METHODOLOGY TO OBTAIN AIRPORT SAFETY INDICATORS USING SAFETY MANAGEMENT SYSTEMS

José Francisco Barboza Lobianco
Aeronautics Institute of Technology
Praça Marechal Eduardo Gomes, 50 - Vila das Acácias - 12228-900
São José dos Campos, SP - Brazil
Phone: +55-12-39476802 - E-mail: *jflobianco@hotmail.com*

Anderson Ribeiro Correia
Aeronautics Institute of Technology
Praça Marechal Eduardo Gomes, 50 - Vila das Acácias - 12228-900
São José dos Campos, SP - Brazil
Phone: +55-12-39476939 - E-mail: *correia@ita.br*

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ABSTRACT

This paper aims to develop and test a quantitative methodology applied in airports for establishing Safety Indicators in accordance with the recommendations of ICAO, and it was motivated by the need to identify which events generate the greatest impact on airport safety and prioritize actions plan and resources allocation. It is also a tool to support airport management decisions and to keep safety levels under control. For the case study, was chosen São Paulo/Guarulhos International Airport, using data from ramp occurrences in the analysis of this paper, due to the fact they generate significant losses for airlines. The proposed methodology consists of transforming the current qualitative Safety risk assessment matrix into a quantitative matrix, adopting values for grading the risk severity in an exponential rate, so as to assign "weights" for each occurrence.

Keywords: safety indicator, airport management, safety management system.

Classification: Airport Strategy, Management and Operations, Aviation Safety.

1. INTRODUCTION

The global growth of civil aviation from the 1990s resulted in a civil aviation market even more competitive. With this, business management (revenue maximization and cost reduction) of companies may eventually jeopardize and endanger the operational safety. In this context, the International Civil Aviation Organization (ICAO), to prevent degradation of safety levels so far achieved, introduced the Safety Management System (SMS) in civil aviation in 2006 after the publication of the 1st edition of Doc 9859 - Safety Management Manual (ICAO, 2006). One of the tools of SMS is continuous monitoring through safety indicators, but usually safety indicators are based on the number of accidents and incidents (reactive method). However, the aim of establishing safety indicators on routine occurrences is to monitoring safety levels and trends, using preventive and predictive methods to achieve acceptable level of safety or maintain risks under control.

This paper proposes a quantitative methodology to establish safety indicators applied in airport management by providing the airport operator a situation or safety level, its trends, and the necessary bases to stipulate acceptable safety levels. Additionally, this methodology allows the manager to indicate the status of the safety of the airport in order to plan their actions and prioritize allocation of resources for risk reduction and mitigation (continuous improvement). For this study, we chose to analyze the ramp events, since they generate great human and material losses, whether direct or indirect.

2. SAFETY PERFORMANCE INDICATORS

In this section we present the importance of ramp events, its costs and statistics, besides comment the risk exposure when analyzing each occurrence. Furthermore, we introduce the concept of individual and global indicators.

2.1. Safety Events

Since this paper is focused on airport management, we chose to analyze the indicators related to ramp events (occurrences, incidents and even accidents) occurring at airports because "the airport ramp can be in intensely busy and confined space where accidents impose substantial costs on the industry, constitute a significant safety issue that costs airlines over US$ 3 billion annually" (MATTHEW, 2004).

Also, the Boeing Company maintains updated statistical summary of accidents with jets in commercial aviation worldwide showing that about 47% of total accidents recorded in the period 2001-2010 occurred on the airport movement area and during the takeoff and landing phases (BOEING, 2011). At Figure 1, it can be verified that the share of accidents represents 15% during taxi, loading / unloading, stop and trailer; 10% at takeoff, and 22% at landing.

