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Civil Aviation Occurrences in Slovakia and Their Evaluation Using Statistical Methods

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Abstract: The nature of a civil aviation occurrence may be defined in three different categories while considering its severity. General categories include civil aviation accidents, serious incidents and incidents. The present article analyses the civil aviation occurrences in Slovakia which happened in the period from 2000 to 2019. In this period, there was a significant increase in the number of civil aviation occurrences, and incidents, in particular, represented the highest percentage. A Pareto analysis was applied to identify the key incident categories (wildlife strike, technical failures of the aviation technology and unauthorised penetration of airspace). A multiple regression analysis and the Poisson regression were used to create two models of correlations between the number of civil aviation occurrences and the selected input variables. Both models are statistically significant, and, based on the AIC (Akaike Information Criterion), the Poisson regression model appeared to be of higher quality. The model showed, for example, that an increase in variables (the number of commercial aircrafts aged over 14 years and the number of total aircraft movements) resulted in a slight increase in the expected number of civil aviation occurrences.

Keywords: civil aviation; occurrence; incidents; regression models

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1. Introduction

Civil aviation is currently the safest, fastest and most comfortable mode of transport. This is a result of strict safety regulations governing the piloting, air traffic and aviation technology maintenance. According to the recommendations of the International Air Transport Association, the demand for civil aviation services is expected to double over the following two decades. This would, however, bring more problems to the field of aviation safety as a result of increased air transport congestion and more load put on the civil aviation system.

Aviation safety is significantly affected by the constant development of novel technologies [1]. However, despite the well thought-out technical and safety precautions, civil aviation occurrences still happen. According to [2,3], a civil aviation occurrence (CAO) is defined as an occurrence associated with the operation of an aircraft that affects or could affect the air traffic safety, and which is due to its consequences assessed as an aviation accident, serious incident, incident or ground incident. The Annual Safety Review [4] stated that the accident rate has been constantly decreasing since 2014, whereas the rate of serious incidents stabilised on the peak value reached in 2016. In 2018, there was an increase in the number of serious incidents compared to the mean value observed in the previous decade.

According to [5], with more intensive air traffic, the number of reported civil aviation occurrences increases, too. The authors of this publication processed the data obtained from

the European Coordination Centre for Aviation Incident Reporting Systems (ECCAIRS), which analyses the reliability and safety of large aircrafts in terms of aviation occurrences by individual categories, as defined by the International Civil Aviation Organisation (ICAO).

Civil aviation occurrences are rarely a result of a single cause. Janic [6] summarised the causes of civil aviation occurrences as follows: pilot human error, mechanical failures, air traffic control errors, ground support failures, and dangerous weather conditions. According to [7], such occurrences are usually caused by various combinations of multiple circumstances. Kharoufah et al. stated that human errors contributed to almost 75% of the aviation accidents and other occurrences [8]. The authors observed that the most important human factor that contributes to aviation accidents and incidents is the situational awareness followed by non-adherence to procedures). According to [9], as much as 79% of the fatal accidents which occurred in the USA in 2006 were attributed to a pilot error. According to Caldwell [10], the tiredness of pilots also negatively affects the crew's capabilities, which may significantly contribute to civil aviation occurrences. The impact of managerial and organisational effects (e.g., pilot errors, ATC errors, maintenance staff errors, and technology failures) on the air traffic failures were examined by Lin et al. [11]. According to [12], maintaining operational safety and the status of airport runway (especially in bad weather) is very important for the overall aviation safety. Li et al. [13] analysed 41 civil aviation accidents which happened to the aircraft registered in the Republic of China in the years 1999–2006. They observed that incorrect decisions at higher control levels may indirectly impair the performance of pilots, and this consequently leads to accidents.

Incidents represent an important subgroup of civil aviation occurrences. According to [14], although incidents are not paid as much attention as is paid to accidents, it is still important to investigate incidents to identify dangerous conditions that might lead to serious occurrences. The most frequent aviation incident, i.e., a collision of an aircraft with a bird, and a correlation between the type of incidents and changes in the temperature cycle are discussed in the paper [15]. The authors proposed a simulation model for predicting the probability of an aviation incident caused by a collision of an aircraft with a bird. According to [14,16], the absence of the aircraft maintenance causes a more intensive wear and ageing of most system components, and this leads to their complete wear or failure and subsequently disrupts the safety of the system. Marais and Robichaud observed, based on the data from the years 1999–2008, that the accidents associated with maintenance are approximately 6.5 times more likely to be fatal than accidents in general [14]. Insley and Turkoglu [16] examined and analysed aviation accidents and serious incidents associated with the aircraft maintenance that occurred in the years 2003–2017. They observed that the most frequent causes of civil aviation occurrences were runway excursions and air turnbacks, while the second-level categories were associated with failures of engine and landing gear systems.

Roelen et al. [17] pointed out a need for the models representing potential scenarios of a succession of causal occurrences, including the technical, human and organisational factors. The authors [18] created a hierarchically structured model containing various accident scenarios in different flight stages. They created the model by applying the methodology combining the event sequence diagrams, fault trees, and Bayesian belief networks. A causal model of air traffic safety, based on a study of accidents and incidents over the last two decades, was described in the paper [19]. The authors created the model by applying the event sequence diagrams, fault trees, and a Bayesian belief network. The paper [20] presents an accident model based on the elementary concepts of the systems theory. According to Leveson, the use of such a model provides the theoretical basis for implementing unique novel types of accident analyses, hazard analyses and accident prevention strategies, including novel approaches to safety designing. Blom and Bloem [21] applied the Bayesian estimation of the function of a combined conditional rate of accidents and statistical data on accidents and flights. A structured process for the creation of a qualitative model of evaluation that might be used by airline companies to identify

human errors and select an intervention strategy with the highest potential for success was described in the paper [22].

Zhang and Mahadevan [23] analysed the accidents of passenger airline companies that happened in the years 1982–2006. They identified the correlations between the causes of accidents by applying the Bayesian network. The paper [24] described the identification of common causes of serious and major incidents in the air traffic by applying the Heinrich's triangle. According to this theory, the causes identified at high severity levels are always located at low levels. In the analysis, the authors of the paper used the data on serious and major incidents for four consecutive years. Boyd and Howell [25] applied the method of statistical analysis (Poisson distribution, contingency tables, hypothesis testing) in order to analyse the rates of aviation accidents. Mannering and Bhat [26] discussed the methods used in the field of accident analyses (e.g., Poisson regression model, generalised estimating equation models, Poisson and negative binomial regression models, etc.). The effects of the financial factors which influence the maintenance policy, procurement and training in airline companies on air traffic safety are described in the paper [27]. The study monitored 110 airline companies operating in 26 countries, and the analyses and evaluations were carried out while applying, for example, testing methods, Poisson regression, etc. Similarly, the paper [28] described the investigation of the effects of particular business decisions of airline companies on the tendency for aircraft accidents. The author studied the probability of an aviation accident using the Poisson and negative binomial regression models. Li et al. applied the geographically weighted Poisson regression to create crash prediction models at the district level [29]. A spatial regression model was used in the analysis of road traffic accidents, as described in the paper [30]. Salvagioni et al. [31] investigated a potential correlation between teachers' burnout and car accidents that happened to teachers. The research was carried out with 509 teachers, and one of the accident occurrence evaluation methods was the Poisson regression model. The investigation, identification and evaluation of the factors affecting car accidents were carried out while applying the negative binomial distribution and the Poisson regression methods [32]. Gildea et al. [33] applied the Poisson regression to analyse the use of antihistamines, which may deteriorate the pilot's performance and hence contribute to an aircraft accident.

