-0.1) with an average noise level (0.6-0.7).

Table 2. *Variants of the FCM concept values sought for the analyzed CPP variable state models*

		Variable state model		Searched concept values	
		Real	Modified	Variant 1	Variant 2
Variables of the operator's work system CPP / FCM concepts [No]	1	0.4	1.0	-	-
	2	1.0	0.4	-	-
	3	0.4	0.8	-	-
	4	0.4	0.8	-	-
	5	0.8	0.4	-	-
	6	0.4	0.8	-	-
	7	0.4	0.8	-	-
	8	0.6	0.8	-	-
	9	0.6	1.0	-	-
	10	0.6	1.0	-	-
	11	1.0	1.0	-	-
	12	1.0	1.0	-	-
	13	0.6	1.0	-	-
	14	0.4	0.7	0.9-1.0	-
	15	0.8	0.3	-	0.0-0.1
	16	0.6	0.2	-	-
	17	0.8	0.6	-	-
	18	1.0	0.4	-	-
	19	1.0	0.4	-	-
	20	0.4	1.0	-	-
	21	0.2	0.6	-	-
	22	0.4	1.0	-	-
	23	0.8	0.2	-	0.6-0.7
	24	1.0	0.4	0.1-0.2	-

Source: *Own study.*

In the modeling of variables, the Data-Driven Nonlinear Hebbian Learning (DD-NHL) approach and the following input inference parameters were used: Transfer functions =

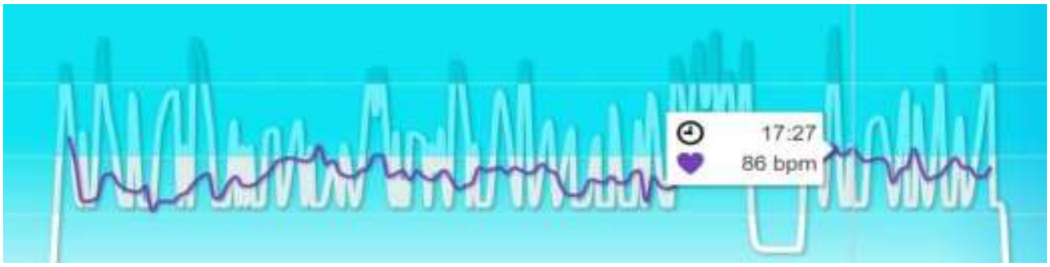
Sigmoid, η = 0.05, e = 0.001 and a 5-step fuzzy map with the following parameters, v1 = 0, v2 = 0.3, v3 = 0.5, v4 = 0.7, and v5 = 1.0.

6. Results

6.1 The Influence of Environmental Conditions on the Operator's Stress

In a few cases, the correlation of HR results with changes in body position, including shifting, was observed (Figure 2). During the work, the operator repeatedly changed the position of the body while sitting, standing, and walking. The highest value of HR was observed at the start of the measurement (HR = 90) while walking, and the lowest value at 09:04 (HR = 66) while sitting.

Figure 2. *The influence of environmental conditions on the operator's stress*



Source: *Own study.*

However, the results of HR measurement and observations showed that the response to stress stimuli, such as talking to a supervisor or solving complex problems and the associated high level of concentration, have the greatest impact on the cardiovascular system load (Figure 2). It was also the most common cause of the increase in HR while sitting and in general. The introduced changes in the conditions of the DW operator's work environment contributed to a small extent to the change in the value of the HR indicator (Table 4).

The input characteristics and the lying body position were the most unfavorable variables of environmental conditions regarding the load. Such results could be influenced by high pace of work, sudden changes in body position and stress related to the new situation. On the other hand, during slow pace of work, silence and, which is quite surprising, performing two tasks in parallel, the lowest HR results were observed during the study of the impact of modification of environmental variables (Table 4).

6.2 Validation of IE Impact Modeling

The IE simulation for the actual working conditions of the DW operator shows that the first variant of the searched states of variables is difficult to obtain (Figure 4). Despite the stress reduction even to 0 (obtained 24 = 0.01), it was not possible to achieve the desired level of effectiveness (obtained 14 = 0.85).

