Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 106 (2022) 9–14

www.elsevier.com/locate/procedia

9th CIRP Conference on Assembly Technology and Systems

An Approach to Analyze Human-caused Work Errors

Barbara Tropschuh[a],*, Stefan Brunner[a], Fabian Dillinger[a], Florian Hagemann[b]

[a]*Technical University of Munich, Institute for Machine Tools and Industrial Management (iwb), Boltzmannstrasse 15, 85748 Garching, Germany*
[b]*MAN Truck & Bus SE, 80995 Munich, Germany*

* Corresponding author. Tel.: +49-89-289-16588; fax: +49-289-15555. *E-mail address:* barbara.tropschuh@iwb.tum.de

Abstract

Due to socio-demographic and technological changes, companies face new challenges to achieve an efficient and competitive production. Increasing cost and time pressure combined with an aging workforce with declining physical and mental performance requirements, as well as the increasing shortage of skilled workers, lead to reduced productivity. Therefore, the reduction of human-caused errors is becoming more important. This paper analyzes the connection between human-caused work errors, mental and physical strain, and workplace ergonomics. Four variables are used to analyze the interaction between ergonomics and work errors within the framework of a study in manual assembly. The study sample consists of 21 employees from a manual truck assembly at six different workstations. Models with different combinations of variables are developed in a multiple linear regression framework. Regression model (RM) 1 predicts the variance of the criterion work error with the predictors NASA-RTLX, Borg, and EAWS. It has high predictive power (adjusted $R^2 = 0.746$) but is not significant.

Keywords: Ergonomics; mental aspects; work error; manual assembly;

1. Introduction

Physical and mental overload at work leads to reduced work performance and ultimately sick days [1, 2]. A health report shows that almost 40 % of all sick days are due to musculoskeletal disorders (MSDs) and mental illnesses in Germany [3]. More than half of these days are attributable to the manufacturing industry. The risk of developing MSDs increases with age, with a simultaneous reduction in physical and mental performance and resilience [4]. In view of demographic change and the aging workforce, more overload and sick days can be expected in the future. Besides, the industrial production environment is confronted with increasing product complexity, a rising number of individual product variants, growing cost, time, and quality pressure [5]. These contrary developments lead to an overload and thus to a rising number of work errors. To cope with these developments and remain competitive in the long term, a human-centered workplace analysis is needed to reduce work errors and maintain employee performance [6, 7]. This paper examines the correlation between human-caused work errors and workplace ergonomics in a truck assembly in the context of mental and physical strain. After describing the literature-based fundamentals of ergonomics in section two, the description of the method follows. Work errors are quantified via physical and mental strain in section three. A discussion of the results follows before this contribution summarizes with a conclusion.

2. Ergonomics

The prevention of ergonomic-based human-induced work errors, e.g., due to physical or mental misload, is part of ergonomics [8]. In order to reduce workload or prevent work errors, the working environment and the tasks are analyzed. To obtain a holistic assessment of physical and mental strain, combinations of objective and subjective measurement

10.1016/j.procir.2022.02.147

methods are used. Thereby, the NASA-Task Load Index (NASA-TLX) is often used to measure subjective strain [2, 9]. According to several research projects [10–13], the Borg Scale is particularly suitable for subjective physical measurement. The analyzed approaches [9–13] do not sufficiently consider human-caused errors due to physical and mental misload. Michalos et al. analyze the effect of job rotation on assembly quality [14]. As they focused on the following three human factors competence, fatigue, and repetitiveness, the ergonomic design of the workplace was not considered. To achieve a comprehensive human-related analysis of error influences and causes, this paper analyzes the correlation between work errors and ergonomic aspects in the sense of physical and mental workload and strain. This serves as a basis for quality measures and strain-oriented employee scheduling.

3. Research method

In this chapter, the methodological procedure for analyzing human-related errors in assembly is described gradually, see Figure 1. In the first step of the procedure, suitable measurement methods are selected based on a literature review to analyze the workplaces and the employees. The workplace evaluations of the chosen methods are the input parameters. Real data is collected in a field study in the industry in the second step of the applied method. The recorded data will be analyzed in the third step by conducting correlation analyses and regression models. In the last step, recommendations are derived based on the interpretation of the results. By analyzing the physical and mental aspects, human-caused work errors from mismanaged workloads can be identified.