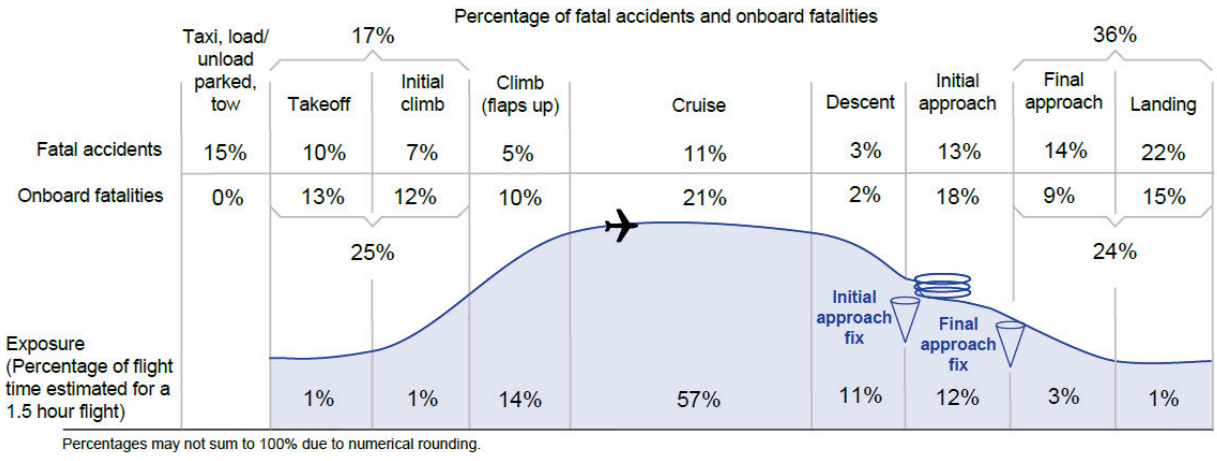


Figure 1: Percentage of fatal accidents and onboard fatalities by phase of flight - Worldwide commercial jet fleet - 2001 through 2010 (BOEING, 2011)

2.2. RISK EXPOSURE ON SAFETY EVENTS

For every event there is a risk factor associated or a risk exposure. In brazilian regulation, the National Agency of Civil Aviation (ANAC) describes in its Safety Program that "indicators shall, to the extent possible, weighted by risk exposure" (ANAC, 2009) and the Department of Airspace Control (DECEA) has a similar approach in Circular of Air Traffic (CIRTRAF) which deals with "Safety Indicators in Operational Air Traffic Services", classifying air traffic incidents by the degree of safety compromising: critical or potential (COMAER, 2004).

2.3. SAFETY INDICATORS

According to ICAO (2009), safety indicators are the parameters that characterize and/or typify the level of safety of a system and that can be used on a data-based for monitoring and assessing safety performance (ICAO, 2013). In this paper we considered two indicator types: Individual consisting of a single variable; and Global as a result of a varying composition. To calculate the Individual Safety Indicator of each event shall be considered the amount of a specific occurrence at an airport, related to the movement of aircraft (monthly or annual).

2.4. GLOBAL SAFETY INDICATOR

The Global Safety Indicator is needed, since the individual indicator can not reflect the trend of operational safety as a whole or translate the airport management effort in reducing the levels of risk. The Global Safety Indicator must include in its calculation the set of all individual indicators; it is not simply an arithmetic average. In this case, the calculation of the overall indicator should be obtained from the weighted average of the risk of exposure for each individual indicator.

3. METHODOLOGY

In this methodology section we explain in details the proposal of Individual and Global Safety Indicators, which will be used in the following section (data analysis).

3.1. SELECTED CASE STUDY AIRPORT

São Paulo / Guarulhos International Airport was chosen for the case study, for having the highest movement of passenger and aircraft in Brazil, and due to the existence of an electronic database of events, whose period was from 2006 to 2010.

3.2. ASSESSING THE RISK AND TOLERABILITY OF AN EVENT

According to ICAO (2012), the safety risk assessment is the result of combining risk probability and risk severity categories into a safety risk assessment matrix, presented in Figure 2, observing that the risk criteria obtained in this process can not set a value for each risk level since they are qualitative.

Risk Probability	Risk Severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely Improbable 1	1A	1B	1C	1D	1E

Figure 2: Safety risk assessment matrix (ICAO, 2012)

The safety risk index obtained at Figure 2 must then be exported to a safety risk tolerability matrix at Figure 3 that describes the tolerability criteria within three regions (ICAO, 2012):

- intolerable;
- tolerable; and
- acceptable.