Tab. 3. *Cognitive map of the state of CPP operator variables*

	Nr	Consistency of management	The complexity of management	Time for making decisions	Quality of work support	Job enrichment level	Quality of the motivation system	Quality of supervision	Quality of HRM procedures	Employee readiness	Employee efficiency	Availability of raw materials / material	Availability of work tools	Leadership quality	Effectiveness of the process implementation	The frequency of non-compliance	The frequency of difficult situations	Lighting level	The pace of work	Parallel tasks	Convenience of body position	Distance from the screen	The position of the upper limbs	Noise	Stress
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Consistency of management	1	0	-1	-0,6	0,6	0	0,2	1	1	0,2	0,6	0,6	0,6	1	0,6	-0,6	-0,6	0	-0,6	-1	0	0	0	0	-0,6
The complexity of management	2	-0,6	0	1	0	0,2	-0,6	-0,6	0	-0,6	-0,2	-0,2	-0,2	-0,6	-1	0,6	0,6	0	-0,6	1	0	0	0	0	1
Time for making decisions	3	-1	0	0	-0,6	0	-0,6	-1	-1	-0,6	-1	-0,6	-0,2	-1	-1	-1	-1	0	0,6	-1	0	0	0	0,3	-1
Quality of work support	4	0,6	-0,2	-0,6	0	0,6	1	1	1	0,6	1	0,6	0,6	1	1	-1	-1	1	-0,6	-1	0,6	0,6	0,6	-0,3	-1
Job enrichment level	5	0,6	0,6	0,2	1	0	1	-0,2	-0,2	-0,2	1	0	-0,6	0,6	0,2	0,6	0,6	0	0,3	1	-0,3	0	0	0,6	1
Quality of the motivation system	6	1	-0,2	-0,6	1	-0,2	0	1	1	1	1	0	0	1	1	-0,6	-1	0	0,3	0	0,3	0,3	0,3	0	-0,3
Quality of supervision	7	1	-0,2	-1	0,6	0	1	0	1	0,6	1	0,6	1	1	1	-0,6	-1	1	0,3	-0,3	0,3	0,6	0,6	0	-0,3
Quality of HRM procedures	8	0,6	-0,2	-0,6	0,6	0,2	0,2	0,2	0	0,2	0,6	0	0	1	0,6	-0,6	-0,6	0	0,3	-0,3	0,3	0,3	0,3	0	-0,3