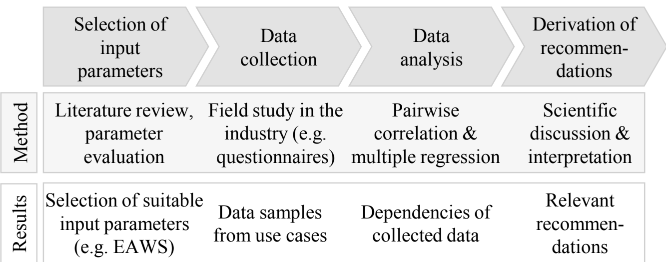


Figure 1: Overview of the approach

The aim was to include a wide variety of workplaces in the study, according to their physical and mental requirements, at different stages of the production process. The evaluation and expert knowledge of the company was the key factor. Six workstations were selected in the three areas: engine assembly line at the beginning of the manufacturing process, frame assembly in the middle, and central electronic (CE) cover and wheel assembly at the end. The selection is intended to prevent area-based bias and provide a representative sample of a wide variety of requirements within manual assembly activities. The test collective consisted of 21 male employees, aged 19 to 60, working in the early and late shifts at the selected workplaces. The competence level of the subjects ranged from beginner to expert.

4. Results of the study

A combination of subjective and objective methods is most suitable for a holistic analysis of human-related work errors. Derived from the literature review, the EAWS method is used for the objective ergonomic workplace analysis. The subjective strain perception of employees is measured using Borg (physical) and NASA-TLX (mental).

4.1. Input parameters

Work Errors

Human-induced work errors represent a deviation from a behavior that is considered correct or from the desired goal of an action. At a truck assembly, employees register work errors digitally in the internal production system. In cooperation with the team coordinators, the works council, occupational safety, and occupational medicine, the error-prone activities were selected, e.g., screw missing. The cause of each error was analyzed together in a workshop to identify human-caused work errors. Table 1 visualizes the recorded work errors in the period from January to the end of July 2020.

Table 1: Quantity of human-caused work errors at the different workstations

Workplace with error-prone activity	Sum of errors
Connection of fuel filter	32
Installation overflow valve	35
Battery cable string assembly	48
Fifth wheel plate bolting	7
CE cover assembly	57
Wheel assembly, (spare wheel excluded)	14

EAWS

In this study, the objective physical workload was determined using EAWS. The evaluation was performed by observing a cycle time and validated by analysis over a longer period. EAWS considers the most relevant risk factors, such as postures and body movements, static and dynamic action forces [15]. In the present study, activities in which work errors can occur were focused. These activities were identified by the workers and the documented error descriptions. The error-prone activity can either cover the entire workplace or only partial activities. The analyzed activities are briefly described below. Table 2 summarizes the EAWS ratings. When using the EAWS, the upper extremity and the total body are rated individually. The worse rating is used for the classification.

Wheel assembly: 200 – 300 wheels are manipulated per shift per worker in a bent forward position at this workstation. Depending on the truck model, one wheel weighs up to 120 kg. An overall EAWS score for the entire workplace is provided for the total body (50.7) and the upper extremity alone (39).

CE cover assembly: At this workplace, two operators screw together the large covers, depending on their height at or well above shoulder level. For a cycle time of 300 seconds, at least 50 seconds require work above shoulder level. These 50 seconds represent the considered error-prone activity. Depending on the employee's anthropometry and the vehicle type, the worker tiptoes on the conveyor line. The activity is dominated by many dynamic and static finger and wrist actions. The error-prone task is in the critical range for the total body (66.5) and the upper extremity (67.9).

Connection of fuel filter: The employee connects four lines to the filter in a bent-forward position. Therefore, the lines must be placed through passages on the truck frame, requiring increased force in fingers and hands. This task is very short compared to the cycle time. Only this error-critical activity was evaluated. The EAWS score in the upper extremity (51.8) is higher than the total body (46.3) due to high finger forces and work in critical hand and elbow joint areas.

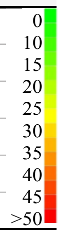
Installation of overflow valve: The overflow valve is connected with hydraulic lines in a narrow working space. The reduced visibility forces the worker into an unergonomic semi-sitting position on a cross strut of the frame, with arms bent forward and extended. The frame and confined space prevent translatory movements and force adduction as well as internal rotation of the arm to connect the valve with the lines. Only the error-critical activity, connecting the valve with the lines, was assessed. The EAWS score of the upper extremity is moderate (36). The higher score of the total body (56.1) is mainly due to the longer statically bent-forward posture of the upper body.

