Use of Selected Adaptive Models to Forecast Accidents During the Repair, Maintenance, Installation of Machines and Equipment

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INTRODUCTION

The provision of safety is one of the basic needs playing a significant role in human life. Numerous persons sustain accidents resulting from various events every day. An analysis of accidental events makes it possible to distinguish events that are not related to the performance of work (traffic or sports accidents) and those related to the performance of work (close or distant relationship) – occupational accidents. It should be observed that this study focuses solely on accidents at work recorded in Poland during the repair, maintenance and installation of machines.

Accidents at work occurring during the operation of machines are one of the problems encountered in manufacturing companies. Given that such events generate considerable social and economic costs, it seems appropriate to conduct an analysis of occupational accidents geared towards the implementation of preventative solutions that may limit their occurrence.

The aim of this study is to present the possibility of using selected adaptive models (naive method, simple and weighted moving average, Brown's single exponential smoothing, Holt's additive trend model) for forecasting accidents occurring during the repair, maintenance and installation of machines. The models presented in this study can be used by enterprises in other industries in the prediction process and make it possible to assess the state of occupational safety. The developed models may also be applied to other areas related to occupational safety.

ACCIDENT AT WORK, FORECASTING

An accident at work is to be understood as a sudden externally caused event related to the performed work which results in injury. This definition of accident is provided in the Act on Social Insurance Against Accidents at Work and Occupational Diseases (Act of October 30, 2002). These features of an accident at work (suddenness of the incident, external cause, injury or death, relationship with work) must occur simultaneously (Małysa et al., 2017; Małysa, 2019) for an event to be classified as an accident at work and to allow the victims to obtain

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benefits to which they are entitled. The occurring events are classified in terms of the severity of the consequences (serious, fatal and other accidents) and the number of victims (individual and collective accidents) (Lis et al., 2005). It should be recalled that all activities related to the prevention of occurrence of such events are the responsibility of employers – the organizers of the work (Act of June 26, 1974).

The conducted analyses of the accident rate are mainly based on historical data (Małysa, 2019; Krause, 2015, Gajdzik et al., 2015). The analysis is thus carried out on events that have already taken place and it obviously does not cover the future and the possibility of the occurrence of accidents at work in the subsequent years. The analysis process may be greatly fostered by forecasting methods. Forecasting is a process of prediction based on empirical data (Sobczyk, 2008). Another definition (Dittmann, 2016) specifies that forecasting is the prediction of future events which seeks to reduce risk in the decision-making process. Combining these two definitions for the purposes of this study, it may be observed that *forecasting is a process of predicting the development of the number of accidents at work in the area under investigation*. The use of the compiled forecasts will allow analyses to be performed regarding the effectiveness of the implemented preventative measures. The forecasting relies on models that are examined in detail in the literature on the subject (Dittmann, 2016; Cieśla, 2001; Sobczyk, 2008; Krawiec, 2014). These models include, among others, naive methods, moving average models, exponential smoothing models, Brown's, Holt's and Winters' exponential models, or ARMA and ARIMA models. Forecast models are widely used in business practice to predict various phenomena, e.g. sales (Puthran et al., 2014), steel production volume (Gajdzik, et al., 2016) or exchange rates (Ortiz, 2016).

The forecasting does not in fact end once the forecast is prepared. The expected forecast error should also be determined (Krawiec, 2014). The literature review (Cieśla, 2001; Krawiec, 2014; Sobczyk, 2008) shows that the most often discussed forecast errors include: mean error – „ψ", Root Mean Square error – „RMSE*" and adjusted average relative ex post error in the verification interval – „Θ". These errors will also be determined for the purposes of this study, from the following mathematical relationships (1-3):

$$\psi = \frac{1}{n-m} \cdot \sum_{t=m+n}^{n} \frac{|y_t - y_t^*|}{y_t} \tag{1}$$

$$RMSE^* = \sqrt{\frac{1}{n-m} \cdot \sum_{t=m+1}^{n} (y_t - y_t^*)^2} \tag{2}$$

$$\Theta = \frac{1}{n-m} \cdot \sum_{t=m+n}^{n} \left| \frac{y_t - y_t^*}{(y_t + y_t^*)/2} \right| \tag{3}$$

where:
n – number of elements of the time series;
m – number of initial time moments t;
y_t – empirical data;
y_t^* – forecasts value.

