RISK ASSESSMENT IN AIRPORT MAINTENANCE RUNWAY CONDITION USING MCDA-C

Daniel A. Cunha
Department of Civil and Environmental Engineering
Faculdade de Tecnologia, Campus Universitário Darcy Ribeiro, Brasília - CEP 70910-900, (55) 61 994262670, danielalvescunha@gmail.com

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

Leonardo O. Santana
National Civil Aviation Agency
Setor Comercial Sul - Quadra 09 - Lote C - Edifício Parque Cidade Corporate Torre A (1º ao 7º andar - Asa Sul, Brasília - DF, 70308-200, (55) 61 983051555, leodfsantana@yahoo.com.br

Lucius A. Prado Author 4 – Text Style 'Author Name'
National Civil Aviation Agency
Setor Comercial Sul - Quadra 09 - Lote C - Edifício Parque Cidade Corporate Torre A (1º ao 7º andar - Asa Sul, Brasília - DF, 70308-200, lucius.prado@anac.gov.br

Marcos Paulo Gonçalves da Silva
National Civil Aviation Agency
Setor Comercial Sul - Quadra 09 - Lote C - Edifício Parque Cidade Corporate Torre A (1º ao 7º andar - Asa Sul, Brasília - DF, 70308-200, marcos.goncalves@anac.gov.br

ABSTRACT

This paper proposed the initial development of a multicriteria methodology for a runway maintenance monitoring using risk perception at airports with the MCDA-C methodology. To support morphological structuring and semantic judgments eight specialists in airport maintenance and operations were interviewed and the model was built based in their perceptions and deep technical knowledge on the subject. We found that the 7 most representative criteria were able to deal with approximately 80% of the perceived risk by the experts, indicating that a considerable part of the resources of the Brazilian airport infrastructure operations could be being redirected towards a more rational application. Finally, we applied the method in a real scenario situation by analyzing real data from the 29 the busiest Brazilian airports. Data showed objectively that 18 airports presented scores that clearly indicated being in a favorable (safer) or unfavorable (risky) condition regarding the criteria analyzed, guiding where the state can spend the resources with the best benefit.

Keywords: MCDA-C Methodology; Airports Predictive Risk Monitoring; Risk Perception; Airport Risk; State Safety Programme (SSP).

1. INTRODUCTION

The Standard and Recommended Practices (SARPs), issued by the International Civil Aviation Organization (ICAO), are standards and best practices for global civil aviation. They are intended to ensure uniformity, efficiency and safety of aviation among all signatory States of the International Civil Aviation Convention.

In 2016 ICAO took the initiative to publish an Annex containing standards and recommendations for operational safety management within the Member States and their respective Civil Aviation Service Providers. The document was named Annex 19 - Safety Management and complemented the guidelines of the same nature contained in DOC 9859 - Safety Management Systems.

According to the initial proposal, this Annex should support the continuous evolution of proactive strategies aiming the improvement of safety. The set of these strategies was then called the State Safety Program (SSP), whose focus is the systematic treatment of the risks inherent to the State's actions when supervising and regulating the civil aviation industry. It is a management system for improving the State's regulatory and administrative capacity on providing safety through the operators.

In parallel, DOC 9734 - State's Safety Oversight System, presents the key elements for structuring the State's regulatory technical functions, so that it can satisfactorily perform its safety oversight functions.

These guidelines specify that each member State should establish their SSP, consistent with the size and complexity of civil aviation activities developed in the state regulation and supervision, and aiming to achieve an acceptable level of safety performance (ALoSP). In addition, it should have specific objectives related to the achievement of the highest practicable level of safety (ALARP) for air transport activities, as set forth in State policy.

In this context, arises a need for the State to monitor and measure the safety results of its civil aviation system. This monitoring should be performed considering acceptable levels of safety performance, identified through safety indicators and targets. This action is also foreseen in Annex 19.

Therefore, in line with these guidelines, Brazilian Civil Aviation Agency - ANAC published in 2015, its Specific Operational Safety Program (PSOE-ANAC), which brings its approach to operational safety management. In it, civil aviation activities under the supervision of the Agency shall be subject to a performance monitoring process based on acceptable indicators, targets and acceptable levels of safety performance, so that the civil aviation risks are properly managed.

This monitoring should be applied to the supervision of the activities under the jurisdiction of the ANAC, ie, the technical activities regulated by the ICAO Annexes, including Annex 14 (Aerodromes), core object of this work.