Fifth wheel plate bolting: The worker bolts the coupling plate to the saddle. Visual inspection is only possible with the upper body bent and twisted. Bolting the plate in this position is the error-critical activity. Experienced workers bolt without visual inspection only with haptic feedback. Therefore, the activity represents an ergonomic workstation for experienced workers. The EAWS score of the total body (30.7) and the upper extremity (30.5) are both in the lower yellow range. Unergonomic bolting and checking can be a source of error when inexperienced employees are assigned to the task.

Battery cable string assembly: The employee attaches the 2–3 m long cables to the motor-gear unit. The working height is unergonomic, mostly at shoulder level. Two safety-critical cable ties can hardly be visually checked due to the working height. Smaller employees climb onto the conveyor to assemble correctly. An overall EAWS assessment of the entire workplace is provided. The critical value of the total body (61.8) arises from activities at shoulder level and exceeds the EAWS value for the upper body (59.5).

Table 2: EAWS evaluation of the error-prone activities at the selected workplaces

Error-prone activity at the workplace	EAWS value
Wheel assembly	50.7
CE cover assembly	67.9
Connection of fuel filter	51.8
Installation overflow valve	56.1
Fifth wheel plate bolting	30.7
Battery cable string assembly	61.8

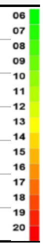


Borg Scale

In this study, the subjective physical strain during the error-prone activities was surveyed with the Borg Scale (Borg). The original RPE (rating of perceived exertion) scale is a linear, fifteen-point scale ranging from 6 to 20 that correlates with heart rate [16]. The practical-oriented use of the method enabled the data collection directly at the assembly line after executing the work task. The resulting 21 Borg values range from 'easy' (11) to 'very strenuous' (17) for the error-critical activities at the different workplaces (table 3).

Table 3: Evaluated Borg values of the error-prone activities at the selected workplaces

Error-prone- activities at the workplace	Borg values	Mean value
Wheel assembly	13, 14, 14	13.7
CE cover assembly	14, 15, 16, 17	15.5
Connection of fuel filter	11, 12, 12, 13	12
Installation overflow valve	12, 13, 14, 15	13.5
Fifth wheel plate bolting	11, 12, 13	12
Battery cable string assembly	14, 14, 15	14.3
Overall average	13.5	



NASA-Task Load Index (NASA-TLX)

The NASA-TLX measures the subjectively experienced mental and physical strain as a multidimensional questionnaire [17]. The queried dimensions are mental demand, physical demand, time demand, performance, effort, and frustration [17]. The rating ranges on a 20-point scale from very low/good to very high/bad, with the dimensions' results adding up to an overall value [17]. The original variant of the NASA-TLX requires a 15-fold pairwise comparison of individually weighted influence variables before the final score of the six dimensions is obtained, whereas the later form of the NASA-Raw TLX (NASA-RTLX) omits the weighting. The two versions have been compared in various studies, with no difference found [17]. The choice should therefore be made for practical and pragmatic reasons [17]. Table 4 shows the individual NASA-RTLX values for each workplace and the overall mean value.

Table 4: NASA-RTLX values of the workplaces

Workplace	NASA-RTLX values	Mean value
Wheel assembly	46, 50, 53	49.7
CE cover assembly	63, 65, 67	65
Connection of fuel filter	51, 55, 58, 66	57.5
Installation overflow valve	56, 61, 61, 67	61.3
Fifth wheel plate bolting	36, 35, 44	38.3
Battery cable string assembly	73, 71, 66, 70	70
Overall average	57.0	

Since six dimensions are rated from 1 to 20, a maximum rating of 120, could be obtained. This maximum value is test-theoretical, whereas in practice, values around 90 are regarded as the maximum level (very high mental strain) [18]. Summarizing the collected data, table 5 provides an overview of all variables. Since several Borg and NASA-RTLX values were surveyed for the error-critical activity at each workplace, the average is indicated in each case.

