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Forecasting trends of safety performance indicators in aviation

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Abstract

This article concerns trends in forecasting safety performance indicators (SPIs) in civil aviation. The main objective is to present a proposal for the method of forecasting trends in air traffic safety performance indicators in the future. For this purpose, a SPI forecasting method based on Holt's exponential smoothing model was proposed. To confirm the correctness of the proposed method, a selected sample safety performance indicator for Airspace Infringement occurrences was forecasted. An analysis of the obtained results was carried out and areas of further research were presented. This article also discusses the issues of forecasting development trends of selected safety performance indicators and their variability over time for the Polish airspace.

Keywords: forecasting trends of indicators, safety management systems, safety performance indicators

1. Introduction

Every area of the transport system subject to risk management should be subject to ongoing control activities. Risk monitoring, under which such control is carried out, is aimed at, for example, detecting new sources of threats, examining the adequacy of the results of risk management and planned results of actions taken in the management of risk and checking the possibility of changes in safety acceptance levels (Jamroz et al., 2010). In accordance with the recommendations resulting from Annex 19 to the Convention on International Civil Aviation (ICAO, 2016), a certain level of safety performance should be achieved by States or entities operating in civil aviation and defined by its safety performance target and indicators. Safety Performance Indicators (SPIs) are specially prepared data-based parameters used to monitor and assess the level of safety in a specific area of analysis (ICAO, 2016). Similarly to the recommendations generally applicable worldwide, Polish aviation entities are also subject to the obligation to develop, implement and monitor safety performance indicators and their periodic reporting to the Civil Aviation Authority (ULC) (ULC, 2022). These indicators allow not only to monitor the current level of safety in a given area but also, if necessary, to take appropriate measures to prevent its deterioration. For aviation entities, they can also be a kind of benchmark for resource management and rational safety decision-making (EU Regulation 965/2012). In many cases, these indicators only illustrate the current level of safety in the organization or the level referring to historical data from the past. Problems may occur in the ongoing analysis of safety performance indicators and their use in attempting to forecast their development trends or fluctuations in values and consequently in defining the future level of safety. Such analyses are still not sufficiently developed or widely practiced among some aviation entities. Therefore, it is justified to conduct research in this area, the benefits of which may be visible in improving safety management systems in aviation organizations. This article discusses the issues of forecasting development trends of selected safety performance indicators and their variability over time for the Polish airspace. As a result, the main objective is to present a proposal for the method of forecasting trends in air traffic safety performance indicators in the future.

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2. Safety management systems

The analysis of the trend of accidents in civil aviation shows that in recent years, despite the increasing number of air operations, the number of accidents has decreased significantly, which means maintaining aviation safety at a high level.

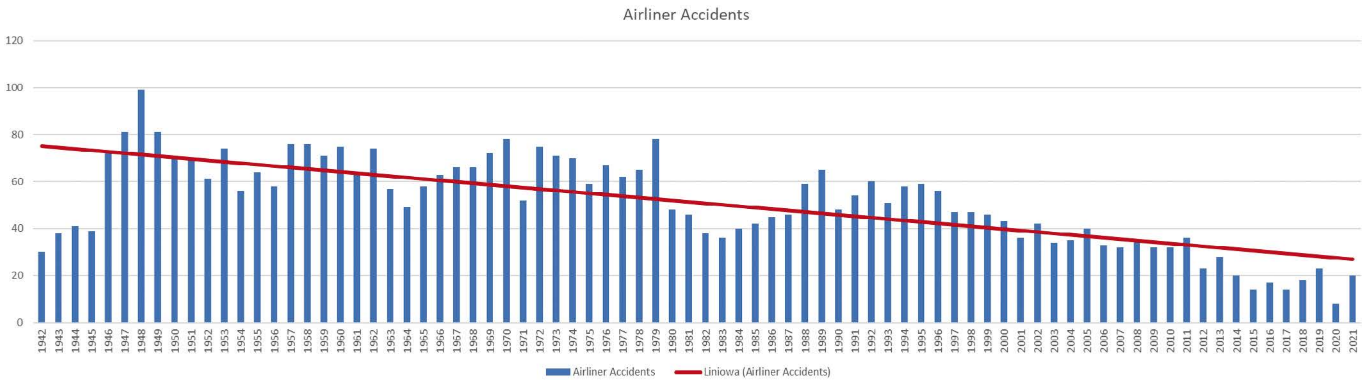

Figure 1. The number of registered air accidents in 1942-2021. Flight Safety Foundation 2022

The decreasing number of air accidents in recent years, especially in commercial aviation, is due, among other things, to the widespread introduction of safety management systems in aviation organizations and continuous improvement of them.