This activity can be based on the assessment of fundamentally four kinds of what Sage and White (1980) call “societal risk”: real or statistical risk, that would be the monitoring of statistical recurrence of significant data from undesired events and/or the estimation of the risk based on perception of individuals or predictions from the models structured on the analysis of latent conditions in a given system before the actual realization of the risk, which are technically called perceived and predictive risk monitoring (Janic, 2000).

Thus, this paper aims to propose the initial development of a multicriteria methodology for predictive risk monitoring by perception at airports in a broad way. To do so, we intend to test the use of the MCDA-C methodology to the aspects of maintenance of airport runways, so that the technique can be replicated to all other operational aspects of an airport, if proved feasible.

In this work, the initial section introduces the subject and the problem posed. Section 2 presents the theoretical framework about the analysis tool used (MCDA-C). Subsequently the tool is used in the construction of the model (section 3) and section 4 brings a sensitivity analysis applied to the real case of the main Brazilian airports. The paper ends in section 5, with the main conclusions.

2. THEORETICAL REFERENCE

The bibliographic study of the theme for airports, as introduced by Bezerra & Gomes (2016), necessarily goes through the survey of relevant sources. Thus, for this article we used some of the main databases of scientific production available online, such as Science Direct and SciELO.

Fetching systematically data associated to the main terms related to this paper was possible to obtain a huge reference base of scientific works. Topics surrounding the generic term "risk" have been discussed in academic and industry environments for many years. However, the objective here is not to bring conceptual definitions for the knowledge linked directly to risk.

The main purpose here is to test the MCDA-C methodology when arises the need of assessing risk factors and there are not available reference parameters and/or not enough evaluators of such factors to make the evaluation more precise. It intends, then, to test a new tool when it comes to risk assessment in an environment not parameterized solely by objective criteria.

Again, there is a large bibliography on the use of MCDA-C for this purpose. However, it was not possible to find its use applied to the evaluation of predictive risk in airports, making this work the first to address this aspect with the use of this tool. This brings the need to build the model together with the process users and decision makers, supported by a solid experience and knowledge on the decision problem, since the lack of knowledge could lead to a poorly structured hierarchy, indicating an erroneous alternative as the best solution to the problem.

In a brief review of rational multi-criteria decision-making models, the most commonly used are the Analytic Hierarchy Process (AHP) proposed by Saaty (1980), Multicriteria Decision Making (MCDM) and Multicriteria Decision Aid (MCDA). The AHP is characterized by hierarchically organizing complex problems, comprising several criteria and decision makers in a flexible and intuitive process (Ceolin, 2005). MCDM and MCDA methodologies, derived from operational research, differ fundamentally in their premises. While the MCDM aims at an optimal solution through a purely mathematical model, independent of the individuals involved, the MCDA uses a model with a decisional context based on the consideration of the convictions and values of the individuals involved (LYRIO et al, 2007).

A MCDA ramification is the MCDA-C methodology, which experienced its consolidation as a scientific management tool from the 1980s with the works of Roy (1996) and Landry (1995) defining the limits of objectivity for processes, Skinner (1986) and Keeney (1992) in recognizing that the attributes (objectives, criteria) are specific to the decision-maker in each context, and Bana and Costa (1993) in making explicit the convictions of the MCDA, among others.

The MCDA-C methodologies and the traditional MCDA differ, in particular, by their constructive logic of the models. While the MCDA is rationalist-deductive, the MCDA-C uses a mixed constructive research logic: inductive and deductive (ROY, 1993).

The MCDA-C relies on the basic beliefs of the French School (ROY, 1996): omnipresence of the subjectivity of the decision-making process, paradigm of participatory learning, constructivism conviction, recognition of the limitations of the excellent mathematician, and use of an approach that is not part of any preconceptions (Ensslin et al, 2013). Therefore, the choice for the use of this branch of methodologies is supported by the comparative study of Neuenfeldt Júnior et al. (2015), which used five criteria: subjectivity, simplicity, adaptability, acceptance and management.

The author demonstrates the advantages of the MCDA-C methodology over AHP specially in terms of simplicity, acceptance and management. For him, the mathematical aspect of the AHP methodology and the more participative model building process helping to identify the impact of an action in the overall performance of the organization makes MCDA-C to stand out over AHP.

In this perspective, the MCDA-C approach fits with the proposed objective, since it seeks to structure the decision-making context where decision-makers can base their decisions on what they believe to be the most appropriate

(Zamcopé, 2012; Bana and Costa, 1992; Bana and Costa et al., 1999; Keeney, 1992). It enables decision-makers to build the knowledge that enables them to understand the consequences of their decisions on those aspects that they consider relevant (their values and preferences) in the specific context (Ensslin et al, 2015).