The present article analyses civil aviation occurrences in Slovakia. A Pareto analysis was used to identify the key categories of civil aviation incidents in Slovakia. A negative trend in the number of civil aviation occurrences is also affected by the development and expansion of air transport in the country. Therefore, the model of correlations between the number of civil aviation occurrences and selected input variables was created while applying the multiple regression analysis and the Poisson regression.

2. Materials and Methods

2.1. Accident Rates in Slovakia

Slovakia (Slovak Republic) is an inland country located in Central Europe (Figure 1), with a total area of 49,035 km^2. Its population is approximately 5.45 million inhabitants, with Bratislava as the capital. Since 2004, it belongs to the European Union.

Natural conditions in Slovakia are less favourable to transport development (mountainous terrain for road transport; rivers not suitable for water transport; poor railway connections in the southern regions of the SR; insufficient use of local airports, etc.).

One of the key problems in the transport sector in Slovakia is a prolonged negative trend in the distribution of transportation jobs in favour of the road transport, in particular the individual (non-public) transport [34]. In 2018, the total length of the state-managed road network was 18,059 km. As much as 57.4% of the total road network represented Class III roads (10,358 km). Only 4.3% of the road network represented highways and expressways.



Figure 1. Slovakia and neighbouring countries.

Class I roads and Class II roads represented 18.3% and 20.0% (accordingly) of the total length of the road network. In 2018, 3580 km of railways were operated. Over the last 5 years, there was a slight upward trend in the performance of the rail passenger transport.

In Slovakia, there are 30 active airports, including 14 civil public airports, 13 civil non-public airports and 3 military airports. Out of the total number of civil airports, only 4 airports perform regular transportation. In addition to the above-stated number, there are also 9 heliports and approximately 60 airports for agricultural, forestry and water management aviation [35].

Water transport is carried out primarily on the Danube River, and partially also on the Váh River, while the length of all navigable lines is only 172 km. The Danube River, as a waterway of international importance, should provide (according to the international classification of inland waterways) a certain transport capacity, determined as min. 300 days per year. However, an analysis indicated that water transport experiences certain problems with the waterway infrastructure. Therefore, a comprehensive review of transport accident rates in Slovakia does not include water transport.

A road traffic accident is an occurrence caused as a result of a moving vehicle in road traffic which results in a fatality, injury or damage to property, regardless of whether it is classified as a crime or an offence, and whether it is resolved by a court or the penal commission of the traffic inspectorate. A rail accident is an accident involving at least one moving rail vehicle. Rail accidents include, for example, collisions, derailments, accidents at railway crossings, accidents of persons caused by a moving railway car, fires in railway fleets, etc.

An aviation accident is an occurrence associated with the operation of an aircraft which, in the case of a manned aircraft, takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked [36]. During such a period, a person involved may be fatally or seriously injured as a result of being in the aircraft or in direct contact with any part of the aircraft, or if the aircraft sustains damage or structural failure, or if an emergency occurs due to the aircraft disappearing from the radars.

The data obtained from the Ministry of Transport of the Slovak Republic indicated that in the period from 2009 to 2019 there were 173,322 accidents altogether in the road, railway and air transport in Slovakia [2]. Basic descriptive characteristics of the number of accidents in Slovakia are presented in Table 1. A graphical representation of traffic accidents in Slovakia which occurred in the period from 2009 to 2019 is shown in Figure 2.

Table 1. Descriptive statistics of accident rates in Slovakia in the period of 2009–2019.

Characteristics	Transport		
	Air	Road	Railway
Number for the entire period	150	172,173	999
Maximum value	26	25,989	190
Minimum value	6	13,307	60
Average number per year	13.64	15,652.09	90.82
Standard deviation	6.772	4169.01	36.989

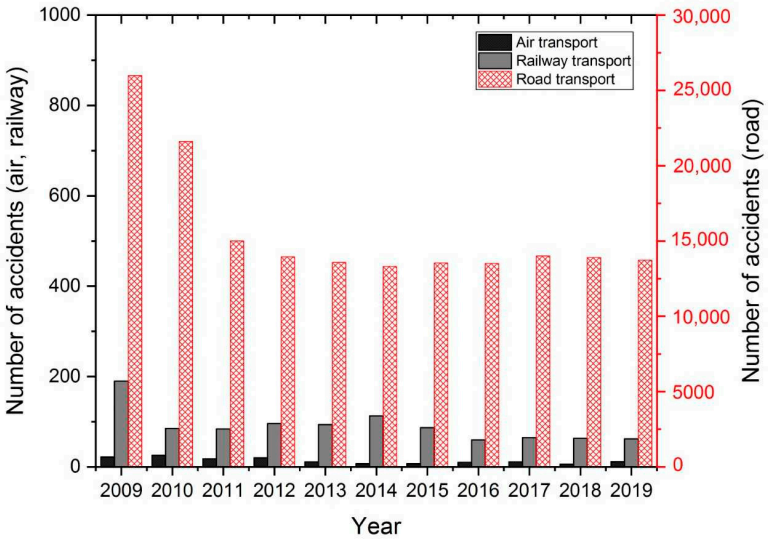


Figure 2. Review of traffic accidents in Slovakia (2009–2019).

As much as 99.2% of all accidents were accidents in road transport. Aviation accidents represented a negligible portion of the total accident rate. Over the last 11 years, only 0.1% of the total number of traffic accidents in Slovakia were aviation accidents.

The basic numerical characteristics of the number of fatal or serious injuries in traffic accidents in Slovakia are listed in Table 2.

Table 2. Descriptive statistics of the number of fatal or serious injuries for the period of 2009–2019.

Characteristics	Number of Injuries in Traffic Accidents					
	Air Transport		Road Transport		Railway Transport	
	Fatal	Serious	Fatal	Serious	Fatal	Serious
Number for the entire period	29	37	3034	12,716	550	411
Maximum value	7	7	347	1408	78	45
Minimum value	0	0	223	1050	26	33
Average number per year	2.64	3.36	275.82	1156	50	37.36
Standard deviation	2.06	2.34	45.40	105.94	19.42	3.83

The number of fatal injuries represents the number of fatalities among the crews (crews of the relevant means of transport), passengers and third parties that occurred in accidents. A serious injury is an injury experienced by a person in an accident that requires hospitalisation for more than 48 h, commencing within 7 days from the date the injury was received, or which results in a fracture of any bone, or an injury to any internal organ, etc. A graphical representation of the number of fatal injuries and the number of serious injuries in traffic accidents in Slovakia is shown in Figure 3.