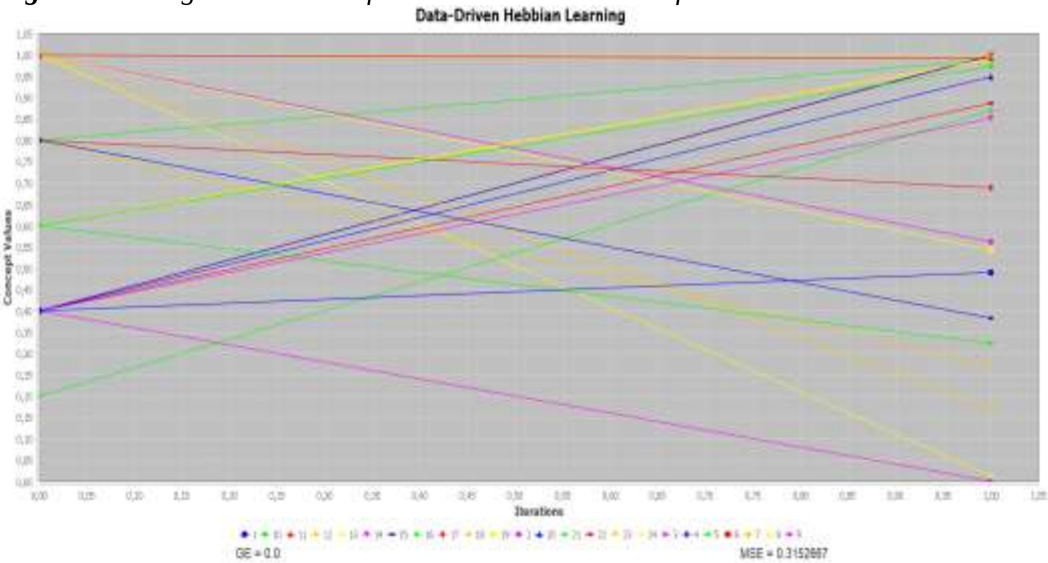
Employee readiness	9	0	0	-1	0	0,2	0,6	1	0,6	0	1	0	0	0,6	1	-0,2	-0,2	0	0	-0,6	0	0	0	0	-0,3
Employee efficiency	10	0,2	0	-0,6	0,6	0,6	0,2	0,2	0,6	1	0	0,6	0,2	1	1	-0,6	-0,6	0	1	-0,6	0	0	0	0,3	-0,3
Availability of raw materials / material.	11	0	0,6	0,6	0	0	0	0	0	0	1	0	0	0	1	0	-0,2	1	1	0,3	0,6	0	0	0	-0,6
Availability of work tools	12	0	0,6	0,6	1	1	0	-0,2	0	0,6	0,6	0	0	0	0,6	0,6	0,6	0	1	0,3	0,6	0	0	0	-0,6
Leadership quality	13	1	-0,2	-0,6	0,6	0	1	1	0,6	1	1	0,6	0,2	0	0,6	-0,6	-1	1	1	-0,6	0,6	1	1	0,3	-1
Effectiveness of the process implementa-tion	14	0	0	-1	0,2	0	0,2	0,2	0,6	1	1	-0,2	-0,2	0,6	0	-1	-0,6	0	0	-0,3	0	0	0	0,3	0,6
The frequency of non-compliance	15	-0,6	1	1	-0,2	0	-0,6	-0,6	0	-1	-1	0	0	-0,6	-1	0	1	-1	-0,6	1	-0,6	0	0	0,3	1
The frequency of difficult situations	16	-0,6	1	1	-0,2	0	-0,6	-0,6	0	-1	-1	0	0	-0,6	-1	1	0	-1	-1	1	-0,6	0	0	1	1
Lighting level	17	0	0	-0,3	0	0	0	0,3	0	0	0	0	0	0	0	0	0	0	0,3	0	0	0	0	0	-0,3
The pace of work	18	0,3	0	-0,6	0	-0,3	-0,3	-0,3	0	-0,6	1	-0,6	-0,3	-0,6	1	0,6	0,6	0	0	-1	-0,6	0	-1	0,3	-1
Parallel tasks	19	0	0,6	-1	0	1	-0,6	-0,3	-0,3	-0,6	-0,3	-0,3	-0,3	-0,6	1	1	1	0	0	0	0	0	0	0	-1
Convenience of body position	20	0	0	-0,3	0,6	0	0,6	0	0,3	0,6	0,6	0	0	0	1	-0,6	-0,6	0	0,3	0,3	0	0	1	0	0
Distance from the screen	21	0	0	-0,3	0,6	0	0,6	0	0,3	0,6	0,6	0	0	0	1	-0,6	-0,6	0,3	-0,3	0	0	0	0	0,3	-0,6
The position of the upper limbs	22	0	0	-0,3	0,6	0	0,6	0	0,3	0,6	0,6	0	0	0	1	-0,6	-0,6	0	0,3	0	0	0	0	0	-0,3
Noise	23	0	0	1	-0,6	0	-0,6	0	-0,3	-0,6	-0,6	0	0	-0,6	-0,6	-0,6	-0,6	0	-0,3	0	0	0	0	0	1
Stress	24	0	0	1	-0,3	-0,6	-1	-0,3	-0,6	-1	-1	0	0	-1	-1	1	1	0	-0,6	-1	0	0	-1	0	0

Table 4. *Influence of the characteristics of variable environmental conditions on the HR index*

Observation	Variables characteristics	Average HR	Observation time
1.	input characteristic	86	04:05
2.	as in the input characteristics + poor lighting	83	03:55
3.	as in the input characteristics + slow pace of work	80	04:35
4.	as in the input characteristics + lying body position	86	03:56
5.	as in the input characteristics + 300 cm distance from the screen	81	04:08
6.	as in the input characteristics + position of the upper knot bent at the elbow joint unsupported; next to the body at the height of the solar plexus	83	03:57
7.	as in the input characteristics + absolute silence	80	03:57
8.	as in the input characteristics + two parallel tasks	80	04:05