RESEARCH METHODOLOGY

The objective of this study is achieved owing to the adopted three-step research methodology. As a **first step**, statistical yearbooks (GUS, 2009-2018) concerning accidents during the repair, maintenance and installation of machines and equipment released by the Central Statistical Office of Poland were subjected to review. The **second step** included the compilation of empirical data on the total number of persons injured in accidents in the years 2009-2018. The forecasting was carried out on the basis of the compiled empirical data and it employed selected adaptive models described by mathematical dependencies (4-16):

- *naive forecasting model* where the forecast is constructed on the basis of the dependency (4):

$$y_t^* = y_{t-1} \tag{4}$$

where:

y_t^* – forecast value;

y_{t-1} – value of the variable y.

- *simple moving average model* in which the forecast is produced on the basis of the mathematical dependency (5), and a *weighted moving average model* based on dependencies (6 i 7):

$$y_t^* = \frac{1}{k}\sum_{i=t-k}^{t-1} y_i \tag{5}$$

$$y_t^* = \sum_{i=t-k}^{t-1} y_i \cdot w_{i-t+k+1} \tag{6}$$

$$\sum_{i=1}^{k} w_i = 1 \quad 0 < w_1 < w_2 < \cdots < w_k < 1 \tag{7}$$

where:

y_t^* – forecast value;

y_i – value of the forecast variable;

k – smoothing constant.

- *Brown's single exponential smoothing model* specified by the dependencies (8-11):

$$G_1 = y_1 \tag{8}$$

$$G_t = \alpha \cdot y_t + (1 - \alpha) \cdot G_{t-1} \qquad for\ t = 2, \dots, n \tag{9}$$

$$F_{t-1} = G_{t-1} + (G_{t-1} - G_{t-2}) \qquad for\ t = 2, \dots, n \tag{10}$$

$$y_t^* = F_{t-1} \qquad for\ t = 3, \dots, n \tag{11}$$

where:

G_t – first order exponential smoothing operator;

y_1 – value of the first element of the time series;

y_t^* – forecast value;

F_t – smooth level assessment (average value);

α – smoothing parameter with values in the range (0,1); α ≠ 0 and α ≠ 1.

In the Brown's model, the smoothing parameter was selected individually based on minimizing the mean error of expired forecasts using the Solver add-on.

- *Holt's additive trend model* described using dependencies (12-16):

$$F_1 = y_1 \tag{12}$$

$$S_1 = y_2 - y_1 \tag{13}$$

$$F_t = \alpha \cdot y_t + (1 - \alpha) \cdot (F_{t-1} + S_{t-1}) \qquad for\ t = 2, ..., n \qquad (14)$$
$$S_t = \beta \cdot (F_t - F_{t-1}) + (1 - \beta) \cdot S_{t-1} \qquad for\ t = 2, ..., n \qquad (15)$$
$$y_t^* = F_{t-1} + S_{t-1} \qquad for\ t = 2, ..., n \qquad (16)$$

where:
y_t – value of the forecast variable;
F_t – an estimate of the level of the series at time t;
S_t – an estimate of the trend (slope) of the series at time t;
α – smoothing parameter for the level, (0,1>; α ≠ 0;
β – smoothing parameter for the trend, (0,1>; β ≠ 0.
In the case of the Holt's model, the α, β smoothing parameters were selected individually, minimizing the mean error of expired forecasts using the Solver add-on. The forecasting models were developed using mathematical dependencies (4-16). The determined forecast values were subjected to a qualitative assessment on the basis of the identified forecast errors set out in dependencies (1-3).