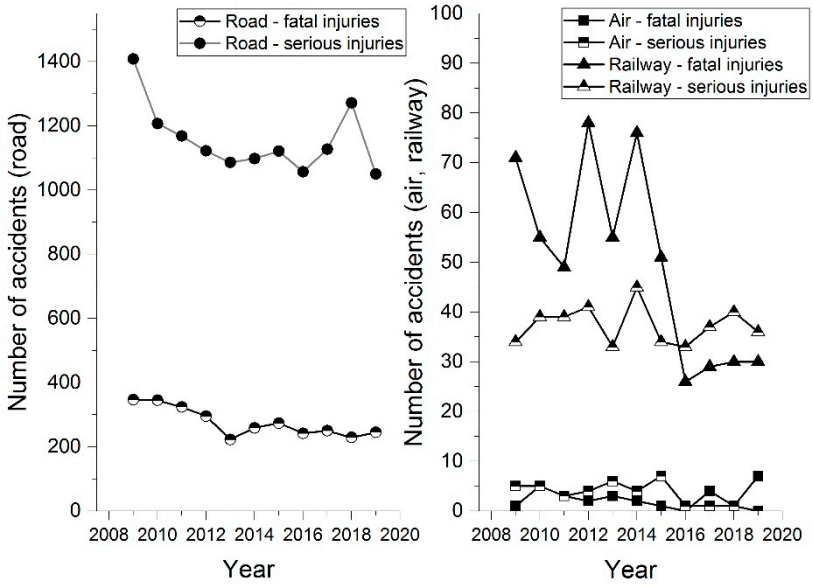


Figure 3. A comparison of the numbers of fatal and serious injuries in traffic accidents.

Within the monitored period, 3613 people died in traffic accidents (83.98% in road transport; 15.22% in railway transport; and 0.80% in civil aviation). As much as 13,164 people suffered serious injuries in traffic accidents (96.60% in road transport; 3.12% in railway transport; and 0.28% in civil aviation).

2.2. Civil Aviation Occurrences

According to Regulation L13 [2], a civil aviation occurrence (CAO) is a general term for occurrences associated with the operation of an aircraft that affect or could affect air traffic safety, and whose consequences are assessed as an aviation accident, a serious incident, an incident or a ground incident.

A serious incident is an incident with a high probability of an accident. It is an occurrence likely to develop into an aviation accident. A serious incident includes, for example, a near collision, hazardous proximity, landing on and takeoff from an engaged runway, fires and smoke in the passenger compartment, etc. Examples of other serious incidents are presented in Annex C to the L13 publication of the Aeronautical Information Services of the Slovak Republic. Aviation occurrences are always classified by a competent authority that is authorised to investigate the causes of civil aviation accidents and incidents [2].

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 the misconduct of a person or an improper operation of civil aviation and ground equipment in air traffic, or management and organisation thereof, with consequences which do not usually require the early termination of the flight or the execution of non-standard or emergency procedures [2]. The causes of incidents also include natural phenomena (e.g., a bird strike, a static electricity discharge, etc.) with consequences that do not jeopardise flight safety to the extent that a serious incident or an aviation accident occurs. According to Regulation L13, aviation incidents are categorised according to their causes as flight incidents, technical incidents, causes associated with air traffic control, support technology, etc. In the disputable cases, decisions on classifying an incident as a serious incident are made by the head of the team, who consults with the director of the Civil Aviation Authority, if necessary.

A ground incident is an incident that occurs outside the period defined in the Regulation L-13 [2] and which is associated with the aircraft preparation for the flight, aircraft attendance, servicing, maintenance or repairs or standby, and which results in an injury or fatality or in aircraft damage or destruction.

A more comprehensive evaluation of civil aviation occurrences in Slovakia was carried out using the data on the number of civil aviation accidents, serious incidents, incidents and ground incidents that occurred in the monitored period. A list of 18 incident categories that were monitored and analysed for civil aviation occurrences is presented in Table 3.

Table 3. Selected incidents in civil aviation according to [3,37].

	Incident Category		Incident Category
I1	Loss of communication during the flight	I10	Unauthorised penetration of airspace
I2	Loss of communication	I11	Failure or malfunction of an aircraft system
I3	Occurrences involving collisions/near collisions with bird(s)/wildlife	I12	Declared Incerfa, Alerfa, Detresfa
I4	Safety landing	I13	Occurrences involving ATM or ATS
I5	Emergency landing	I14	Laser
I6	Loss of separation	I15	Loss of aircraft control while the aircraft is on the ground
I7	STCA, ACAS, MSAW, APW, GPWS, A-SMGCS	I16	Miscellaneous occurrences in the passenger cabin
I8	ACFT deviation from the ATM approval or from the planned ATC procedures	I17	Medical emergency
I9	Runway Incursion	I18	Illegal radio broadcasting

Notes: Short Term Conflict Alert (STCA), Airborne Collision Avoidance System (ACAS), Minimum Safe Altitude Warning (MSAW), Area Proximity Warning (APW), Ground Proximity Warning System (GPWS), Advanced Surface Movement Guidance & Control System (A-SMGCS), Army Combat Fitness Test (ACFT), Air Traffic Management (ATM), Air Traffic Control (ATC), Air Traffic Services (ATS).

The uncertainty phase (Incerfa) is a situation wherein uncertainty exists as to the safety of an aircraft and its occupants. Alert phase (Alerfa) is a situation wherein apprehension exists as to the safety of an aircraft and its occupants. Distress phase (Detresfa) is a situation wherein there is a reasonable certainty that an aircraft and its occupants are threatened by grave and imminent danger and require immediate assistance [38].

For a more comprehensive assessment of the CAO rates, the following additional parameters were determined: millions of passengers transported in Slovakia in a given year; the amount of transported goods (thousands of tonnes) in a monitored year; the number of civil planes in the Register of SR (in pieces); the number of commercial aircraft (in pieces); the number of commercial aircraft aged above 14 years in a given year (in pieces); and the number of total aircraft movements (in thousands) in a given year. The total aircraft movements include landings and takeoffs of aircrafts to/from airports.

The analysis was carried out using the data obtained from the sources published by the Ministry of Transport of the Slovak Republic [37] and from the Eurostat [39] and STATdat databases [40].

2.3. Statistical Methods

The analysis of the current situation regarding CAOs in Slovakia was carried out by applying basic statistical methods (descriptive statistics and hypothesis testing), a Pareto analysis, a classical multiple regression model and a Poisson regression model. All data were evaluated, and the results were obtained using the R package software.

2.3.1. Hypothesis Testing

Statistical hypotheses were tested using a p-value, based on the principle that 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 is higher than the determined significance level α, then the null hypothesis is not rejected.

2.3.2. Pareto Analysis

The Pareto analysis is an important decision-making tool, as it facilitates the determination of priorities when solving a problem. The purpose of the Pareto analysis was

to separate important factors, causes of a certain problem, from those less important, and show where our efforts should be primarily directed to improve the process. The Pareto analysis uses the 80/20 rule, i.e., a more detailed analysis of causes should be carried out with a cumulative frequency from 0 to 80%, or from 0 to 75%. A graphical tool of the Pareto analysis is a Pareto diagram. The Pareto diagram is a bar chart of absolute or absolute relative frequencies of the occurrence of individual causes; it also contains the Lorentz curve representing the polygon of cumulative relative frequencies of the occurrence of individual causes (in %) [41].

2.3.3. Multiple Linear Regression

The correlations between a dependent variable and several input variables were described and modelled by applying a regression analysis. We assumed that the correlation between the dependent variable Y and k-explanatory variables X_i, $i = 1, \ldots, k$ was expressed by the following model:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \varepsilon, \quad (1)$$

where β_0 and β_i for $i = 1, \ldots, k$ are the regression model coefficients and ε is the random error. The model coefficients were identified by applying the method of least squares. The statistical significance of the regression model was determined by the t-test of statistical significance of the model. A degree of the correlation between variable Y and k-explanatory variables was expressed by the coefficient of multiple determination r^2. The coefficient values ranged within the interval $\langle 0;1 \rangle$. As the value approached 1, the correlation was stronger.

