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Analysis of safety indicators in air transport

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The fundamental issues of safety management in air transportation systems are addressed based on the relevant safety indicators and their target levels. These are the so-called Safety Performance Indicators (SPI) and Safety Performance Targets (SPT). The values of the indicated characteristics are derived from past events, using accepted statistical models. Although such a retrospective approach is justified, the authors of this article feel that it requires certain conditions that would allow their use in subsequent years. Therefore, the purpose of the article was to calculate and present current SPI values for selected aviation events and to anticipate problems of their application in the future. In pursuit of this goal, the classification of safety level indicators and methods of their determination are presented. Their use in various situations, including the formation of a number of aviation events and operations, is discussed. Additional statistical measures and the algorithm for using SPI, SPT, and correlation coefficient to support the analysis of safety indicators were proposed.

Key words: *air transport, safety performance indicators, safety performance target, safety level, the Pearson correlation coefficient*

1. Introduction

A key element for the proper operation of national safety programs (SSPs) and safety management systems (SMS) in aviation is safety level management [9]. Its proper implementation can provide aviation entities with the means to take effective action to achieve safety goals. The safety level of a country or an aviation entity should be achieved by identifying Safety Performance Indicators (SPI) and defining Safety Performance Targets (SPT). The process of managing this level identifies the main risks to the safety of operations, establishes safety goals and, defines ways to achieve them, and determines what data and information are necessary to make sound decisions in the context of safety. It also establishes an Acceptable Level of Safety Performance (ALoSP) [1,4]. An example of how organizations could design, implement and use a proactive, performance-based measurement tool for assessing and measuring ALoSP at the sigma (σ) level, a statistical measurement unit, has been presented in paper [5]. Measuring and monitoring the level of safety using indicators developed for this purpose is important not only for individual aviation entities, but also for the country as a whole [13]. In Poland, aviation entities such as training centers, aircraft operators, airport managers, air navigation service providers and continuing airworthiness management organizations are subject to the obligation to measure safety levels. However, measurement of safety levels is also desirable among the exempted entities. This is because a larger proportion of entities reporting indicator values more reliably informs about the level of safety in civil aviation nationwide [10]. The safety level management process is also used to establish the ALoSP. It expresses the levels of safety a country expects from its aviation system. The ALoSP is a reflection of the country's most important safety provisions. It should be developed taking into account the strategic guidance of higher levels (derived from GASP and EPAS) and the safety objectives established in the SSP [4]. The purpose of this article is to calculate and present the values of the SSP for 2011–2021 for selected aviation events and to anticipate the problems of their application in the future.

2. About the indicators

Several types of divisions are used to classify safety level indicators. The first is the division of indicators by the levels in which they are used. There are four such levels [11]:

– Global – at this level, indicators are developed and used based on the Global Aviation Safety Plan (GASP). Based on their results, actions are taken for implementation by ICAO to monitor and improve the level of safety globally.
– European – at this level, indicators make it possible to monitor the level of safety and identify areas of risk, which are then published in the European Plan for Aviation Safety (EPAS) along with actions to mitigate the risks associated with them.
– National – indicators of this level are created as part of the National Civil Aviation Safety Programs and Plans of the member states. They reflect the level of safety on a national scale.
– Internal – these include indicators developed by entities involved in aviation activities that reflect the specifics of their areas. They relate directly to the threat areas identified and defined by specific entities.

There are also two approaches: qualitative and quantitative. Indicators defined by the qualitative approach are descriptive and are measured through quality. Quantitative indicators, on the other hand, refer to measurements through quantity and can be written in the form of a number or ratio [4]. The preferred choice of indicators among aviation entities tends to be those defined quantitatively, as they are more accessible to measure and compare with other indicators.

The most common classification of SPI indicators used by countries and aviation entities is their division by nature. This division distinguishes two types of indicators [4, 11]:

- leading indicators – these are based on processes and inputs that are implemented to improve or maintain safety level
- lagging indicators, also called reactive – are based on information about events that have already occurred in the past and may affect the level of safety. They usually refer to negative consequences that the organization or the state intends to avoid. Outcome indicators can be divided into high severity indicators (of low probability and high severity of consequences of an event, which relate to accidents and serious incidents) and low severity indicators (of high probability and low severity of consequences of an event, which relate to incidents or other events related to daily operations).

