AIRPORT ALoSP AND INTEGRATED RISK APPROACH FOR SSPs

Daniel Cunha
Department of Civil and Environmental Engineering
Faculdade de Tecnologia, Campus Universitário Darcy Ribeiro, Brasília - CEP 70910-900

Michelle Andrade
Department of Civil and Environmental Engineering
Faculdade de Tecnologia, Campus Universitário Darcy Ribeiro, Brasília - CEP 70910-900

Javã Silva
National Civil Aviation Agency - ANAC
SCS Q9 - Lote C – Ed. Parque Cidade Corporate - Torre A - Brasília - CEP: 70.308-200

ABSTRACT

The paper proposes the development of a methodology regarding the risk management in airports for ICAO's State Safety Programmes (SSP). To achieve that, researchers investigated the nature of the airport safety events occurred in busiest Brazilian airports and proposed a risk index capable to provide the Acceptable Level of Safety Performance (ALoSP) ICAO demands to their signatory States. This approach allowed researchers to rank several airports per their risk in relation to the calculated ALoSP calculated and proposed State optimized regulatory actions to address accordingly where the risk observed. The research found the high concentration on risk recurrence among 31 airports. Only 4 concentrated 30% out of all the recurrence of risk, 8 were responsible for 50% and 17 represented approximately 80% of the total risk load in Brazilian airport operations. Five groups of airports are proposed as per their safety performance (Safety+2, Safety+1, Neutral, Safety-1 and Safety-2). The measurement of their performance results presented several statistically significant differences. Safety+1 group presented a safety performance of 1.49 times better than the standard ALoSP as well as 3.52 times better than the worst group of airports (Safety-2). The Safety+2 group was 3.76 times safer than ALoSP and 8.88 times safer than Safety-2 group. Safety-1 group presented a risk level of 1.51 times higher than ALoSP and Safety-2 performed 2.35 times riskier than the ALoSP. This proposed matrix, woks as a tool for airports to identify their safety weaknesses and promote efficiency and rationality to the SSP's by amplifying their effectiveness.

KEYWORDS

Acceptable Level of Safety Performance (ALOSP). Airport. Risk. Risk Assessment. Risk Management. State Safety Programme (SSP).

1. INTRODUCTION

1.1 Background

Annex 19 - Safety Management (2016), DOC 9734 "State Safety Programme - SSP" (2006) and DOC 9859 - Safety Management Manual (2018) are the main documents orienting the implementation of an efficient and effective safety oversight system among all signatory States of the International Civil Aviation Convention.

They guide the States to perform their oversight functions by systematically dealing with the air transport risks keeping it in an ALARP (As Low As Reasonably Possible) level.

In this line, they specify that each SSP should establish for each aviation activity (*i.e.* aerodrome operations) the called Acceptable Level of Safety Performance (ALoSP). This monitoring should be done through safety indicators and targets.

The Brazilian Civil Aviation SSP (ANAC, 2019), in line with these guidelines, commands that civil aviation activities shall be subject to a performance monitoring process based on acceptable indicators, targets and acceptable levels of safety performance.

However, to regulate and control risk it is necessary to be able to identify it (Ashford *et al.*, 1997; ICAO, 2019). This activity can be based on two forms of evaluation that Sage & White (1980) called "social risk": the reactive model and the predictive model.

The first refers to the real or statistical risk, which would occur through the monitoring of the statistical recurrence of significant data of unwanted events. The second would be the estimation of risk based on the perception of individuals or on predictions via structured models for the analysis of latent conditions in a given system before the actual realization of the risk (Janic, 2000; ICAO, 2016).

Despite of the fact that predictive models present a better cost-benefit relationship, they require a more sophisticated data acquisition and a more complex knowledge on the system managed.

Thus, due to the fact that because reactive approach is simpler to implement, despite of being highly dependent on the availability and quality of data, this approach has been the main source of evolution of aviation safety, (Das & Dey, 2016; Ayhan & Tokdemir, 2020).

OACI (2019), IATA (2020), Braithwaite (2001), Eddowes *et al.* (2001), Wagner & Barker (2013), Boyd (2015), Roelen & Blom, (2013) and Iwadare & Oyama (2015) are examples of the use of this approach.

1.2 Efficient regulation

Statistically, almost 80% of aviation accidents occur at airports (Feng & Chung, 2013). Boeing (2019) records to commercial jet fleet worldwide that 40% of all fatal accidents occur in airport procedures (parking, taxi, take-off, landing), despite of only 2% of flight time are spent in this environment.

Most of them occur on or near runways. The total costs of runway events from 2015 to 2018 are estimated at $500 Million per month. In this period were recorded around 2.100 events worldwide (Eekeren *et al.*, 2018).

Flight Safety Foundation (FSF, 2020) estimates that 27,000 ramp accidents and incidents (one per 1,000 departures) occur worldwide every year. About 243,000 people are injured each year in these accidents and incidents (9 per 1,000 departures). Apron accidents cost major airlines worldwide at least US$10 billion a year.

Risk regulation has been inefficient, according to Gowda (1999), and could be improved (Ketbadari *et al.*, 2018) with the use methodologically validated techniques (Florig *et al.*, 2001).

A significant number of studies tried to set predictively or reactively, the importance for airport safety events. However, the practical result of the lack of an efficient regulation on airport safety oversight lies on the fact that, there are currently no risk rankings of airports in public statistics combining two or more "not miscible" unwanted operational events. The former statement summarizes the main focus of this work.

As State does not map the risks involved in the operations under its supervision in a broad way, it becomes impossible to adopt risk mitigation strategies to ensure its best operational performance (FAA, 2000; ICAO, 2018; ACRP, 2015).

As a result, the need to advance in the quality of airport safety monitoring implemented by the SSP's is vital. This work aims to propose the development of a methodology for the risk management in airports for the SSP in a broad way.

The research intends to investigate the nature of the airport safety events occurred in busiest Brazilian airports, proposing the combined use of the recurrence of such events and their relative severities, generating a dimensionless risk index capable of compare and rank them.

