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Improvement of Occupational Safety: Investigation on the Correlation of Ergonomic Conditions on Workplace Accidents in the Automotive Industry

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Abstract: This quantitative study aims to investigate a possible link between improving the ergonomic conditions at the workplace and reducing the number of accidents. The study will be based on a review of accident reports and using an ergonomic assessment tool to collect relevant data. To ensure the reliability of the individual variables, they were tested for multicollinearity. It was investigated which factors correlate with one another using a correlation matrix. Three of the original seven variables were found to have substantial multicollinearity. These three variables were eliminated from the data to decrease multicollinearity and increase the stability of the data analysis. Using a linear regression model without a constant term is justified. A model reliability of over 60% was achieved by identifying four significant variables and choosing the correct model approach. Thus, this work provides the first approach in the automotive industry to demonstrate that ergonomic evaluation of workstations impacts accident frequency. The results show parallels with existing studies in the literature, even though the study relates to a different industry.

Keywords: Ergonomic conditions, Workplace accidents, Linear regression model

1. Introduction

Considering ergonomic factors in the workplace leads to numerous advantages for both the employer and the employee. In addition to lower absenteeism and higher productivity, it also promotes employee motivation (Liaudanskienė et al. 2010). The study revealed that working conditions significantly improve employee motivation, with a p-value of 0.003 at a 5% significance level (Chintalapti 2021). Despite improved working conditions, the frequency of accidents plays a role. An accident is a sudden event occurring within a limited time frame and caused by an external force or influence that can lead to injury, adverse health effects, or even fatality. In the German wood and steel industry, approximately 977,070 accidents occur annually, of which around 737 are fatal (DGUV 2022). According to a study conducted from 2010 to 2019, an accident happens about every 44 minutes, and a fatal accident occurs every three days (Aljbour 2022). Thus, the reduction of accidents is increasingly crucial as it can impact not only the well-being of employees but also impose a financial burden on companies. When considering direct and indirect costs, the average cost of an accident in Germany amounts to €44,919 (Anders et al. 2013). Indirect expenses of an industrial injury can include lost output, downtime, replacement workers, and legal fees. The direct costs of an occupational injury include medical care, rehabilitation, and compensation payments. To reduce strains, stresses, and prevent occupational disorders, it is essential to consider ergonomics. By reducing potential dangers, ergonomic methods, including modifying workstations, employing ergonomic gear, and training staff, can increase productivity and health.

This quantitative work investigates the relationship between accidents and ergonomic factors in the workplace. The data on ergonomic conditions is collected using an IT assessment tool. This tool evaluates seven criteria distributed over the entire body when the forces operating on the body and posture are both present. The resulting key indicators will be used to develop a preventive model for enhancing accident prevention. While there are existing approaches to accident prevention and early detection of hazardous conditions in industries such as construction, chemical, mining, and agriculture (Baker et al. 2020), the automotive production industry lacks a similar approach. This study aims to close this research gap.

2. Theoretical background

The importance of ergonomic assessment of the workplace clearly emerges from a study by Kumar et al. (2019). In this study, using the RULA (Rapid Upper Limb Assessment) method, an evaluation of the upper limbs is conducted, leading to risk reduction and the establishment of a safer working environment. RULA is a proven approach for measuring musculoskeletal hazards in the workplace, particularly in the upper limbs, neck, and trunk. It does not require any extra equipment and allows for a rapid assessment of posture, strength, and movement in sedentary employment (McAtamney and Corlett 1993). A direct relationship between accidents and RULA assessments could not be derived (Kumar et al. 2019).

Falkner et al. (2012) also considers ergonomic workplace conditions, although Kumar et al. (2019) concentrated on them. To prevent accidents and long-term work-related illnesses, ergonomic evaluation methods are not specifically discussed in this article; instead, it just discusses them in general terms. This study has found that each nation's safety culture affects how many accidents occur. Great Britain and the USA are leaders in reducing accidents and the associated expenses when compared directly to Austria and Germany (Falkner et al. 2012).

