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APPLICATION OF THE CREEPING TREND MODEL FOR FORECASTING OF ACCIDENT EVENTS IN THE STEEL INDUSTRY IN POLAND

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Purpose: The aim of the study to assess the possibility of using the creeping trend model in the forecasting of accidents at work in the steel sector in Poland, was presented.
Design/methodology/approach: A four-stage research methodology was used to analyze the accident rate trend in the steel sector, based on: collecting empirical data, forecasting (creeping trend model), qualitative assessment of forecasts and determining the direction of activities in the field of health and safety.
Findings: Based on the conducted research, it was found that it is possible to use the creeping trend model in forecasting the number of persons injured in accidents at work. The forecasts and their acceptance based on the criteria adopted in the methodology of own work made it possible to determine the directions of activities in the field of occupational health and safety in the steel sector in Poland.
Research limitation/implications: The conducted analyses were limited to statistical data published by Statistic Poland. Forecasts of the number of persons injured in accidents in the steel sector were possible to determine thanks to the forecasting process using the creeping trend model. The forecasts are subject to errors, which is why it is important to interpret them more broadly, taking into account the specificity of the industry being the subject of the analyses.
Practical implications: The forecasts can be important information on health and safety issues for the steel sector in Poland. The use of the creeping trend model, with the fulfillment of methodological assumptions (qualitative ocean of forecasts), can be useful in determining the direction of OSH activities in enterprises.
Social implications: The article addresses the issue of the occurrence of accidents at work, the implementation of effective preventive measures in order to reduce them.
Originality/value: The article presents the possibility of using the creeping trend model in the forecasting of the total number of persons injured in accidents in the steel sector in Poland. The forecasts and trend analysis can provide information for employers and employees of health and safety services regarding the effectiveness of the implemented preventive measures.

Keywords: Creeping trend model, forecasting, accidents at work, steel industry.

Category of the paper: Research paper.

1. Introduction

Professional work plays an important role in human functioning and is of interest to many scientific disciplines, including psychology, sociology, economics and medicine. In the field of labor law, the subject of analysis is subordinate work, under voluntarily accepted conditions, performed personally by an employee, for an employer and under his control (Florek, 2017). Only work that meets the definition becomes relevant in terms of occupational health and safety. The totality of material factors characterizes the place where the work process is carried out. The occurring factors may be dangerous, harmful or burdensome for an employee. And it is against the negative impact of those factors that protective prevention should be implemented, which is most often a combination of technical and organizational solutions.

Accidents at work and occupational diseases are the adverse effects of the factors related to material working environment. The issue of examining accidents at work and occupational diseases is still a valid subject of numerous scientific studies, which is why solutions (Hoła et al., 2017; Jacinto et al., 2009; Rydlewska-Liszkowska, 2006; Piňosová et al., 2021), methods and tools supporting – effective occupational health and safety management are still being sought.

Therefore, the study presents the possibility of using forecasting for an assessment of the trend in the number of registered accidental events in the steel sector. The forecasts will allow for an initial assessment of the effectiveness of the implemented preventive solutions. They will also be helpful for the managerial staff, allowing them to set further directions for occupational health and safety activities.

The purpose of this article is to evaluate the possibility of using the creeping trend model for the forecasting of the number of persons injured in accidents at work, and to determine the function that forecasting performs, in the area of accident rate in the steel sector.

2. Literature review

Forecasting is a science-based prediction of future phenomena and processes (Nowak, 1998), the aim of which is to reduce risk in the decision-making process (Dittmann, 2003). The root of the term forecast (Greek prognosis) consists of two parts, in which the prefix pro indicates the initial preparatory phase, while gnosis means knowledge about something that has not yet happened (Sobczyk, 2008).

The main purpose of forecasting is to support decision-making processes (Cieślak, 2001), which also includes actions taken to improve work safety. Therefore, forecasting becomes a valuable tool for employers as the possibility of assessing the effectiveness of the implemented preventive solutions, as well as taking other actions to improve occupational safety. Forecasts perform the following functions (Nowak, 1998; Cieślak, 2001; Sobczyk, 2008; Zeliaś, 2013), i.e.:

- informative function – informing about upcoming changes,
- preparatory function – forecasting is a preparation – it is a preparation for any other action taken by a decision-maker,
- activating function – involving stimulation to action, which is to support the implementation of the forecast if it announces a favorable event or abandonment in the case of actions that may be unfavorable for a decision-maker,
- warning function – the forecast is intended to warn against the arrival of undesirable events for a recipient of the forecast.