Thus, the option for this methodology is based on the fact that it is able to encapsulate the users perceptions regarding the attractiveness difference between each evaluation elements generating adequate numerical scales and weights to them (Ensslin et al., 2009).

At this point it is important to remember that the development of a decision tree for risk assessment in airports prior to an undesirable event occurrence is essentially part of a subjective risk assessment activity. Since MCDA-C is better used for this kind of problem, if its use is proven feasible, it will be possible to standardize the technique and replicate it to all other operational aspects of an airport.

3. METHODS AND PROCEDURES

The MCDA-C methodology is basically composed of three basic phases, differentiated, but intrinsically correlated (Bana and Costa et al., 1999), which will be used for the construction of the model:

(1) Structuring Phase: structuration of the decision-making context;

(2) Evaluation Phase: construction of the evaluation criteria; and

(3) Result Assessment: final data analysis and the decision proposal (discussed on the "result assessment" section).

To support elementary calculations of the comparisons between differences in attractiveness, impact levels, value functions, substitution rates, semantic judgments and other evaluations, eight specialists in airport maintenance and operations were interviewed and the model was built based in their deep technical knowledge on the subject.

3.1. Structuring Phase

According to Ensslin (2001) the structure of the model is composed by:

a) The choice of the decision makers who will participate actively in the construction of the model;

b) Identification of the types of potential actions that will be evaluated in the model;

c) Define a label (title) for the model;

d) Identify the dimensions, criteria and sub criteria to evaluate the potential actions;

e) Define the descriptors (scales) of each evaluation axis.

For the development of this research were conducted semi-structured interviews using a brainstorming technique with the purpose of generating knowledge about the decision context. The expert opinion led to a structured decision tree in 12 final elements of judgement organized in up to 4 levels for the purpose of the better theoretical organization and more appropriate treatment of the problem, giving the model a good measurement capability without redundancy of the analyzed factors (figure 1)

3.2. Evaluation Phase

From the new decision tree, the other elements of the MCDA-C modeling were defined. We outlined the descriptors for the last level of each branch of the tree indicating and the acceptable minima (regulatory assumptions or subjective assumptions). The scale chosen for the descriptors varies according to (1) the minima clearly defined in regulation or (2) the point of view of the specialists and the descriptor, when acceptable levels are not defined and their definition become purely subjective (table 1).

A direct numerical normalization was introduced for each descriptor value, so comparisons between them can be properly done in the same basis. It is one of the most widely used numerical technique and is considered essential to make the model operational, more objective and intuitive (therefore more acceptable) for the users (Fishburn, 1967; Winterfeldt e Eduwards, 1968; Goodwin e Wright, 1991; Beinat, 1995).



Figure 1 - Decision tree of the proposed methodology

Table 1 - Descriptors, Reference Levels and Value Functions

Hierarchical level				Descriptor		Normalization
Level 1	Level 2	Level 3	Level 4	Nature	Value	
1	1.1	1.1.1		Subjective	Compliant	1
					Non-compliant	-1
		1.1.2		Regulatory	Compliant	1
					Non-compliant	-1
		1.1.3		Regulatory	Compliant	1
					Non-compliant	-1
	1.2	1.2.1	1.2.1.1	Regulatory	Compliant	1
					Non-compliant	-1
			1.2.1.2	Regulatory	Compliant	1
					Non-compliant	-1
		1.2.2	1.2.2.1	Regulatory	Compliant	1
					Non-compliant	-1
			1.2.2.2	Regulatory	Compliant	1
					Non-compliant	-1
2	2.1			Regulatory	85 - 100 (Compliant ++)	1
					70 - 84 (Compliant +)	0,5
					55 - 69 (Compliant)	0
					40 - 54 (Non-compliant)	-0,25
					25 - 39 (Non-compliant -)	-0,5
					10 - 24 (Non-compliant --)	-0,75
					0 - 09 (Non-compliant ---)	-1

	2.2			Regulatory	≤2,5 m/km (Compliant)	1
					>2,5 m/km (Non-compliant)	-1
	2.3	2.3.1		Regulatory	P > 1,2 (Compliant ++)	1
					0,8 < P ≤ 1,2 (Compliant +)	0,5
					0,4 < P ≤ 0,8 (Compliant)	0
					0,2 < P ≤ 0,4 (Non-compliant)	-0,5
					P ≤ 0,2 (Non-compliant -)	-1,0
		2.3.2		Regulatory	μ > Maintenance Level (Compliant +)	1
					Maintenance Level ≥ μ ≥ Minimum Level (Compliant)	0
					μ < Minimum Level (Noncompliant)	-1
3	3.1			Regulatory	Highest PCN	1
					Lowest PCN	-1

Finally, were defined the relative weights for each hierarchical level of evaluation. All the experts voted individually and together crosschecked the resulting mean values into a semantic judgment matrix. The collegiate action is essential to control the results and amplify the level of certainty of the judgement as a whole. Results are shown in Figure 2.