Fianu and Papoe (2018) discuss safety management techniques, cost reduction, and ergonomic circumstances. Most workers in their study had unfavorable opinions of workplace safety management systems. Only the existence of these systems in the workplace was confirmed by 33% of the respondents. The importance of a safety culture, management involvement in health and safety discussions, attention to safety aspects in equipment and work practices, availability of contacts for safety issues, access to medical care for injuries, control of hazards, and adequate health and safety training were areas where an agreement was deficient. Less than 50% of workers promptly reported dangers due to fear of the consequences, and many workers voiced worries about doing so. This demonstrates that preventative steps may still need to be taken and that better reporting practices, communication, and training are required to reduce accidents and increase workplace safety. No precise expenses were given, but it was assumed that the cost of these actions would be swiftly recovered (Fianu and Papoe, 2018).

3. Methodology

The study made use of accident data as well as information from an ergonomic evaluation tool. The four BMW vehicle factories in Germany were all considered. The study aimed to determine whether workplace accidents and ergonomic conditions are related. The ergonomic data and the accident data were initially analyzed and processed individually.

3.1 Ergonomic assessment

The assembly department provides monthly updated data for the ergonomics assessment on the assembly line, which is then compared to the production group. Seven factors are used to evaluate the stress level of employees at each company. The difference between static and dynamic load is made. These seven standards include:

1. Criterion: Stress on neck muscles
   a. Flexion of the visual field with head flexion > 40° downwards or >10° upwards
   b. Tilting of the head or neck (>10°)
   c. Rotation of the head > 45°
2. Criterion: Mobility of shoulder joints
   a. Level 1: Flexion in shoulder joint > 60° and/or hand(s) positioned between the shoulder and head
   b. Level 2: Elbows above shoulder height and/or hand(s) over head
3. Criterion: Mobility of trunk
   a. Flexion
   b. Rotation
   c. Lateral flexion
   d. Extension (any)
4. Criterion: Body forces
5. Criterion: Hand and finger forces
6. Criterion: Standing, walking, sitting, kneeling/crouching
7. Criterion: Handling of loads
   a. Lift
   b. Hold
   c. Carry
   d. Pull/push

A Stress Hazard Index (SHI) is calculated for each criterion and provides information about the level of stress imposed on employees during their work. Each attribute's upper and lower bounds are obtained from scholarly works like the

Assembly-Specific Force Atlas (Deutsche Gesetzliche Unfallversicherung e.V. 2009) and the Leitmerkmalmethode (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA) 2019).

3.2 Accidents

To analyze the accident data, all accidents involving internal employees were evaluated, regardless of the duration of time lost. The accidents were classified according to months and departments, which were further abbreviated. Since the accident frequency rate (AFR) only considers accidents with n-1 lost days, it was not suitable for this analysis. Instead, accidents per 1000 hours worked were used as the unit of measurement. This unit was first introduced by the National Safety Council in the 1930s (National Safety Council 1977).

3.3 Model

The ergonomics data were checked for multicollinearity before modelling could start. Multicollinearity is a high correlation between two or more independent variables in a statistical model, which can lead to bias in coefficient estimates and interpretation. Multicollinearity is illustrated and explored in depth using correlation matrices to establish the theoretical justification and guarantee that the independent variables in the model do not display problematic multicollinearity.

The regression equation could be put up after attributes 1, 5, and 6 were eliminated because of their potential for collinearity. Here, the dependent variable (y) is the number of accidents per 1000 hours worked, and the independent variables (x) are the other four features. The data are logarithmized to ensure a linear data relationship since linear models presume a linear relationship between the variables. Non-linear connections are converted into linear forms by applying a logarithm transformation to the variables, enabling the assumption of linearity to be satisfied and increasing modelling precision.