Table 5: Summary of all results

	EAWS	NASA-RTLX Ø	Borg Ø	Work error
Wheel assembly	50.7	49.7	13.7	14
CE cover assembly	67.9	65	15.5	57
Connection of fuel filter	51.8	57.5	12	32
Installation overflow valve	56.1	61.3	13.5	35
Fifth wheel plate bolting	30.7	38.3	12	7
Battery cable string assembly	61.8	70	14.3	48

4.2. Data analysis and results

As part of the data analysis, correlation analyses are performed first. Subsequently, it is verified whether a linear regression model can predict a variable. The cost-free statistical software JASP was used to ensure applicability in practice.

Correlation analysis

Prior to statistical analysis, the requirements of a Pearson correlation analysis are examined. In the case of a cross-sectional survey, these are a normal distribution of the data, interval scaling, approximate linearity of the correlation, and freedom of outliers [19, 20]. The collected variables are quantitatively and metrically scaled. The assumption of linearity can be verified via scatterplots [20] (figure 2). Three pairwise correlations show direct linearity (NASA-RTLX-EAWS, Borg-EAWS, Borg-NASA-RTLX), whereas no clear trend is graphically evident in pairs with work errors. It can be assumed that the trends would be more precise with a higher number of samples. In the error-EAWS combination, an outlier can be identified visually (marker in figure 2). A box plot statistically confirms this. After removing the outlier, the correlation between EAWS and work errors is linear. Since Eid et al. [21] recommend approximate linearity, this pair is assumed to be linear even with the outlier. Since the trend will continue with an increasing number of measurements, and data loss should be avoided here as a priority. Overall, four out of six pairs can be regarded as linear.

The values are tested for normal distribution using a Q-Q-Plot (Quantile-Quantile-Plot) and a Shapiro-Wilk test. As no significance could be found, a normal distribution is assumed. The requirements are considered to be fulfilled, allowing a Pearson correlation analysis to be performed (table 6).

The pairs EAWS-Borg, EAWS-error, and Borg-error, correlate significantly ($p < 0.05$) with a strong correlation. EAWS-NASA-RTLX and NASA-RTLX-error are evaluated as non-significant correlations according to the p-value. Since both are only minimally above the p-value of 0.05, they are rated as correlated for factual derivation and practical relevance. The NASA-RTLX-Borg pair correlates weakly and is not significant. Following the literature and operational practice, it can be assumed that ergonomics influences the number of work errors. Likewise, a causal relationship between

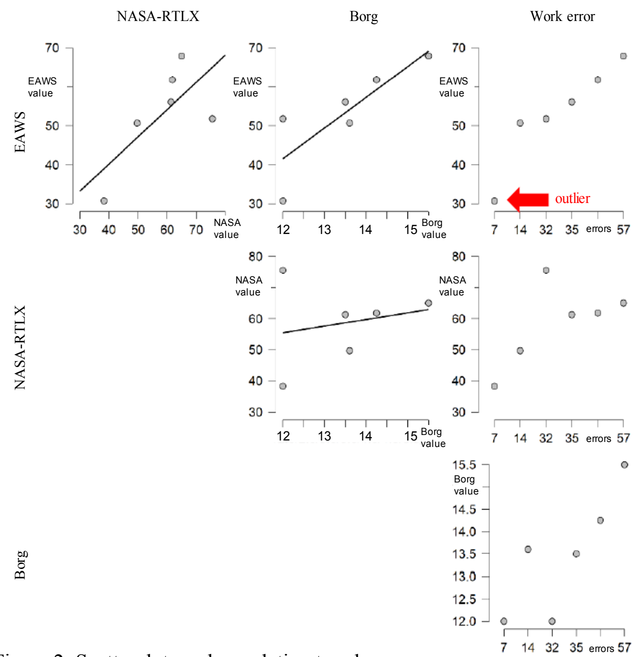


Figure 2: Scatterplots and correlation trends

Table 6: Pearson correlation of the paired variables

		Pearson r		p
EAWS	NASA-RTLX	0.710		0.057
EAWS	Borg	0.832	*	0.020
EAWS	Work error	0.971	**	0.005
NASA-RTLX	Borg	0.223		0.336
NASA-RTLX	Work error	0.716		0.055
Borg	Work error	0.757	*	0.041

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

subjective perception and the probability of committing work errors has been identified in the study. The fundamental choice of variables can be described as reasonable and purposeful since three out of six possible pairs show a statistically perfect correlation. With minimal adjustment of the significance level, two other pairs can be described as sufficiently statistically correlated.

