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IMPLEMENTATION OF STATISTICAL METHODS FOR ANALYSIS OF THE CIVIL AVIATION OCCURRENCES IN SLOVAKIA

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Abstract:
Civil aviation is currently the safest, fastest and most comfortable mode of transport. However, despite the well-thought-out technical and safety precautions, civil aviation occurrences (CAO) still happen. The article deals with the civil aviation occurrences in Slovakia in the period from 2011 to 2020. Using basic statistical method, the various categories of CAO (civil aviation accidents, serious incidents, incidents and ground incidents) are analysed. The basic methods of time series analysis (method of least squares, exponential equalization method) were used to create the model of the trend of the number of civil aviation occurrences in Slovakia and a forecast of the number of civil aviation occurrences for the next period.

Key words:
civil aviation, occurrence, statistics, time series

1 INTRODUCTION

Air transport as part of any country's transportation system plays a strategic role, especially with regard to providing international transport services, and contributes to the social and economic development of the country. Despite constantly advancing new technologies (Latorella, 2000) and sophisticated technical and safety measures, civil aviation occurrences (CAOs) still occur. Safety evaluation and risk assessment are therefore crucial for the safety of civil aviation (Le-ping Yuan et al., 2020, Dudek et al., 2022). A Civil Aviation Occurrence (CAO) (Regulation L13, 2007) is defined as an event related to the operation of an aircraft which affects or could affect the safety of operation and which is classified, depending on consequences, as an aviation accident, serious incident, incident or a ground incident.

As the intensity of civil aviation increases on the global level, more and more researchers pay attention to analysing accidents in civil aviation (Li, 2019). Author of the paper analysed global occurrence of civil aviation accidents over the period from 1942 to

2016 while the trend analysis of the number of accidents was carried out by applying the method of time series analysis.

According to (Saleh et al., 2010), civil aviation occurrences are generally a result of multiple circumstances combined. According to (Kharoufah et al., 2018), approximately 75% of aviation accidents and occurrences are contributed by human factors. In paper (Krey, 2007), author states that as much as 79% of fatal accidents that occurred in the USA in 2006 were caused by a pilot’s fault. And important portion of CAOs is represented by incidents. According to (Marais et al., 2012), even though the incidents are not paid as much attention as is paid to accidents, investigation of incidents may still be very helpful for identifying hazardous conditions that may lead to serious events. Authors (Pramono et al., 2020) investigated into factors that contributed to civil aviation occurrences in commercial Indonesian aviation operations. In their study, they analysed 97 investigation reports regarding the incidents and aviation accidents that happened over the period from 2007 to 2015. The most common occurrences involved Runway Excursions, Loss of Control In-Flight, and Controlled Flight into Terrain.

In paper (Andrejiova et al., 2021), authors analysed CAOs that happened over the period from 2000 to 2016 in Slovakia. By applying a Pareto analysis, they identified the key incident categories. Authors created a model of a correlation between the number of CAOs and selected input parameters by applying the multiple regression analysis and the Poisson regression. Airplane accident rates were also analysed by applying the methods of statistical analysis (Boyd et al., 2020). A spatial regression model was used in an analysis of road traffic accidents described in article (Al-Hasani et al., 2019). According to (Zhou, 2021), research into safety of civil aviation includes not only understanding current situation based on historical data, but it also requires accurate forecasts of future safety trends. Civil aviation incidents were analysed by applying the methods of time series analysis. Time series were also applied to the creation of a model of passenger demand in civil aviation (Kanavos et al., 2021).

This article deals with the evaluation of civil aviation occurrences in Slovakia by applying the basic statistical methods. The purpose of the article is to monitor the development of the number of CAOs in Slovakia through a time series analysis. The method of least squares and the method of exponential smoothing were applied to create a model and predict the number of CAOs for the upcoming period

2 METHODS AND METHODOLOGY

2.1 Civil aviation occurrences

The Slovak Republic (Slovakia) is a landlocked country located in Central Europe; since 2004, it is a member of the European Union. Approximately 5.45 million inhabitants live on the surface area of 49,035 km². In Slovakia, there are 30 airports; out of them, there are 14 civil public, 13 civil private, and 3 military airports. Out of the total number of civil airports, only 4 offer regular lines. In addition to these numbers, 9 heliports and about 60 airports for aviation works in the forest and water management and in agriculture are in operation.