This work also proposes the identification of an ALoSP for airports in Brazilian SSP, so State can have a reference point of performance to better direct resources on market risk management.

In order to achieve that, the research proposes a methodology which combines the Abbreviated Injury Scale (AIS) proposed by Eurocontrol (2018) and ICAO ADREP taxonomy. Using the former template, the risk analysis-based approach, demanded by ICAO, can be fully implemented at first in Brazil as well as can suit as a trial for future expansion.

The initial section introduces the subject and the problem posed. Section 2 presents the theoretical framework about the integrated risk model for the monitoring purposed in this work. The construction of the model is brought in section 3, and section 4 shows a sensitivity analysis applied to the real case of the main Brazilian airports. The paper concludes in section 5, with the main outcomes.

2. LITERATURE REVIEW

2.1 Risk

Currently the concept of risk penetrates virtually all human activities, and there is no consensus as to its formal definition (Čokorilo *et al.*, 2010, Makowski, 2005). However, there is a common sense towards the concept of risk as being the quantification of the consequences of an unwanted danger or event, expressed in terms of probability and severity (Reason, 1997; NASA, 2007; INCOSE, 2010; Stolzer *et al.*, 2012; ICAO, 2018; FAA, 2014; ACRP, 2015; Lopez-Lago, *et al.*, 2017).

Severity is the risk parameter that informs the potential for damage that an event can cause in a given system. It refers to the intensity, size, extent, scope, and other potential measures of magnitude of an event. Losses and gains, for example, expressed by money or the number of fatalities, are ways of defining the severity of the consequences (Aven & Renn, 2009).

There are many possible consequences in the operational mix of an airport due to the great complexity of this environment. It can be used as severity parameter ground operation accident costs, life injuries or losses, potential reduction on profit caused by a disrupted runway, image losses, insurance values increase, etc. (ACRP, 2011; 2015).

It is also used in airport risk monitoring as severity parameter the classification of undesired events that aims to control, based on the typical occurrences verified in historical data of operation (Distefano *et. al.*, 2013).

ICAO (2018) recommend generically that an operator or State may adapt their severity parameter selection to better serve their monitoring models.

The process of controlling risks also involves assessing the probability of the occurrence of unwanted events. It is possible to identify in the literature criteria ranging from merely subjective approaches to objective approaches with probabilistic calculations where possible (ACRP, 2015).

For this parameter ICAO also recommend users to adopt criteria that best fit their operational realities, with the aim of better managing their safety environment. Yilmaz (2019) states that two types of approaches in predictive risk analysis are used for this: quantitative and qualitative methods.

In the qualitative method, the author argues that its subjectivity is better applied in techniques that seek to capture the perception of those involved regarding a specific risk in an environment with scarce data. There are many qualitative techniques widely used in risk management processes: What-if, HAZOP, FMEA, FTA, BowTie, Event Tree, etc.

With some variations, they all go through the essential risk management process that identifies hazards and present barriers, estimates the magnitude of the initial risk, implements mitigation solutions and monitors the results. These are descriptive techniques that seek to study the logic of the occurrence of a given risk, with use more applicable to the day-to-day operations in an organization.

The quantitative method also contains the fundamental phases of the risk management process, however the risk level is objectively measured. It is more used when there is enough information to allow the decision maker to more assertively choose the best path. This technique dates back to the mid-17th century with mathematicians Blaise Pascal and Pierre de Fermat and there is a large amount of material published in this line (BERNSTEIN, 1997).

Janic (2000) suggests that the management of safety in transportation is a practical problem, with many ways of acting, all of which going necessarily through the statistical evaluation of the probability of an event and its consequences, with the use of recurrence time for cases where raw data is needed.

The author argues that the more adequate approach to use in state policies is the use of the so-called "statistical risk", which is nothing more than the analysis of the actual frequencies of occurrences of different severities from real data. ICAO also supports this approach in the state's regulatory balance analysis as the safest form of action (ICAO, 2018).

Knowing, therefore, the current statistical safety environment through recurrence analysis of an unwanted event is basic input for the planning of a quality regulation.

2.2 Integrated risk analysis approach

Risk integration for SSP's is a practice brought, as cutting edge, in the update of the SMM (OACI, 2018). Integrated risk analysis (IRA) aims to address this problem (NASA, 2014).

It consists of assessing the risks of the system. Rather than focusing on a set of separate analyses, IRA can fill gaps that remain after the compartmentalized study, and that influence the final performance of a system.

In this regard, as Wong *et al*. (2009) states, an integrated approach to risk management at airports crosses existing regulatory boundaries because it reflects the conceptually continuous nature of risk. It facilitates more efficient global policies rather than current fragmented and compartmentalized risk control measures.

Fischhoff (1994) argues that risks are never perceived in an absolute sense, but always when contextualized in relation to other risks. For Slovic (1987) this concept is named "perspective risk".

In addition to comparing risk values with each other, a good practice is to relativize them in front of previously established performance levels (Curtis & Carry, 2012; Slovic & Peters, 2006), measuring their distances to reach acceptable levels for a given system.

Risk ranking is also considered an effective way for analysis and communication on risk management (Johnson, 2004; NAS, 2017).

Knowing the value of the total risk of the system and its composition, prioritizing its main elements, is an important step to direct the optimized application of resources in the formulation of regulatory policies (Watson, 2005; Wong *et al.*, 2009; Yilmaz, 2019), as is the case of the SSP.

Finally, this integrated and compared analysis will allow a systemic address of the major risks across the airports and at the same time identify the critical airports that need an increased oversight (Baldwin *et al.*, 2012).

3. METHOD

The purposed methodology is based on previous knowledge acquisition on the main subjects approached: quantitative risk assessment as is theorized and integrated risk monitoring.

Then is brought the airport integrated risk model for SSP's. After that is necessary to define scope matters, such as the group of airports selected to test the model (which must be representative so the model can be validated), the nature of the safety events and the period data will be collected.

After that are applied the severity and probability weighting for the risk model, and finally, it is done a sensitivity analysis on data returned and presented conclusions and remarks.