The **third step** of the study involved assessing the forecasts of the total number of persons injured in accidents at work during the repair, maintenance and installation of machines and equipment. Forecast errors were evaluated for their permissibility (Sobczyk, 2008; Zeliaś et al., 2003; Nazarko, 2018), i.e. forecasts with the ex post error:
- less than 3% were classified as very good;
- between 3% and 5 % – good;
- between 5% and 10% – permissible;
- exceeding 10% – impermissible.
As indicated in the literature (Snarska, 2005), forecasts are considered satisfactory where RMSE* ≤ S_e. The standard deviation of the residuals (S_e) is determined using the mathematical dependency (17):

$$S_e = \sqrt{\frac{1}{n-2} \cdot \sum_{i=1}^{n}(y_t - y_t^*)^2} \qquad (17)$$

where:
y_t^* – forecasts value;
y_t – empirical data;
n – sample size.
Based on the tests carried out and the qualitative assessment of forecasts, proposals for solutions having an impact on improving the safety of work at the repair, maintenance and installation of machinery and equipment were presented.

OWN STUDIES AND RESULTS ANALYSIS

The conducted research and a qualitative assessment of the forecasts allow for the formulation of proposals for solutions that have an impact on improving the safety of work during the repair, maintenance and installation of machines and equipment. The subject of the analyses covered by this study are accidents at work related to the repair, maintenance and installation of machines and

equipment. In order to implement the step-wise approach specified in the methods of this study, the total number of persons injured in accidents (serious, fatal and other accidents) was compiled (GUS, 2009-2018). The compiled empirical data (Fig. 1) show a decline in the number of persons injured in accidents during the repair, maintenance and installation of machines and equipment (although fluctuations occur, the trend is downward). The highest total number of persons injured in accidents at work was recorded in 2009 (1190), whereas year 2018 was the most favorable from the point of view of occupational safety – i.e. 1002 injuries in total resulting from accidents at work during the repair, maintenance and installation of machines and equipment were reported.
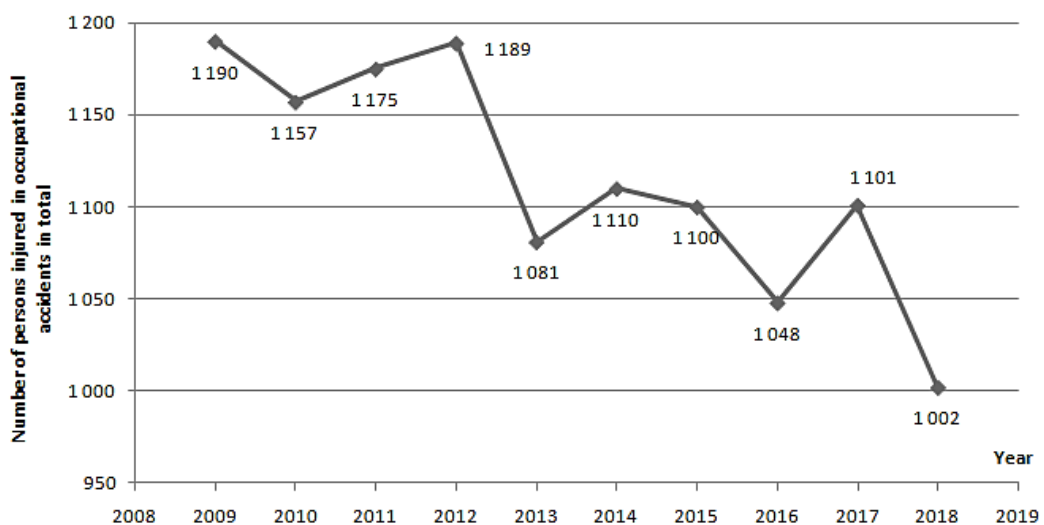
Fig. 1 Number of persons injured in accidents at work related to the repair, maintenance and installation of machinery and equipment in the years 2010-2018
Own study based on Statistics Poland data (GUS, 2009-2018)

In 2009, 1190 injuries in accidents were reported to be followed by a drop down to 1157 cases in 2010. Within the years 2010-2012, an increase in the number of accidents at work was recorded (upward trend). Then there was a fall in 2013, an increase in 2014 and a downward trend continued until 2016. The year 2017 saw an increase in the number of persons injured in accidents during the repair, maintenance and installation of machines and equipment (1101). Notably, the lowest overall number of persons injured in accidents in the entire period under investigation was reported in 2018 – i.e. 1002 persons in total were injured in accidents.