4. RESULT ASSESSMENT

4.1. On the model

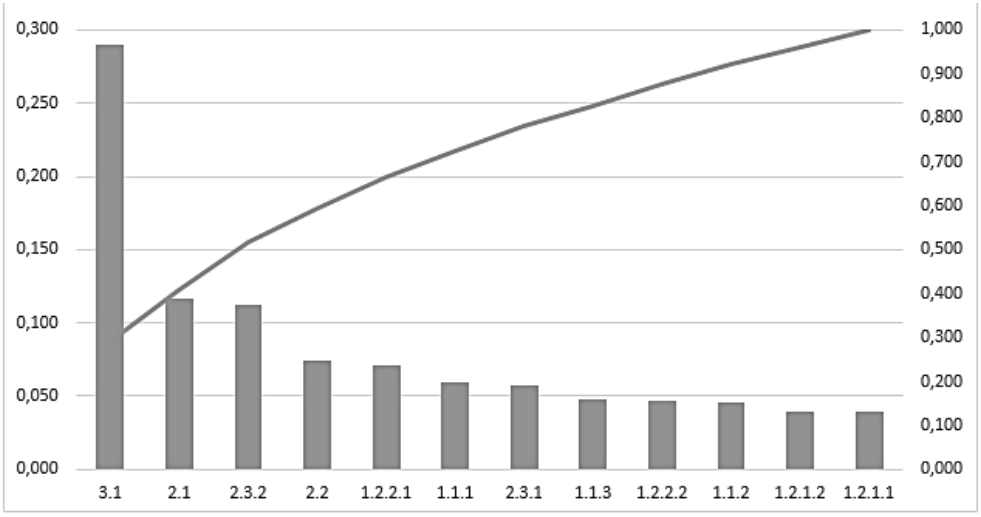
A sensitivity assessment of the data obtained was performed to reveal the relative representativeness of each evaluation element of the model. The relative analysis of the twelve criteria showed that the experts judged nine of them with approximate and relatively low values. The other three criteria (3.1 ACN/PCN, 2.1 PCI and 2.3.2 Friction Coefficient) stood out, demonstrating that the evaluating body agreed on its importance for airports runway maintenance (Chart 1).

We did not find a large disparity between most of the criteria assessed. It could be attributed to three factors: the first would be related to the high level of technical capacity of the experts. As said before, it increases the level of precision of the evaluation. The second could be the fact

Hierarchical level	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Weight in each level	Weight general
1	0,33	0,50	0,33	0,40	0,25	0,34	0,25	0,40	0,35	0,350
1.1	0,40	0,50	0,40	0,40	0,40	0,50	0,60	0,30	0,44	0,153
1.1.1	0,40	0,30	0,50	0,40	0,30	0,50	0,40	0,30	0,39	0,059
1.1.2	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,046
1.1.3	0,30	0,40	0,20	0,30	0,40	0,20	0,30	0,40	0,31	0,048
1.2	0,60	0,50	0,60	0,60	0,60	0,50	0,40	0,70	0,56	0,197
1.2.1	0,40	0,50	0,40	0,30	0,40	0,30	0,50	0,40	0,40	0,079
1.2.1.1	0,50	0,40	0,50	0,50	0,70	0,50	0,50	0,40	0,50	0,039
1.2.1.2	0,50	0,60	0,50	0,50	0,30	0,50	0,50	0,60	0,50	0,039
1.2.2	0,60	0,50	0,60	0,70	0,60	0,70	0,50	0,60	0,60	0,118
1.2.2.1	0,60	0,70	0,60	0,70	0,60	0,50	0,60	0,50	0,60	0,071
1.2.2.2	0,40	0,30	0,40	0,30	0,40	0,50	0,40	0,50	0,40	0,047
2	0,34	0,25	0,33	0,30	0,50	0,33	0,50	0,30	0,36	0,360
2.1	0,30	0,20	0,34	0,30	0,50	0,30	0,34	0,30	0,32	0,116
2.2	0,20	0,10	0,33	0,10	0,20	0,10	0,33	0,30	0,21	0,075
2.3	0,50	0,70	0,33	0,60	0,30	0,60	0,33	0,40	0,47	0,169
2.3.1	0,30	0,30	0,40	0,30	0,40	0,30	0,30	0,40	0,34	0,057
2.3.2	0,70	0,70	0,60	0,70	0,60	0,70	0,70	0,60	0,66	0,112
3	0,33	0,25	0,34	0,30	0,25	0,33	0,25	0,30	0,29	0,290
3.1	1	1	1	1	1	1	1	1	1,00	0,290

Figure 2 - Replacement rates by hierarchical leve

Chart 1 - Relative and cumulative impact of each final evaluation element



that we used the mean values after their judgement, which can correct any possible "outlier misjudgment", if it occurs. Finally, the third could be attributed to the large number of evaluation elements related by them.