Multiple linear regression

Before performing the regression, it is necessary to verify the prerequisites for it. According to Eid et al. [21] and Field et al. [19], these are listed in table 7 with the respective tests. The requirement of internal consistency is added since variables of different scales come together as predictors in this study. The Q-Q-Plot indicates a normal distribution of the residuals. The predictors' internal consistency is good according to Cronbach's alpha ($\alpha = 0.811$) since the value is below 0.9, whereby excessive similarity of the queried criteria can be ruled out. Based on a random arrangement of the scatterplot of the residuals over the predicted values, an expected value of zero and homoscedasticity is assumed. Testing for multicollinearity reveals abnormalities, as the recommended range of tolerance above 0.1 and VIF below 10 is not met [19]. A violation of multicollinearity should not be regarded as an exclusion criterion if the other requirements are met [19].

This is a resupply of March 2023 as the template used in the publication of the original article contained errors. The content of the article has remained unaffected.

Table 7: Requirements of multiple regression

	Requirements	Test
1	Normal distribution of residuals	Q-Q-Plot
2	Homoskedasticity and expected value = 0	Scatterplot; residuals vs. prediction
3	Interval scaled data at least	Data review, already confirmed
4	Independence of the residuals	Durbin-Watson (autocorrelation)
5	Multicollinearity	Variance Inflation Factor (VIF)
	Own addition	
6	Internal consistency of the predictors	Cronbach's alpha

The value of a multiple correlation is expressed as R (value range [-1; 1]). It describes the correlation of the dependent variable with the independent variables. R^2 (value range [0; 1]) as a corrected multiple determination coefficient is the ratio of the variance of predicted values (e.g., work error) and the predictors (e.g., Borg, EAWS) [20]. As more predictors are included, it is more likely to obtain coincidentally a significant correlation that does not exist in reality. The adjusted R^2 is used for multiple predictors and is corrected for the predictor number. The adjusted R^2 provides information on how well the dependent variable can be predicted with the selected predictors. The highest model quality would be achieved if the variables EAWS, Borg, and NASA-RTLX could explain 100 % of the variance in the criterion work errors.

Regression model 1 defines work error as the predicted value and Borg, NASA-RTLX, and EAWS as the predictors. The model has high predictive power with the adjusted $R^2 = 0.746$ but is not significant with $p = 0{,}149$ (significance from $p < 0.05$) (table 8). Based on the three predictors, 74.6 % of the differences in work errors can be predicted. The standardized regression equation is (1):

$$\text{work error} = 0{,}995 \times \text{NASA-RTLX} + 1{,}168 \times \text{Borg} + (-0{,}760) \times \text{EAWS} \quad (1)$$

Table 8: Regression model 1

Model	R	R^2	Adjusted R^2	RMSE
1	0.948	0.898	0.746	9.675

Model		Sum of Squares	df	Mean Square	F	p
1	Regression	1651.641	3	550.547	5.882	0.149
	Residual	187.192	2	93.596		
	Total	1838.833	5			

Coefficients						
Model		Unstan-dardized	Standard Error	Stan-dardized	t	p
1	(Intercept)	-217.548	177.759		-1.224	0.346
	EAWS	-1.143	2.487	-0.760	-0.460	0.691
	NASA-RTLX	1.476	1.396	0.995	1.057	0.401
	Borg	16.625	17.020	1.168	0.977	0.432

Regression model 2 is calculated without EAWS as a predictor. The remaining constellation stays the same as in model 1. No prerequisites are violated. The predictors NASA-RTLX and Borg prove to be informative (adjusted $R^2 = 0.812$), 81 % of the variance of work errors can be predicted. Regression model 2 becomes significant with $p = 0.038$. Thus, using model 2, significantly better predictions of the number of work errors can be made. None of the predictors becomes significant, as both values are slightly above the significance level of $p = 0.05$ (table 9). However, for practical relevance, they are considered critical in the context of model 2. According to the results, the employees' physical and mental strain perception greatly impacts the number of work errors. The standardized regression equation is (2):

$$\text{work error} = 0{,}576 \times \text{NASA-RTLX} + 0{,}628 \times \text{Borg} \quad (2)$$

Table 9: Regression model 2

Model	R	R^2	Adjusted R^2	RMSE
2	0.942	0.887	0.812	8.306

Model		Sum of Squares	df	Mean Square	F	p
2	Regression	1631.861	2	815.930	11.827	0.038
	Residual	206.973	3	68.991		
	Total	1838.833	5			