An aviation accident is defined as an event associated with the operation of an aircraft which takes place from the time any person boards the aircraft with the intention of flight until all such persons have disembarked (Regulation L13, 2007). A serious incident is an incident involving circumstances indicating that there was a high probability of an accident. It is an event that is likely to result in an aviation accident. Serious incidents include, for example, risk of collision, dangerous landing on and take-off from an engaged runway, fire and smoke in the passenger compartment etc. (Regulation L13, 2007). An aviation incident is an occurrence, other than an accident, associated with the operation of an aircraft that affects or could affect the safety of operation. It consists in misconduct of a person or persons, or improper operation of civil aviation and ground equipment within the air traffic, or management and organisation thereof, with the consequences that usually do not require early flight termination or execution of non-standard or emergency procedures (Regulation L13, 2007). The causes of incidents also include natural phenomena (e.g. a bird strike, an electrostatic discharge, etc.) with the consequences that do not jeopardise flight safety to the extent that a serious incident or an aviation accident occurs. A ground incident is an incident that happens outside the period defined in Section 1.1 of L-13 Regulation and is associated with an aircraft preparation for a flight, operation, handling, maintenance, repairs or idle time, with a consequence of an injury or death or damage to/destruction of the aircraft (Regulation L13, 2007).

The analysis of civil aviation occurrences in Slovakia was carried out using the data on the number of aviation accidents, serious incidents, incidents and ground incidents for the monitoring period. The data were obtained from the sources published by the Ministry of Transport of the Slovak Republic.

2.2 Statistical methods

The analysis of CAOs in Slovakia was carried out by applying the basic statistical methods (descriptive statistics and statistical hypothesis test) and the method of time series analysis. In a test of statistical hypotheses, a decision on accepting or rejecting the null hypothesis is made on the basis of a p-value. If the p-value is lower than the determined significance level α, then the null hypothesis is rejected in favour of the alternative hypothesis. If the p-value equals or is higher than the determined significance level α, then the null hypothesis is not rejected. The time series model for the number of CAOs and the prognosis for the upcoming period were created by applying the method of least squares and the method of exponential smoothing (ETS). In order to estimate the model parameters by applying the method of least squares, the sum of squares of deviations of empirical values from the theoretical values must be minimal. ETS is a method for predicting a future value based on existing (historical) values using the algorithm of exponential smoothing (Hyndman et al., 2018). It is based on all previous observations while their weights decrease exponentially as they approximate the distant past. Each model consists of three components: Error, Trend and Seasonal. The model for predicting the time series was created in the R programming language.

3 RESULTS

According to the data obtained from the Ministry of Transport of the Slovak Republic, in the period from 2011 to 2020 there were 2,821 civil aviation occurrences in Slovakia (https://www.mindop.sk/). The basic descriptive characteristics of the number of CAOs in Slovakia are listed in Table 1.

***Tab. 1** Descriptive characteristics of the number of CAOs in Slovakia (2011-2020)*

Characteristics	**Number of CAOs**				**Sum**
	Aviation	**Serious**	**Incident**	**Ground**	

	accident	**incident**		**incident**	
Number for the entire period	99	29	2650	43	2821
Maximum value	20	6	338	12	355
Minimum value	2	0	195	0	202
Average number per year	9.9	2.9	265.0	4.3	282.1
Standard deviation	5.5	2.0	41.6	3.9	43.4

Out of the total number of 2,821 CAOs, a large proportion consisted of reported incidents (2,650), representing as much as 93.9% of the total CAOs. The average annual number of reported CAOs was 282. A significant decline was observed in 2020, from 355 reports (in 2019) to 202 reports (in 2020), representing a decrease by almost 43%.

A graphical representation of the number of CAOs in Slovakia over the period from 2011 to 2020 is shown in Fig. 1. The graph indicates that until 2018 the number of CAOs exhibited almost a constant trend with only minor fluctuations, whereas in 2017 the number of CAOs began to rise. In 2019, the number of CAOs reached its peak value (347 CAOs). In 2020, a steep decline was observed (202 reported CAOs, almost a 57% decrease) compared to the previous year.