Together they could represent a disadvantage when using the model because it could bring the need for a larger effort in data acquisition, but in the other hand, it could also be an advantage because it represents a reduction in the impact of a possible asymmetry of information in some element.

According to their risk judgment, the 7 most representative criteria are able to deal with approximately 80% of the perceived risk in airport runways. Together, top 3 criteria (3.1 ACN/PCN, 2.1 PCI and 2.3.2 Friction Coefficient) represented 52% of the importance given by the runway maintenance experts. Their risk perception indicated by the semantic judgment that in a group of 12 elements, alone the 3 most significant represented the risk of the 9 least significant.

This data is a strong indication that a considerable amount of public and private resources of the sector can be being applied in actions of low importance. Given the high concentration of the risk in some few elements, it means that a considerable part of the resources of the Brazilian airport infrastructure operations could be being redirected towards a more rational application, since they would reduce the expense in elements of low risk and high cost.

If we consider that the Brazilian aviation market has approximately 110 airports who are required to meet those runway maintenance requirements and that infrastructure costs are amongst the most representative in economy, we can briefly assess how important this kind of model can be to assure a more cost effective (and then more safe) market.

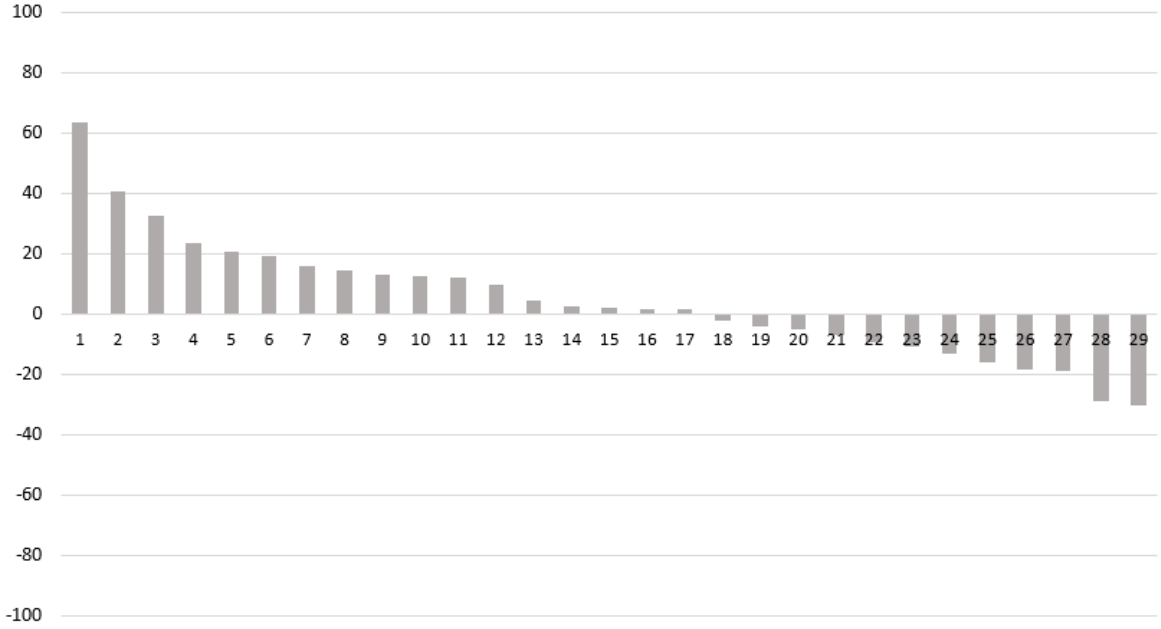
4.2. Application in real scenario

Model was applied in the assessment of 29 the busiest Brazilian airports, concentrating 94% of the country`s passenger movement in 2018. For the analysis, we used de-characterized data of the 5 most sensitive parameters (3.1 PCN, 2.1 PCI, 2.3.2 Friction Coefficient, 2.2 IRI e 2.3.1 Macrotexture Depth), representing 65% of the perceived risk by the group of experts, within the 12 developed.