Implementing and maintaining the Safety Management System (SMS) is currently a prerequisite for the activities of aviation organizations such as airports, air traffic service providers or air carriers. These requirements result primarily on a global scale from Annex 19 to the Convention on International Civil Aviation issued by the International Civil Aviation Organization – ICAO (ICAO, 2016) As defined therein, SMS is a systematic approach to managing safety that includes the necessary organizational structures, accountability, responsibilities, policies and procedures. On a European scale, the provisions governing the requirements for the implementation and maintenance of an effective safety management system are contained in the following selected Regulations:

- for air operators in EU Regulation 965/2012 of the European Commission of 5 October 2012, laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council (EU Regulation 956/2012)
- for airport operators in EU Regulation 139/2014 of the European Commission of 12 February 2014, laying down requirements and administrative procedures related to aerodromes pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council (EU Regulation 139/2014)
- for air traffic management/air navigation service (ATM/ANS) providers in EU Implementing Regulation 2017/373 of the European Commission of 1 March 2017, laying down common requirements for providers of air traffic management/ air navigation services and other air traffic management network functions and their oversight repealing Regulation (EC) No 482/2008, Implementing Regulation (EU) No 1034/2011, (EU) No 1035/2011 and (EU) 2016/1377 and amending Regulation (EU) No 677/2011 (EU Regulation 373/2017).

The main objectives of safety management in an aviation organization are:

- proactively mitigating safety risks for the aviation organization before they cause aviation accidents and incidents,
- prioritizing the activities of the aviation organization to counter safety risks and managing its resources more effectively in order to achieve optimal aviation safety benefits,
- continuously improving the aviation organization's safety performance through hazard identification, data collection and analysis, and continuous assessment and management of safety risks.

The main benefits that safety management can bring in an aviation organization are:

- compliance with legal regulations and certification requirements,
- safety-based decision-making and the ability to collect safety data for safety analysis purposes,
- financial savings – avoiding costs related to accidents and incidents, obtaining discounts on insurance premiums for aviation activities and reducing employee insurance premiums based on the performance of the safety management system.

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In the SMS model, according to the ICAO, four main pillars can be distinguished:
1) Safety policy and objectives
2) Safety risk management
3) Safety assurance
4) Safety promotion

Monitoring and measuring the level of safety is one of the building blocks of the safety assurance pillar. Safety measurement in an aviation organization is carried out primarily through the collection, development and analysis of safety indicators that have been adopted for monitoring based on internal statistical data of a given aviation organization regarding aviation safety risk areas and in accordance with the State Safety Program and Plan for Civil Aviation Safety. As part of the exchange of best practices, monitoring indicators is also based on the recommendations of international industry organizations such as EUROCONTROL, CANSO, ACI or IATA. As part of harmonizing concepts on a European scale and the state scale, the term Safety Performance Indicator, abbreviated as SPI, is adopted for indicators used for aviation safety monitoring. Implementing the safety monitoring task in an aviation organization such as ANSP (Air Navigation Service Provider) is carried out using two types of safety performance indicators: leading and lagging. Leading indicators are introduced to support continuous system improvement and indicate likely future safety actions in the organization. They are intended to help aviation organizations and regulators take action on whether they have the appropriate processes that effectively reduce aviation safety risks. Lagging indicators are used to measure output data, for example, ATM/ANS services. They concern events that have already occurred and that have an impact on the safety of air operations. Lagging indicators are divided into two subgroups: outcome indicators and precursor indicators. Outcome indicators mainly include aviation accidents and serious incidents, which, depending on the organization's risk classification scheme, are investigated and classified considering severity level. Precursor indicators are used to monitor trends and assess the likelihood of less severe events turning into serious incidents or accidents. This article and the proposed method of trend forecasting refer precisely to monitoring precursor indicators.

The above-mentioned SPIs are used to measure and monitor safety performance, identify aviation safety hazards, analyze safety risks, and set safety targets. Specific benchmarks may be applied to the SPIs: alert levels and target levels. Alert levels are established reference levels, the exceeding of which may be symptomatic of a deterioration in aviation safety. In accordance with the methods described in the ICAO Safety Management Manual (ICAO Doc. 9859, 2018), by default, alert levels are the average value of the previous year increased by one, two and three standard deviations of those values whose exceedances are intended to initiate action to improve safety. Target levels, on the other hand, are benchmarks set at the level of the aviation organization, for which maintaining the index values below these values may mean an improvement or maintenance of the safety status at the planned level, for example, for a given year.

