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A Ranking Method to Prioritize VFR Airports to Be Provided With Instrument Approach Procedures

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Aviation Management Program – Class of 2020

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A Capstone Project Submitted to Embry-Riddle Aeronautical University in Partial Fulfillment of the Requirements for the Aviation Management Certificate Program

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This Capstone Project was prepared and approved under the direction of the
Group's Capstone Project Chair, Dr. Leila Halawi
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ABSTRACT

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The primary purpose of this work is to investigate the necessity of a more comprehensive and systematic method to prioritize airports to be provided with instrument approach and landing procedures in the Brazilian air transportation landscape. An overview of the main contributors to risks associated with the approach and landing phases is provided, covering the most important aspects of unstable approaches and CFIT events. Considering the emergence of Terrain Awareness and Alerting Systems (TAWS), the role of its contribution to safety is discussed, as well as the certification context related to the design, installation, and operation of those systems. A ranking method is developed based on the analysis of TAWS alert events in several Brazilian airports. The method results in a ranking list of airports eligible for instrument procedures and points to objective means to improve safety, accessibility, and efficiency on the flight operations to those locations.

DEDICATION

This work is humbly dedicated to all aviation professionals working hard to get the job done with safety and efficiency amid a pandemic.

ACKNOWLEDGMENTS

This research results from a wider collaboration effort between Embry-Riddle Aeronautical University (ERAU) and the Brazilian *Instituto de Transporte e Logística* (ITL) towards providing better preparation to Brazilian air transportation professionals to contribute to the development of the Brazilian aviation industry.

The authors also thank the Brazilian Air Force Department of Airspace Control (DECEA – *Departamento de Controle do Espaço Aéreo*), SEST/SENAT, ABEAR, and BCAST, for the institutional and technical support, including the data utilized in this research.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

Introduction

Several airports across the country, including those operated by regional and major commercial airlines, are not certificated to operate IFR (Instrument Flight Rules). These airports are provided with only visual approach procedures or instrument approach procedures to a point in the airspace where the approach continues under visual meteorological conditions (VMC). That is a significant issue for the development of regional and commercial air transport. Accessibility to those airports is affected by weather conditions and increased approach minimums in terms of altitude and required ceiling, causing flight cancellations and diversions to alternate airports.

Table 1

Frequent Contributing Factors for Flight Cancellations in Top 15 VFR-only Airports, per traffic volume (2016 – 2017).

Contributing Factors	**Percentage**
Adverse weather	84.2 %
Airport infrastructure	1.2 %
The airline, Aircraft maintenance	12.7 %
Airline, Operations	0.7 %
Other	1.2 %

Note. Adapted from (ANAC, 2017).

Adverse weather has accounted as the contributing factor of 84.2 % of total flight cancellations in high traffic volume VFR-only airports, as illustrated in Table 1.

The Commercial Aviation Safety Team (CAST) is an industry-wide multidisciplinary, international working group comprising representatives from airlines, manufacturers, labor, and government institutions tasked with developing and implementing comprehensive safety enhancement plans. According to CAST, safety concerns must be addressed to the topic. Visual approaches have been commonly associated with a higher number of unstable approaches and potentially higher ground proximity warning alerts (CAST, 2018).

Unstable approaches have been significantly present in most safety events related to approach and landing phases, as depicted in Figure 1. Additionally, the highly irregular approach event rate observed in the first months of 2020 has been associated with the overall flight downturn effects caused by the covid-19 pandemic. The reductions in operations, followed by a slow recovery, may have affected the flight crew's proficiency (IATA, 2020).

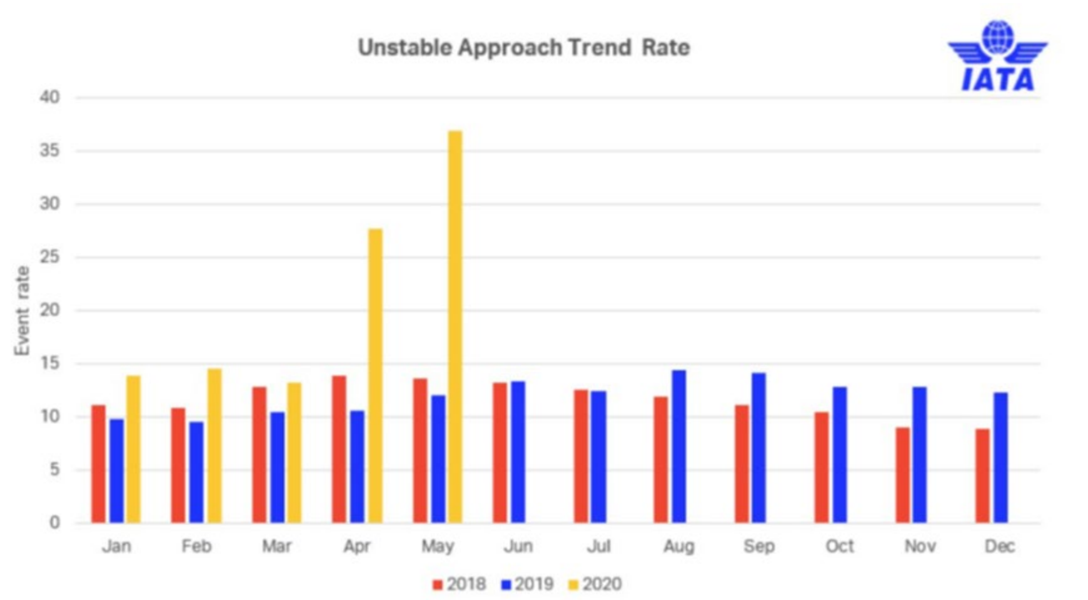

Figure 1 – Unstable Approach Trend Rate (2018 – 2020) (IATA, 2020).