The logarithm transformation is chosen based on several factors. One advantage is that it can aid in linearizing non-linear interactions between variables and improve modelling accuracy. Second, the lowering of heteroscedasticity is a benefit of using logarithmic data. When the variance of the errors in regression is not constant, there is a systematic shift in the variance over the range of values of the independent variables. This is known as heteroscedasticity. The variance differences can be decreased by logarithmizing the variables, which also improves data modelling and restores homoscedasticity or the consistency of error variance.

A linear regression model is then constructed using this database, excluding the constant factor. The model can pass through the origin without the constant factor, and no additional constant needs to be calculated as a parameter.

4. Results

There are two chapters in the results section. First, a correlation matrix is used to check for multicollinearity. Then, linear regression without constant term results is presented.

4.1 Correlation matrix

A correlation matrix was created for all criteria to examine the correlation between the individual criteria. The correlations are presented in the table 1. Based on the logarithmic values, ergonomic assessment, and comprehensive understanding, certain criteria were excluded from the analysis.

Criterion 1 did not significantly correlate with the other factors, indicating no linear relationship. As a result, we have excluded criterion 1 from further analysis in this study. The absence of correlation between criterion 1 and the other variables indicates the possibility of alternative or non-linear relationship.

On the other hand, criterion 2 had a significant correlation coefficient ($r = 0.853$) with the other variables, suggesting a strong relationship. Similarly, criterion 4 had a high correlation coefficient ($r = 0.865$) with the other variables, indicating its importance in capturing the underlying relationships. As a result, criteria 2 and 4 were considered more influential in our examination of the factors.

Criterion 5 showed moderate to strong correlations with the other variables. Since a force, greater than 40 Newtons assessed in Criterion 5 immediately transferred to Criterion 4, a strong relationship was found between Criterion 4 and 5. Given that Criterion 4 covers all borderline cases, Criterion 5 was excluded from further consideration and was not included in this study.

While criterion 6 had moderate to strong correlations with the other variables, criteria 2 and 4 had higher correlation coefficients. Given the lower importance of criterion 6 in the stress analysis, it was decided to remove it from the model.

Overall, our analysis highlighted the significance of criteria 2, 3, 4, and 7 in capturing relationships between variables. These criteria had significant correlations with other factors and were considered more relevant for this study. Table 1 details the statistical measures, including correlation coefficients and significance levels.

Table 1: Correlation matrix of criterion 1 to 7 (CR = Criterion)

Variable	Correlation coefficient	*CR 1*	CR 2	CR 3	CR 4	CR 5	CR 6	CR 7
1. CR 1	Pearsons r	—						
	p-Value	—						
2. CR 2	Pearsons r	0.824	—					
	p-Value	< .001	—					
3. CR 3	Pearsons r	0.785	0.690	—				
	p-Value	< .001	< .001	—				
4. CR 4	Pearsons r	0.747	0.915	0.642	—			
	p-Value	< .001	< .001	< .001	—			
5. CR 5	Pearsons r	0.860	0.853	0.739	0.865	—		
	p-Value	< .001	< .001	< .001	< .001	—		
6. CR 6	Pearsons r	0.692	0.596	0.862	0.654	0.716	—	
	p-Value	< .001	< .001	< .001	< .001	< .001	—	
7. CR 7	Pearsons r	0.661	0.869	0.545	0.877	0.824	0.486	—
	p-Value	< .001	< .001	< .001	< .001	< .001	< .001	—

4.2 Linear regression model without a constant

Criteria 2, 3, 4 and 7 were applied to the linear regression model without a constant. The following formula (1) illustrates the linear regression with more than one variable and formula (2) how to calculate the coefficient of determination for this model.

$$y = \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \cdots + \beta_i \cdot x_i \tag{1}$$

$$R^2 = 1 - \frac{SQR}{SQT} = 1 - \frac{\sum(y_i - \tilde{\beta}_i x_i)^2}{\sum(y_i - \bar{y})^2} \tag{2}$$

SQT refers to the sum of squares total, while SQR is the explained sum of squares residual.