Therefore, there is a need to develop a method for forecasting trends in safety indicators to be able to take preventive action by aviation organizations and regulators at an early stage based on the results of such predictions and to be able to reduce the risk of safety threats appearing and turning into serious incidents or accidents. Such activities are part of the forecasting strategy of a given aviation organization, which could significantly support the decision-making process and the development of strategic plans in the field of safety activities. It could also reduce the possible costs of the organization resulting from the lack of anticipation of serious system failures or human errors that may affect the occurrence of a serious aviation incident or accident.

2.1. Classification of safety performance indicators

There are several types of divisions for classifying the safety performance indicators. The subdivision of indicators, according to the levels they are used at, divides them into the following categories (ULC, 2021):
- Global – at this level, indicators are developed and used based on the Global Aviation Safety Plan (GASP),
- European – at this level, indicators allow to monitor the level of safety and indicate areas of threats, which are then published in the European Plan for Aviation Safety (EPAS) along with activities aimed at mitigating the risks associated with them,
- State – indicators of this level are created as a part of the State Safety Programs and Plans for Civil Aviation of the Member States,
- Internal – these include indicators developed by entities involved in aviation activities, reflecting their areas' specificity. They refer directly to the identified risk areas and are defined by them.
- The classification of SPIs by nature includes, as already mentioned above (ULC, 2021; ICAO Doc. 9859, 2018):
- Leading indicators – based on processes and inputs that are implemented to improve or maintain the level of safety (e.g. Effectiveness of Safety Management (EoSM), Effectiveness of the Just Culture Policy),

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- Lagging indicators, reactive indicators – based on information about occurrences that have already occurred in the past and may affect the level of safety. Lagging indicators can be divided into high and low-weight indicators depending on the magnitude of the probabilities and the severity of the effects (e.g., Airspace Infringements, Runway Incursion, Laser blinding).

Evaluation using indicators can be carried out in a qualitative (descriptive) and quantitative (numerical) way. Quantitative indicators are usually preferred among aviation entities as they are more accessible to measure and compare with other indicators. Such indicators also more accurately reflect the state of civil aviation safety in the country so that the public can better understand it.

Another breakdown of the safety performance indicators is the division of their structure into groups with specific levels of detail (Skorupski, 2018; EASA, 2021; SM ICG):

- Row I – synthetic indicators, relating to the whole system. They aim to provide an overall assessment of the safety performance and to inform the public about general safety trends and significant risk areas (e.g., number of serious incidents per 10,000 flight movements or number of serious incidents per 1 million checked-in passengers),
- Row II – functional indicators, based on effects. They help to monitor specific areas of the system that require additional safety measures (e.g., number of runway excursions per 10000 flight operations),
- Row III – causal indicators, referring to the factors that make up the aviation system's problem area, determined by row I and row II indicators. The row III indicators are intended to provide information on the effectiveness of safety measures (e.g., for runway excursions, the number of incorrect runway contacts or the number of aborted take-offs at exceedingly high ground speeds can be monitored).

2.2. Defining safety performance indicators

The benchmarks should consider linking the indicators to the safety objectives that intend to indicate their practical meaning, considering the capabilities and limitations of the organization. The SPIs should also be sufficiently detailed and measurable, and their selection and compilation should consider the availability of data and the reliability of measurements (ICAO Doc. 9859, 2018). The process of defining safety level indicators usually consists of three stages (ULC, 2021; EASA, 2021):

1. Identification of the organization's main objectives and key problems – review of the organization's safety policy and objectives.
2. Data acquisition – gathering all available information that can help define indicators. The basic sources of obtaining information for Polish aviation entities will be documents containing important safety data in a given area, such as the State Safety Plan issued by the Civil Aviation Authority (ULC) or the European Plan for Aviation Safety (EPAS) issued by EASA.
3. Defining indicator parameters – specifying parameters.

The relationship most often determines the value of the safety performance indicator:

$$SPI = \frac{L_z \cdot a}{N}, \tag{1}$$

where:
SPI – the value of the safety performance indicator,
L_z – number of occurrences,
a – weighting factor for the number of operations, occurrences or flight hours (e.g., 1000, 10,000, etc.),
N – number of operations, occurrences, or flight hours.

Alert levels are determined from the relationship:

$$P_n = \bar{X} + n\sigma, \tag{2}$$

where:
P_n – next alarm level (n = 1, 2, 3),
$\bar{X}$ – the average value of the safety performance indicator,
σ – standard deviation.