The survey of the other data from the judgement tree created in the model, less sensitive in terms of risk would disproportionately increase the cost of the risk assessment, without an equivalent return in risk control. This point was considered as the optimum point of the cost-benefit data assessment.

Sensitivity analysis was performed descriptively in two ways. The first on a scale of values relative to the maximum possible values to obtain: +0.65 (maximum safety = +100 points) to -0.65 (maximum risk = -100 points). So, for example, if a given airport obtained maximum performance on the assessed criteria, its safety grade would be 100 points (Chart 2).

Chart 2 - Airport performances relatively to maximum possible scores (+0,65 = 100 pts. / -0,65 = -100 pts.)



As we can see, any airport obtained maximum safety performance. The best one obtained +0,41 (64 points) and the least performant obtained -0,20 (-30 points). Out of 29 airports, 17 had positive scores and 12 stayed in negative spectrum. The average score of the safest airports was 0,11 (17 points) and the among the less safe airports was -0,09 (-14 points). It is possible to conclude that, according to criteria developed in this article, the runway condition of the analyzed airports tends to be safer than risky

From this point we can look the numbers in a normalized scale assessing how safe are the airports relatively to their own scores (Chart 3). We disposed the airports in a dispersion analysis, comparing how are their performance relatively to the standard deviation of the sample ($\sigma = 0,13$.

Were identified 11 airports surrounding +0,5 and -0,5 standard deviations. They can be seen as statistically similar in terms of runway safety performance. Their score differences can be attributed to some possible imprecision since the airport on site testing method, until the data collection phase in this article.

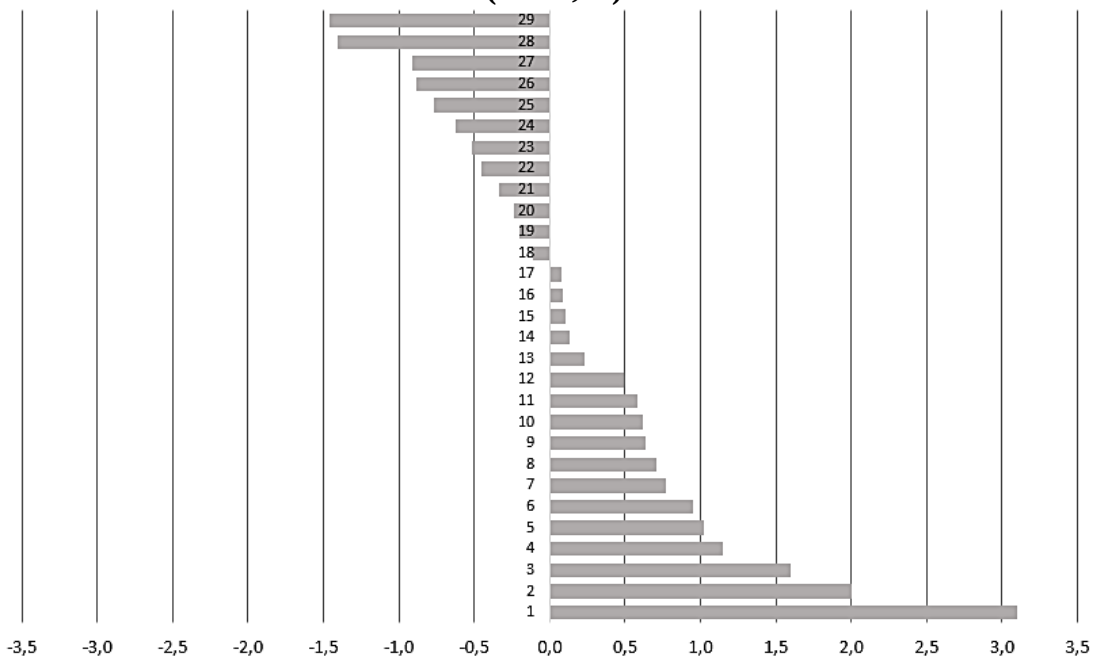
The other 18 airports presented scores above +/-0,5 standard deviations. Among then, 7 were placed in the region of the riskier ones, while in the other side of the scale, were placed 11 airports in the safest group. We can securely stand that they are safer or riskier than the 11 placed in the central area of the chart.