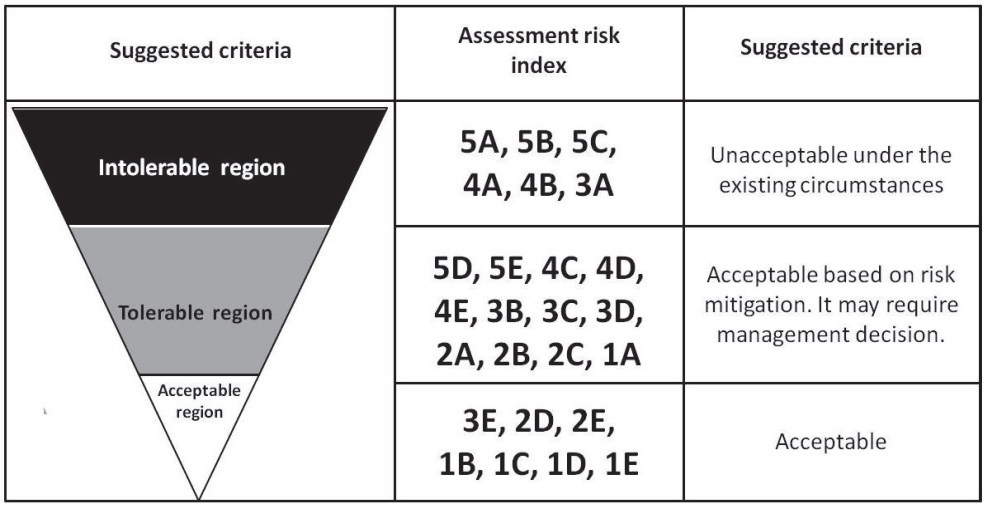


Figure 3: Safety risk tolerability matrix (ICAO, 2012)

3.3. ASSESSING THE RISK IN A QUANTITATIVE WAY

There are few references available that assessed quantitatively the risks, whom we highlight hereafter two of them:

- William T. Fine (1971) developed a mathematical method for the U.S. Navy, in order to "calculate the risk" of a hazardous situation, giving a numerical evaluation to the urgency for remedial attention to the hazard of engineering projects. The objective was to furnish solid foundation for safety recommendations for engineering action or for cancel costly projects which the risks did not justify, saving millions of dollars. This method worked as a serving guide to estimate the cost of risk mitigation related to engineering projects. The risk of a project varies according to its severity, exposure and probability, whose value is derived by multiplying these three variables;

- Analogously, in a research proposed by Cardoso and Mauriño (2008), it was also adopted a different risk assessment for each event, giving them a "weight" (from 1 to 10) depending on the priority and occurrence place (runway, taxiway or apron), assigning a higher weight to runway and lower for apron, observing that these weights were evaluated by the airports.

Although these previously presented methods do not contradict those established by ICAO, once we are dealing with a high regulated activity as the air transportation, it is necessary to identify and assign the level of risk / severity indicator from ICAO standards and recommendations. (ICAO, 2010a) (ICAO, 2010b).

3.4. INDIVIDUAL SAFETY INDICATORS AND OPERATIONAL MOVEMENT

The criteria defined in Brazilian regulation, e.g. the movement of 100,000 aircraft for each calendar year will be adopted for the calculation of Individual Safety Indicators (BRASIL, 2009), (ANAC, 2009). The calculation of the Individual Safety Indicator is represented by a dimensionless numeral accurate to two decimal places (Equation 1)

$$II_n = (Quantity\ of\ events\ "I" / acft\ movs) \times 100{,}000$$

(Equation 1)

where:
II_n = Individual Safety Indicator based on aircraft movement;
"n" = specific event in a given period; and
acft movs = number of landings and take-offs in a given period.

3.5. INDIVIDUAL SAFETY INDICATORS AND QUANTITATIVE RISK ASSESSMENT

In this section we propose a numerical method to quantitatively assess the risks of each event in order to assign a weight to each single indicator, and thus be able to calculate the airport Global Safety Indicator. The initial purpose of this paper is to replace the five letters corresponding to the severity (A, B, C, D, E) of Table 1, by numbers (5, 4, 3, 2, 1). The risk is then calculated for each of the 25 levels of the matrix, as we can see at Table 1.