2.3.4. Poisson Regression Model

The Poisson regression model was a basic model used for modelling the number of occurrences, and the general linear regression model was used for modelling real continuous data. According to [42], it is a special type of the generalised linear model. The application of the Poisson regression model was based on the assumption that a random parameter Y exhibited the Poisson distribution.

Let X_i, $i = 1, \ldots, k$ be the k-independent variables. The equation of the Poisson model, which considers all input variables, is generally as follows:

$$ln(Y) = \beta_0 + \sum_{i=1}^{k} \beta_i X_i \quad (2)$$

where β_0 and β_i for $i = 1, \ldots, k$ are the model coefficients. Sometimes, a modified form of the model is used:

$$Y = e^{\beta_0 + \sum_{i=1}^{k} \beta_i X_i} = e^{\beta_0} e^{\sum_{i=1}^{k} \beta_i X_i} = e^{\beta_0} e^{\beta_1 X_1} e^{\beta_2 X_2} e^{\beta_3 X_3} e^{\beta_4 X_4} \ldots e^{\beta_k X_k} \quad (3)$$

The model coefficients were estimated by applying the maximum likelihood method for the regression model. In Model (2), coefficient β_i represented an expected change in the *ln* of the variable Y per unit change in the input variable X_i. Coefficient e^{β_i} in Model (3) represented a multiplicative effect on the variable Y if the ith—variable X_i changes by one unit, with the remaining variables unchanged. A positive value of coefficient β_i means that as the value of variable X_i increases by 1 (with the remaining variables unchanged), the monitored output variable Y increases too. A negative value of coefficient β_i indicates that if the X_i value increases by 1 (with the remaining variables unchanged), the output variable Y decreases.

The Poisson regression does not allow for a calculation of the coefficient of determination r^2, as it is in the multiple regression analysis. A degree of the correlation between variable Y and explanatory variables in the Poisson regression was determined using the

pseudo R^2 for Poisson regression, which may be interpreted similarly to r^2 [43]. All data were evaluated, and the results were obtained using the R package software [44].

3. Results and Discussion

The investigation was carried out with the aim of:

- Analysing civil aviation occurrences for the period from 2000 to 2019;
- Determining the key categories of incidents that largely affect the occurrence of incidents in civil aviation;
- Modelling a correlation between the civil aviation occurrences (CAOs) and selected input variables by applying the multiple and Poisson regressions.

3.1. Analysis of Civil Aviation Occurrences for the Period from 2000 to 2019

The number of CAOs in Slovakia that occurred in the period from 2000 to 2019 is graphically represented in Figure 4. The chart indicates that the number of CAOs exhibited an upward trend before 2012 and reached the peak value in 2012, when the number of CAOs was 453. In the years 2013–2017, the CAO development was almost constant, and since 2017 the number of CAOs has been rising again.

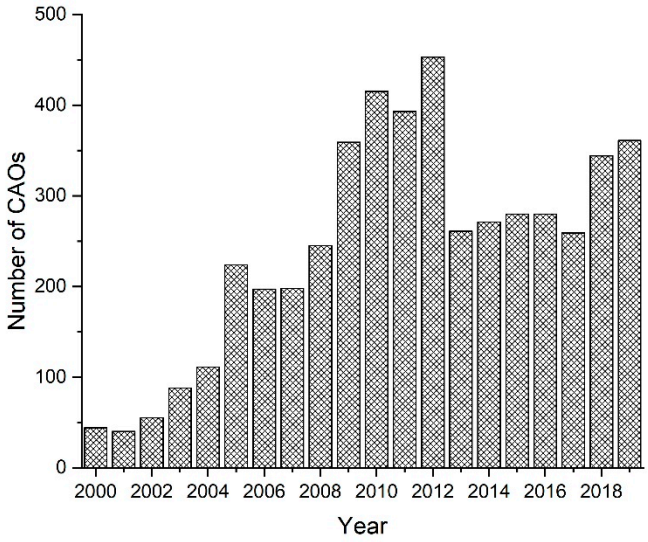


Figure 4. Civil aviation occurrences (period 2000–2019).

The development of civil aviation accidents in the period from 2000 to 2019 is shown in Figure 5. In 2004, the number of civil aviation accidents reached the maximum value in the monitored period, i.e., 30 accidents. The average annual number of civil aviation accidents for the monitored period was 17.

The number of fatal and serious injuries in civil aviation accidents for the period from 2000 to 2019 is shown in Figure 5. The highest number of fatal injuries was observed in 2006 when 42 Slovak soldiers of KFOR peacekeeping forces died in an accident of the Slovak Air Force aircraft.

The percentages of individual CAO types in the total number of CAOs are listed in Table 4. The data analysis published by the Ministry of Transport indicated that since 2003 incidents represent the highest percentage in all CAOs. The percentages of aviation accidents, serious incidents, incidents and ground incidents in of the total number of CAOs are listed in Table 4.

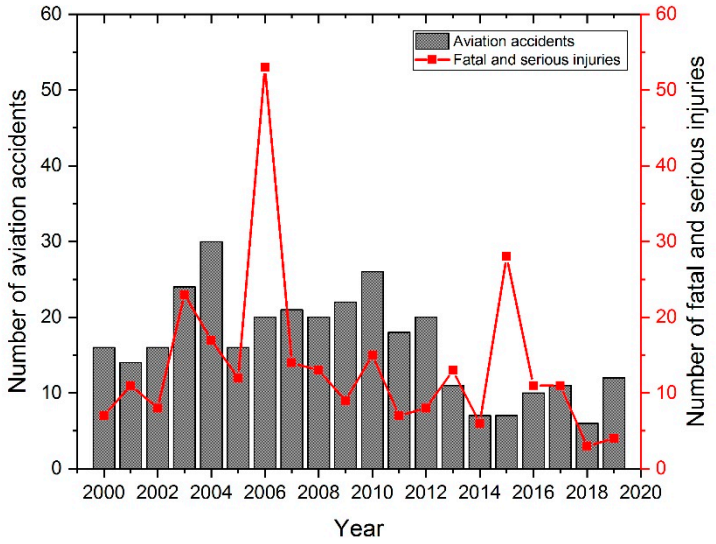


Figure 5. Aviation accidents, the number of fatalities and injuries in civil aviation accidents (period 2000–2019).

Table 4. List of CAOs and their percentages in the total number of CAOs [%].

Year	AA	SI	I	GI	Year	AA	SI	I	GI
2000	36.4	34.1	9.1	20.5	2010	6.3	0.5	60.5	32.8
2001	35.0	35.0	22.5	7.5	2011	4.6	0.8	66.4	28.2
2002	29.1	23.6	36.4	10.9	2012	4.4	1.1	56.9	37.5
2003	27.3	17.0	52.3	3.4	2013	4.2	3.4	89.3	3.1
2004	27.0	21.6	51.4	0.0	2014	2.6	0.7	95.6	1.1
2005	7.1	4.0	84.8	4.0	2015	2.5	1.1	96.1	0.3
2006	10.2	3.6	83.2	3.0	2016	3.6	0.7	95.7	0.0
2007	10.6	1.0	79.8	8.6	2017	4.2	0.8	93.8	1.2
2008	8.2	4.1	65.3	22.4	2018	1.7	0.0	94.8	3.5
2009	6.1	2.2	56.5	35.1	2019	3.3	0.0	94.2	2.5

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

The data show that the percentage of civil aviation accidents in the total number of CAOs has been decreasing since 2005. Since that year, the number of serious incidents dramatically decreased; in 2005, the number of serious incidents decreased by almost 62% compared to the previous year, 2004. Since 2005, the average number of serious incidents was 7. A graphical representation of the number of serious incidents, incidents and ground incidents in civil aviation in Slovakia for the period from 2000 to 2019 is shown in Figure 6.