Thus, this work uses an analytical approach when investigates the scenario where the research is, and an inductive approach to adapt the revised risk models and, based on the integrated data, seek the solution of the proposed problem (Gil, 1999).

3.1 Phasing

The work is divided in 6 phases and 10 steps as follows (Figure 1) so it can be checked, challenged and replicated in other transportation systems, which have fundamentally the same characteristics.

Phase 1	Theoretical review			Step 1
Phase 2	Airport integrated risk model →	$r_j = \sum_{i=1}^{N} \frac{a_i S_{AISi}}{A_i}$	$R_t = \sum_{j=1}^{K} r_j$	Step 2
Phase 3	Scope definitions →	*Airports selected*		Step 3
		Safety event data →	*Nature*	Step 4
			Period	Step 5
Phase 4	Weighting →	*Event severity* →	*EUROCONTROL approach*	Step 6
		Probability →	*Event recurrence*	Step 7
			Event relative frequencies	Step 8
Phase 5	Sensivity analysis			Step 9
Phase 6	Conclusions and Remarks			Step 10

FIGURE 1: Study phasing

3.2 Scope

Airports and period of study

The data collected for this work refer to the group of the busiest 31 aerodromes, among the 116 with regular flights currently in Brazil, accounting for 1.89 billion passengers transported in the country from 2010 to 2019 in 94% of the total commercial ATM's on the period.

This sampling took into consideration the regulatory balance between the cost of acquisition of data *versus* the marginal benefit of adding more airports to the group on result of the model (Kirkpatrick *et al.*, 2003).

Catchment of the model

Although it is known that every safety event is given by a multiplicity of factors resulting from many different sources (Feng & Chung, 2013), and many of them can be attributed to pilot performance for example, the model is developed to measure the risk occurred in airport ground operations. The objective is to capture, measure and map those risks, so State can direct more efficiently its efforts to control these issues (Figure 2).

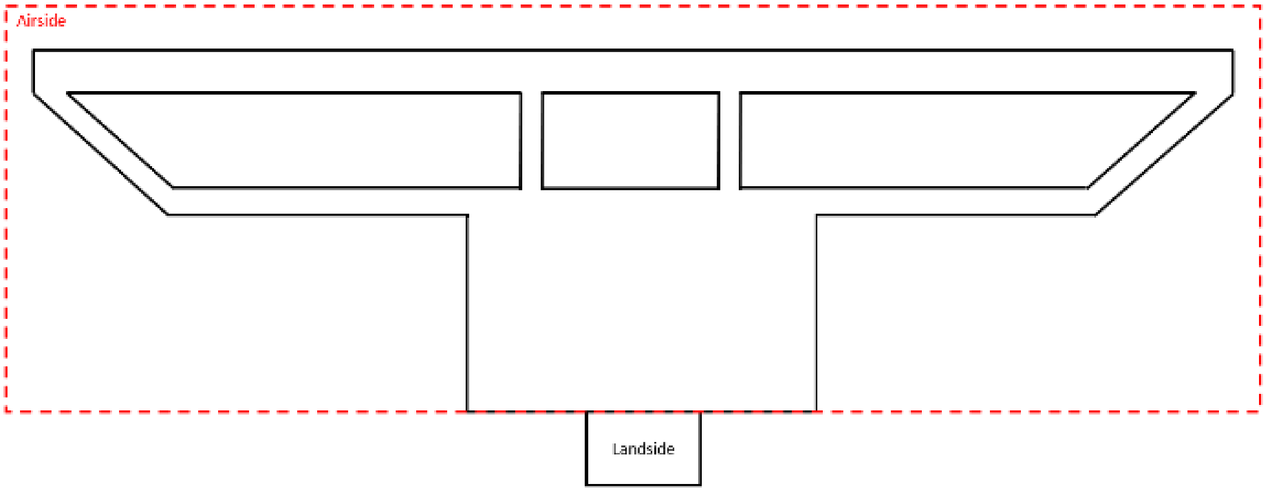

FIGURE 2: Catchment of the model

3.3 Safety data

Safety data collection refers to the period of study. It has been provided by CENIPA (Brazilian accident investigation bureau), which concentrates the safety reports on civil aviation. In this period, as well as for the number of the selected airports for this study, a total of 1.278 safety events were registered. They were classified, categorized and counted accordingly.

Classification

Data from safety events are reported by airports, and CENIPA performs a quality analysis, filtering and classifying according to ICAO ADREP standardized taxonomy. Those safety event classes were correlated to the (AIS) Abbreviated Injury Scale (Eurocontrol, 2018) in order to be determined its actual numerical significance in terms of contribution of risk to the system (Figure 3).

AIS scale (Eurcontrol, 2018)			ICAO Occurrence ADREP Classification*
AIS Level	Severity	Fraction of VSL	
AIS 6	Fatal	1	Accident - Fatal (AF)
AIS 5	Critical	0,593	Accident - Non-fatal (AN)
AIS 4	Severe	0,266	Serious Incident (SI)
AIS 3	Serious	0,105	Incident - Major (IM)
AIS 2	Moderate	0,047	Incident - Significant (IS)
AIS 1	Minor	0,003	Occurence without safety effect (OW)

* Acronyms AF, NA, SI, IM, IS, OW defined in this research

FIGURE 3: Correlation between Eurocontrol AIS scale and ICAO ADREP classification

This methodology is a tool used by Eurocontrol and by the European Union for regulatory impact studies. The AIS scale refers to the degree of injury of an accident victim, where injuries are classified into six categories, from AIS 6 for fatal injuries to AIS 1 for minor injuries. The assessment of each level of injury is related to loss of quality and amount of life resulting from an injury typical of that level. This loss is expressed as a fraction of a fatality, or fraction of the Value of Statistical Life - VSL (Day, 1999; Viscusi & Aldy, 2003).

Categorization

After classification, occurrences were categorized and given an acronym as per ICAO ADREP methodology. Figure 4 brings the events that can occur in airport movement area.