Coefficients						
Model		Unstan-dardized	Standard Error	Stan-dardized	t	p
2	(Intercept)	-138.450	38.338		-3.611	0.036
	NASA-RTLX	0.854	0.295	0.576	2.896	0.063
	Borg	8.948	2.829	0.628	3.163	0.051

In **regression model 3**, Borg is excluded as a predictor, resulting in two predicting variables (NASA-RTLX, EAWS) for the criterion work error (table 10). The preconditions were tested and are fulfilled, there is no multicollinearity. The model is slightly not significant, with $p = 0.058$. The model traces almost 75 % (adjusted $R^2 = 0.749$) of human-induced work errors due to workplace ergonomics and strain perception. With a standardized regression weight of 0.824, EAWS has a significant influence.

Table 10: Regression model 3

Model	R	R^2	Adjusted R^2	RMSE
3	0.922	0.850	0.749	9.600

Model		Sum of Squares	df	Mean Square	F	p
3	Regression	1562.342	2	781.171	8.476	0.058
	Residual	276.492	3	92.164		
	Total	1838.833	5			

Coefficients						
Model		Unstan-dardized	Standard Error	Stan-dardized	t	p
3	(Intercept)	-45.116	20.686		-2.181	0.117
	EAWS	1.240	0.478	0.824	2.595	0.081
	NASA-RTLX	0.194	0.471	0.131	0.411	0.709

5. Interpretation and Discussion

This study analyzed the correlation between human-caused work errors and workplace ergonomics in a truck assembly. To reduce these errors, physical and mental workload and the individual strain need to be analyzed. The study showed that ergonomic workplace design, measured with EAWS, has a strong and significant influence on the number of human-induced work errors ($p = 0.005$, $r = 0.917$). Thus, the higher the EAWS rating of the activity, the more work errors were recorded. The study results confirm the described correlation between ergonomics and work errors based on the literature research. In addition, an approximately linear relationship of Borg and NASA-RTLX could be identified ($p = 0.336$, $r = 0.223$). Increased physical strain perception resulted in more work errors ($p = 0.041$, $r = 0.757$). With a lower number of work errors, there is high volatility of physical strain perception. As a result, linearity cannot be assumed, and the requirements of correlation analysis are not met. This limits the interpretation of the correlation of this pair. Due to the high dispersion of the NASA-RTLX rating at a very low Borg rating, the correlation did not become significant based on the sample. NASA-RTLX and work error correlate strongly but not significantly ($p = 0.055$, $r = 0.716$). A tendency to produce more work errors with increased mental strain is evident.

The initial selection of the representative workplaces and activities as well as the classification of work errors by an interdisciplinary team influences the results of the method, which is why the method should be validated at other workplaces and companies. Since only the error-prone activities were considered in the EAWS assessment, possible pre-exposures from previous activities were not considered. In addition, there is a risk of unconscious and conscious misstatements by employees to indicate a higher or lower workload, depending on individual attitudes. Furthermore, the small sample size of 21 test persons reduces the generalizability and significance of the results. Therefore, the findings must be interpreted with restrictions despite statistical validation.

6. Conclusion

Due to socio-demographic and technological changes, human-induced work errors need to be reduced to remain competitive. This paper's objective was to structurally analyze and quantify human-caused work errors based on strain perception and workplace ergonomics. At different workplaces in truck assembly, human-caused work errors were extracted from the production system, employee strain was queried using Borg and NASA-RTLX, and objective workplace ergonomics were recorded using EAWS. After building linear regression models, it can be noted that regression model 1 explains 74.6 % of the variance in work error, including all predictors. To summarize, high dependence of work errors on workplace ergonomics and subjective physical and mental strain can be established. The assumption that strain reduction and ergonomic improvements at the investigated workplaces lead to decreased work errors can be confirmed. Furthermore, the elaborated procedure can serve as a guideline for action, which enables the analysis of human-caused work errors in a structured way for practical application in manufacturing companies. Due to its modular structure, the method allows an exchange of each variable. In further research, detailed complexity criteria at the different workstations can be identified, e.g., with the technique of Falck et al. [22], to prevent human-caused errors. Based on the results, workplace analysis, e.g., using virtual reality methods [23]can be improved, e.g., introducing exoskeletons [24].