While the number of serious incidents has decreased since 2004, the number of incidents has dramatically increased since 2005 (Figure 6, Table 4). Similarly, their percentage in the total number of CAOs has increased too. In 2015, incidents represented the highest percentage of all CAOs (as much as 96%, i.e., as much as 259 incidents out of the total number of 271 CAOs in that year, Table 4). The same trend of a high number of incidents was observed in the following years. A negative upward trend in the number of incidents is largely associated with air traffic intensity, which increases year by year, and hence with the denser air space above the Slovak Republic.

Since 2013, there was also a significant decrease in the number of ground incidents. The average percentage in the period from 2013 to 2019 was 1.7% of the total number of CAOs.

A comparison of two years, 2000 and 2019, showed significant changes in the number of CAOs. The number of CAOs in 2019 was 8.2 times higher than that in 2000. The highest increase, when compared to 2000, was observed in the number of incidents (84.5 times more than in 2000).

The increased number of CAOs is related to the increase of air transport in Slovakia. While in 2000 there were almost 0.43 mil. passengers, in 2005 there were more than 1.6 mil. passengers (an increase of around 270% compared with 2000). In 2010, there were more than 1.97 mil. passengers (an increase of about 23% compared with 2005) and in 2018 there were almost 2.97 mil. passengers (an increase of around 50% compared with 2010).

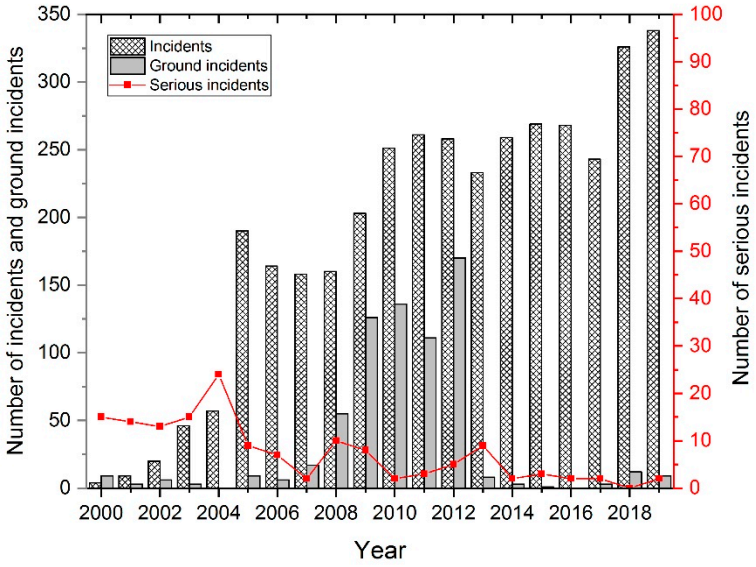


Figure 6. Serious incidents, incidents and ground incidents (period 2000–2019).

3.2. Determination of the Key Categories of Civil Aviation Incidents in Slovakia

The number of incidents has been rising since 2009, which represents a significant portion of the total number of CAOs. The analysis of the causes of incidents in civil aviation was carried out with 18 incident categories (Table 5), as published in the reports on CAOs for the period from 2009 to 2018. A review of individual incident categories is shown in Figure 7.

Table 5. Descriptive statistics of the number of incidents for the period 2009–2018.

Characteristics	Incident Category [Number]								
	I1	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**	**I9**
Number for the whole period	267	57	607	19	19	61	96	191	13
Maximum value	44	13	78	7	5	14	45	46	5
Minimum value	11	1	35	0	0	0	2	9	0
Average number per year	26.70	5.70	60.70	2.38	2.38	6.10	9.60	19.1	2.17
Standard deviation	10.10	3.80	12.91	2.45	1.85	3.70	13.01	10.79	1.72
Percentage for the monitored period [%]	12.19	2.60	27.72	0.87	0.87	2.79	4.38	8.72	0.59
Characteristics	**I10**	**I11**	**I12**	**I13**	**I14**	**I15**	**I16**	**I17**	**I18**
Number for the whole period	197	343	50	3	237	13	5	9	3
Maximum value	44	60	22	2	37	4	2	3	2
Minimum value	7	20	1	0	22	1	0	1	0
Average number per year	28.14	38.11	5.56	0.50	29.63	2.60	0.83	1.80	0.60
Standard deviation	11.91	10.79	6.67	0.84	5.95	1.14	0.75	0.84	0.89
Percentage for the monitored period [%]	9.00	15.67	2.28	0.14	10.82	0.59	0.23	0.41	0.14

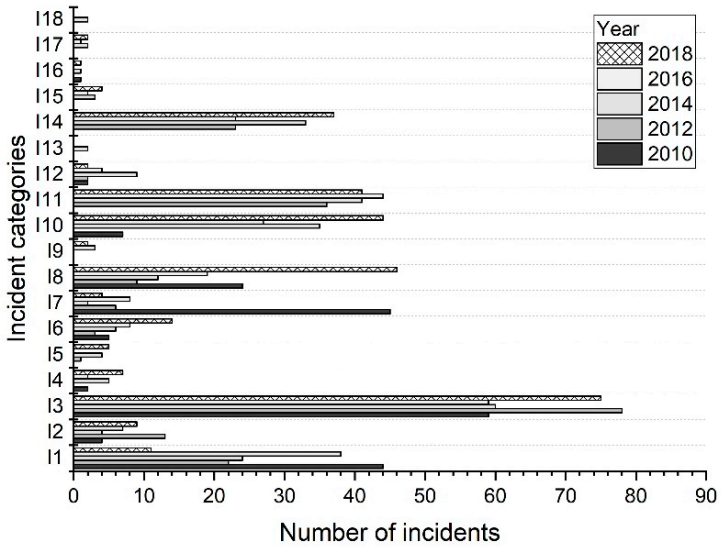


Figure 7. Review of incident categories in the years 2009 through 2018.

The highest number of incidents was observed in the following categories: I3 (occurrences involving collisions/near collisions with bird(s)/wildlife), I11 (failure or malfunction of an aircraft system), I1 (loss of communication during the flight), I14 (laser) and I10 (unauthorised penetration of air space). The characteristics of individual incidents (number of incidents for the monitored period, average annual number, standard deviation, maximum and minimum number of incidents) are shown in Table 5.

2190 incidents of the monitored categories occurred during the whole monitored period. The highest percentage was observed in Category I3 (occurrences involving collisions/near collisions with bird(s)/wildlife; 27.72%) and Category I11 (failure or malfunction of an aircraft system; 15.67%). Almost 12.19% of the incidents belong to Category I1 (loss of communication during the flight) and 10.82% to Category I14 (laser). The percentages of individual categories in the total number of incidents that occurred in the monitored period are shown in Table 5.