The obtained values of the safety performance indicator per 10,000 operations for airspace infringements in the years 2011-2021, together with the calculated alert levels, are presented in Table 1 and Figure 2.

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Table 1. Summary of calculated values of the safety performance indicator per 10,000 operations for airspace infringements in the years 2011-2021. Author's own work based on https://www.eurocontrol.int/.

Year	Number of occurrences	Number of operations	SPI value per 10000 operations
2011	62	246 679	2.51
2012	87	276 696	3.14
2013	63	263 028	2.40
2014	96	268 999	3.57
2015	91	283 341	3.21
2016	108	309 795	3.49
2017	97	341 199	2.84
2018	285	381 547	7.47
2019	246	398 073	6.18
2020	179	165 327	10.83
2021	187	202 874	9.22
Average SPI			4.56
Standard deviation			2.61
I alarm level			7.17
II alarm level			9.78
III Alarm level			12.40

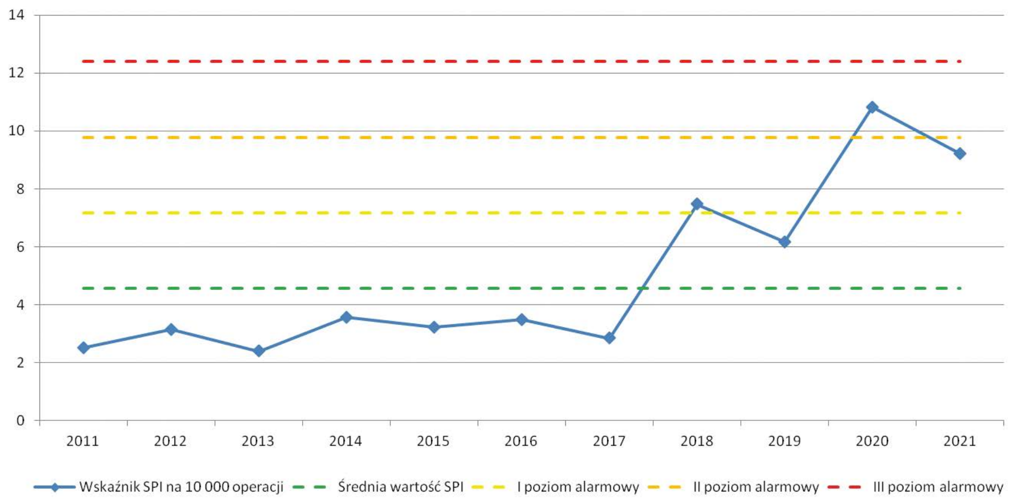

Figure 2. SPI indicators per 10,000 operations for airspace infringements in 2011-2021. Author's own work

3. Forecasting methods

Forecasting is the prediction of future events in a rational and scientific manner. It is the choice of the most probable path of development of a given event or phenomenon in the near future, where its basis is the previous course of this phenomenon (Ampuła, 2012; Żurowska, 2005). The forecast process takes place in several stages, which include (Ampuła, 2012; Żurowska, 2005; Cieślak, 2005):

1. Defining a predictive problem – determining the object, phenomena or variables,
2. Data collection and analysis – will make hypotheses regarding the probable course of the forecasted phenomena in the future,
3. Selection of prediction method,
4. Determination of the forecast,
5. Assessment and verification of the forecast.

Methods of making predictions can be divided into quantitative, which use mathematical-statistical dependencies to make a forecast, and qualitative, which is based on heuristic methods. A detailed description of forecasting methods can be found in various literature such as (Żurowska, 2005; Cieślak, 2005; Dragu et al., 2017). This paper only describes the method chosen and used by the authors for forecasting SPI indicators, the Holt method.

3.1. Holt method

The linear exponential smoothing model, also called the Holt model, is used to smooth out a time series in which there is a trend and random fluctuations. The following equations are used to describe the Holt model (Żurowska, 2005; Cieślak, 2005; Ampuła, 2013):

$$F_{t-1} = \alpha \cdot y_{t-1} + (1-\alpha) \cdot (F_{t-2} + S_{t-2}), \tag{3}$$

and

$$\mathrm{S}_{t-1} = \beta \cdot (\mathrm{F}_{t-1} - \mathrm{F}_{t-2}) + (1-\beta) \cdot \mathrm{S}_{t-2}, \tag{4}$$

where:
F_{t-1} – evaluation of the average value at the moment t-1 (equivalent to the smoothed value obtained from a simple exponential smoothing model),
S_{t-1} – evaluation (smoothed value) of trend growth at the moment t-1,
α, β – exponential smoothing parameters, $\alpha, \beta \in (0,1)$

Forecasts for the moment $t \le n$ are determined from the following equation:

$$y_t^* = \mathrm{F}_{t-1} + \mathrm{S}_{t-1} \tag{5}$$

The equation of the forecast for the moment has the following form: $t > n$

$$y_t^* = \mathrm{F}_n + (t-n) \cdot \mathrm{S}_n, \tag{6}$$

where:
y_t^* – variable forecast determined at the moment t,
F_n – smoothed value of the forecasted variable for moment n,
S_n – smoothed value of trend increments at moment n,
n – number of terms in the time series of the forecast variable.