Examples of leading and lagging indicators are shown in Table 1.

Table 1. Summary of sample leading indicators of safety level; own compilation based on [4, 7, 10, 12]

Indicator	Indicator description
Effectiveness of Safety Management	An indicator relating to the level of effectiveness of safety management in an organization. Includes the areas of safety policy and objectives, risk management, safety assurance, safety promotion and safety culture.
Runway Incursion	Number of incidents involving the unauthorized presence of an aircraft, motor vehicle or human being on the runway.
Runway Excursion	Number of incidents where aircraft leave the runway in an uncontrolled manner.
Laser (green)	The number of incidents involving the deliberate blinding of aircraft crews with lights from the ground by third parties.
Unmanned Aerial Vehicle	Number of incidents affecting aviation safety related to unmanned aircraft traffic.

An important division of safety level indicators is their grouping into specific levels of detail. According to this methodology, there are three tiers/orders of SPI indicators (SPI tiers) [2, 6, 7]:

- Tier I – synthetic indicators, referring to the entire system. They are designed to provide an overall assessment of the level of safety and inform the public about overall safety trends and significant areas of risk. First-order indicators may include SPIs, such as accident, incident or fatality rates, and may be divided into areas of significant risk. Examples of synthetic indicators are the number of serious incidents per 10,000 flight operations or the number of serious incidents per 1 million passengers checked in.
- Tier II – functional indicators, based on effects. They help monitor specific areas of the system that require additional safety measures. Tier II indicators are used by operators and/or regulators to identify key problems in specific areas so that proper safety measures can be developed, implemented and monitored. Functional indicators by their nature, correspond to outcome indicators. An example of such an indicator would be the number of runway excursions per 10,000 aircraft operations.
- Tier III – causal indicators referring to the factors that make up the problem area of the aviation system, as defined by the first- and second-order indicators. Tier III indicators are designed to provide information on the effectiveness of safety measures. They are used to identify various activities and initiatives relating to specific risk areas and the effectiveness of the organization's risk control. Order III indicators correspond to the causes of events classified as functional indicators. For example, the number of improper runway contact or aborted takeoffs at too high a speed can be monitored for runway excursions.

The European indicators for 2022–2025 presented in the National Safety Plan are: Runway Incursion, Runway Excursion, Abnormal Runway Contact, Fire, Smoke&Fumes, Ground Safety, Controlled Flight Into Terrain, Loss of Control in Flight, Mid-Air Collision/Aircraft Proximity, Aircraft Condition SCF-NP and SCF-PP, Language Proficiency Requirements Implementation, Examination Fraud and Implementation of SESAR Solutions. On the other hand, the national ones included Birdstrike, Wildlife hazards, Operations (UAV/RPAS), Blinding pilots with lights from the ground, Aircraft incidents related to glider towing, Performing flight operations below permissible Hazardous materials transport incidents, Helicopter incidents and Foreign Object Debris incidents.

The annex to the National Safety Plan, which is updated once a year, provides a list of specific SPIs that are monitored at the national level and mandatorily reported quarterly with a monthly breakdown to the Civil Aviation Authority. Entities subject to mandatory SPI reporting include aviation training centers (ATOs), aircraft operators (OPS), public use airport managers (ADRs) and air navigation service providers (ATM/ANS), as well as ground handling agents for handling hazardous materials or supplying aircraft with propellants (AHACs).

3. Calculation of SPI indicators and their target values

Measurement of the level of safety in an aviation organization, should take into account a combination of all possible types of indicator classification. These indicators should be defined and grouped to best suit the specifics of the entity. Their definition should take into account factors such as the connection of the indicators with the safety objectives they intend to indicate and their realism, taking into account the capabilities and limitations of the organization [4]. The process of defining safety level indicators usually consists of three stages [2, 10]:

1. Identification of the organization's main goals and key issues – reviewing the organization's safety policy and security objectives
2. Data acquisition – gathering available information that can help define indicators
3. Defining the parameters of the indicators – defining the SPI indicators and determining their parameters.

The value of the safety level indicator is most often determined from the relationship:

$$\mathrm{SPI} = \frac{\mathrm{Lz} \cdot \mathrm{a}}{\mathrm{N}} \quad (1)$$

where: SPI – value of the safety level index, Lz– number of events, a – weighting factor for the number of operations, events or flight hours (e.g. 1000, 10,000, etc.),N – number of operations, events or flight hours.