ICAO ADREP Acronym	Definition
ADRM	Aerodrome (aerodrome design, service, or functionality issues are evident)
ARC	Abnormal runway contact (any landing or takeoff involving abnormal runway or landing surface contact)
ATM/CNS	Air traffic management (ATM) or communications/navigation/surveillance (CNS) service issues are evident
BIRD	Occurrences involving collisions / near collisions with bird(s); A collision / near collision with or ingestion of one or several birds.
CFIT	Controlled flight into or toward terrain (in-flight collision or near collision with terrain, water, or obstacle without indication of loss of control)
F-NI	Fire/smoke (nonimpact) (fire or smoke in or on the aircraft, in flight, or on the ground, which is not the result of impact)
F-POST	Fire/Smoke resulting from impact
FUEL	Fuel related occurrence
GCOL	Ground collision (collision while taxiing to or from a runway)
ICE	Icing (accumulation of snow, ice, or frost on aircraft surfaces that adversely affects aircraft control or performance)
LOC-G	Loss of aircraft control while the aircraft is on the ground
OTHR	Other events
RAMP	Ground handling (occurrences during or from ground handling operations)
RE	Runway excursion (a veer off or overrun off the runway surface)
RI-A	Runway incursion-animal (collision with, risk of collision, or evasive action taken by an aircraft to avoid an animal on a runway in use)
RI-VAP	Runway incursion-vehicle, a/c or person (any occurrence 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)
SCF-NP	System/component failure or malfunction (non-powerplant)
SCF-PP	Powerplant failure or malfunction
UNK	Unknown or undetermined
USOS	Undershoot/overshoot (a touchdown off the runway surface)
WILD	Occurrences involving collisions / near collisions with wildlife; A collision / near collision with or ingestion of one or several animals.

FIGURE 4: Airport safety events as per ICAO ADREP taxonomy

Quantification

The recurrence of all safety events occurred in selected airports were computed following the classification and categorization proposed. For data protection and feasibility purposes of the study, randomized codes were inserted in the ICAO airport identifier in a way that their identification was hidden.

Finally, these data were used in the risk model of this work, which distributes the risk values of each airport per passenger handled (V_{pax}).

3.4 Reactive ALoSP in airports for SSP

Errors and faults will occur in any system projected or operated by humans, so current thinking on aviation safety stands that an absolute safe system, although desirable, is impossible to be reached (ICAO, 2018).

Because of this fact, aviation safety is given as a relative notion where risks are tolerated at a certain acceptable level, and safety must be managed so continuous improvement is achieved in the whole aviation system. This level is called Acceptable Level of Safety Performance (ALoSP) (ACRP, 2015; OACI, 2016).

In this research this reference level is obtained by the average risk measured of the airports. In this sense, airports are individually relativized from this reference value and aggregated according to their performance in safety categories events.

Continuous improvement encouraged by ICAO is reached by using Baldwin's positive incentive regulation (Baldwin *et al.*, 2012), providing incentives for the top safety ranked airports.

It is believed that all the airports will tend to look for better performance in persecution for those benefits. This behaviour tends to increase the average safety level of the market, reaching the so-called safety continuous improvement.

Another way to improve the ALoSP using this technique is the implementation by the State of thematic programs on the issues that are mapped as the largest source of risk, *e.g.* financial help for RSA obstacle removal, correction in runway signs deficiencies, pavement grip corrections, etc.

3.5 Airport integrated risk model

This research proposes an integrated risk model for SSP's based on a reactive approach. Thus, adapting the general risk model concept to the purposes of this research, the result is the reactive value of the risk represented by the airport infrastructure for the SSP.

Basically, the probability to encounter an event that occurred in certain airport is the number of events that happened in the airport divided by the total the occurrences of that category according to ICAO ADREP taxonomy (Figure 4). As a result, the risk of that category of occurrence in that airport is its probability multiplied by its relative severity (Figure 3).

Considering that the events are mutually exclusive, the total "Risk index" of a specific airport can be assumed as (Equation 1):

$$r_j = \sum_{i=1}^{N} \frac{a_i . S_{AISi}}{A_i} \qquad [1]$$

Where:

r_j: is the total risk of a specific airport.

N: is the total number of AIS levels of severity.

$a_{i:}$ is the total number of occurrences of certain AIS level in the airport.

A_i: is the total number of occurrences of the system.

S_{AISi}: is severity weighting given by the correlation of Brazilian regulations and AIS Eurocontrol severity scale for that ICAO ADREP occurrence category.

Numerator: is the "Risk recurrence".

Then, the total risk of the system R_t with K airports is found by the sum of the risk performances of each airport, which is:

$$R_t = \sum_{j=1}^{K} r_j \qquad [2]$$

3.6 Data quality

Data provided were evaluated according to their consistency to enable the execution of calculations and risk mapping accurately. This assessment should, whenever possible, be carried out considering the seven principles of data quality provided for in ICAO (2018): validity, fullness, consistency, accessibility, temporality, safety and accuracy.

4. RESULTS AND DISCUSSION

4.1 Previous description of safety events and risk recurrence

A total of 1.278 safety events were reported in the 31 airports selected from 2010 to 2019. After the classification, categorization and quantification they were distributed in (Figure 5).

ICAO ADREP Taxonomy		ICAO ADREP Classification + AIS Severity scale						Total
		OW AIS 1 0,003	IS AIS 2 0,047	IM AIS 3 0,105	SI AIS 4 0,266	AN AIS 5 0,593	AF AIS 6 1	
ICAO ADREP Taxonomy	SCF-NP	0	544	6	45	15	0	610
	OTHR	0	198	5	10	2	0	215
	SCF-PP	0	112	3	6	3	3	127
	BIRD	0	115	6	0	1	0	122
	LOC-G	0	30	1	14	9	1	55
	GCOL	0	28	3	2	2	0	35
	ARC	0	10	2	10	6	0	28
	RE	0	6	0	11	10	0	27
	F-NI	0	23	0	2	0	0	25
	RI	0	8	0	2	0	0	10
	FUEL	0	4	0	4	1	0	9
	UNK	0	4	0	0	0	1	5
	WILD	0	2	0	0	1	0	3
	ATM/CNS	0	1	0	1	0	0	2
	USOS	0	0	0	1	1	0	2
	ICE	0	0	0	1	0	0	1
	RAMP	0	1	0	0	0	0	1
	CFIT	0	0	0	1	0	0	1
	Total	0	1086	26	110	51	5	1278

FIGURE 5: Safety event recurrence per classification and categorization

Brazilian official reports do not record OW events. Since they have an extreme low severity significance, they pollute the samples and increase costs of information acquisition without returning equivalent values in risk.