The Pareto analysis was carried out while applying the 75/25 rule, under which it is recommended to analyse in more detail the causes of defects that exhibit a cumulative relative frequency of 75%. The Pareto analysis indicated (Figure 8) that almost 76% of the causes of all incidents out of all CAOs were only in 5 categories: I3 (occurrences involving collisions/near collisions with bird(s)/wildlife); I11 (failure or malfunction of an aircraft system); I1 (loss of communication during the flight); I14 (laser); and I10 (unauthorised penetration of air space). These categories represent the few vital causes that contribute to the occurrence of incidents in civil aviation in Slovakia.

3.3. Modelling the Number of CAOs Depending on Selected Parameters

A negative trend in the number of civil aviation occurrences is affected by multiple factors. In the present investigation, the factors which were taken into consideration included the millions of passengers transported in Slovakia, the amount of the transported goods (thousands of tonnes), the number of commercial aircrafts aged above 14 years and the total aircraft movements in a given year (in thousands).

The output count variable Y represents the number of CAOs per year. We assumed that the investigated variable exhibited the Poisson distribution. The modelling of the number of CAOs was carried out using seven input (independent) variables, as described in Table 6. The data for all variables are related to the period of 10 consecutive years.

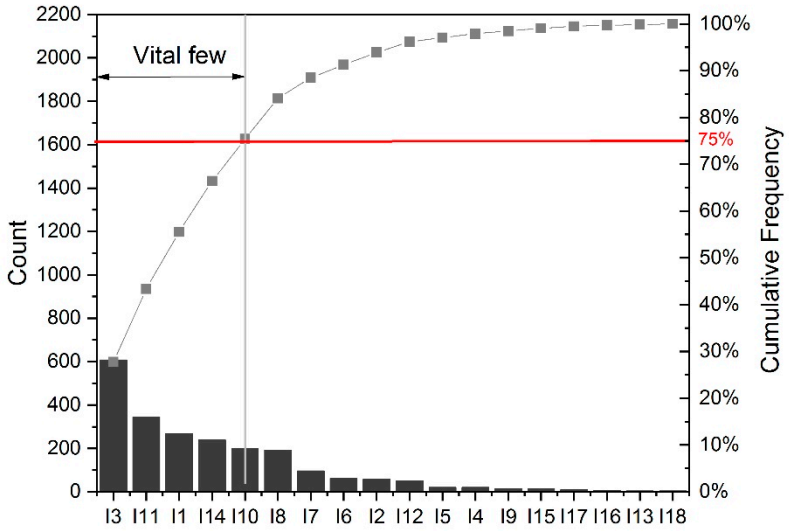


Figure 8. Pareto diagram.

Table 6. Characteristics of the variables.

Variables	Description
Dependent Variables	
CAO (Y)	Number of CAOs in a given year
Independent Variables	
Year (X_1)	Time variable, Year = 1 for year 2009, ..., Year = 10 for year 2018
Passenger (X_2)	Number of passengers transported in Slovakia in a given year (in mil.)
Goods (X_3)	Amount of transported goods in a given year (in thousands of tonnes)
Civil Planes (X_4)	Number of all civil planes registered in Slovakia in a given year
Aircraft (X_5)	Number of commercial aircraft with the weight of 9000 kg and more in a given year
Age (X_6)	Number of commercial aircraft with the weight of 9000 kg and more and aged over 14 years in a given year
Movement (X_7)	Number of landings or takeoffs at airports in a given year (in thousands)

3.3.1. Classical Regression Model (Model I)

The investigation of the impact of selected input variables on the number of CAOs was based on the following model:

$$Y = \beta_0 + \sum_{i=1}^{7} \beta_i X_i, \tag{4}$$

where β_0, β_i, $i = 1, 2, \ldots, 7$ are the coefficients of the regression model. Output variable Y represents the total number of civil aviation occurrences in a given year. The result of testing indicated that only two variables, X_4 (Civil Planes) and X_7 (Movement), had statistically significant effects on the number of CAOs. The equation of the best regression model is as follows:

$$Y = \beta_0 + \beta_4 X_4 + \beta_7 X_7, \tag{5}$$

The estimated coefficients of the new model together with the 95% confidence interval are shown in Table 7.

All coefficients of the new regression model, as well as the regression model, are statistically significant (p-value = 0.003 < α). The value of the coefficient of multiple determination is 88.82%.

Table 7. Estimated coefficients of the resulting regression model ($\alpha = 0.05$).

Coefficient	Estimate	Standard Error	*p*-Value	95% Confidence Interval
Intercept	1302.904	356.161	0.008	(604.841; 2000.967)
Civil Planes (β_4)	−1.993	0.543	0.008	(−3.058; −0.928)
Movement (β_7)	7.792	1.919	0.005	(4.031; 11.552)

3.3.2. Poisson Regression Model (Model II)

The equation of the Poisson model, which considers all input variables, is as follows:

$$\ln(Y) = \beta_0 + \sum_{i=1}^{7} \beta_i X_i, \quad (6)$$

or

$$Y = e^{\beta_0 + \sum_{i=1}^{7} \beta_i X_i} = e^{\beta_0 + \prod_{i=1}^{7} \beta_i X_i}, \quad (7)$$

where β_0, β_i, $i = 1, \ldots, 7$ are the model coefficients. Output variable Y represents the total number of civil aviation occurrences in a given year. The result of testing indicated that variables X_1 (Year), X_4 (Civil Planes), X_6 (Age) and X_7 (Movement) had statistically significant effects on the number of CAOs. It seems that the best resulting model is as follows:

$$Y = e^{\beta_0 + \beta_1 X_1 + \beta_4 X_4 + \beta_6 X_6 + \beta_7 X_7}, \quad (8)$$

The estimated coefficients of the new model together with the 95% confidence interval are shown in Table 8.

Table 8. Estimated coefficients of the resulting Poisson model ($\alpha = 0.05$).

Coefficient	Estimate	Standard Error	*p*-Value	95% Confidence Interval
Intercept	11.043	0.823	2×10^{-16}	(9.427; 12.63)
Year (β_1)	0.029	0.012	1×10^{-2}	(0.005; 0.052)
Civil Planes (β_4)	−0.011	0.001	4×10^{-13}	(−0.014; −0.008)
Age (β_6)	0.035	0.011	2×10^{-3}	(0.012; 0.057)
Movement (β_7)	0.038	0.004	2×10^{-16}	(0.029; 0.046)

The model coefficients, as well as the resulting model, were statistically significant (*p*-value = 0.031 < α). The Pseudo-R^2 value was 0.909; this means that the model explains 90.9% of the variability of the dependent variable CAOs, which is explained by the input variables. A positive value of coefficient β_i means that as the value of variable X_i increases by 1 (with the remaining variables unchanged), the expected variable CAOs increase. A negative value of coefficient β_i indicates that if the Xi value increases by 1 (with the remaining variables unchanged), the expected value of CAOs decreases.