To build a linear model of exponential Holt smoothing, the initial smoothed value of the forecast variable (F_1) and the initial smoothed value of trend increment (S_1) should be determined. This can be done by (Żurowska, 2005; Cieślak, 2005; Ampuła, 2013):

- taking the forecast variable F1 as the first value y1 and the value 0 as S_1,
- taking the forecast variable F1 as the first value y1, and the difference $y_2 - y_1$ as S_1,
- taking the forecast variable F1 as free word, while the directional coefficient of the trend function estimated on the basis of the preliminary sample (e.g., the first few observations) as S1.

The parameters of exponential smoothing α and β are obtained experimentally. A series of calculations should then be carried out for different combinations of these parameters and the one that minimizes the average ex-post error of expired forecasts (Żurowska, 2005; Cieślak, 2005) should be chosen:

$$q_t = y_t - y_t^*, \tag{7}$$

where:
q_t – the ex-post error value,
y_t – realization of the forecast variable y at time t,
y_t^* – the forecast of the variable y for the moment t obtained from a given method.

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4. Forecast of the trends in safety performance indicators

Data from the State Safety Plan 2022-2025 were used to analyze the safety performance indicators in the Polish airspace in the years 2011-2021. Examples of performance indicators monitored by ATM service providers and their calculation algorithms are presented in Table 2.

Table 2. Examples of lagging indicators for ANSP [author's own study]

No.	Indicator name	Definition of benchmark
1	Airspace Infringement (AI)	The number of airspace infringements, when an aircraft enters notified airspace without previously requesting and obtaining clearance from the controlling authority of that airspace, or enters the airspace under conditions that were not contained in the clearance, counted per 10,000 flight operations.
2	Runway Incursion (RI)	The number of any occurrences at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft calculated per 10,000 flight operations.
3	Runway Excursion (RE)	The number of runway excursions when the aircraft is a veer off or overrun from the runway surface, and these surface events occur while an aircraft is taking off or landing, or when an aircraft departs the runway in use during the take-off or landing run, which may be intentional or unintentional calculated per 10,000 flight operations.
4	Level Bust (LB)	The number of any unauthorized vertical deviations of more than 300 feet and more than 200 feet in RVSM (Reduced Vertical Separation Minima) air space from an ATC flight clearance, calculated per 10,000 flight operations.
5	Separation Minima Infringement (SMI)	The number of situations where separation minima requirements between aircraft or between aircraft and airspace for which separation minima have been defined have not been maintained, calculated per 10,000 flight operations.
6	Laser blinding of the aircraft (LASER)	The number of occurrences in which glare or glow is induced by the flight crew due to the use of a device emitting electromagnetic radiation in the visible, ultraviolet, or infrared range, using the phenomenon of forced emission, which is treated as a hazard in air traffic and calculated per 10,000 flight operations.
7	Drone Events (Aircraft - RPAS)	The number of aviation safety incidents involving aircraft or systems that do not require a crew present on board and do not have the ability to take passengers, piloted remotely (RPAS) or operating autonomously, e.g., unmanned aerial vehicles (UAVs) or unmanned aerial systems (UAS), counted per 10,000 flight operations.

In addition to the above-mentioned examples of lagging indicators monitored by all European ANSPs, lagging indicators resulting from the requirements of the State Safety Plan are additionally monitored, updated and published by the Polish Civil Aviation Authority (ULC). These indicators are monitored by aviation organizations such as airports (ADR indicators), air operators (OPS indicators), flight training organizations (ATO indicators), air traffic management service providers (ATM/ANS indicators) and ground handling agents for handling hazardous materials or supplying propellants to aircraft (AHAC indicators) and sent to CAA after the end of each quarter. For example, for the Polish Air Navigation Services Agency (PANSA), which monitors the SPIs on a monthly basis, in 2022, the ATM/ANS indicators required for monitoring and reporting under this plan were:

- The number of "Airspace Infringements",
- The number of observed "Level Bust",
- The number of "Separation Minima Infringement",
- The number of commenced approaches when the RVR minima were below those permitted for ILS in a given RWY direction,
- The number of occurrences in the LASER category,
- The number of occurrences related to communication problems in English,
- The number of occurrences involving UAV / RPAS,
- The number of staff fatigue occurrences (ATCO, FISO, AFISO) due to Fatigue Reports / Number of personnel (ATCO, FISO, AFISO) on duty in a given month.