In this sense these numbers could be acquired for the objective of this research, but they would have a high granularity and a low level of standardization in their capture.

Many previous considerations and assessments can be made only by using initially equation [1]. When attributed the AIS relative severity values to those occurrences it is possible to rank them in risk recurrence (Figure 6).

		ICAO ADREP Classification + AIS Severity scale						Total		
		OW	IS	IM	SI	AN	AF			
		AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6			
		0,003	0,047	0,105	0,266	0,593	1	∑ Risk	% total	Cum. %
Taxonomy ICAO	SCF-NP	0	25,568	0,63	11,97	8,895	0	47,063	39,79%	39,79%
	OTHR	0	9,306	0,525	2,66	1,186	0	13,677	11,56%	51%
	SCF-PP	0	5,264	0,315	1,596	1,779	3	11,954	10,11%	61,46%
	LOC-G	0	1,41	0,105	3,724	5,337	1	11,576	9,79%	71,25%
	RE	0	0,282	0	2,926	5,93	0	9,138	7,73%	78,98%
	ARC	0	0,47	0,21	2,66	3,558	0	6,898	5,83%	85%
	BIRD	0	5,405	0,63	0	0,593	0	6,628	5,60%	90,41%
	GCOL	0	1,316	0,315	0,532	1,186	0	3,349	2,83%	93,24%
	FUEL	0	0,188	0	1,064	0,593	0	1,845	1,56%	94,80%
	F-NI	0	1,081	0	0,532	0	0	1,613	1,36%	96,17%
	UNK	0	0,188	0	0	0	1	1,188	1,00%	97,17%
	RI	0	0,376	0	0,532	0	0	0,908	0,77%	97,94%
	USOS	0	0	0	0,266	0,593	0	0,859	0,73%	98,66%
	WILD	0	0,094	0	0	0,593	0	0,687	0,58%	99,25%
	ATM/CNS	0	0,047	0	0,266	0	0	0,313	0,26%	99,51%
	ICE	0	0	0	0,266	0	0	0,266	0,22%	99,74%
	CFIT	0	0	0	0,266	0	0	0,266	0,22%	99,96%
	RAMP	0	0,047	0	0	0	0	0,047	0,04%	100%
	Total Risk	0	51,042	2,73	29,26	30,243	5	118,28	100%	
	% Total Risk	0%	43,16%	2,31%	24,74%	25,57%	4,23%	100%		

FIGURE 6: Risk recurrence in airports per ICAO ADREP Class and Category

Risk recurrence represents the most direct number to use when dealing with safety assessments in order to mitigate risk.

The initial order sensitivity analysis shows that approximately 50% of the airport safety events are due 2 category of events and only 5, among the 21 possible events in airports, represent almost 80% of the risk recurrence (Figure 7) in an airport.

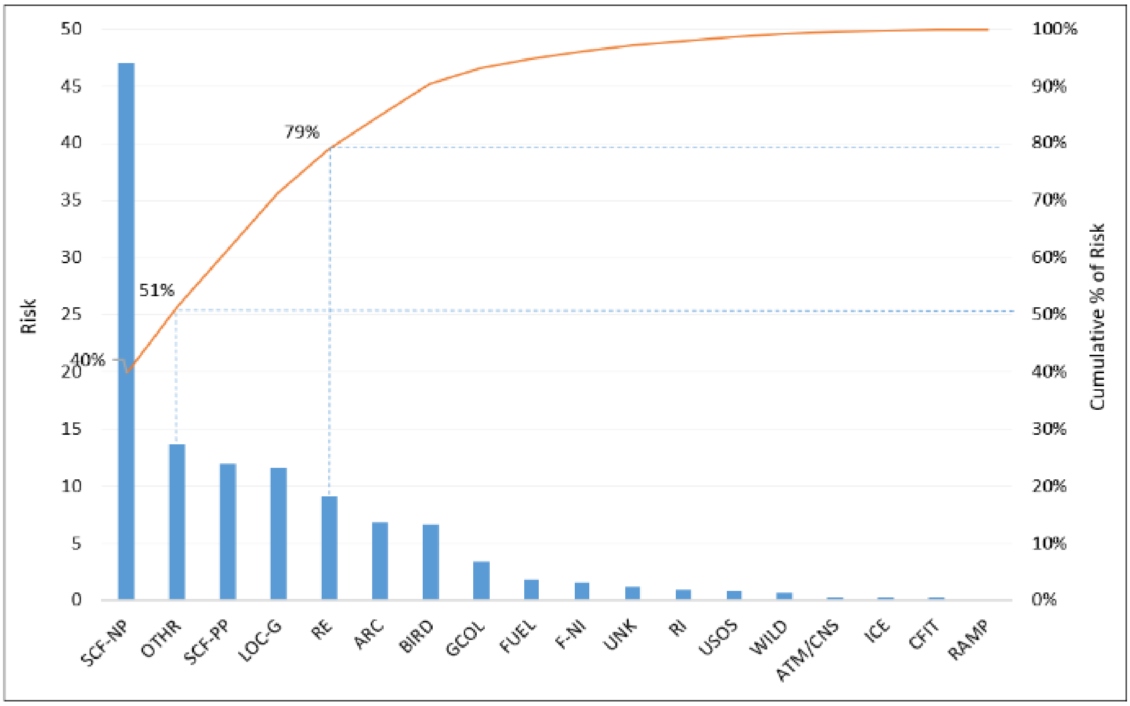

FIGURE 7: Risk recurrence by ICAO Taxonomy - order sensitivity analysis

Another possible initial assessment is to point out in a generic airport, represented by the sum of all 31 airports studied, where the risk recurrence is spatially positioned (Figure 8). Brazilian safety numbers showed a worldwide-like pattern, concentrating the majority of the airport risk recurrence on runway areas and adjacencies.