Forecasting plays a vital role in occupational health and safety management as managers make different decisions on a day-to-day basis. These forecast functions may refer, among others, to decisions related to the need to introduce radical changes in the existing working conditions (e.g. a growing trend in the number of persons injured in accidents at work, occupational diseases, potential accidents). The classification of events defined as accidents at work or the recognition of occupational diseases is defined in legal regulations (Ustawa, 2002; Rozporządzenie, 2009). In accordance with applicable law, an employer should prevent their occurrence and implement preventive measures.

In the forecasting process, various methods are used, which can be divided into quantitative (mathematical and statistical) and qualitative (non-mathematical, heuristic). The mathematical and statistical methods are based on deterministic or econometric models (e.g. Holt's, Winters', Brown's, moving average, creeping trend model, etc.). On the other hand, the non-mathematical methods include survey methods, expert opinions, intuitive methods, etc. (Sobczyk, 2008).

As part of this work, the possibility of using the creeping trend model in the forecasting of accidents at work in the steel sector was presented. The creeping trend model - the method of harmonic weights – has been widely used in the literature on the subject, among others, in the field of forecasting: prices (Szilágyi et al., 2016), freight transport by rail (Mróz, 2019), demographic variables (Sojka, 2016), annual electricity (Piotrowski et al., 2017), steel production volume (Gajdzik, et al. 2016), electricity production volume from RES (Mularczyk, 2016), plant yields (Sroka et al., 2008), number of grid failures water supply system (Iwanejko et al., 2012), hard coal mining (Gworek et al., 2005), demand for mineral resources (Uberman, 2016), which is collectively presented in Table 1.

Table 1.
Creeping trend model - harmonic weights method – literature review

No	Author, year of publication	Application of the method of harmonic weights
1	Mróz, 2019	Forecasting the volume of freight transport using rail transport in Poland
2	Sojka, 2016	Forecasting demographic variables (including population, age)
3	Piotrowski, Marzecki, 2017	Forecasting the annual demand for electricity in field transformer stations
4	Gajdzik, Szymszal, 2016	Forecasting the volume of steel production in millions of tons
5	Sroka et al., 2008	Plant yield forecasting (wheat, barley, rape, rye)
6	Iwanejko, Bajer, 2012	Forecasting the number of water supply network failures on the example of the city of Kraków
7	Gworek, Utrata, 2005	Forecasting hard coal production in million tons
8	Mularczyk, 2016	Forecasting the volume of electricity production from renewable sources in Poland
9	Uberman et al., 2016	Forecasting the demand of the Polish economy for mineral resources (e.g. aluminum, antimony raw materials, zinc, tin raw materials, fluorite, phosphates, cobalt raw materials, copper, etc.)
10	Szilágyi et al., 2016	Methanol price forecasting

Source: Own elaboration.

Choosing the method and then determining the forecasts does not end the forecasting process. Therefore, it is necessary to determine their accuracy using metrics that allow to determine and compare the accuracy of forecasts. Therefore, for the purposes of the study, ex post measures were used, which are often used in the qualitative assessment of forecasts – Table 2.

Table 2.
Measures used in the assessment of forecasts

No	Error	Mathematical dependence
1	mean error ψ	$\psi = \frac{1}{T-n}\sum_{t=n+1}^{T}\frac{\lvert y_t - y_t^*\rvert}{y_t}$ n - number of elements of the time series T - number of the last period
2	adjusted average relative ex post error Θ	$\Theta = \frac{1}{T-n}\cdot\sum_{t=n+1}^{T}\left\lvert\frac{y_t - y_t^*}{(y_t + y_t^*)/2}\right\rvert$
3	Rot Mean Square Error RMSE	$RMSE = \sqrt{\frac{1}{T-n}\cdot\sum_{t=n+1}^{T}(y_t - y_t^*)^2}$
4	standard deviation of the S_e model residuals	$S_e = \sqrt{\frac{1}{n-2}\cdot\sum_{i=1}^{n}(y_t - y_t^*)^2}$
5	Theil coefficient I^2	$I^2 = \frac{\sum_{t=n+1}^{T}(y_t - y_t^*)}{\sum_{t=n+1}^{T} y_t^2}$

Source: Own elaboration based on: Cieślak, 2001; Dittmann, 2003; Nowak, 1998; Halicka, 2013; Hong, 2020; Nazarko, 2018; Nowak, 1998; Sobczyk, 2008; Zeliaś, 2003; Snarska, 2005, Gajda, 2001; Sopelsa Neto et al., 2022; Chai et al., 2014).