Table 2: Results of linear regression without a constant with variables 2, 3, 4, and 7 for the years 2021 and 2022

Model for the year	*R*	R^2	Fixed R^2	RMSE
2021	0.786	0.618	0.613	1.275
2022	0.832	0.692	0.689	1.118

(R= correlation coefficient; R2= coefficient of determination; RMSE= for Root Mean Squared Error)

Table 2 shows that in 2021, the coefficient of determination is 61.8%, and in 2022, it rises to 69.2%. This suggests that in 2022 the model's explanatory power will be slightly higher. In addition, it is essential to remember that the deviation from the adjusted R-squared value in 2021 is 0.5%. This variation shows how the coefficient of determination has been modified to consider the number of predictors. This gap is much less noticeable in 2022, at 0.3%. This means that the model will match the data better in 2022 and will be less prone to overfitting.

5. Discussion

This study aimed to fill the gap in preventive workplace safety in the automobile sector. The ergonomic data was compared to the accident data first. Four of the seven criteria were then chosen using correlation matrices. Here, it would be possible to demonstrate a link between the accidents and the ergonomic information. Taking ergonomic factors into account may have an impact on the accident rate.

Mathematical and theoretical considerations led to the exclusion of the three criteria. Due to collinearity with criterion 2, criterion 1 was excluded. The exclusion of criterion 5 was due to its close relationship with criterion 4. Criterion 6 was removed due to its low importance. These decisions help make the model more focused and precise by making the remaining criteria (2, 3, 4 and 7) the ones that contribute most to explaining the dependent variable.

However, based on the model with a constant term, where the constant has a significant p-value of <0.001, this can be omitted on the grounds of appropriateness. Including a constant term in the model would have the effect that there is a baseline level of accidents at all times, regardless of the ergonomic assessment of the workstations. Therefore, a different formula and interpretation apply to the coefficient of determination. The coefficient of determination cannot contain an absolute value range because the constant term is omitted. Therefore, its range of values is not 0 to 1 but $-\infty$ to 1. A positive R^2 value means that the regression line can explain some or all of the variation in the data. The closer the value of R^2 is to 1, the better the model fits the data. A negative R^2 value indicates that the regression model fits the data less well than a simple horizontal line. It means that the variation explained by the model is less than the variation around the mean of the dependent variable. In the standard coefficient of determination formula, the denominator includes the variation because the model has a constant term. This results in a sum of zero residuals and the normalized sums of the squared residuals are automatically explained by the variance. As these squared residuals represent unexplained variation, they should be as small as possible relative to the total variation in the dependent variable. This variation was higher in the constant factor model, so it was removed. In this paper, the numerator of the quotient (SQR) indicates the unexplained variation in the data. It is the sum of the squared deviations between the observed y-values and the y-values predicted by the regression line. A higher value of the SQR indicates a more significant amount of unexplained variation. The denominator of the quotient (SQT) measures the total variation in the dependent variable. It is the sum of the squared deviations between the observed y-values and the average of all y-values. A more significant value of the SQT indicates greater total variation. The proportion of unexplained variation compared to the total variation is obtained by dividing the SQR by the SQT. Subtracting this value from 1 gives the proportion of variation explained by the regression line.

To summaries, a coefficient of determination >0.6 is an excellent result for this work. This indicates that the regression model developed can explain a significant proportion of the variation in the data, thus providing a solid basis for further analysis and conclusions.

These findings concur with Falkner et al. (2012) and Kumar et al. (2019). In the later study, there was no connection between accident incidence and ergonomic circumstances. However, as the data is specialized for the automobile sector, there are few direct comparisons between the specific findings of this study and others described in the literature. The RULA approach does not consider the critical component of the lower limbs because only the upper limbs are considered.

In this area, Vogel et al. (2022) showed how to leverage various model versions for accident prediction. In this context, various sectors have adopted neural networks and the Random Forrest model based on machine learning and self-improves through self-optimization (Vogel et al. 2022).

This study creates a fundamental framework for key performance metrics in the automobile sector that can be used going forward for proactive accident prevention and prediction.

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