	ICAO ADREP Classification + AIS Severity scale						
	OW AIS 1 0,003	IS AIS 2 0,047	IM AIS 3 0,105	SI AIS 4 0,266	AN AIS 5 0,593	AF AIS 6 1	∑ Risk
Apron	0	73	2	2	3	0	80
Risk recurrence	0	3,431	0,21	0,532	1,779	0	5,952
Apron %	0%	6,72%	7,69%	1,82%	5,88%	0%	5,03%
Runway	0	858	18	102	48	5	1031
Risk recurrence	0	40,326	1,89	27,132	28,464	5	102,812
Runway %	0%	79,01%	69,23%	92,73%	94,12%	100%	86,93%
Taxiway	0	155	6	6	0	0	167
Risk recurrence	0	7,285	0,63	1,596	0	0	9,511
Taxiway %	0%	14,27%	23,08%	5,45%	0%	0%	8,04%
Total Risk recurrence	0	51,042	2,73	29,26	30,243	5	118,275
% Total Risk recurrence	0%	100%	100%	100%	100%	100%	100%

FIGURE 8: Spatial distribution on airport risk recurrence

Given the fact that 86.93% of the risk recurrence is concentrated in runways, it helps the State to direct resources more efficiently in order to face more severe events on riskier airports.Thus, the proposed model amplifies the SSP effectiveness.

4.2 Risk index and airport performance

By using equation [2] it is possible to establish the proposed relativization among airports by knowing their 10-year risk index (Figure 9).

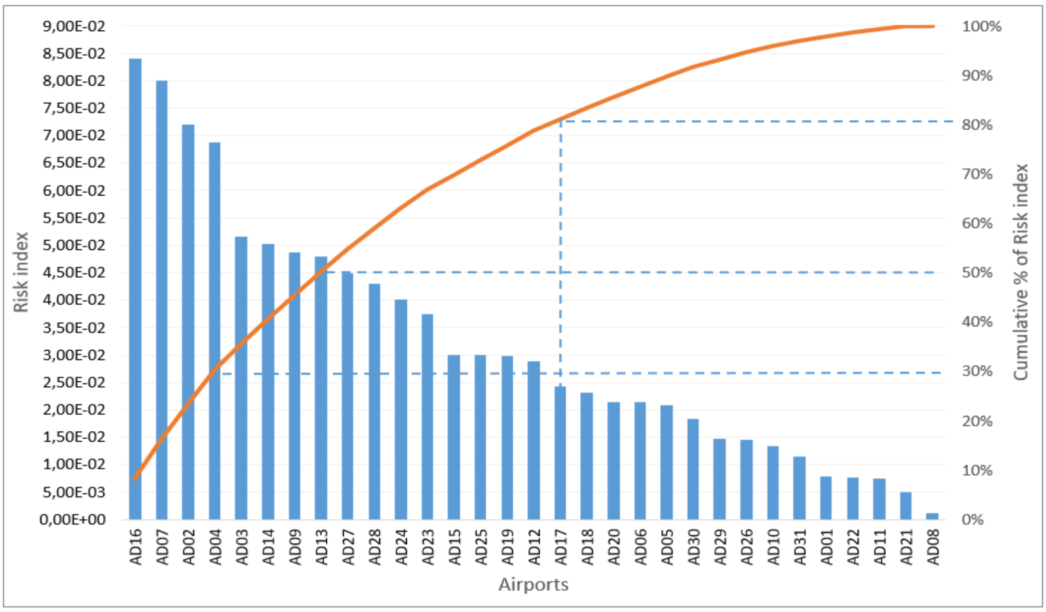

FIGURE 9: Airport 10-year risk index and ALoSP

Among 31 airports, only 4 concentrate 30% of all the risk, 8 are responsible for 50% and 17 represent approximately 80% of the total risk load in Brazilian airport operations.

The mean risk for the 31 airports, studied during 10-year period time, was in 3.23×10^{-2}. As proposed before, this number can be assumed as the initial ALoSP for airports in Brazilian SSP in 2020 (Figure 10). The baseline safety performance (ICAO, 2018).

Since this number is known, and it represents the performance of 10 years of airport safety in Brazil, it can be assumed as a trusted number, be tracked in the future, reassessed yearly and be used as the airport market safety reference.

From this new reference, other risk sensitivity analysis can be made in order to better direct SSP resources and effort. Figure 9 still shows initially 19 airports performing better than the market average and 12 worst. Although it is possible to identify safer and riskier airports from the reference point, a more statistically safe approach is needed so SSP can be handled more effectively.

Since the main objectives of SSP's are (1) reduce risk to ALARP and (2) set a safety continuous improvement environment, is necessary to be certain on which airports are statistically performing different from ALoSP.

In order to fulfil those two objectives five groups of airports are proposed as per their risk index performance (Safety+2, Safety+1, Neutral, Safety-1 and Safety-2).

Despite the attention on selecting only reliable source of data, many imprecisions can be imbedded in the process, since the report is yet in airport grounds to the ICAO ADREP categorization and classification.

Assuming that those imprecisions could corrupt somehow the data, Neutral group is proposed. It represents a "judgement cushion" where 20% of airports who presented a safety performance around ALoSP are in this group

The other 4 where set by trying to divide equally better and worst performant groups. This criterion reduces misjudgement caused by possible inaccuracies in data collection, while ensuring that there are always airports in the other 4 regions, stimulating competitiveness and consequent evolution in ALOSP over time (Figure 10).