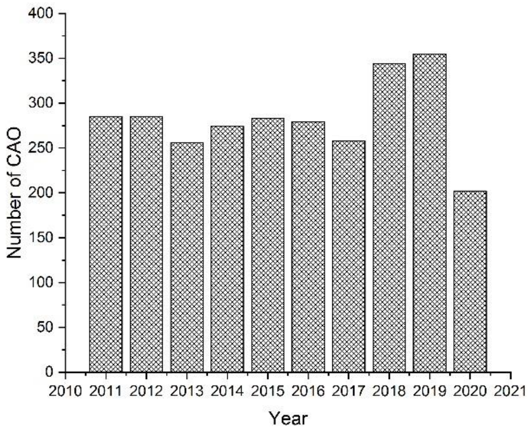

Fig. 1 *Number of CAOs in Slovakia (2011–2020)*
Source: (https://www.mindop.sk/)

The development of aviation accidents, serious incidents, incidents and ground incidents over the period from 2011 to 2020 is shown in Fig 2.

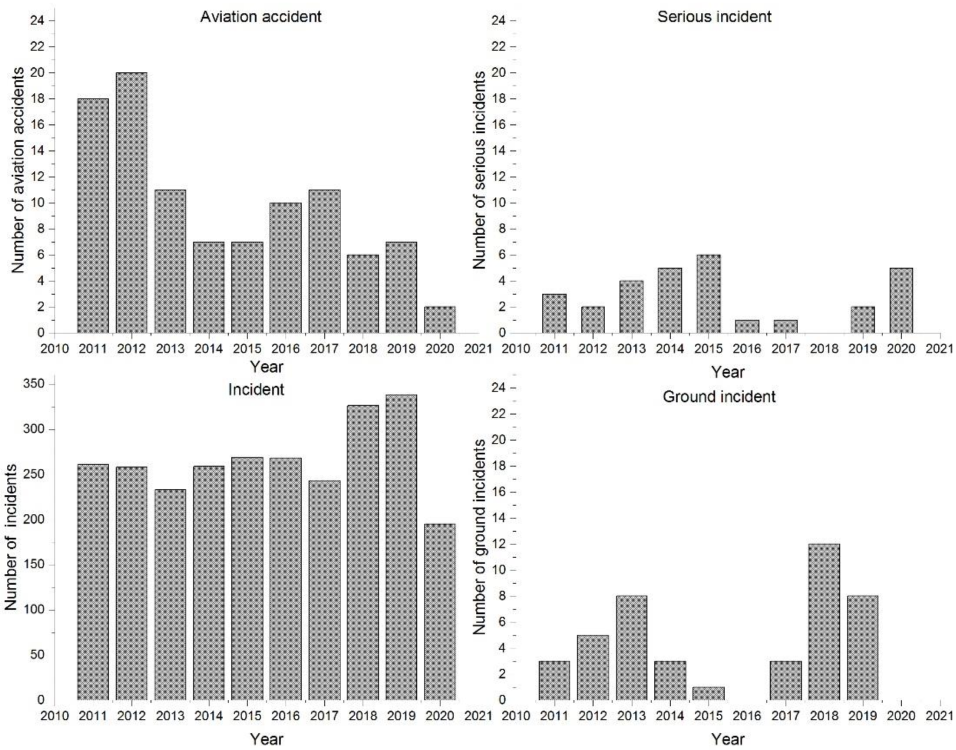

Fig. 2 *Aviation accidents, serious incidents, incidents and ground incidents*
Source: (https://www.mindop.sk/)

In 2012, the number of aviation accidents reached its peak value, i.e. 20, for the entire monitoring period. The average annual number of aviation accidents over the monitoring period was almost 10. As for serious incidents, their occurrence was minor. The average annual number of incidents was almost 3, whereas a higher number, i.e. 5, was reported in 2014.

While the number of serious incidents was negligible, the number of incidents was increasing, and so was their percentage in the total number of CAOs. A negative growing trend in the number of incidents is primarily associated with year-over-year increasing intensity of air traffic, and thus more crowded airspace above the country.

Percentages of the individual types of CAOs in the total number of CAOs are listed in Table 2. The analysis of data published by the Ministry of Transport of the Slovak Republic indicated that incidents represent the largest percentage in all CAOs that happened over the entire monitoring period.