Acknowledgments

We want to thank the Bavarian Research Foundation (BFS) for funding this work as part of the research project "Strain and competence-oriented employee scheduling" (AZ-1336-18).

References

[1] Das, S., Maiti, J., Krishna, O.B., 2020. Assessing mental workload in virtual reality based EOT crane operations: A multi-measure approach 80, p. 103017.
[2] Rusnock, C.F., Borghetti, B.J., 2018. Workload profiles: A continuous measure of mental workload 63, p. 49.
[3] Storm, A., Marschall, J., Hildebrandt-Heene, S., Sydow, H., Nolting, H.-D., 2017. Update: Schlafstörungen. medhochzwei, Heidelberg.
[4] Dalecki, M., Kalicinski, M., Steinberg, F., Bock, O., 2017. Age-related operator deficits in a realistic instrument-control task: Assessment of possssible motor, cognitive and mental causes 59, p. 100.
[5] ElMaraghy, H., Schuh, G., ElMaraghy, W., Piller, F. et al., 2013. Product variety management 62, p. 629.
[6] Landstad, B.J., Gelin, G., Malmquist, C., Vinberg, S., 2002. A statistical human resources costing and accounting model for analysing the economic effects of an intervention at a workplace. Ergonomics 45, p. 764.
[7] Tropschuh, B., Reinhart, G., 2020. Concept for an Employee-Specific Resource Planning in Manual Assembly, in AHFE 2020: Advances in Neuroergonomics and Cognitive Engineering: Proceedings of the ahfe, Springer, [S.l.], p. 409.
[8] Wilson, J.R., 2000. Fundamentals of ergonomics in theory and practice. Appl Ergon 31, p. 557.
[9] Bommer, S.C., Fendley, M., 2018. A theoretical framework for evaluating mental workload resources in human systems design for manufacturing operations 63, p. 7.
[10] Morris, C.E., Winchester, L.J., Jackson, A.J., Tomes, A.S. et al., 2018. Effect of a simulated tactical occupation stressor and task complexity on mental focus and related physiological parameters 66, p. 200.
[11] Dode, P., Greig, M., Zolfaghari, S., Neumann, W.P., 2016. Integrating human factors into discrete event simulation: a proactive approach to simultaneously design for system performance and employees' well being 54, p. 3105.
[12] Raso, R., Emrich, A., Burghardt, T., Schlenker, M., Gudehus, T., Strter, O., Fettke, P., Loos, P., Editors, 2018. Activity monitoring using wearable sensors in manual production processes-an application of CPS for automated ergonomic assessments.
[13] Mehta, R.K., Agnew, M.J., 2011. Effects of concurrent physical and mental demands for a short duration static task 41, p. 488.
[14] Michalos, G., Makris, S., Chryssolouris, G., 2013. The effect of job rotation during assembly on the quality of final product 6, p. 187.
[15] Schaub, K., Caragnano, G., Britzke, B., Bruder, R., 2013. The European Assembly Worksheet 14, p. 616.
[16] Borg, G., 1985. An introduction to Borg's RPE-scale. Mouvement Publications.
[17] Hart, S., 2006. Nasa-Task Load Index; 20 Years Later 50, p. 904.
[18] Grier, R.A., 2015. How High is High? A Meta-Analysis of NASA-TLX Global Workload Scores 59, p. 1727.
[19] Field, A., Miles, J., Field, Z., 2013. Discovering statistics using R. Sage, Los Angeles, Calif.
[20] Jawlik, A.A., 2016. Statistics from A to Z: Confusing Concepts Clarified. John Wiley & Sons, Inc, Hoboken, NJ, USA.
[21] Eid, M., Gollwitzer, M., Schmitt, M., 2017. Statistik und Forschungsmethoden: Mit Online-Materialien, 5th edn. Beltz, Weinheim, Basel.
[22] Falck, A.-C., Örtengren, R., Rosenqvist, M., Söderberg, R., 2017. Proactive assessment of basic complexity in manual assembly: development of a tool to predict and control operator-induced quality errors 55, p. 4248.
[23] Michalos, G., Karvouniari, A., Dimitropoulos, N., Togias, T. et al., 2018. Workplace analysis and design using virtual reality techniques 67, p. 141.
[24] Fox, S., Aranko, O., Heilala, J., Vahala, P., 2020. Exoskeletons 31, p. 1261.