Group	Airport	Risk index (10y)	Group average risk index (10y)	Group risk relative to ALOSP	Group risk relative to Safety -2 Group
Safety +2	AD08	1,19E-03	8,57E-03	3.76 times safer than ALoSP	8.88 times safer than Safety -2 Group
	AD21	5,03E-03			
	AD11	7,40E-03			
	AD22	7,68E-03			
	AD01	7,89E-03			
	AD31	1,15E-02			
	AD10	1,33E-02			
	AD26	1,46E-02			
Safety +1	AD29	1,48E-02	2,16E-02	1.49 times safer than ALoSP	3.52 times safer than Safety -2 Group
	AD30	1,84E-02			
	AD05	2,08E-02			
	AD06	2,14E-02			
	AD20	2,14E-02			
	AD18	2,31E-02			
	AD17	2,42E-02			
	AD12	2,88E-02			
Neutral	AD19	2,99E-02	3,51E-02	1	2.17 times safer than Safety -2 Group
	AD25	3,00E-02			
	AD15	3,01E-02			
	ALOSP	3,23E-02			
	AD23	3,75E-02			
	AD24	4,01E-02			
	AD28	4,30E-02			
Safety -1	AD27	4,49E-02	4,87E-02	1.51 times riskier than ALoSP	1.56 times safer than Safety -2 Group
	AD13	4,80E-02			
	AD09	4,87E-02			
	AD14	5,02E-02			
	AD03	5,15E-02			
Safety -2	AD04	6,87E-02	7,61E-02	2.35 times riskier than ALoSP	1
	AD02	7,19E-02			
	AD07	8,00E-02			
	AD16	8,40E-02			

FIGURE 10: Airport safety performance groups

In research point of view, the precise knowledge regarding airports' effectiveness on safety (Safety-1 and Safety-2) or risk (Safety-1 and Safety-2) issues adds a layer of convenience. Safety+1 group presented a safety performance 1.49 times better than ALoSP and 3.52 times better than the worst group of airports (Safety-2). The Safety+2 group is 3.76 times safer than ALoSP and 8.88 times safer than Safety-2 group. Safety-1 group presented a risk level 1.51 times higher than ALoSP and Safety-2 performed 2.35 times riskier than the ALoSP.

4.3 Effective SSP action plan

Setting the ALoSP and the statistical difference of safety performance from airport groups contain the initiation for SSP to establish clearer approach, focusing on those which actually require guidance.

Firstly, the most intuitive movement would be the investigation of which events are more significant on Safety-1 and Safety-2 groups (Figure 11).

		ICAO ADREP Classification + AIS Severity scale						Total	
		OW AIS 1	IS AIS 2	IM AIS 3	SI AIS 4	AN AIS 5	AF AIS 6	Risk recurrence	% risk recurrence
		0,003	0,047	0,105	0,266	0,593	1		
Apron	F-NI	0	0,141	0	0	0	0	0,141	0,1%
	GCOL	0	0,188	0,105	0	0,593	0	0,886	0,7%
	OTHR	0	0,564	0	0	0	0	0,564	0,5%
	RAMP	0	0,047	0	0	0	0	0,047	0,0%
	SCF-NP	0	0,376	0	0	0,593	0	0,969	0,8%
	SCF-PP	0	0,047	0	0	0	0	0,047	0,0%
	Total	**0**	**1,363**	**0,105**	**0**	**1,186**	**0**	**2,654**	**2,2%**
Runway	ARC	0	0,141	0	0,798	1,779	0	2,718	2,3%
	ATM/CNS	0	0	0	0,266	0	0	0,266	0,2%
	BIRD	0	2,256	0,525	0	0	0	2,781	2,4%
	CFIT	0	0	0	0,266	0	0	0,266	0,2%
	F-NI	0	0,282	0	0,266	0	0	0,548	0,5%
	FUEL	0	0,188	0	0	0,593	0	0,781	0,7%
	GCOL	0	0,141	0	0	0	0	0,141	0,1%
	LOC-G	0	0,799	0	1,33	3,558	1	6,687	5,7%
	OTHR	0	3,055	0,315	2,394	0,593	0	6,357	5,4%
	RE	0	0,188	0	1,596	4,151	0	5,935	5,0%
	RI	0	0,047	0	0,532	0	0	0,579	0,5%
	SCF-NP	0	10,387	0,105	6,118	5,337	0	21,947	18,6%
	SCF-PP	0	2,115	0,105	1,33	1,779	1	6,329	5,4%
	UNK	0	0,141	0	0	0	0	0,141	0,1%
	USOS	0	0	0	0,266	0,593	0	0,859	0,7%
	WILD	0	0,047	0	0	0,593	0	0,64	0,5%
	Total	**0**	**19,787**	**1,05**	**15,162**	**18,976**	**2**	**56,975**	**48,2%**
Taxiway	ATM/CNS	0	0,047	0	0	0	0	0,047	0,0%
	BIRD	0	0,047	0	0	0	0	0,047	0,0%
	GCOL	0	0,329	0,21	0	0	0	0,539	0,5%
	LOC-G	0	0,047	0,105	0	0	0	0,152	0,1%
	OTHR	0	0,705	0	0	0	0	0,705	0,6%
	RI	0	0,047	0	0	0	0	0,047	0,0%
	SCF-NP	0	2,961	0,315	0,266	0	0	3,542	3,0%
	SCF-PP	0	0,094	0	0	0	0	0,094	0,1%
	Total	**0**	**4,277**	**0,63**	**0,266**	**0**	**0**	**5,173**	**4,4%**
Risk recurrence		**0**	**25,427**	**1,785**	**15,428**	**20,162**	**2**	**64,802**	
% Risk recurrence		**-**	**49,8%**	**65,4%**	**52,7%**	**66,7%**	**40,0%**	**54,8%**	

FIGURE 11: Risk investigation on Safety-1 and Safety-2 groups

Having the risk matrix, it becomes easier to highlight where and how an airport in both groups performed. For example, having as reference the risk recurrence measured in the 10-year period time for the 31 airports, together both groups represent 54,8% of the total risk recurrence, of which 18,6% are given by SCF-NP events in runways.