For this study, data on the Airspace Infringement (AI) indicator was selected, which was predicted for three consecutive years, i.e., 2022-2024. The forecast was made using the Holt model. The calculations were carried out using a Microsoft Excel spreadsheet. The next steps of the procedure in accordance with the algorithm of this method and its results are presented below.

The first step of the analysis is to calculate the value of the safety performance indicator per 10,000 flight operations according to equation (1) and the alarm levels according to equation (2). Then, summarize these values in the subsequent analyzed years (as in Table 1).

Proper prediction begins with the creation of a prediction model table, the columns of which correspond in turn (for the analyzed SPI indicator – Table 3):

- the column "Year" indicates the consecutive years of occurrence of the SPI value,
- the column "y_t" indicates the actual values of the projected SPI (corresponds to the column "SPI value per 10 000 operations" from Table 1),

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- the column "F_t" indicates smoothed values of the forecasted SPI,
- the column "S_t" indicates smoothed SPI trend increment values,
- the column "y_t^*" indicates the SPI forecast values,
- the column "q_t" indicates the error of ex-post forecasts determined from equation (7),
- the column "$|q_t|$" indicates an absolute error in ex-post forecasts,
- the column "$|q_t^2|$" indicates the square error of ex-post forecasts.

Then, for the calculations, three types of errors are determined that will help assess the reliability and accuracy of the forecast:
- the Mean Absolute Error (MAE), obtained by determining the arithmetic mean from the column "$|q_t|$" of the prediction model table. For the analyzed indicator, an MAE = 1.27 was obtained;
- Mean Square Error (MSE), obtained by determining the arithmetic mean from the column "q_t^2" of the prediction model table. For the analyzed indicator, MSE = 3.14 was obtained;
- the root of the mean square error of the ex-post forecasts, ($\sqrt{MSE}$) which characterizes the average deviation of the forecasts within the verification interval. For the analyzed indicator $\sqrt{MSE}$ = 1.77 was obtained.

According to equations (3) and (4), determine the exponential smoothing parameters and β. They were determined using the Solver optimization tool. They have been adjusted to obtain the lowest possible average error of ex-post forecasts in accordance with the assumed limiting conditions. The parameters of exponential smoothing α and β for the calculation of the prediction of the indicator "Airspace Infringement" were: α = 0.424, β = 0.

The construction of the prediction model began with the determination of the values of F_1 and S_1. According to the assumptions, for F_1 the first value of the forecast variable was assumed y_1, while for S_1 assumed the difference $y_2 - y_1$. For the case under consideration: $F_1 = 2.51$ and $S_1 = 3.14 - 2.51 = 0.63$. The subsequent values of F_n and Sn are calculated from equations (3) and (4). In accordance with this, the following values were obtained:

$$F_2 = \alpha \cdot y_2 + (1-\alpha) \cdot (F_1 + S_1) = 0.424 \cdot 3.14 + (1 - 0.424) \cdot (2.51 + 0.63) = 3.14$$

and

$$S_2 = \beta \cdot (F_2 - F_1) + (1-\beta) \cdot S_1 = 0 \cdot (3.14 - 2.51) + (1 - 0) \cdot 0.63 = 0.63$$

The obtained SPI prediction model for Airspace Infringements in the years 2011-2024, together with calculations of its individual components, is presented in Table 3.

Table 3. SPI prediction model "Airspace Infringement" in the years 2011-2024. Own work.

No.	Year	y_t	F_t	S_t	y^*_t	q_t	$\|q_t\|$	q_t^2
1	2011	2.51	2.51	0.63	–	–	–	–
2	2012	3.14	3.14	0.63	3.14	0.00	0.00	0.00
3	2013	2.40	3.19	0.63	3.77	-1.37	1.37	1.88
4	2014	3.57	3.71	0.63	3.82	-0.25	0.25	0.06
5	2015	3.21	3.86	0.63	4.34	-1.13	1.13	1.29
6	2016	3.49	4.07	0.63	4.49	-1.00	1.00	1.01
7	2017	2.84	3.91	0.63	4.70	-1.86	1.86	3.45
8	2018	7.47	5.78	0.63	4.54	2.93	2.93	8.58
9	2019	6.18	6.31	0.63	6.41	-0.23	0.23	0.05
10	2020	10.83	8.59	0.63	6.94	3.89	3.89	15.10
11	2021	9.22	9.22	0.63	9.22	0.00	0.00	0.00
12	2022	-	-	-	9.85	–	–	–
13	2023	-	-	-	10.48	–	–	–
14	2024	-	-	-	11.11	–	–	–

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The next stage was to supplement the list of safety performance indicators in 2011-2021 with the results of predictions for 2022-2024 (Table 4).