The objective of this study is to provide a forecast for 2019 and the years 2019-2021 in line with the adopted methodology. Given the above, models making it possible to produce forecasts have been developed. In the naive model, the last value of the forecast variable is used to make the forecast. The forecast for the number of persons injured in accidents at work is thus equal to the total number of persons injured in accidents at work in 2018 (y^{*}_{2019} = 1002). As indicated in

the applied naive forecasting model, the total number of persons injured in accidents at work will not undergo a change.

As regards the moving average model – k = 2 (dependency 5), the total number of persons injured in accidents is projected to grow from 1002 in 2018 to 1074 in 2019 (increase by 6.7%). This should be viewed as negative information in terms of occupational safety and health. Similarly, an increase in the total number of persons injured in accidents during the repair, maintenance and installation of machines and equipment is recorded for the developed model of the moving average for k = 3 (y_{2019}^*= 1050).

The weighted moving average model was developed in conformity with dependency (6). Within the model, optimal values of weights w_i were determined, provided that the condition determined by the dependency (7) was fulfilled. The estimated weight values $w_1 = 0.735$; $w_2 = 0.207$; $w_3 = 0.003$ made it possible to produce a forecast for 2019. As shown in the weighted moving average model, there is a decline in the total number of persons injured in accidents (y_{2019}^* = 1000) in 2019 in relation to 2018.

For the developed model of Brown's single exponential smoothing (dependencies 8-11), the forecast value y_{2019}^*= 1030 indicates a growth in the total number of persons injured in accidents (an increase of 2.7% as compared to 2018). The forecast was determined at the optimal value of the smoothing parameter α = 0.335. The mean relative ex post forecast error 'ψ' was minimized.

The Holt's additive trend model shows an increase in the total number of persons injured in accidents y_{2019}^* = 1012 (increase by 1 %). The optimal values of the parameters were α = 0.183 and β = 0.427. The mean relative ex post forecast error'ψ'was minimized. Moreover, the Holt's model made it possible to prepare forecasts for the years 2019-2021. It is concluded on the basis of the forecasts that the number of persons injured in accidents in total in the years 2020-2021 follows a downward trend. That forecast must naturally be regarded as positive information in the context of occupational safety and health. The forecasts, values of smoothing parameters and values of ex post forecast errors are summarized in Table 1.

The obtained forecasts were subjected to an assessment on the basis of the determined errors of the forecasting method (dependencies 1-3). The obtained error values of the relative ex post forecast error „ψ", the root-mean-square error of ex post forecasts (RMSE*) and the adjusted mean relative ex post error 'Θ' are summarized in Table 1. The values of ex post forecast errors are within the range of 2.5%-4.3%, which according to the adopted methodology makes it possible to regard such forecasts as very good (up to 3%) and good (from 3% to 5%). With respect to the estimated RMSE* values, as given in the adopted assumption, the error values are less than the standard deviation of the residuals (S_e).

The conducted qualitative analysis indicates that the obtained forecast values may provide information relevant to occupational safety and health. The values of the obtained forecasts point to possible changes in trends related to reported accidents at work.

The analysis of the forecasts for 2019 led to some interesting conclusions. The weighted moving average model shows a decrease in the total number of persons injured in accidents (↓). As for the naive model, no changes in accidents at work (no changes) are reported. In contrast, the moving average model, Brown's single exponential smoothing model as well as the Holt's additive trend model point to an increase in the total number of persons injured in accidents (↑). The forecast predicting an increase in the number of persons injured in accidents at work is by no means positive information in the context of occupational safety and health and should be a warning to employers.