Table 1: Risk assessment expressed numerically

Risk Probability		Risk Severity				
		Catastrophic A=5	Hazardous B=4	Major C=3	Minor D=2	Negligible E=1
Frequent	5	25	20	15	10	5
Occasional	4	20	16	12	8	4
Remote	3	15	12	9	6	3
Improbable	2	10	8	6	4	2
Extremely Improbable	1	5	4	3	2	1

Analyzing the results in Table 1, it is observed that the "steps" between the three criteria of risk tolerance (intolerable/black, tolerable/grey, acceptable/white) are very close, influencing the low definition of the weights. In this case, it is considered that both the probability and severity of risk were separated linearly. It is proposed, therefore, to adopt an exponential rate between the degrees of probability and severity, similar to the one adopted by William T. Fine, in his study entitled "Mathematical Evaluation for Controlling Hazards - NOLTR 71-31" (FINE, 1971). In this case, it is considered that the separation would have a ratio squared. The result is shown in Table 2, noting that in this situation, the limits of tolerance of the three criteria were better defined.

Table 2: Risk assessment with exponential rate (squared)

Risk Probability		Risk Severity				
		Catastrophic A=16	Hazardous B=8	Major C=4	Minor D=2	Negligible E=1
Frequent	16	256	128	64	32	16
Occasional	8	128	64	32	16	8
Remote	4	64	32	16	8	4
Improbable	2	32	16	8	4	2
Extremely Improbable	1	16	8	4	2	1

It is observed in Table 2 a possible discrepancy in the numerical values assigned probability "very unlikely" when severity is harzadous. To avoid this discrepancy, ICAO had proposed on the 3rd edition of Doc 9859 (ICAO, 2012) an alternate Table of Tolerability with five regions of tolerability (Extreme; High; Moderate; Low; Negligible) as presented on Table 3, noting that this table was converted in a numerical table, as shown in Table 4.

Table 3: Risk Acceptability (Tolerability) Table (ICAO, 2012)

Likehood		Severity				
		Catastrophic 5	Major 4	Moderate 3	Minor 2	Insignificant 1
certain / frequent	A	*Extreme*	*Extreme*	*High*	*Moderate*	*Moderate*
likely / occasional	B	*Extreme*	*High*	*Moderate*	*Moderate*	*Low*
possible / remote	C	*High*	*Moderate*	*Moderate*	*Low*	*Low*
unlikely / improbable	D	*Moderate*	*Moderate*	*Low*	*Low*	*Negligible*
exceptional	E	*Moderate*	*Low*	*Low*	*Negligible*	*Negligible*

Table 4: Risk Acceptability converted in a numerical table with exponential rate (squared)

Likehood		Severity				
		Catastrophic 16	Major 8	Moderate 4	Minor 2	Insignificant 1
certain / frequent	16	*256*	*128*	*64*	*32*	*16*
likely / occasional	8	*128*	*64*	*32*	*16*	*8*
possible / remote	4	*64*	*32*	*16*	*8*	*4*
unlikely / improbable	2	*32*	*16*	*8*	*4*	*2*
exceptional	1	*16*	*8*	*4*	*2*	*1*

At this point, it will be possible to evaluate quantitatively the Individual Indicator in accordance with the risk exposure, just by multiplying the value obtained in Table 2 with the indicator calculated in Equation 1.

$$\boldsymbol{ISI}_{n1} = (II_{n1} \; x \; Wr_1)$$

(Equation 2)

where:
ISI_n = Individual Safety Indicator based on risk exposure;
II_n = Individual Safety Indicator based on aircraft movement; and
Wr = weight of risk assessment obtained from Table 2.
"n" = specific event in a given period.

By using the rationale previously mentioned, the Global Safety Indicator is presented in Equation 3, observing that the denominator is the sum of risk weight:

$$\boldsymbol{GSI} = \frac{(II_{n1} \text{ x } Wr_1) + (II_{n2} \text{ x } Wr_2) + (II_{n3} \text{ x } Wr_3) + (II_{n4} \text{ x } Wr_4) + (II_{n5} \text{ x } Wr_5) + \ldots}{(Wr_1 + Wr_2 + Wr_3 + Wr_4 + Wr_5 \ldots)}$$

(Equation 3)

where:
GSI = Global Safety Indicator;
II_n = Individual Safety Indicator based on aircraft movement;
Wr = weight of risk assessment obtained from Table 2; and
"n" = specific event in a given period.