Table 4. Summary of forecasted SPI values for Airspace Infringements. Own work.

Year	Number of occurrences	Number of operations	SPI value per 10,000 operations
2011	62	246 679	2.51
2012	87	276 696	3.14
2013	63	263 028	2.40
2014	96	268 999	3.57
2015	91	283 341	3.21
2016	108	309 795	3.49
2017	97	341 199	2.84
2018	285	381 547	7.47
2019	246	398 073	6.18
2020	179	165 327	10.83
2021	187	202 874	9.22
2022	–	–	9.85
2023	–	–	10.48
2024	–	–	11.11
Average SPI $_{(2011-2021)}$			4.99
Standard deviation			2.83
I alarm level			7.81
II alarm level			10.64
III alarm level			13.46

The obtained forecast results for the safety performance indicator defined as the number of Airspace Infringements per 10,000 flight operations for the years 2022-2024 were as follows: 9.85, 10.48, 11.11. The projected value of the SPI for Airspace Infringement will increase, which may be caused by an increase in the number of flight operations performed after the pandemic and, accordingly, an increase in the number of reported events. For the purposes of a real reference the safety level in this area, it was decided to set alert levels based on the average value of the SPI indicator and the standard deviation from these values for the years 2011-2021. However, the values from the forecast years were not considered. The obtained results and the designated alarm levels are presented in graphic form (Figure 3).

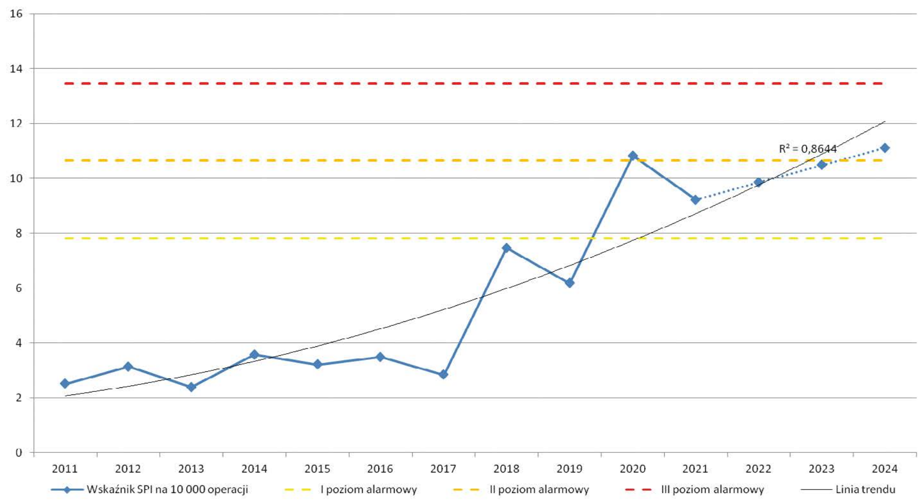

Figure. 3. SPI indicators prediction for Airspace Infringement in 2022-2024.
Author's own work.

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Exceeding the I alert level by all forecasted values of the indicator can be noted. The II alert level was exceeded in 2024. During the calculations, by using the MS Excel tool, a trend line was also determined to check the course of the function and the coefficient of determination R2, which amounted to 86.4%, which means that the determined trend function describes the development trend of the forecasted variable well. With a well-made forecast, it can be concluded that the SPI values for Airspace Infringements will be higher from year to year; therefore, appropriate corrective and preventive actions should be taken to improve safety. The accuracy of a forecast by comparing actual values with forecast values may be checked.

5. Conclusion

An element of safety management systems is the management of the level of safety, which consists of its measurement and monitoring. This is done by defining targets and developing and implementing safety performance indicators. The article explains their concept and classifies them by use, methods of measurement and notation, as well as the nature and level of detail. The algorithm of conduct in defining safety performance indicators and the most frequently used methodology for calculating quantitative outcome indicators are also presented.