Alert levels for SPI are determined from the relationship:

$$\text{Pn} = \overline{\text{X}} + \text{n}\sigma \qquad (2)$$

where: Pn– the next alert level (n = 1, 2, 3), $\overline{\text{X}}$ – average value of the safety level indicator, σ – standard deviation.

On the basis of the National Safety Plan and Program for 2022–2025, national and European indicators were selected, according to the authors, as the most important for traffic aviation. Table 2 summarizes the number of operations and incidents in the analyzed years. Table 3 shows the values of SPIs (formula 1) and their alert levels (formula 2) for 2023. Thus:

NO – a flight between takeoff and landing is considered an operation for this indicator, regardless of the nature of the flight (training, commercial, technical, etc.). In the case of, for example, a route with a stopover, it will then count as two operations (two takeoffs – two landings. It also considers "touch and go" as an operation (in that case counted as two operations). It does not consider "go-around" or "low pass" as an operation.

Mid-Air Collision/Aircraft Proximity. MAC – **AIR** – defines events involving a mid-air collision between two aircraft. Despite the fact that this type of CAT event has not been recorded in Europe for several years, the ever-increasing number of dangerous proximity (AIRPROX) does not allow to ignore this hazard area. SPI but ATM operators are determined as the number of airspace violations/10,000 operations.

Runway Incursion – **RI** – incursion refers to: a vehicle, a person, another aircraft. Incursion is considered to be the appearance of the aforementioned entity on the plane provided for takeoffs and landings, taxiing or parking, respectively, in a situation when the object/person should not be there ("incorrect presence"). This also includes situations where the incident occurred through incorrect execution of ATC instructions or execution of incorrect ATC instructions.

Blinding of aircraft crews [8] – **LASER** – is a threat resulting from deliberate violations of standards and regulations by third parties. Due to the growing scale of the phenomenon (number of reports), preventive measures have been taken by including these incidents in the scope of mandatory CFIT.

Controlled Flight Into Terrain – **CFIT** – and all GPWS and TAWS alerts. Accidents classified as Controlled Flight Into Terrain CFIT do not often appear in statistics, but if they do occur, they usually generate a high number of fatalities (especially in CAT). GPWS (Ground Proximity Warning Systems) and TAWS (Terrain Awareness and Warning Systems) have significantly improved the safety of operations, but the CTIF threat has not been completely eliminated. In order to better monitor the level of risk associated with the CFIT area, it was decided to extend monitoring to the activation of GPWS and TAWS distress signals themselves – they account for the majority of reported aviation incidents in this category. For this reason, EASA mandated the inclusion of CFIT in national safety plans (task MST.006) and placed CFIT in the European plan.

Birdstrike – **BS** – In recent years, no aviation accident has been reported due to a collision with a bird. However, the number of incidents is increasing. For CAT air traffic, an almost 5-fold increase in the aggregate numbers of non-safety incidents and undetermined incidents is observed between 2012 and 2020.

Ground Safety. **GCOL** – ground safety includes two basic categories:

– Ground Collisions (GCOL)
– ground handling incidents (RAMP).

An aircraft collision that occurs while taxiing from a runway or onto a runway is considered a GCOL and includes a collision with:

– another aircraft
– a person
– an animal
– a vehicle
– an obstacle (object)
– a building
– etc.

provided that the incident did not occur on the runway on which the aircraft landed or from which it intends to takeoff. In the case of helicopters, taxiing may involve a sub-landing. Crashes on the runway (usually as a result of RI) or crashes during handling (RAMP) are excluded from this category.

RAMP incidents alone make up the fourth largest category of fatal accidents in the world. In addition to endangering life and health, GCOL and RAMP cause property damage (damaged aircraft, equipment and machinery, and airport and handling agent equipment). Thus, this threat has found a special place in the monitoring framework in EPAS. In addition, EASA has indicated the obligation to implement specific surveillance of these types of hazards to Member States.

Wildlife hazards – **RI-A** hazard associated with the presence of animals on the maneuvering field of airports. Events of this type also occur at major airports which can negatively affect the safety of passenger operations.

Unmanned aerial vehicle (**UAV**/RPAS) operations – Unmanned aerial vehicle operations are the latest threat in civil aviation. Incidents involving violations of airport CTR zones by drone operators who used these devices without the required authorization and knowledge of airspace regulations, have become a particular challenge.