If the value of input variable X_1 (Year) changes by one unit and the values of the remaining input variables remain fixed, the expected number of CAOs will be exp(0.029) = 1.029 times higher than the value at the unchanged variable X_1 (there will be an increase by 2.9%). This means that the number of aviation occurrences increases annually by 2.9% on average. If the value of input variable X_4 (Civil Planes) changes by one unit and the values of the remaining input variables remain fixed, the expected number of CAOs will be exp(−0.008) = 0.99 times lower than the value at the unchanged variable X_4 (there will be almost a negligible 1% decrease in the number of occurrences). An increase in variable X_6 (Age) by 1, with the remaining variables unchanged, will cause an increase in the expected number of CAOs by 3.9% (exp(0.039) = 1.039 > 1). This means that if the number of commercial aircrafts aged over 14 years increases by 1 (with the remaining variables unchanged), the number of aviation occurrences will increase by 3.9%. The same applies to variable X_7 (Movement, in thousands). An increase in variable X_7 by 1 (with the remaining variables unchanged) will also cause a very slight increase in the expected number of CAOs

by 3.1% (exp(0.031) = 1.031 > 1). When the total number of aircraft movements increases by 1 (in thousands), there will be an increase in the number of aviation occurrences by 3.1%.

3.3.3. Comparison of Models

The following step comprised a comparison of the real number of CAOs and the theoretical (expected) number of CAOs obtained from the models. A graphical comparison of the classical regression model (Model I) and the Poisson regression model (Model II) is shown in Figure 9.

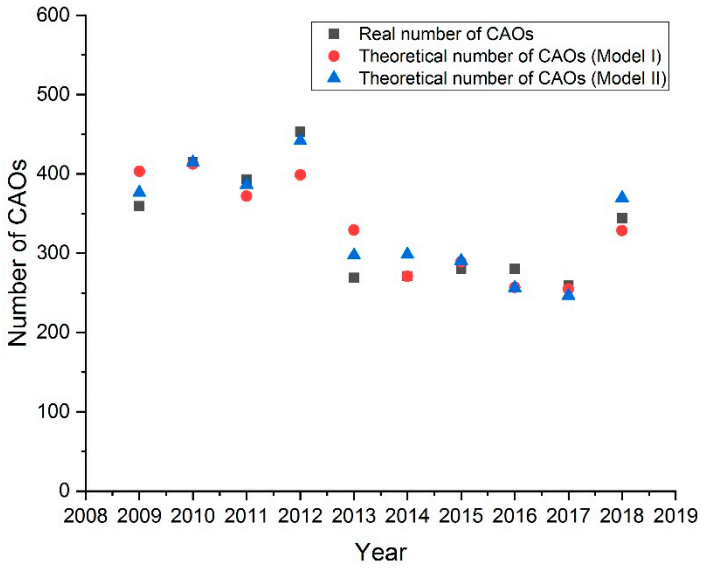


Figure 9. Graphical representation of the real and theoretical number of CAOs.

Both models were compared using the AIC value. The lower the value of the AIC criterion, the lower the residual components of the model. Hence, such a model exhibits a better agreement with the empirical values of the dependent variable. The value of the AIC criterion for the multiple regression model was 106.29, while the value for the Poisson regression model was 98.45. It is therefore possible to conclude that the Poisson regression model may be regarded as more appropriate.

4. Conclusions

The present study investigated occurrences in civil aviation which happened in Slovakia during the period from 2000 to 2019. The published statistics indicate that since 2017, the number of civil aviation occurrences in Slovakia has been increasing. While the number of serious incidents exhibited a downward trend, the number of incidents exhibited a dramatic increase. The percentage of incidents in the total civil aviation occurrences over the last 5 years reached the alarming level of almost 95%. It is therefore very important to investigate the causes of the incidents. The monitoring of civil aviation occurrences over 10 consecutive years in Slovakia facilitated the identification of the most important categories of incident causes, including a collision with a bird or an animal, technical failures of aviation technology, unauthorised penetration of air space, laser and lost connection during the flight. The information from the mathematical models can be applied to the accident risk assessment in civil aviation.

The multiple regression analysis and the Poisson regression were used to create two models of correlations between the number of civil aviation occurrences and selected input variables for 10 years. Apparently, the Poisson regression model exhibited a higher quality than the model created by the multiple regression analysis. The model indicated, for example, that an increase in the number of commercial aircrafts aged over 14 years and an

increase in the total number of aircraft movements significantly affect the increase in the number of civil aviation occurrences in Slovakia in a given year.

Understanding civil aviation occurrences and their causes leads to a higher safety of air traffic. The experiences show that there are many different minor occurrences that may indicate the existence of a hazard and the development of a risk that might result in an accident. It is important to know such minor occurrences; that is why the relevant data should be collected and assessed to take adequate preventive measures. Each CAO is unique, and finding the causes of the event is not always easy. The proven method of preventing CAOs is the implementation of an integrated Safety Management System that allows a real change in the organisation's ability to increase safety.

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References

1. Latorella, K.A.; Prabhu, P.V. A review of human error in aviation maintenance and inspection. *Int. J. Ind. Ergonom.* **2000**, *26*, 133–161. [CrossRef]
2. *Regulation L 13 Investigation of Accidents and Incidents, Ministry of Transport of the Slovak Republic*; Air traffic services of the Slovak Republic: Bratislava, Slovakia, 2007.
3. Annex 13 To the Convention on International Civil Aviation Aircraft Accident and Incident Investigation. Available online: https://www.emsa.europa.eu/retro/Docs/marine_casualties/annex_13.pdf (accessed on 13 April 2021).
4. Annual Safety Review 2019. Available online: https://www.easa.europa.eu/sites/default/files/dfu/Annual%20Safety%20Review%202019.pdf (accessed on 13 April 2021).
5. Balicki, W.; Głowacki, P.; Loroch, L. Large aircraft reliability study as important aspect of the aircraft systems' design changes and improvements. *Proc. Inst. Mech. Eng. Part G J. Aerosp. Eng.* **2020**. [CrossRef]
6. Janic, M. An assessment of risk and safety in civil aviation. *J. Air Transp. Manag.* **2000**, *6*, 43–50. [CrossRef]
7. Saleh, J.H.; Marais, K.B.; Bakolas, E.; Cowlagi, R.V. Highlights from the literature on accident causation and system safety: Review of major ideas, recent contributions, and challenges. *Reliab. Eng. Syst. Safe* **2010**, *95*, 1105–1116. [CrossRef]
8. Kharoufah, H.; Murray, J.; Baxter, G.; Wild, G. A review of human factors causations in commercial air transport accidents and incidents: From to 2000–2016. *Prog. Aerosp. Sci.* **2018**, *99*, 1–13. [CrossRef]
9. The Nall Report 2007: Accidents Trends and Factors for 2006. Available online: https://www.aopa.org/-/media/Files/AOPA/Home/Training-and-Safety/Nall-Report/07nall.pdf (accessed on 13 April 2021).
10. Caldwell, J. Crew schedules, sleep deprivation, and aviation performance. *SAGE J.* **2012**, *21*, 85–89. [CrossRef]
11. Lin, P.H.; Hale, A.R.; Van Gulijk, C.; Ale, B.J.M.; Roelen, A.L.C.; Bellamy, L.J. Testing a safety management system in aviation. In Proceedings of the 9th International Conference on Probabilistic Safety Assessment and Management 2008, Hong Kong, China, 18–23 May 2008. Code 96615.
12. Koščák, P.; Berežný, S.; Vajdová, I.; Koblen, I.; Ojciec, M.; Matisková, D.; Puškáš, T. Reducing the negative environmental impact of winter airport maintenance through its model design and simulation. *Int. J. Environ. Res. Pub. Health* **2020**, *17*, 1296. [CrossRef] [PubMed]
13. Li, W.C.; Harris, D. Routes to failure: Analysis of 41 civil aviation accidents from the Republic of China using the human factors analysis and classification system. *Accid. Anal. Prev.* **2008**, *40*, 426–434. [CrossRef] [PubMed]
14. Marais, K.B.; Robichaud, M.R. Analysis of trends in aviation maintenance risk: An empirical approach. *Reliab. Eng. Syst. Saf.* **2012**, *106*, 104–118. [CrossRef]