An analysis of the selected indicator was carried out, whose main objective was to propose a method of forecasting trends in air traffic safety indicators in Poland, which can be used as part of a safety management system (SMS) by entities involved in aviation activities, as well as rail and maritime transport, taking into account a proactive and predictive approach. An example of the indicator chosen by the authors was the Airspace Infringement. The forecasting process was presented to predict the most likely pattern of their trends in the future. The prediction was made for the next three years, i.e., 2022-2024. Further directions of work and research may include the prediction of other safety performance indicators, including those having the greatest impact on the safety of a given aviation entity. It should be remembered that SPI indicators should be developed considering a given organization's specifics, capabilities and limitations. The direction of further work can also be indicated by redefining alarm levels. The alarm levels calculated for this work took into account the average values of indicators and standard deviations of these values throughout the monitoring period, i.e., 2011-2021. In the recent past, however, there has been a significant development of aviation, which also brought with its requirements in changing the approach to safety management. Currently, the safety culture and risk awareness is at a much higher level than in previous years. Operational personnel are increasingly willing and more likely to report any occurrences and incidents that may threaten aviation safety. It would, therefore, be possible to calculate alarm levels on a seasonal or other selected basis that would better reflect the specificity of the given area. The proposed prediction method can be used for any SPI both in air transport and after appropriate adjustment in the rail and maritime transport field.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

References

1. Ampuła, D. (2013). Adaptacyjne metody predykcji. *Problemy Techniki Uzbrojenia, 42*(127), 75–85.
2. Ampuła, D. (2012). Proces predykcji zdarzeń i zjawisk. *Problemy Techniki Uzbrojenia, 41*(122), 29–40.
3. Cieślak, M. (Ed.). (2005). *Prognozowanie gospodarcze: Metody i zastosowania*. Wydawnictwo Naukowe PWN.
4. Dragu, V., Dinu, O., Oprea, C., & Roman, E. A. (2017). The transport forecast: An important stage of transport management. *IOP Conf. Series: Materials Science and Engineering*. https://10.1088/1757-899X/252/1/012050
5. EU Regulation 139/2014. (2014). *Commission Regulation (EU) No 139/2014 of 12 February 2014 laying down requirements and administrative procedures related to aerodromes pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council Text with EEA relevance*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0139
6. EU Regulation 373/2017. (2017). *Commission Implementing Regulation laying down common requirements for providers of air traffic management/air navigation services and other air traffic management network functions and their oversight, repealing Regulation (EC). No 482/2008. Implementing Regulations (EU). No 1034/2011. (EU) No 1035/2011 and (EU) 2016/1377 and amending Regulation (EU) No 677/2011*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R0373
7. EU Regulation 965/2012. (2012). *EU Commission Regulation laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012R0965
8. EASA [European Union Aviation Safety Agency]. (2021). *European Plan for Aviation Safety (EPAS 2022-2026)*.
9. ICAO [International Civil Aviation Organization]. (2016). *Annex 19 to the Convention on International Civil Aviation*: *Safety Management* (2nd ed.).

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DOI: https://doi.org/10.37105/sd.201

10. ICAO Doc. 9859. (2018). *Safety Management Manual* (4th ed.).
11. Jamroz, K., Chruzik, K., Gucma, L., Kadziński, A., Skorupski, J., & Szymanek A. (2010). Koncepcja metody zarządzania ryzykiem w transporcie. In R. Krystek (Ed.), *Zintegrowany system bezpieczeństwa transportu (vol. 2.): Uwarunkowania rozwoju integracji systemów bezpieczeństwa transportu*. Politechnika Gdańska.
12. SM ICG [Safety Management International Collaboration Group]. (2019). *Guidance for Comprehensive Safety Performance Management in a State Safety Programme*. https://www.skybrary.aero/sites/default/files/bookshelf/5436.pdf
13. Skorupski, J. (2018). *Ilościowe metody analizy incydentów w ruchu lotniczym.* Oficyna Wydawnicza Politechniki Warszawskiej.
14. ULC [Urząd Lotnictwa Cywilnego]. (2021). *Wskaźniki Poziomu Bezpieczeństwa (SPIs): Materiał doradczy z zakresu Zarządzania Bezpieczeństwem w Lotnictwie (SMS).* Warszawa.
15. ULC [Urząd Lotnictwa Cywilnego]. (2022). *Krajowy Plan Bezpieczeństwa 2022-2025. Załącznik do Krajowego Programu Bezpieczeństwa w Lotnictwie Cywilnym*. Warszawa.
16. Żurowska, J. (2005). *Prognozowanie przewozów: modele, metody, przykłady*. Wydawnictwo Politechniki Krakowskiej im. Tadeusza Kościuszki.