Source: *Own study.*

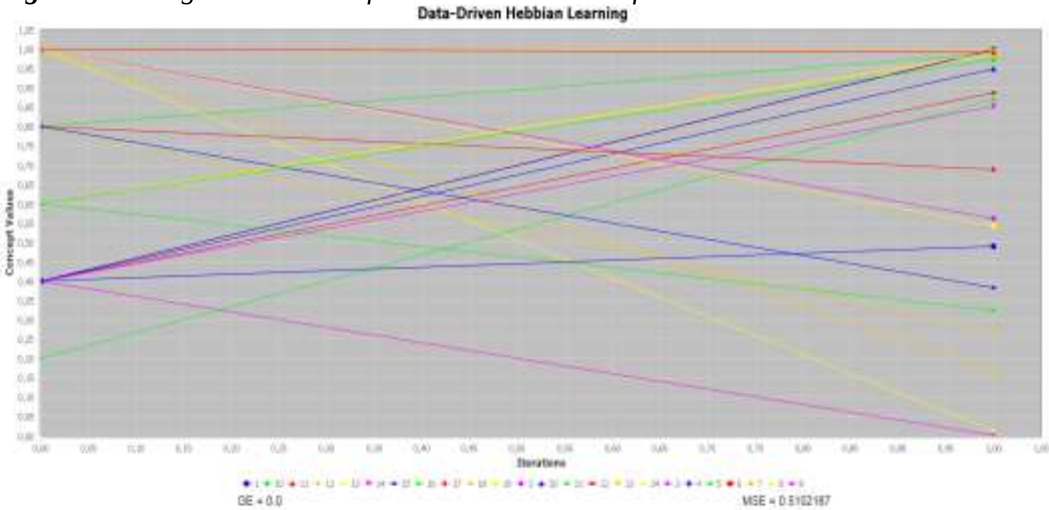
Figure 4. *Change in the state of the real model variables for Variant 1*



Source: *Own study.*

The real model for variant 2 is also not adaptable (Figure 5), because despite the achievement of a lower noise level (obtained 23 = 0.27), it was not possible to obtain the desired state of inconsistency frequency (obtained 15 = 0.38). Nevertheless, activities aimed at reducing stress and noise are appropriate IE for the variables of the tested DW model, which is confirmed by the input data and the results of inference for the modified model (Figures 6 and 7).

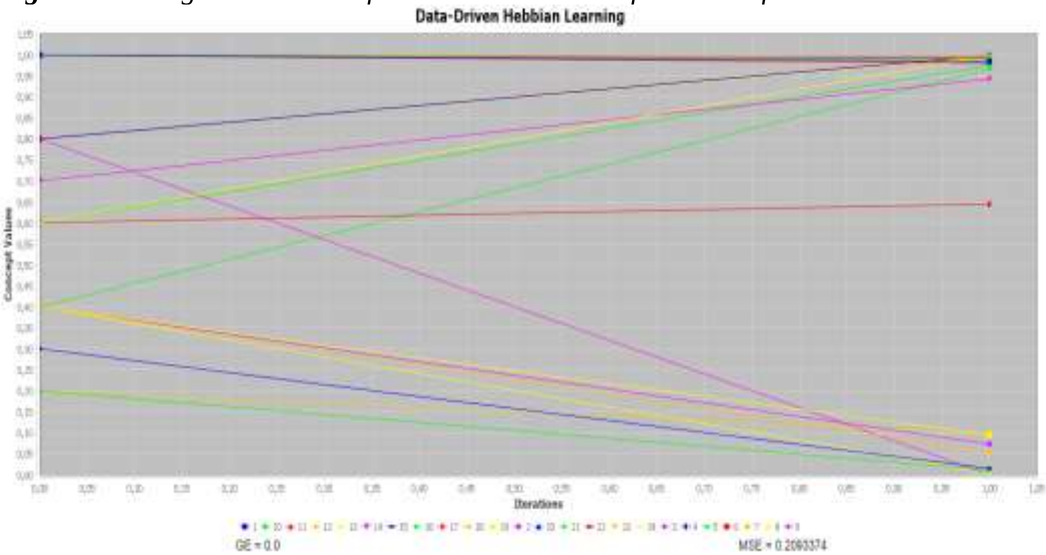
Figure 5. *Change in the state of real model variables for variant 2*



Source: *Own study.*

Modeling of IE for the modified model indicates that the first variant of the searched states of variables can be obtained (Figure 6), although it requires a lower stress state (obtained 24 = 0.00). The process implementation efficiency status was equal to 0.94.