15. Burmistrova, V.G.; Butov, A.A.; Volkov, M.A.; Yavtushenko, M.S.; Kostishko, B.M.; Moskvicheva, M.G.; Pchelkina, Y.Z. The change in the probability of aviation accidents "collision of an aircraft with a bird" in accordance with of a change in the temperature cycle. Journal of Physics: Conference Series, Volume 1745. In Proceedings of the VI International Conference on Information Technology and Nanotechnology (ITNT-2020), Samara, Russia, 26–29 May 2020. Code 167456.
16. Insley, J.; Turkoglu, C.A. Contemporary Analysis of Aircraft Maintenance-Related Accidents and Serious Incidents. *Aerospace* **2020**, *7*, 81. [CrossRef]
17. Roelen, A.L.C.; Lin, P.H.; Hale, A.R. Accident models and organisational factors in air transport: The need for multi-method models. *Saf. Sci.* **2011**, *49*, 5–10. [CrossRef]
18. Roelen, A.; Wever, R.; Mosleh, A.; Groth, K. Development and validation of a comprehensive hybrid causal model for safety assessment and management of aviation systems. In Proceedings of the 9th International Conference on Probabilistic Safety Assessment and Management 2008, Hong Kong, China, 18–23 May 2008. Code 96615.
19. Ale, B.J.M.; Bellamy, L.J.; Van Der Boom, R.; Cooper, J.; Cooke, R.M.; Goossens, L.H.J.; Hale, A.R.; Kurowicka, D.; Morales, O.; Roelen, A.L.C.; et al. Further development of a Causal model for Air Transport Safety (CATS): Building the mathematical heart. *Reliab. Eng. Syst. Safe* **2009**, *94*, 1433–1441. [CrossRef]
20. Leveson, N. A new accident model for engineering safer systems. *Saf. Sci.* **2004**, *42*, 237–270. [CrossRef]
21. Blom, H.A.P.; Bloem, E.A. Modeling and estimation of accident rate and trend in air transport. In Proceedings of the 13th Conference on Information Fusion, Fusion 2010, Edinburgh, UK, 26–29 July 2010. Article number 5711871. [CrossRef]
22. Chen, J.C.; Lin, S.C.; Yu, W.F. Structuring an effective human error intervention strategy selection model for commercial aviation. *J. Air Transp. Manag.* **2017**, *60*, 65–75. [CrossRef]
23. Zhang, X.; Mahadevan, S. Bayesian network modeling of accident investigation reports for aviation safety assessment. *Reliab. Eng. Syst. Safe* **2021**, *209*. [CrossRef]
24. Cheng, S.Z.Y.L.; Valdés, R.M.A.; Comendador, V.F.G.; Nieto, F.J.S. Detection of common causes between air traffic serious and major incidents in applying the convolution operator to Heinrich pyramid theory. *Entropy* **2019**, *21*, 1166. [CrossRef]
25. Boyd, D.D.; Howell, C. Accident rates, causes, and occupant injury involving high-performance general aviation aircraft. *Aerosp Med. Hum. Perf.* **2020**, *91*, 387–393. [CrossRef]
26. Mannering, F.L.; Bhat, C.H.R. Analytic methods in accident research: Methodological frontier and future directions. *Anal. Methods Accid. Res.* **2014**, *1*, 1–22. [CrossRef]
27. Fardnia, P.; Kaspereit, T.; Walker, T.; Xu, S. Financial performance and safety in the aviation industry. *Int. J. Manag. Financ.* **2020**, *17*, 138–165. [CrossRef]
28. Brown, A.S. The effects of airline behavior on aircraft accidents. *Gettysbg. Econ. Rev.* **2017**, *10*, 70–105.
29. Li, Z.; Wang, W.; Liu, P.; Bigham, J.M.; Ragland, D.R. Using geographically weighted Poisson regression for county-level crash modeling in California. *Saf. Sci.* **2013**, *58*, 89–97. [CrossRef]
30. Al-Hasani, G.; Asaduzzaman, M.; Soliman, A.H. Comparison of Spatial Regression Models with Road Traffic Accidents Data. In Proceedings of the International Conference on Statistic: Theory and Applications, Lisbon, Portugal, 13–14 August 2019. Paper No. 31. [CrossRef]
31. Salvagioni, D.A.J.; Mesas, A.E.; Melanda, F.N.; dos Santos, H.G.; González, A.D.; Girotto, E.; de Andrade, S.M. Prospective association between burnout and road traffic accidents in teachers. *Stress Health* **2020**, *36*, 629–638. [CrossRef]
32. Sajed, Y.; Shafabakhsh, G.; Bagheri, M. Hotspot location identification using accident data, traffic and geometric characteristics. *Eng. J. Can.* **2019**, *23*, 191–207. [CrossRef]
33. Gildea, K.M.; Hileman, C.R.; Rogers, P.; Salazar, G.J.; Paskoff, L.N. The use of a poisson regression to evaluate antihistamines and fatal aircraft mishaps in instrument meteorological conditions. *Aerosp. Med. Hum. Perf.* **2018**, *89*, 389–395. [CrossRef]
34. *Strategic Transport Development Plan of the Slovak Republic up to 2030–Phase II*; Ministry of Transport, Construction and Regional Development of the Slovak Republic: Bratislava, Slovakia, 2016.
35. List of Airports and Heliports. Transport Authority. Available online: http://letectvo.nsat.sk/airporta-a-stavby/airporta/zoznam-airport-a-heliportov/ (accessed on 13 April 2021).
36. Civil Aviation Accidents and Incidents. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=LEGISSUM:tr0046 (accessed on 13 April 2021).
37. Statistics in Civil Aviation Report. Ministry of Transport, Construction and Regional Development of the Slovak Republic. Available online: https://www.mindop.sk/ (accessed on 13 April 2021).
38. ICAO Emergency Phases—SKYbrary Aviation Safety. Available online: https://www.skybrary.aero/index.php/ICAO_Emergency_Phases (accessed on 13 April 2021).
39. Eurostat Database. Available online: https://ec.europa.eu/eurostat/data/database (accessed on 13 April 2021).
40. STATdat. Public Database. Available online: http://statdat.statistics.sk (accessed on 13 April 2021).
41. Montgomery, D.C. *Introduction to Statistical Quality Control*, 6th ed.; John Wiley & Sons: New York, NY, USA, 2009; pp. 199–202.
42. Agresti, A. *An Introduction to Categorical Data Analysis*, 3rd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2019; pp. 63–83.
43. Cameron, A.C.; Windmeijer, F.F.G. R-Squared Measures for Count Data Regression Models with Applications to Health Care Utilization. *J. Bus. Econ. Stat.* **1996**, *14*, 209–220. [CrossRef]
44. Roback, P.; Legler, J. *Beyond Multiple Linear Regression: Applied Generalized Linear Models and Multilevel Models in R*, 1st ed.; CRC Press: New York, NY, USA, 2021.