Performing flight operations below the permissible visibility of the so-called "Approach below **RVR** minima" (ApBRM) – as a precursor to the CFIT or CTOL hazard from the European area. The hazard of performing landing operations below RVR minima can result in one of the most serious categories of aviation accidents, which is CFIT or CTOL (a collision with an obstacle during landing is classified as CTOL, while a possible collision after aborting the landing procedure and starting the go-around procedure should be classified as CFIT – if there were no other causes). Due to the fact that there are attempts to continue such operations despite the knowledge of RVR below the minimum, it is necessary to determine whether such practice on the territory of the Republic of Poland is of an incidental nature, or whether a dangerous precedent of taking unjustified risks has been established. Foreign Object Damage events. **FOD**s can have negative consequences not only on the ground (damage to aircraft and associated repair costs and from delaying flight operations), but also in the air (e.g., if not detected during pre-take off inspection). FODs are divided into those found on the runway, taxiways, and aprons and those related to aircraft maintenance and ground handling. Due to the fact that the orderliness of the aviation part of the airport is influenced not only by the work of the airport manager but also by the growing number of ground handling agents (so-called handling agents), FOD incidents are increasingly taking place in civil aviation.

4. Analysis of the value of safety indicators

As can be seen from the definition of SPI, it is a relative measure, showing the relationship between the number of aviation incidents and the number of flight operations. The number of aircraft incidents may or may not depend on the number of aircraft operations. Therefore, in addition to determining the SPI and SPT, the analysis decided to introduce a correlation coefficient to show the degree of the aforementioned relationship.

For this purpose, the Pearson correlation coefficient was used, given by the following formula [3]:

$$r = \mathrm{cov}(N, Lz) \cdot [s(N) \cdot s(Lz)]^{-1} \tag{3}$$

where: cov(.) – covariance of variables, s(N) – standard deviation of the number of flight operations, s(y) – standard deviation of the number of incidents.

The interpretation of the value of the correlation coefficient from the point of view of the level of safety is as follows. If the correlation is strong (it is usually assumed such above the value of 0.5 of the correlation index), this may indicate properly functioning safety systems (here we understand safety systems not only as technical solutions but as a set of human, procedural and technical resources established to bring and maintain the risk of hazards at least tolerable level [4]). SPI values are then close to each other (small standard deviation), and the number of aviation incidents varies proportionally to the number of flight operations. In this case, we exclude the situation, which cannot be verified without additional information, that safety systems are not functioning properly, but the number of sources (factors) of hazards causing aviation incidents has decreased.

If the correlation is insignificant (we assume such below the value of 0.5), then the number of aviation incidents is not dependent on flight operations in the sense that an increase in the number of these operations does not entail an increase in the number of aviation incidents, and vice versa – a decrease in the number of flight operations does not guarantee a decrease in the number of aviation incidents. As in the case of a strong correlation, it is not possible to say unequivocally whether such a situation is the result of malfunctioning safety systems or an increase in the activity of other sources (factors) of danger not covered by these systems.

The values of correlation coefficients and other statistical characteristics for SPI are given in Table 4.

Table 2. Number of incidents by category; own compilation based on [10]

Year	NO	AIR	RI	LR	CTIF	BS	RI-A	UAV	RVR	FOD	GCOL
2011	246 679	62	33	57	9	181	22	6	3	24	8
2012	276 696	87	35	92	9	194	30	7	13	14	8
2013	263 028	63	47	88	10	204	25	3	11	12	6
2014	268 999	96	24	129	5	287	23	2	3	13	5
2015	283 341	91	61	107	6	387	26	18	8	24	5
2016	309 795	108	80	101	12	501	31	21	1	17	12
2017	341 199	97	104	135	21	547	42	12	1	33	16
2018	381 547	285	110	112	74	652	44	57	7	45	22
2019	398 073	246	169	170	97	850	50	77	4	70	11
2020	165 327	179	88	86	79	496	23	82	0	63	23
2021	202 874	187	132	113	108	1019	31	103	1	44	43