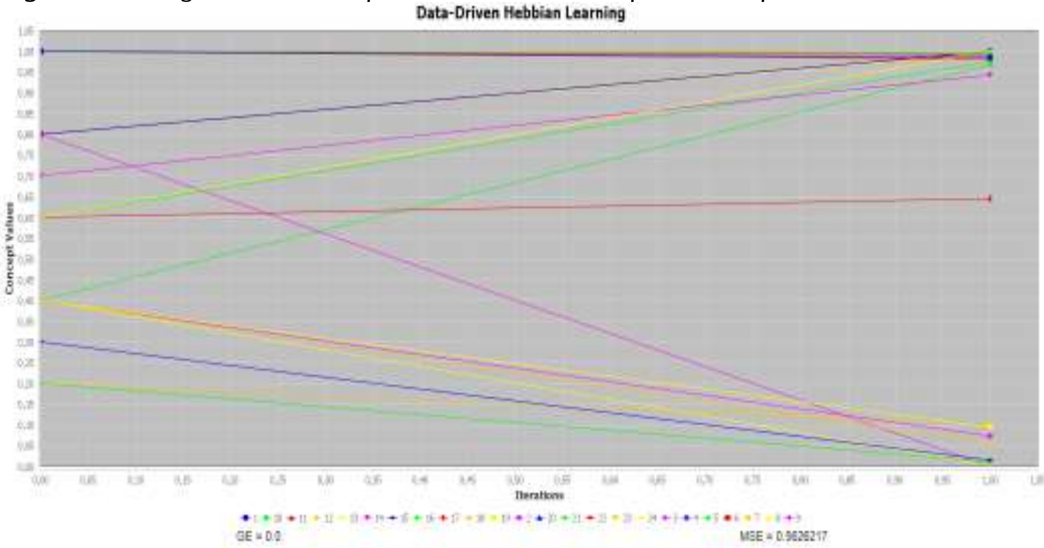
Figure 6. *Change in the state of variables in the modified model for variant 1*



Source: *Own study.*

The model modified for variant 2 is also to be adapted (Figure 7), because the desired state of inconsistency frequency was obtained (obtained 15 = 0.01), although it required a significant reduction of the noise level (23 = 0.1).

Figure 7. *Change in the state of variables in the modified model for variant 2*



Source: *Own study.*

Despite other searched variable states, the applied inference algorithm recalculated the variable values for both variants in exactly the same way (Figs. 4, 5, 6 and 7), which is quite surprising. Such situations occurred for various map parameters previously checked. One iteration was obtained for all simulations, which is a good indicator. The mean square error (GE) for all simulations was 0.0, indicating that the data is favorable. On the other hand, the index of statistical evaluation criteria (HSE), depending on the simulation, ranged from 0.20 to 0.56. The HSE values in the case of variant 1 were more favorable. Generally, results with HSE ≥0.5 are not very accurate.

7. Summary

7.1 Summary of Interaction Validation

Changing the working environment of the DW operator has little effect on the HR values. The body position does not always translate directly into an increase in the value of HR - there were situations when the operator was sitting and the HR was high - this conclusion develops the observation that there is a relationship with AC situations and the HR indicator, which can be used in monitoring and modeling the operator's workload and DW terms.

7.2 Summary of Modeling EI Impact Validation

Thanks to simulations, it is possible to plan proactive and reactive activities in terms of shaping the operator's load and working conditions at various levels of detail - with different machines or more detail. FCM allows you to search and track changes for many variables at the same time. The statistical parameters of the obtained results are partially good and partially indicate the need to redefine the map, e.g., based on more accurate or supplemented data, which will be the subject of further research. The concept of applying HR and FCM has been validated and confirmed, although it requires refinement by more precise linking of HR values with error mechanisms and fine-tuning of the cognitive map.

8. Discussion

The introduced changes to the working conditions of the DW operator contributed little to the change in the value of the HR indicator. It may be caused by acquired skills or experience in dealing with the studied disturbance factors (Sławińska *et al.*, 2018). The impact of the operators' experience and skills on the disruptive factors was not investigated in this work. Variable environmental conditions most unfavorably influencing the load could be high pace of work, sudden changes in body position and stress related to the new situation (putting on and activating the HR sensor). Stress is one of the strongest factors affecting work ergonomics (Ratajczak, 1988).

On the other hand, during slow pace of work, silence and, surprisingly, performing two tasks in a specific time, the lowest HR results were observed when examining the influence of modification of environmental variables. These results contradict the research of Lindsay and Norman (Lindsay and Norman, 1984) showing that the performance of many tasks in a specific unit of time increases stress and the level of HR. HR results, on the other hand, are consistent with the knowledge about energy requirements while taking various positions and physical activity (Butlewski *et al.*, 2020).

The obtained results of system state modeling are consistent with the knowledge of shaping working conditions (Sławińska, 2019). The simulations also showed the regularities of the necessity to significantly reduce noise to obtain the desired level of efficiency and reliability. A satisfactory state of process implementation efficiency was achieved, although it required a lower state of stress, which may turn out to be high cost in the real sustainable management of the organization.

The desired state of the non-compliance frequency was achieved, although it required a significant reduction in the noise level), which is consistent with the knowledge about the impact of noise on human reliability (Wieczorek, 2005) and may turn out to be high cost.

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