The core equation proposed in this paper is the Equation 3: the Global Safety Indicator is an average of Individual Safety Indicators, but not a simple arithmetic mean, but a weighted arithmetic mean, once the Individual Safety Indicators have been weighted according to the risk exposure obtained of Table 4. Therefore, the denominator of Equation 4 must be the sum of the weights of all the individual indicators.

4. DATA ANALYSIS

This section contains (1) tables relating to events between 2006 and 2010 at the São Paulo / Guarulhos International Airport and their respective indicators; (2) charts with trend lines and tendencies (polynomial regression and the average of the last twelve months); and (3) the aircraft movement of the period. However, as the description of all indicators would be too extensive for this article, we chose to address in more detail the event of property damage (aircraft collision) for illustration purposes. The whole analysis was described by these authors at dissertation titled "*Indicadores de Segurança Operacional aplicados na Gestão Aeroportuária*" (LOBIANCO, 2012).

4.1. INDIVIDUAL INDICATOR - PROPERTY DAMAGE (AIRCRAFT COLLISION)

The property damage basically refers to collisions and may be against aircraft (static or towed), equipment, vehicles and infrastructure (e.g. boarding bridge). For purposes of analysis, it was decided to target collisions into two groups: one involving aircraft with no intention of flight and another involving vehicles and equipment. In general, the risk assessment of property damage is considered occasional (occasional - value "4") with major severity (major - value "C"). Thus, the level 4C requires risk mitigation measures to make such events acceptable or tolerable.

Collisions of aircraft that are in the apron with no intention of flight occur primarily when they are towed when they are outside the limits of the parking area or even when vehicles and equipment break off and/or exceed the safety area and collide against the aircraft. Such events represent a significant cost for airlines due to, in most cases, removing the aircraft

operation for repair and maintenance of the value itself. Tables 6 and 7, and Figure 4 present the absolute and Individual Safety Indicator of aircraft collisions, that was obtained by using the aircraft movement present on Table 5 and application of Equation 1.

Table 5: Aircraft movement of São Paulo/Guarulhos International Airport (INFRAERO, 2010)

MONTH/ YEAR	2006	2007	2008	2009	2010
JAN	13,786	15,018	17,359	17,306	20,382
FEB	12,508	13,552	15,673	15,074	18,009
MAR	13,616	15,028	16,445	16,704	20,239
APR	12,700	14,362	16,083	16,077	19,664
MAY	12,698	16,300	16,372	16,449	20,385
JUNE	12,231	16,128	15,223	16,684	20,090
JULY	12,803	16,675	16,732	18,395	21,945
AUG	12,154	16,337	15,970	18,001	21,619
SEPT	12,311	15,550	15,339	17,625	21,489
OCT	13,246	16,299	16,162	19,032	22,278
NOV	12,647	15,731	15,931	18,673	21,716
DEC	14,248	16,980	16,895	19,616	22,677
TOTAL	**154,948**	**187,960**	**194,184**	**209,636**	**250,493**

Table 6: Data collision of aircraft in the apron (INFRAERO, 2010)

MONTH/ YEAR	2006	2007	2008	2009	2010
JAN	4	2	2	2	4
FEB	1	1	2	-	-
MAR	-	2	2	-	2
APR	-	-	-	-	1
MAY	-	1	2	2	1
JUNE	-	-	-	-	1
JULY	1	-	1	1	2
AUG	-	-	-	3	2
SEPT	-	-	1	-	1
OCT	-	1	-	2	1
NOV	-	1	-	1	2
DEC	-	-	-	1	1
TOTAL	**6**	**8**	**10**	**12**	**18**

Table 7: Individual Indicator: aircraft collision in the apron (INFRAERO, 2010)

MONTH / YEAR	2006	2007	2008	2009	2010
JAN	29.01	13.32	11.52	11.56	19.63
FEB	7.99	7.38	12.76	0	0
MAR	0	13.31	12.16	0	9.88
APR	0	0	0	0	5.09
MAY	0	6.13	12.22	12.16	4.91
JUNE	0	0	0	0	4.98
JULY	7.81	0	5.98	5.44	9.11
AUG	0	0	0	16.67	9.25
SEPT	0	0	6.52	0	4.65
OCT	0	6.14	0	10.51	4.49
NOV	0	6.36	0	5.36	9.21
DEC	0	0	0	5.10	4.41
TOTAL	**3.87**	**4.26**	**5.15**	**5.72**	**7.19**