This kind of relativization allows regulatory and economic agents to act according to the outputs produced. From the point of view of public regulatory agencies, they can adopt more precise and objective regulatory actions. It is possible to optimize the appropriate application of resources to monitor factors that most significantly influence risk, especially if we consider that there is a considerable part of the monitored data that returns a small part of the risk to the state. They can, for example, increase the frequency of surveillance at airports with higher levels of risk and reduce it for the safest operators group.

From the point of view of the airports, being among the safest airport group can be advantageous due to the financial benefit of being submitted to lower frequencies of state`s enforcement. Additionally, the "willing" to be on the positive safety score region can lead to a continuous improvement of safety records since this effort can increase the average score of the whole group.

However, analyzing the actions from the data assessment is not objective of this article. This last section was brought here only to demonstrate the use of the model to the real case, which was clearly proved feasible.

Chart 3 - Airport performances relatively to standard deviation (σ = 0,13)



5. CONCLUSIONS

The objective of this work was to test the use of MCDA-C methodology in proposing a predictive risk assessment for airports runway maintenance in Brazil. To support morphological structuring and semantic judgments eight specialists in airport maintenance and operations were interviewed and the model was built based in their perceptions and deep technical knowledge on the subject.

The methodology, already consolidated for use in other spheres of the economy, has proved versatile enough to encapsulate the different forms of assessment that emerge for civil aviation, namely, qualitative and quantitative, with clearly defined reference levels in regulations technical or merely perceptive from the point of view of the actors involved, either in risk assessment or in decision making.

Data collected was able to assist in the risk analysis in a clear and objective manner, and the experts expressed that the final adjusted results were aligned with their perception in relation to the risk represented by the noncompliance of each of the elements analyzed.

We found that the 7 most representative criteria were able to deal with approximately 80% of the perceived risk in airport runways. Together, top 3 criteria represented 52% of the importance given by the runway maintenance experts.

Their risk perception indicated by the semantic judgment that in a group of 12 elements, alone the 3 most representative represents the risk of the 9 least representative. This data is a strong indication, a considerable part of the resources of the Brazilian airport infrastructure operations could be being redirected towards a more rational application, since they would reduce the expense in elements of low risk and high cost

As a final step, we applied the method in a real scenario situation by analyzing real data from the 29 the busiest Brazilian airports, concentrating 94% of the country passenger movement in 2018. For the assessment we used de-characterized data of the 5 most sensitive parameters (3.1 PCN, 2.1 PCI, 2.3.2 Friction Coefficient, 2.2 IRI e 2.3.1 Macrotexture Depth), representing 65% of the perceived risk by the group of experts, within the 12 developed.

We were able to conclude objectively that 18 airports presented scores that clearly indicated being in a favorable or unfavorable condition regarding the criteria analyzed. Among then, 7 were placed in the region of

the riskier ones, while in the other side of the scale, were placed 11 airports in the safest group.

It allows regulatory agencies to optimize the appropriate application of resources to monitor factors that most significantly influence risk, especially if we consider that there is a considerable part of the monitored data that returns a small part of the risk to the state.

The conclusion on the method application is that the MCDA-C methodology is able to be used as a tool for risk assessment in scenarios with objective or subjective data in airport safety management, enabling us to replicate the method for other airport elements with similar conditions of the regulatory requirements.

6. REFERENCES

FISHBURN, P. C. (1967) Conjoint measurement in utility theory with incomplete product sets - Journal of Mathematical Psychology - Volume 4, Issue 1, February 1967, Pages 104-119.

ANAC (2015) Agencia Nacional de Aviação Civil. Programa de Segurança Operacional Específico (PSOE-ANAC). Brasília. 30p.

ANAC (2012) Agencia Nacional de Aviação Civil. *Regulamento Brasileiro de Aviação Civil 153.*

ANAC (2012) Agencia Nacional de Aviação Civil. *Regulamento Brasileiro de Aviação Civil 154.*

BANA e COSTA, C. A. (1992) *Structuration, construction et exploitation d'un modèle multicritère d'aide à la décision.* Tese (Doutorado) - Engenharia de Sistemas, Universidade Técnica de Lisboa. Instituto Superior Técnico, Lisboa, 1992.

BEINAT, E. (1995) Multi attribute value functions for environmental management. Amsterdam: Timbergen Institute Research Series.

BEZERRA, G. C. L., Gomes, C. F. (2016) "Performance Measurement in Airport Settings: A Systematic Literature Review". *Benchmarking An International Journal*, v. 23. i. 4 p. 1027-1050.