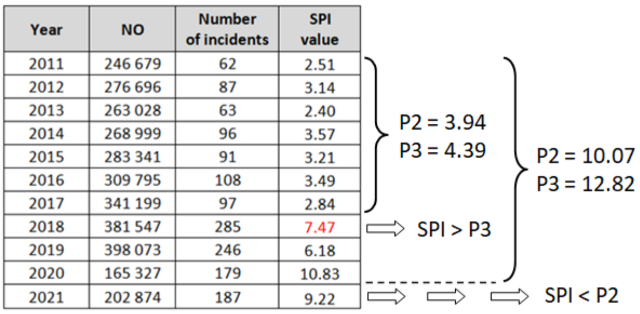
Table 3. SPIs and their alert levels; own compilation based on [10]

Year	AIR	RI	LASER	CTIF	BS	GCOL	RI-A	UAV	RVR	FOD
2011	2.51	1.34	2.3.1	0.36	7.34	0.32	0.89	0.24	3	0.97
2012	3.14	1.26	3.32	0.33	7.01	0.29	1.08	0.25	13	0.51
2013	2.40	1.79	3.35	0.38	7.76	0.23	0.95	0.11	11	0.46
2014	3.57	0.89	4.80	0.19	10.67	0.19	0.86	0.07	3	0.48
2015	3.21	2.15	3.78	0.21	13.66	0.18	0.92	0.64	8	0.85
2016	3.49	2.58	3.26	0.39	16.17	0.39	1.00	0.68	1	0.55
2017	2.84	3.05	3.96	0.62	16.03	0.47	1.23	0.35	1	0.97
2018	7.47	2.88	2.94	1.94	17.09	0.58	1.15	1.49	7	1.18
2019	6.18	4.25	4.27	2.44	21.35	0.28	1.26	1.93	4	1.76
2020	10.83	5.32	5.20	4.78	30.00	1.39	1.39	4.96	0	3.81
2021	9.22	6.51	5.57	5.32	50.23	2.12	1.53	5.08	1	2.17
Level	7.95	4.69	4.88	3.43	30.64	1.20	1.33	3.30	9.13	2.26
Level	10.91	6.47	5.88	5.32	43.34	1.81	1.55	5.17	13.54	3.27
Level	13.88	8.26	6.88	7.21	56.05	2.42	1.77	7.03	17.95	4.28

Table 4. Values of Pearson's correlation coefficients and selected statistical characteristics for SPI in various aviation incidents over an eleven-year period (2011–2021)

Event	Value of the correlation coefficient	Value of the testing statistic (Tcr = 2.2622)	Mean value SPI	Standard deviation SPI
AIR	0.378	1.2239	4.99	2.96
RI	0.402	1.3156	2.91	1.78
LASER	0.630	2.4363	3.89	1.00
CFIT	0.015	0.0455	1.54	1.89
SS	0.206	0.6308 (correlation significant)	17.94	12.70
GCOL	–0.294	–0.9222	0.58	0.61
RI-A	0.833	4.5093 (correlation significant)	1.11	0.22
UAV	–0.129	–0.3911	1.44	1.86
RVR	0.191	0.5822	4.73	4.41
FOD	0.123	0.3704	1.25	1.01

The situation's lack of correlation, in addition to the indicated difficulties in assessing the performance of the system from a safety perspective, raises questions about the sensitivity of the SPT indicator. An example is the situation regarding the number of airspace violation events shown in Fig. 1.



Year	NO	Number of incidents	SPI value
2011	246 679	62	2.51
2012	276 696	87	3.14
2013	263 028	63	2.40
2014	268 999	96	3.57
2015	283 341	91	3.21
2016	309 795	108	3.49
2017	341 199	97	2.84
2018	381 547	285	7.47
2019	398 073	246	6.18
2020	165 327	179	10.83
2021	202 874	187	9.22

Fig. 1. An example of data generating difficulties in assessing the performance of the system from a safety perspective

The limiting SPT values, that is, P2 and P3, calculated up to and including 2017, qualify the 2018 SPI value into the unacceptable range, as indicated in Fig. 1 (SPI(2018) = = 7.47 < P3). After a few years, that is, until 2021, the SPT values change due to changes in the SPI. This causes the SPI value in 2021 to no longer exceed the critical alert level, despite a proportionally higher number of events than in 2018 (and with fewer flight operations than in 2018). Such qualification as an accepted (non-alert) level would be acceptable if, during the years under consideration, the acceptance (e.g., by the public, aviation entities, national authorities) of a given number of aviation incidents relative to the number of flight operations actually increased. Otherwise, SPIs in 2020 or 2021 should be valued differently or subjected to detailed analysis before they are considered non-alarming.