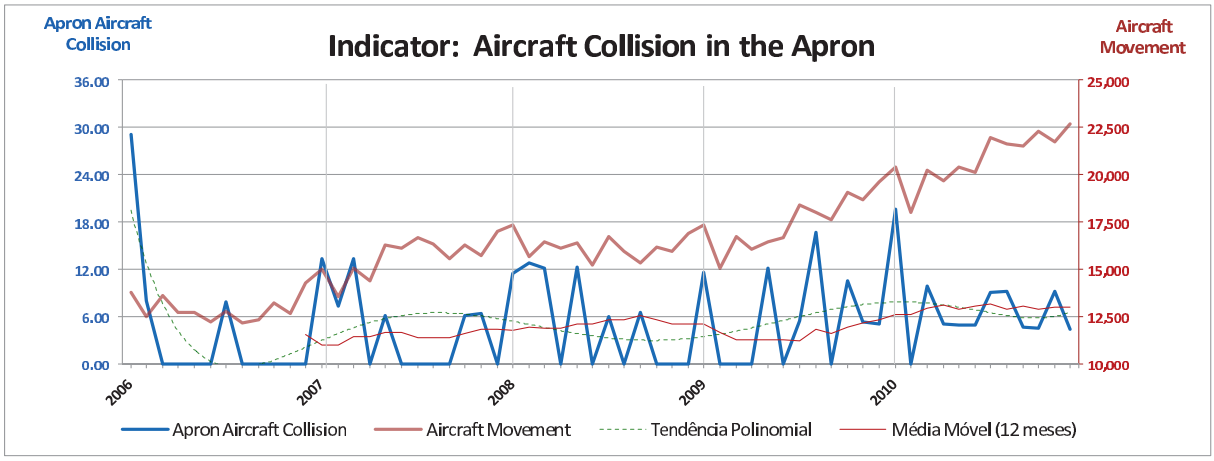


Figure 4: Graph of Individual Indicator: aircraft collision in the apron

When debugging the data, it was found that most of the events were due to carelessness of the operators; there is also a percentage of equipment failure, procedure failure and violation of rules. By analyzing Tables 6 and 7, there was an increase of about 50% in 2009/2010 (12 in 2009 to 18 in 2010), while the values of the individual indicator increased by 25% (5.72 in 2009 to 7.19 in 2010) due to the growth of aircraft movements. Thus, it is observed that the trend lines (polynomial and moving annual average) of the graph contained in Figure 4 follows the growth of aircraft movements. Considering that the individual indicator has had a steady growth, it is understood that the airport should adopt additional measures to improve safety.

4.2. GLOBAL SAFETY INDICATOR

In this chapter, the previously proposed methodology is applied, whose results are consolidated into a single table (Table 8), containing:

- Safety events description;

- Weight value assigned to each Individual Indicator;

- Annual values of each Individual Indicator (2006-2010);

- Weighted values after application of the weight on the Individual indicators; and

- Percentage of participation of each event on the total in 2010.

Table 8 present the values of Global Safety Indicator, but only the annual average values for a better interpretation, noting that the monthly values were plotted in Figure 5.