3. Methodology

The achievement of the aim of the work was possible thanks to the development of a four-stage methodology of own work (Fig. 1). As part of the first stage, statistical data (Statistic Poland, 2022) on the total number of persons injured in accidents in the steel sector in Poland were compiled (a ten-year period of analyses – 2011-2021). The analyses were carried out using the PQstat computer software and an Excel spreadsheet.

The second stage consisted in setting forecasts for 2022-2023 using the creeping trend model – the harmonic weights method (Goryl et al., 2004; Cieślak, 2001; Dittmann, 2003; Nowak, 1998; Zelisaś, 2003; Sobczyk, 2008; Witkowska, 2006).

As part of the third stage, a qualitative assessment of the forecasts was made based on ex post forecast errors. For the determined values of ex post errors, the following criteria were adopted for the purposes of this study (Sobczyk, 2008; Cieślak, 2001; Snarska 2005):

- the value of the estimated relative error of the ex post forecast $\psi < 10$ %,
- the forecasts will be considered satisfactory when RMSE $\leq S_e$ (S_e – standard deviation of the S_e model residuals),
- the values of the adjusted mean ex post relative error are in the range [0% to 200%].

Due to the impossibility of determining ex ante prediction accuracy measures (no publication of statistical data on accidents for 2022 and 2024), the Theil I^2 coefficient was determined a measure of the total relative prediction error, which has been extensively described in the literature on the subject (Goryl et al., 2004; Dittmann, 2003; Nowak, 1998; Zelisaś, 2003; Sobczyk, 2008; Sojda, 2014; Czyżycki et al., 2006; Mróz, 2021). According to the literature assumptions, the value of the coefficient should be equal to zero – then the forecast is perfectly accurate. In practice, however, it assumes numerical values in the range [0;1] (Sobczyk, 2008).

The fourth stage consisted of assessing the possibility of using the creeping trend method (harmonic weights) for predicting a total number of persons injured in accidents. The estimated forecasts were assessed in OSH field regarding the trend in the number of persons injured. Directions for further actions aimed at creating safe and hygienic working conditions for employees were also defined.

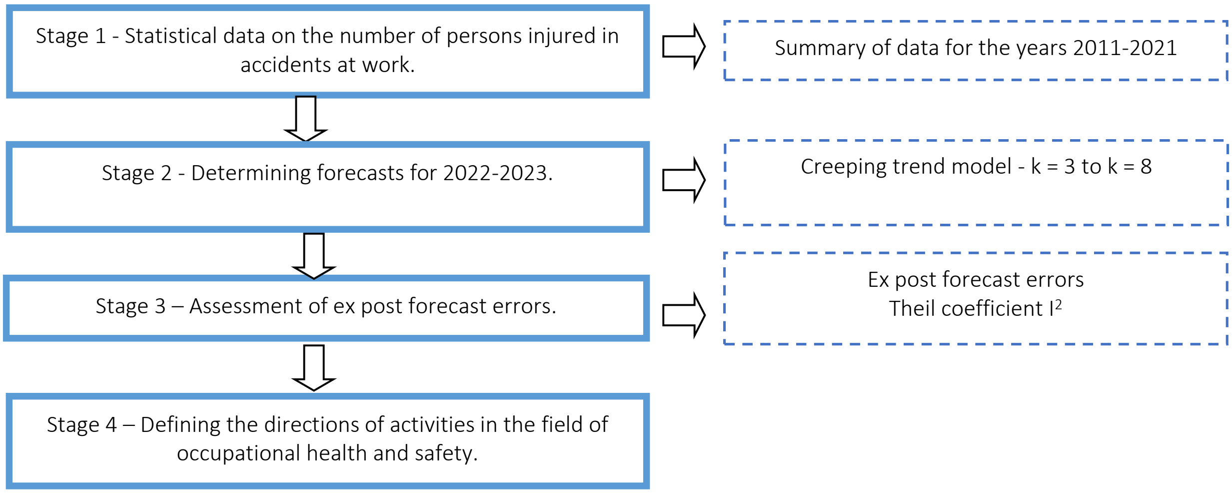

Figure 1. Methodology of own work.