It can be noted that SPTs alert to changes in SPIs, but only when SPI volatility is low. When the variability is high, as it were, they ensure acceptance of such a state of affairs regardless of whether the values of individual SPIs are actually critical. This generates a doubt – can the achievement of a state of safety be considered at high SPI variability, treating such variability as typical for the system?

The problem is that alarm thresholds "follow" changing data. Any large SPI value, even once occurring, raises the alarm thresholds a lot (the standard deviation increases), which may falsely fail to alarm in the following year. In other words, SPT alerts to the abnormality of SPI, but only if it exceeds 99.87% of cases. What's more, an ever-increasing SPI value can be accepted up to significant values of aviation event numbers. This is shown in Table 5, which shows the example of CFIT events together with GPWS and TAWS alarms. For this type of event, the value of the correlation coefficient is very low (0.015; Table 4), which suggests that the number of events is not dependent on the number of flight operations. Therefore, one can theoretically assume a worst-case scenario in which the number of flight incidents increases with a constant number of flight operations. This is shown in Table 5 by assuming that the number of flight operations from 2022 onward is constant and takes the value of the average of previous years.

In Table 5, the number of CFIT events, together with GPWS and TAWS alarms, has been assumed from 2022 as the maximum possible number of events, resulting from the P3 threshold value (minus one event to not exceed the P3 value) i.e.:

$$Lz_i = 10^{-4} \cdot (285233 \cdot P3_i) - 1 \tag{4}$$

where: Lz_i is the maximum possible number of events in the i-th year, resulting from the value of the $P3_i$ threshold for that year.

Table 5. Number of CFIT events including GPWS and TAWS alarms with the maximum possible number of events resulting from the P3 threshold adopted from 2022

Year	No	CFIT	SPI value*	Value of the P3 alarm**	Exceeding the P3 alarm threshold
2011	246679	9	0.365	–	–
2012	276696	9	0.325	–	–
2013	263028	10	0.380	0.429	NO
2014	268999	5	0.186	0.442	NO
2015	283341	6	0.212	0.580	NO
2016	309795	12	0.387	0.561	NO
2017	341199	21	0.615	0.575	YES
2018	381547	74	1.939	0.777	YES
2019	398073	97	2.437	2.279	YES
2020	165327	79	4.778	3.244	YES
2021	202874	108	5.324	5.636	NO
2022	285233	205	7.178	7.213	NO
2023	285233	264	9.261	9.296	NO
2024	285233	335	11.756	11.791	NO
2025	285233	420	14.712	14.747	NO
2026	285233	519	18.185	18.220	NO
2027	285233	634	22.229	22.264	NO
2028	285233	767	26.906	26.941	NO
2029	285233	921	32.278	32.313	NO
2030	285233	1096	38.409	38.444	NO

*SPI value per 10,000 flight operations
**Value of the P3 alarm threshold in effect for the year

This allows us to observe the maximum possible values of aviation events in subsequent years that do not activate the P3 alert threshold. For example, the value of the P3 alert threshold for 2022 was 7.213. This means that in 2022 the number of aviation events could be as high as $10^{-4}\cdot$ (285233 · 7.213) – 1 = 205 events. Of course, this assumes only theoretically that such a large number of incidents is possible in a year with a given number of flight operations. However, if such a situation actually occurred in the following years as well, then in 2030 there would already be 1,096 events without activation of the alert threshold, which is a considerable increase in this number, for example, compared to 2017 when the P3 alert threshold was exceeded.

Similarly, a situation of no alarm occurs when assuming a random number of flight operations in successive years. The results are shown in Table 6 for one sample implementation of the number of flight operations as a random variable with a uniform distribution on the interval <165327; 398073>. The range of random number generation was taken as the minimum and maximum number of flight operations in 2011–2021.

However, setting SPT thresholds in the current manner may be justified when the standard deviation of SPI is small, which is the case, for example, when N and Lz are highly correlated (see, for example, Lz– animal threats). Otherwise, consideration should be given to adopting an alternative acceptance or alarm threshold (designated or otherwise adopted). Figure 2 shows a proposal for such an approach in the case of low correlation of N and Lz. It should be noted that this is only an example of how to look for target SPT thresholds and is not a definitive solution for all possible cases of SPI changes.