Table 1 Forecasts, smoothing parameters, forecast errors for developed models

No	Forecasts			α	β	ψ	RMSE*	Θ	S_e
	2019	2020	2021						
1	Naive forecasting model								
	1002 (=)	-	-	-	-	0.043	57.279	0.010	64.948
2	Simple moving average model k = 2								
	1074 (↑)	-	-	-	-	0.036	50.759	0.009	58.611
3	Simple moving average model k = 3								
	1050 (↑)	-	-	-	-	0.043	53.692	0.010	63.529
4	Weighted moving average model (w_1 = 0.735; w_2 = 0.207; w_3 = 0.003)								
	1000 (↓)	-	-	-	-	0.025	37.226	0.006	44.046
5	Brown's single exponential smoothing model								
	1030 (↑)	-	-	0.355	-	0.040	56.855	0.010	65.651
6	Holt's additive trend model								
	1012 (↑)	998 (↓)	984 (↓)	0.183	0.427	0.033	46.203	0.008	52.389

Source: Own elaboration

Attention is also paid in this study to an analysis of changes in the accident rate. The forecasts prepared on the basis of the Holt's model indicate a decrease (↓) in the total number of persons injured in accidents in the years 2020-2021. The downward trend must be viewed as positive in terms of the analyzed issue of providing safe and hygienic working conditions for employees.

PROTECTIVE PREVENTION WITH REGARD TO OBTAINED FORECASTS

It seems essential to draw attention to the need to reduce the number of accidents at work and to the trend of such events when carrying out an analysis of the accident rate during the repair, maintenance and installation of machines and equipment. The produced forecasts for 2019 point to an increase in the total number of persons injured in accidents during the repair, maintenance and installation of machines. Given the above, measures should be taken to reduce accidents at work – a downward trend recorded in the case of forecasts prepared on the basis of the Holt's additive trend model (Table 1). In order to maintain such a tendency, preventative solutions should be put in place to ensure improvement of work safety during the repair, maintenance and

installation of machines. Selected LM tools can be effectively implemented in this regard, namely 5S, visual management (Furamn, 2019; Furman et al., 2017). Moreover, the Lockout-Tagout system, which also falls within the scope of management through visualization, may possibly be an effective solution to be applied during the repair and maintenance of machines.

SUMMARY AND CONCLUSIONS

It may be inferred from the conducted research that prognostic models are adequate to make an assessment of changes in the accident rate during the repair, maintenance and installation of machines. The obtained forecast values for 2019 in the case of the moving average model, Brown's single exponential smoothing model and Holt's model can be considered as negative information on the state of occupational safety and health in the area under investigation. The obtained forecast values may serve as a warning that solutions contributing to improved occupational safety should be implemented.

In contrast, forecasts developed on the basis of the Holt's additive trend model provided positive information, as they indicate a decrease in the number of accidents during the repair, maintenance and installation of machines as compared to 2019 (1012), i.e. a drop of 1.4% in 2020 and 2.7% in 2021, respectively. The implemented preventative measures should clearly contribute to maintaining the downward trend of reported accidents at work. It may therefore seem appropriate to use various forecasting models to compare what the tendency of predicted accidental events may be.

The possibility of using prognostic models to assess the trend in the accident rate presented in this study may also be considered for the analysis of events and their trends in any enterprise in which accidents at work are recorded.

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Abstract: In the article the possibility of using selected adaptive models to forecast accidents at work during repairing, maintaining and installing machines, was presented. On the basis of statistical data on persons injured in accidents at work (2009-2018), the process of their forecasting was carried out (for 2019 and the years 2019-2021) and the errors of expired forecasts were determined. Prediction of empirical data allowed for the assessment of accident rates among persons injured in total accidents and allowed for the assessment of the state of occupational safety in the area with was analyzed. The presented models can be used to assess accidents in other sectors of the economy and be a tool used to assess the state of occupational safety in an enterprise.