Source: Own elaboration.

4. Problems of accidents at work and their forecasting

4.1. Accidents at work in steel sector in Poland

The specificity of the work performed and occupational hazards translate into the occurrence of accidents at work. Accidents at work are still recorded although the applicable legal regulations (Rozporządzenie…, 1997, 2010, 2017) impose an obligation on employers to ensure safe and hygienic working conditions and to indicate the types of work that carry a risk of accidents (e.g. blast furnace operation, transport work, sorting scrap, etc.).

In 2011-2021, an average of 896 victims of accidents at work were registered in the steel industry in Poland. In 2011, 1.127 victims of accidents at work were registered, while a significant decrease in the number of victims of accidents at work, compared to the analyzed period, was recorded in 2020 (620 victims of accidents in total). That decrease was related to the COVID-19 pandemic, which significantly affected the production capacity and operation of enterprises (Casella, 2021; Saniuk et al., 2021; Nowacki et al., 2021). An increase in the total victims of accidents was recorded in 2021, where the total number of such victims was 782 (an increase of approx. 21% compared to 2020). In connection with the above, it becomes important to conduct analyses of accidents in the steel sector in Poland. The total number of persons injured in accidents at work (Table 3) in the period under analysis was characterized by low variability (13%) (Małysa et al., 2021). The average rate of change was -3.59%, which means that the average rate of decrease in the number of employees in the period in question amounted to 3.59%.

Table 3.
Selected statistics of descriptive characteristics for the number of persons injured in accidents at work - years 2011-2021

Specification	Min	Max	Median	Average	Deviation standard	Coefficient of variation	Average rate of change, %
Selected characteristics statistics for the total number of persons injured in accidents at work	620	1127	901	896	125.08	0.13	3.59

Source: Own elaboration based on Statistic Poland.

4.2. Creeping trend model – forecasting accidents at work

The implementation of the assumed goal of the work (stage 2) was possible thanks to the adaptation of the creeping trend model for the prediction of statistical data (Statistics Poland, 2011-2021) regarding the total number of persons injured in accidents. For the purposes of the study, six variants of the creeping trend model were adopted, allowing for the determination of ex ante forecasts for 2022-2023. The adopted variants differ from each other by constant k, which was a variable value for the developed models. For the first model k = 3, therefore, 9 creep steps were adopted, the first for t = 1-3, the last for t = 9-11); and the same method was applied by analogy to the subsequent models.

Based on the analyses of the ex ante forecasts (Table 4, Fig. 2), a decrease in the total number of persons injured in accidents was recorded in 2022 compared to 2021 – which is important information in relation to OSH issues. The highest value (max) of the forecast of the number of injured persons was obtained for the creeping trend model – k = 8 (757 persons injured in accidents at work). The lowest value (min) of the forecast was obtained for models where constant k was 3 and 4, respectively – 738 injured persons in accidents in total. In 2023, the forecast values show a decrease in the total number of persons injured in accidents. The highest forecast value (max) was recorded for the creeping trend model k = 8 (732 injured persons), while the lowest forecast value (min) was recorded for the creeping trend model, where k = 3 – 694 persons injured in accidents at work (Table 4).

Table 4.
Forecasts for 2022-2023 and ex post forecast errors

Specification	Forecast		Ex post forecast errors			
	2022	2023	Ψ	Θ	RMSE	S_e
creeping trend model, k = 3	738	694	0.05	0.013	53.05	59.31
creeping trend model, k = 4	738	695	0.05	0.013	54.31	60.72
creeping trend model, k = 5	739	695	0.06	0.015	63.20	70.66
creeping trend model, k = 6	748	714	0.06	0.015	65.83	73.60
creeping trend model, k = 7	753	723	0.07	0.016	71.85	80.33
creeping trend model, k = 8	757	732	0.07	0.017	76.99	86.08

Source: Own elaboration.

According to the adopted assumptions specified in the methodology of own work, forecasts can be considered acceptable when (Table 4):

- the values for the estimated relative ex post forecast error ψ are less than 10% - for the developed models they ranged from 5% to 7%,
- the values of the RMSE error (the mean square error of the forecast) for each model (Table 4) are smaller than the value of the standard deviation of the residuals of the S_e model,
- the values of the adjusted ex post mean relative error in the verification interval Θ are within the accepted range of 1.3% to 1.7%.