Tab. 2 *List of CAOs and their percentages in the total number of CAOs [%].*

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
AA	6.3	7.0	4.3	2.6	2.5	3.5	4.3	1.7	2.0	1.0
SI	1.1	0.7	1.6	1.8	2.1	0.4	0.4	0.0	0.6	2.5
I	91.5	90.6	91.0	94.5	95.0	96.1	94.1	94.8	95.1	96.5
GI	1.1	1.7	3.1	1.1	0.4	0.0	1.2	3.5	2.3	0.0

Notes: Aviation accidents (AA), serious incidents (SI), incidents (I), ground incidents (GI)

The time series model and the prognosis of CAOs for the upcoming period were created by applying two methods: the method of least squares and the method of exponential smoothing (ETS). The results indicated that the values of the time series of the number of

CAOs for the period from 2011 to 2020 fluctuated around the average value; this means that this time series does not exhibit any trend and remains at a constant level.

The time series model is described by the following equation

$$y_t = \beta_0 + \varepsilon_t = b_0 + \varepsilon_t, \text{ pre } t = 1,2, \dots, T, \tag{1}$$

wherein: y_t is the actual value; ε_t is the random component at time t; and T is the duration of the time series. Value $b_0 = 282.1$ represents a point estimate of parameter β_0 and equals the average annual value of the number of CAOs over the monitoring period. An undistorted estimate of the standard deviation of the random component was 43.35. The test of statistical significance of parameter β_0 of the model was used to verify the model's significance. $H_0: \beta_0 = 0$ was tested against $H_1: \beta_0 \neq 0$. Since the p-value=$7.10^{-9} < \alpha$, the null hypothesis was rejected. It is possible to assume that the mean value is statistically significantly different from the null and that the model is statistically significant.

Considering the fact that the model was statistically significant and the model's residues met the white noise criteria, the point and interval forecasts of the number of CAOs were determined for the upcoming period. Based on the results, the point forecast of the number of reported CAOS is 282.1 and the 95% confidence interval for the number of CAOs is determined by the interval (251.09; 313.11).

An analogical result was observed when the model was identified by applying the ETS method. The resulting time series prediction model consists of three components: Error, Trend and Seasonal. The Error component can be described as "Additive=A" or "Multiplicative=M". The Trend component can be described as "None=N", "Additive=A", "Additive damped=Ad", "Multiplicative=M" or "Multiplicative damped=Md". The Seasonal component can be "None=N", "Additive=A" or "Multiplicative=M" (Hyndman et al., 2018). There are 15 prediction models with additive errors and 15 models with multiplicative errors. We have taken into account several models (Table 5) with different suitable combinations of the types of all three components. Akaike's Information Criterion (AIC) can be used to determine the best model. In general, the lower the AIC value, the better the model compares to a model with a higher AIC value.

Tab. 3 *Overview of ETS models*

Model	AIC	Model	AIC
M, M, N	107.06	M, N, N	103.37
M, Md, N	109.10	A, N, N	103.38
M, A, N	107.09	A, A, N	107.33
M, Ad, N	109.05	A, Ad, N	109.32

Note: M-multiplicative, A-Additive, N-None.

Apparently, the best model is ETS(M,N,N), i.e. without any trend and with a multiplicative random component (M) and without a seasonal component (N). A very similar result was observed for the ETS(A,N,N) model with an additional random component. In both these cases, the point estimate of the number of CAOs for the upcoming period was approximately 281 and the 95% confidence interval was (191;371).

4 CONCLUSIONS

The present study examined the civil aviation occurrences (CAO) that happened in Slovakia over the period from 2011 to 2020. The analysis of the relevant data indicated that the number of CAOs exhibited almost a constant trend until 2018. In 2018, there was a sharp increase in the number of CAOs, by almost 34%, compared to the previous year, and in 2019 the number of CAOs reached its peak value (347 CAOs). Year 2020 brought a sharp decline (by almost 57%) compared to the previous year; this may have been caused by COVID-19 pandemic and depression in civil aviation that was observed in that period.

Based on the implementation of the time series methods, it is possible to state that the development of the number of CAOs in Slovakia exhibited a constant trend over the 10-year monitoring period. A negative trend was observed for the number of incidents which represented, on average, 94% of all civil aviation occurrences over the last five years.

In order to improve the accuracy of future time series forecasts, it is advisable to take into consideration additional input variables, such as the population, number of airports and flights etc., because a complex analysis of aviation accidents is important part of the research into safety of civil aviation.

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