BORTOLUZZI, S. C., ENSSLIN, S., LYRIO, M. V. L., ENSSLIN, L - Avaliação de desempenho econômico-financeiro: uma proposta de integração de indicadores contábeis tradicionais por meio da metodologia multicritério de apoio à decisão construtivista (MCDA-C) - *Revista Alcance - Eletrônica*, Vol. 18 - n. 2 - p. 200-218 / abr-jun 2011

CEOLIM, A.J. Aplicação de Metodologias Multicritério na Avaliação dos Cursos da UNESPAR/FECILCAM. Dissertação de Mestrado. Universidade Federal do Paraná, Curitiba, PR, 2005.

ENSSLIN, L., CORRÊA, E. C., VANSNICK, J. C. (1999) Decision Support Systems in Action: Integrated Application in a Multicriteria Decision Aid Process. *European Journal of Operational Research*, v. 113, n. 2. p. 315-335.

ENSSLIN, L., ENSSLIN, S., MACHADO, T. (2015) Desenvolvimento de produtos usando a abordagem MCDA-C. *Revista Produção*, v. 25, n. 3. versão online.

ENSSLIN, L., MONTIBELLER, G. N., & NORONHA, S. M. (2001) *Apoio à decisão: metodologias para estruturação de problemas e avaliação multicritério de alternativas*. 1ª Edição - Florianópolis: Insular. 296 p.

ENSSLIN, L., ZAMCOPÉ, F. C., TERZA, R. (2009) Metodologia multicritério de apoio à decisão construtivista para a identificação e avaliação de habilidades para o setor de estamparia têxtil. *Revista GEPROS. a. 5.* n. 1. p. 125-142.

ENSSLIN, L. *et al*. Modelo multicritério de apoio à decisão construtivista no processo de avaliação de fornecedores. Revista Produção, v. 23, n. 2, p. 402-421, abr./jun. 2013 (http://www.scielo.br/pdf/prod/v23n2/aop_t6_0006_0628.pdf)

FISHBURN, P. C. (1967) Conjoint measurement in utility theory with incomplete product sets - Journal of Mathematical Psychology - Volume 4, Issue 1, February 1967, Pages 104-119.

JANIC, M. (2000) An assessment of risk and safety in civil aviation. *Journal of Air Transport Management.* v. 6. p. 43-50.

GOODWIN, P. & WRIGHT, G. (1991) Decision Analysis for Management Judgment. New York: John Wiley& Sons, p. 308.

JANIC, M. (2000) An assessment of risk and safety in civil aviation. Journal of Air Transport Management. v. 6. p. 43-50.

LYRIO, M. V. L. et al. Construção de um Modelo de Avaliação de Desempenho da Secretaria de Desenvolvimento Regional da Grande Florianópolis: a Proposta da Metodologia Multicritério de Apoio à Decisão Construtivista. 5. ed. Florianópolis*: Contextus*, 2007.

NEUENFELDT JÚNIOR, A. L., MACHADO, C. M., SILUK, J. C. M., SOLIMAN, M., HUPFER, N. T., PARIS, S. R. - Comparativo entre as metodologias MCDA-C, DEA e AHP - *Revista F A E* , Curitiba, Vol. 18 – n. 1 – p. 6-19 / jan.-jun. 2015.

OACI (2013) Organização de Aviação Civil Internacional. *Doc 9859 - Safety Management Manual (SMM)*. 3ª Edição - Montreal. 254p.

OACI (2014) Organização de Aviação Civil Internacional. *Annex 14 Volume 1 - Aerodrome Design and Operation*. 6ª Edição - Montreal. 336p.

OACI (2006) Organização de Aviação Civil Internacional. *Doc 9734 – Safety Oversight Manual – Part A.* 2ª Edição - Montreal. 48p.

OACI (2011) Organização de Aviação Civil Internacional. *Doc 9734 – Safety Oversight Manual – Part B.* 2ª Edição - Montreal. 92p.

ROY, B. *Decision-aid and decision making*. In: BANA e COSTA (Ed.) Readings in Multiple Criteria Decision Aid, Berlin: Springer, p. 17-35, 1990.

SAATY, T.L. The Analytic Hierarchy Process, McGraw-Hill, New York, NY, USA, 1980.

SAGE, A.P., WHITE, E.B., 1980. Methodologies for risk and hazard assessment: a survey and status report. IEEE Transaction on System, Man, and Cybernetics SMC-10, 425-441.

VON WINTERFELT, D., EDWARDS, W. (1986) Decision analysis and behavioral research. Cambridge University Press, Cambridge.

ZAMCOPÉ, F. C. (2012) Construção de um modelo para avaliação da sustentabilidade corporativa - Um estudo de caso na industria têxtil. 260p. Gestão da Produção, São Carlos, v. 19, n. 2, p. 303-321, 2012.