Table 6. SPI and P3 values for one realization of the number of flight operations as a random variable with a uniform distribution on the interval <165327; 398073>

Year	Random number of air operations	CFi T	SPI value*	The value of the P3 alarm**	Exceeding the alarm threshold P3
2022	379,589	273	7.187	7.213	NO
2023	222,486	206	9.257	9.302	NO
2024	303,332	357	11.759	11.792	NO
2025	175,232	257	14.693	14.750	NO
2026	363,142	660	18.184	18.211	NO
2027	352,584	784	22.229	22.258	NO
2028	369,275	994	26.909	26.936	NO
2029	310,388	1002	32.278	32.310	NO
2030	222,266	853	38.398	38.443	NO

*SPI value per 10,000 flight operations
**The value of the P3 alarm threshold in effect in a given year

In the first step of the algorithm, on the basis of the input data, that is, the number of flight operations and the number of flight incidents in consecutive years (on the basis of which the CFI is to be estimated), the correlation coefficient is determined according to formula (3). Then, it is necessary to check whether the value of the correlation

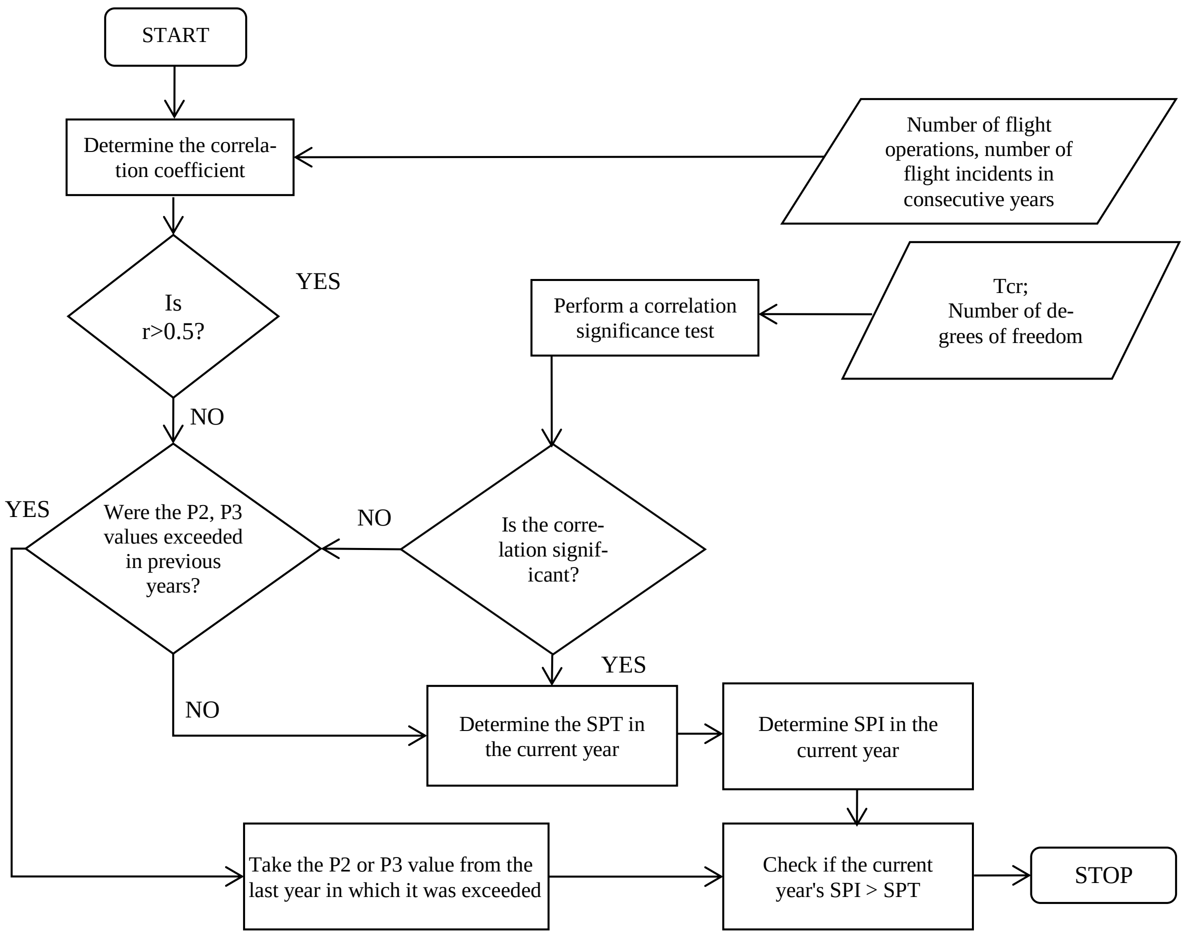


Fig. 2. Algorithm for proceeding in using SPI, SPT and correlation coefficient

coefficient exceeds the value of 0.5, indicating a strong correlation, and to perform a test of the significance of the correlation, allowing to consider its statistical significance. For this, it is necessary to determine the critical value of the Tcr statistic with the appropriate number of degrees of freedom. In the event that the correlation is statistically significant, you can proceed to determine the SPT and SPI sequentially for the selected year in the standard way (formulas 1 and 2).The results of such estimates of SPT and SPI are shown in Tables 3 and 4, among others. If the correlation between the number of aircraft incidents and the number of aircraft operations is not confirmed, then, according to the proposal shown for an alternative approach to estimating SPT, it is necessary to check whether in the years prior to the current year (for which one wants to determine SPI), the target safety threshold value P2 or P3 was exceeded. The analyzer's decision to use either P2 or P3 values is left to the analyzer. If in the last year of the years preceding the current year (or the one for which you want to determine the SPI), the P2 or P3 threshold was exceeded, this value is taken as valid for the current year. The final step of the algorithm is to note whether the SPI value exceeds the adopted SPT value.

Summary

In air transport safety management, safety indicators (SPI, SPT) have been accepted as measures to monitor safety levels. SPT alert values (P1, P2, P3), determined by the mean value and standard deviation of the SPI in specific years, are used to signal unacceptable safety levels. The SPI values, and consequently the SPT, are estimated on the basis of aviation events that occurred in earlier years and the number of flight operations in those years. While this retrospective approach is reasonable, it is felt that the