Table 8: Consolidated Results of Safety Indicators

SAFETY EVENTS	WEIGHT	2006	2007	2008	2009	2010	%
INJURIES TO PEOPLE	*(3C)* 16	14.84 **237.44**	13.30 **212.80**	23.69 **379.04**	26.24 **419.84**	24.35 **389.60**	18.3%
FAUNA	*(3E)* 4	18.72 **74.88**	9.58 **38.32**	7.21 **28.84**	11.93 **47.72**	6.79 **27.16**	1.3%
BIRD STRIKE	*(3D)* 8	17.43 **139.44**	5.85 **46.8**	14.42 **115.36**	20.99 **167.92**	10.78 **86.24**	4.1%
RUNWAY INCURSION	*(2A)* 32	4.52 **144.64**	6.38 **204.16**	4.63 **148.16**	3.34 **106.88**	3.19 **102.08**	4.8%
PROPERTY DAMAGE (airplanes)	*(4C)* 32	3.87 **123.84**	4.26 **136.32**	5.15 **164.8**	5.72 **183.04**	7.19 **230.08**	10.8%
PROPERTY DAMAGE (vehicles and others)	*(4C)* 32	13.55 **433.6**	11.17 **357.44**	12.87 **411.84**	19.08 **610.56**	28.34 **906.88**	42.7%
DETACHMENT OF TRAILER/DOLLIES	*(4C)* 32	3.23 **103.36**	3.19 **102.08**	4.12 **131.84**	1.43 **45.76**	0.80 **25.6**	1,2%
PARKING OUT OF SAFETY AREA	*(2E)* 2	33.56 **67.12**	26.07 **52.14**	24.72 **49.44**	21.94 **43.88**	19.16 **38.32**	1.8%
UNSAFE ACTS AND VIOLATIONS	*(3D)* 8	- -	- -	- -	- -	20.36 **162.88**	7.7%
FOREIGN OBJECT DEBRIS (FOD) and OTHERS	*(2D)* 4	10.33 **41.32**	7.98 **31.92**	8.24 **32.96**	10.97 **43.88**	10.38 **41.52**	2.0%
ABNORMAL EVENTS	*(5D)* 32	- -	- -	2.06 **65.92**	2.39 **76.48**	3.59 **114.88**	5.4%
TOTAL WEIGHTED	**202**	**1,365.64**	**1,181.98**	**1,528.20**	**1,745.96**	**2,125.24**	**100,0%**
GLOBAL INDICATOR		**6.76**	**5.85**	**7.57**	**8.64**	**10.52**	

To illustrate, in 2010 the value of the Global Safety Indicator was 10.52. In the analysis period (2006-2010), there was a continuous increase in the Global Indicator, as can be seen in the graph of Figure 5.

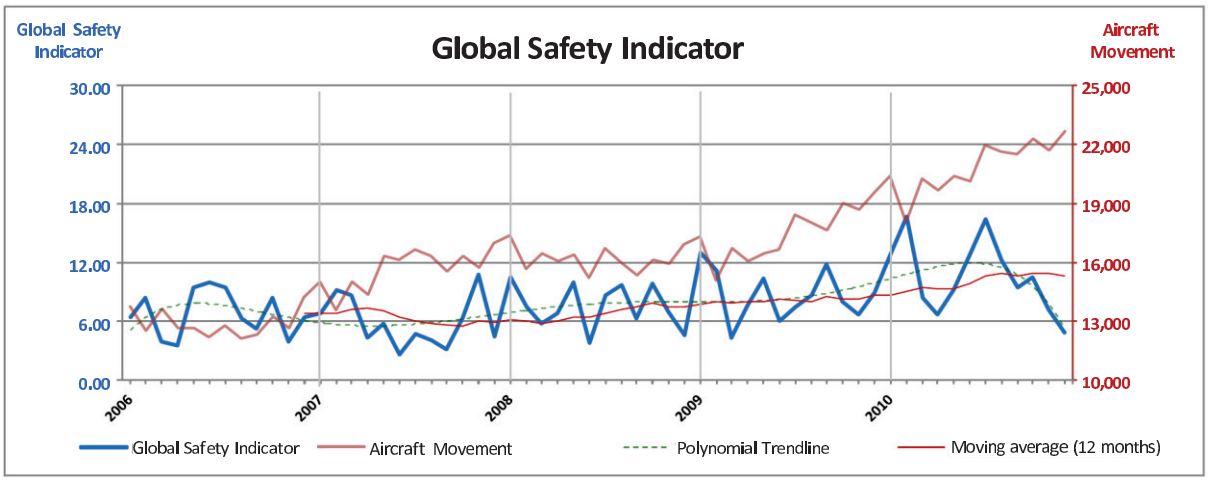


Figure 5: Graph of Global Safety Indicator

Also based on Table 6, it is found that more than 71% of the global indicator corresponds to three events: injuries to people (18.3%); property damage to aircraft (10.8%); and property damage on vehicles (42.7%), the latter being a result of frequent vehicle collisions.