For the purposes of the study, the Theil's divergence coefficient was also determined. The lowest value of Theil coefficient was obtained for the creeping trend model k = 3 (I^2 = 0.0033), and the highest value for the creeping trend model k = 8 (I^2 = 0.0091). The total error of forecasts of the number of persons injured in accidents at work ranged from 0.00572 (a model with constant k = 3) to 0.0953 (a model with constant k = 8). These errors should be considered not high – close to zero. The analyses lead to the conclusion that, the model of creeping trend k = 3 was the best because of, the lowest values of the forecast errors.

Table 5.
Theil coefficient and relative error values of ex post forecasts

Specification	Theil coefficient I^2	Total error forecasts
creeping trend model, k = 3	0.0033	0.0572
creeping trend model, k = 4	0.0037	0.0641
creeping trend model, k = 5	0.0054	0.0737
creeping trend model, k = 6	0.0061	0.0782
creeping trend model, k = 7	0.0079	0.0892
creeping trend model, k = 8	0.0091	0.0953

Source: Own elaboration.

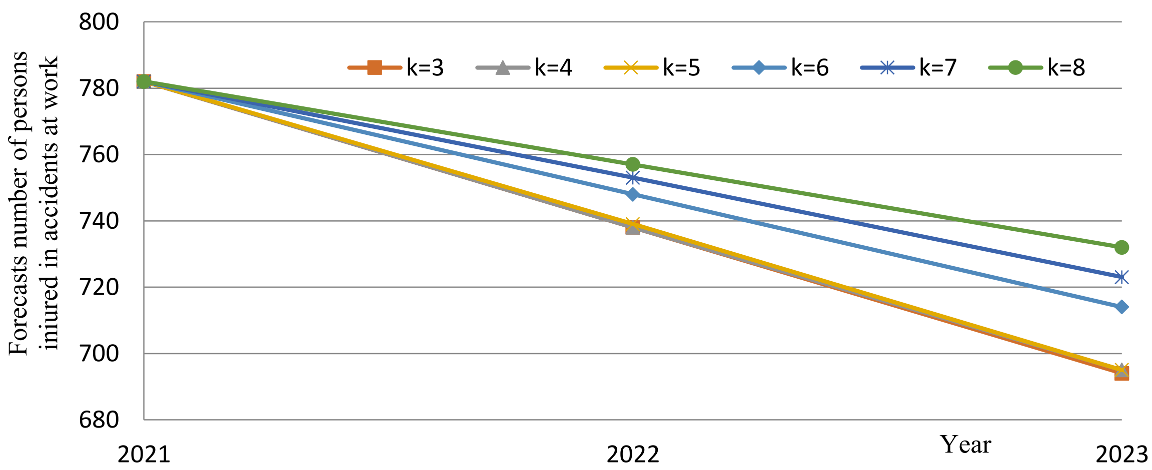

Figure 2. Trends and forecasts of the total number of persons injured in accidents at work (2022-2023) for creeping trend models (k = 3 – k = 8).

Source: Own elaboration.

5. Discussion and conclusion

Accidents at work contribute to the occurrence of social and economic problems (Usnar et al., 2009), and they are therefore the subject of many scientific studies. Methods and tools allowing for their effective reduction or the monitoring of health and safety in enterprises are still sought after. The use of econometric models in the field of health and safety issues allows for an assessment of the trend in registered accidental events, as well as for the promotion of solutions that have an impact on reducing the number of registered accidental events. The use of the harmonic weights' method (the creeping trend model) made it possible to determine the trend in the number of persons injured in accidents – a downward trend. In the scope of the OHS issues in question, the numerical values determined for the number of persons injured in accidents at work (models k = 3 to k = 8) are positive information for the management staff (information function of the forecast). The results of the forecasts obtained under the creeping trend model k = 3 would be the most optimistic because, the lowest forecast values of the number of persons injured in accidents were obtained for that model – 738 persons injured in 2022 and 694 in 2023, with the simultaneous acceptability of the forecast errors values.

The conducted analyses lead to the conclusion that the use of forecasting made it possible to assess the trend in the number of persons injured in accidents at work. On the basis of the forecast values, it is possible to propose implementing actions aimed at improving occupational safety, as well as to determine further actions in the field of occupational health and safety and, determining further actions in the field of occupational health and safety.

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