authors of this article require certain conditions that would allow their use in subsequent years. The purpose of the article was to calculate Safety Performance SPI values for selected aviation incidents from 2011 to 2021 and to assess their usefulness in monitoring and managing safety in the future. The paper emphasizes the importance of SPI and SPT in aviation safety management but also points out the limitations of existing analysis methods. It has been noted that SPTs alert to critical SPI values, but only when SPI variability is low. When the variability is high, as it were, they ensure acceptance of such a condition regardless of whether the values of individual SPIs are actually critical. The problem may lie in the fact that alarm thresholds adjust to changing data. Any large (much larger relative to the others) SPI value, even once occurring in the years of analysis, raises the alarm thresholds a lot. The standard deviation of the SPI and thus the SPT threshold values increase significantly, which may falsely fail to alarm in the following year. What's more, an ever-increasing SPI value may be accepted, up to significant values of the number of aviation events. Therefore, it was proposed to supplement the existing methodology for estimating SPT with an analysis of the correlation coefficient of the number of aviation events and flight operations. This is because it was noted that while the situation of significant correlation makes it possible to estimate SPT thresholds on the currently accepted principles, the situation of its absence, in addition to certain difficulties in assessing the performance of the system from the safety point of view, raises questions about the sensitivity of the SPT indicator. Consideration should then be given to adopting an alternative acceptance or alert threshold (designated or otherwise adopted). The article proposes such an approach in the case of a low correlation between the number of aviation events and flight operations. However, it should be made clear that this is only an example of how to look for target SPT thresholds and is not a definitive solution for all possible cases of SPI changes. Consideration should also be given to supplementing SPI monitoring with additional qualitative indicators and causal analyses for a better understanding of the sources of risk, as well as an analysis of the acceptability of a given number of aviation incidents relative to the number of flight operations, e.g., by the public, aviation and other entities that shape safety policy in air transportation systems.

Nomenclature

CFIT	controlled flight into terrain
EPAS	European Plan for Aviation Safety
FOD	foreign object damage
GASP	global aviation safety plan
GCOL	ground collisions
GPWS	ground proximity warning systems
ICAO	International Civil Aviation Organization
RAMP	ground handling incidents
SPI	safety performance indicators
SPT	safety performance targets
TAWS	terrain awareness and warning systems

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