Many lines of action have been discussed in literature on how manage market performance and stimulate behaviour on economic agents, such as direct interventions, penalties, liberalization, etc.

Positive incentive regulation as proposed by Baldwin has been identified as the most appropriate in this work.

First, regarding safety issues it is known that punitive actions hinder voluntarily safety report, which may initially mask the recurrence of lower severity events that may result in more severe events over time.

Secondly, because safety equals essentially to financial spent. The lower the risk and further away from ALoSP, the higher is the expense of a given airport. This effort needs to be rewarded, otherwise this benefit will be socialized. Any uncompensated financial or safety effort could be seen as a waste since (1) only the minimum is required and (2) there is no difference in dealing with agent's different performances. In this scenario, better performant airports could ease their safety actions resulting in a general drop of ALoSP, movement opposite to the desired.

Third, the strategy of fitting airports in groups stimulate them to compete one each other to be in better performant group. This behaviour results in positive feedback of the system, when it increases the average performance of the market, resulting in an even more demanding ALoSP, which in turn requires more safety efforts of the participant to remain in the best-positioned groups.

Many actions can be proposed, depending on the State's reality and regulatory framework. In Brazil for example it is possible to propose some, always proportional to verified performances.

Safety prizes in recognition to better performant airports in order to get returns in market image. Safer organizations acting in complex risky systems are seen as "role models" of behaviour. They can act as compliance reference and amplify their market power and relevance by capitalizing on these image gains.

Once safer airports have proven to be fulfilling the overall objective or regulation, which is to be safe when offering public services, State can reduce oversight frequency in those two groups. This results into lower regulatory costs to airports and to State itself.

Provide better follow up actions in worst performant airports, investigating what are their safety problems and offering means to cope with them.

Total absence of punishment in any possible ways to lower performant airports in order to stimulate the just culture and a healthy safety reports system.

Nevertheless, there is one threat for the proposed methodology, which is the safety data evasion. Since airports can be benefited in many ways by being safe, it can encourage them to not report safety events properly. Events could be hidden or reclassified to less representative categories. In such cases it is recommended to apply severe punitive measures, so the system can work in its better fit.

5. CONCLUSIONS

This work aimed to develop a methodology for risk management in airports for the SSP in a broad way. In order to achieve that, researchers investigated the nature of the airport safety events occurred in busiest Brazilian airports.

Then was proposed the combined use of the recurrence of safety events and their relative severities to generate a dimensionless risk index capable of compare and rank airports.

Research also presented the ALoSP for airports in Brazilian SSP, so State can have a reference point of performance to better direct resources on market risk management.

The inquiry resulted that, both airports and State already do not consider extreme low severity events in their actual risk monitoring system, given that they only raise safety expenses and do not return benefits in the same amount.

The proposed methodology made possible to present a picture of the safety situation (or a risk map) in Brazilian airport system. The sensitivity analysis showed that among 21 possible airport safety events, approximately 50% of the total risk is due to 2 categories of events and only 5 represent almost 80% of the measured risk.

It was found too that Brazilian safety numbers showed a worldwide-like pattern, concentrating the majority of the airport risk on runway areas and adjacencies.

Research also found the high concentration on risk recurrence among 31 airports. Only 4 concentrated 30% of all the recurrence of risk, 8 were responsible for 50% and 17 represented approximately 80% of the total risk load in Brazilian airport operations.

The mean risk for the 31 airports studied during 10-year period time was in 3.23×10^{-2}. This number can be assumed as the baseline safety performance initial and reliable ALoSP for airports in Brazilian SSP, since it represents the performance of 94% of all the airport movement in Brazilian system.

From this new reference point it was possible to find safer and riskier airports so SSP resources can be handled more effectively.

Five groups of airports are proposed as per their safety performance (Safety+2, Safety+1, Neutral, Safety-1 and Safety-2).

Their measured performance showed statistically significant differences. Safety+1 group presented a safety performance of 1.49 times better than ALoSP and 3.52 times better than worst group of airports (Safety-2).

The Safety+2 group presented as 3.76 times safer than ALoSP and 8.88 times safer than Safety-2 group. Safety-1 group presented a risk level 1.51 times higher than ALoSP and Safety-2 performed 2.35 times riskier than the ALoSP.

By knowing ALoSP and the statistical difference of safety performance from airport groups, it became possible to focus efforts on dealing with more severe events on riskier airports

Together, both worst performant groups represented 54,8% of the total risk recurrence of the system. Most sensitive event in these airports is SCF-NP and 18,6% of the risk are given by SCF-NP events in runways.

This proposed matrix, woks as a tool for airports to identify their safety weaknesses and promote efficiency and rationality to the SSP's by amplifying their effectiveness. Research also found that not only reducing risks to ALARP is needed to an SSP, but also is imperative to create a safety continuous improvement environment.

This work also proposed a positive incentive regulation approach, in line to a less interventionist model. In this line was proposed some actions to stimulate airports on compete among themselves in exchange for market reputational gains and its intrinsic financial benefits.

Finally, it was found that state oversight in a proactive approach should be used for the worst performant airports in pursuit for a just culture environment. Severe enforcement was recommended only to those airports who might evade information in order to appear safer than real.

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AUTHORS' BIO

Mr. Daniel Alves da Cunha (corresponding author) is a Civil Aviation Specialist and Pilot Checkrider of Civil Aviation Agency (ANAC) in Brazil for over 14 years. Has two MSc. and is currently ongoing a DSc., with his research in airport risk and regulatory quality at Universidade de Brasilia/Brazil – UnB. Email: danielalvescunha@gmail.com

Dr. Michelle Andrade is a Professor of Civil Engineering and Transportation at Universidade de Brasilia/Brazil – UnB. Her publications focus on topics involving transportation safety and engineering. Email: maccivil@gmail.com

Mr. Javã Silva is a Civil Aviation Specialist of Civil Aviation Agency (ANAC). He is a Physics graduate and currently is the Airport Operations Manager in the Agency. Email: java.pedreira@anac.gov.br