Aiming to visually compare the participation of the Individual Indicator (property damage to vehicles) on the Global Safety Indicator, Figure 6 is presented. It is noteworthy that from 2009 the correlation between indicators increased, becoming stronger in 2010, whose trend lines become nearly coincident.

Thus, this methodology could signalize to airport operator and safety manager which event is contributing to reduce the airport safety level, allowing airport managers to prioritize efforts in order to reduce the frequency of these events and/or reducing the risk and the values of individual and global indicators.

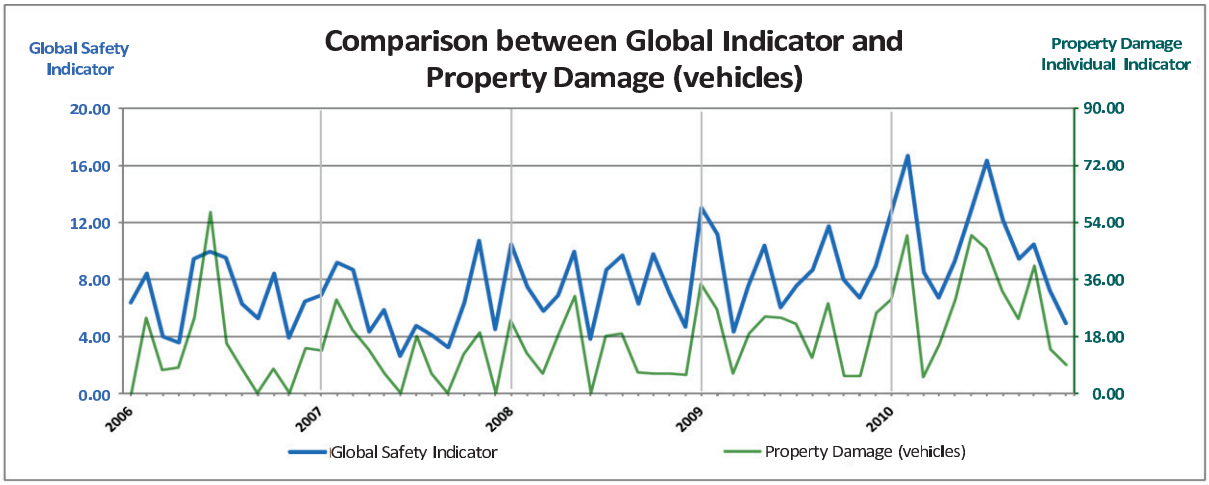


Figure 6: Comparison between Global Indicator and Property Damage (vehicles)

5. CONCLUSIONS

This paper conducted a case study research, proposing and testing a methodology for obtaining airport safety indicators, whose main conclusions are as follows:

(a) The methodology proved to be an applicable tool for use at airports with consistent results and coherent with the proposed objectives. In turn, the indicators demonstrated to be practical and efficient;

(b) Safety indicator can and should be used by airports to identify and evaluate, individually, the most critical risk situations, assisting in the identification of urgent and priority actions and measures to reduce hazards and/or risk mitigation, bringing savings in time and resources; and

(c) The proposed graphics are useful to support aviation agencies and airport operators to keep safety levels under control and to facilitate the monitoring of indicators, emphasizing that the Global Safety Indicator allows comparing whether the risk mitigation actions are being effective.

The results indicate that Global Safety Indicators are increasing at São Paulo/Guarulhos airport; that indicates that airport management and authorities should keep closer attention to safety, and propose actions to mitigate events. According to the numbers, the three greatest impacts (in terms of weighting relevance) on safety are property to damage and injures to people, representing almost 72% of importance. Besides being relevant in terms of lives and direct and indirect costs, these impacts might be latent events that could lead to more serious events. We propose that airport management and aviation authorities establish targets for reduction of the global indicator and individual indicators, especially those that have greatest contribution on the global indicator.

For greater effectiveness in mitigation actions is recommended to verify the causes and/or contributory factors for such events, grouping or selecting them. In this case, all occurrences were originated from Unsafe Acts, and therefore actions should be directed to training, alerts, and other forms of dissemination. Thus, the result of a more thorough analysis is essential to reduce levels of operational safety.

Future research could be undertaken to model the weights of indicators using risk assessment techniques and/or multi-criteria methods. The research could also be extended to a higher number of airports in order to verify the differences across several airport types.

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