IATA's FDX (Flight Data eXchange), from the GADM program (Global Aviation Data Management), also details the most significant contributing factors to unstable approaches, from which airspeed, thrust, and GPWS are the most relevant to the maintenance of stable approaches (including a constant descent flight path angle), as depicted in Figure 2.

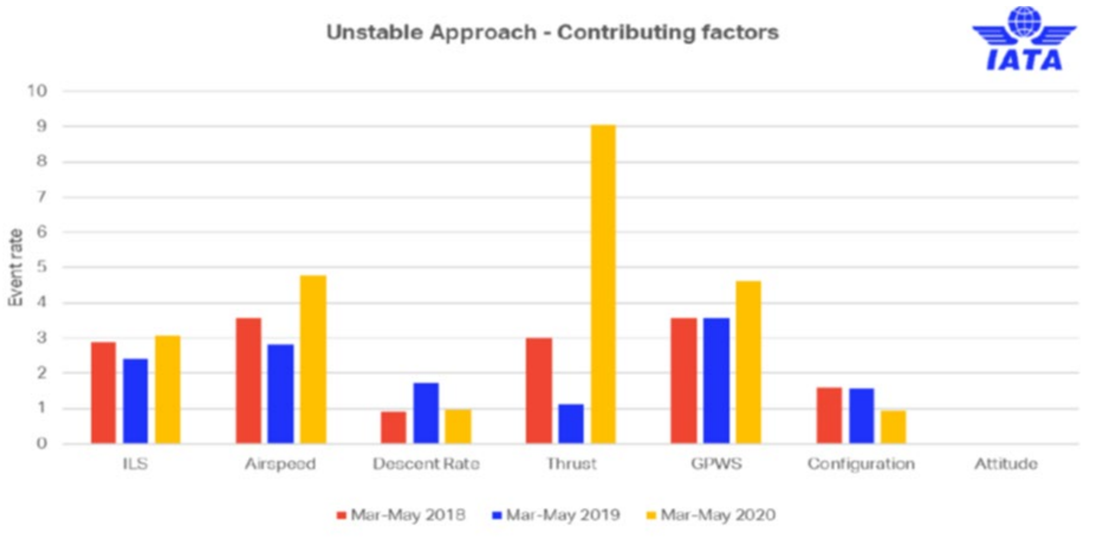

Figure 2 – Unstable Approach Contributing Factors (2018 – 2020) (IATA, 2020).

Moreover, unstable approaches have been significantly associated with safety events as the following (IATA, 2017):

- Hard landing;
- Runway excursion;
- Short landing;
- Loss of Control In-Flight (LOC-I);
- Controlled Flight Into Terrain (CFIT).

The International Civil Aviation Organization (ICAO) also has identified high-risk accident categories as safety priorities in its latest edition of the Global Aviation Safety

Plan (GASP) (ICAO, 2019): runway safety-related events, Loss of Control In-Flight (LOC-I), and Controlled Flight into Terrain (CFIT).

The high-risk categories pointed in 2018 are detailed in Figure 3, which depicts the distribution of accidents, fatal accidents, fatalities, and accidents in which aircraft were damaged or destroyed.

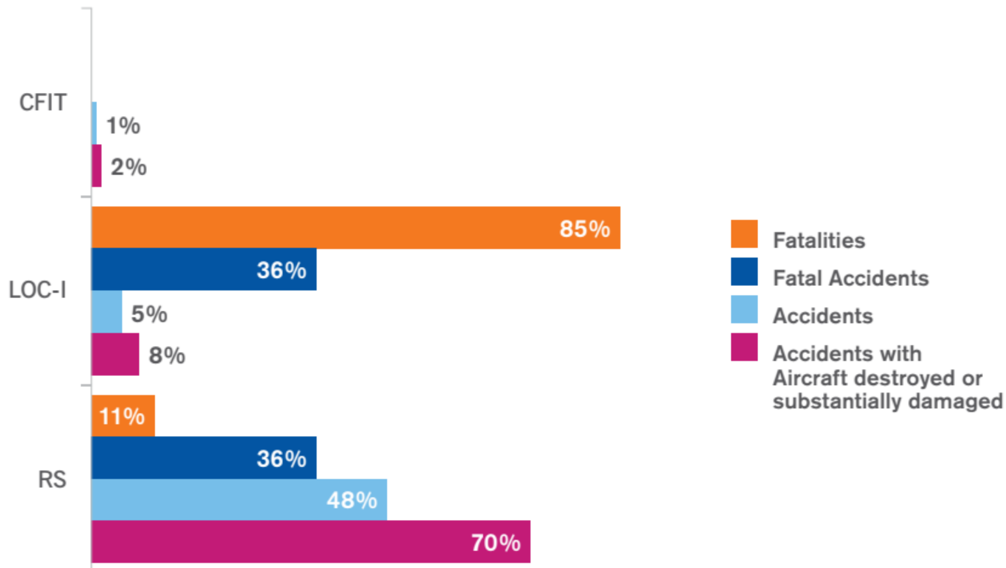

Figure 3 – High-Risk Category Accident Overview in 2018 (ICAO, 2019).

CFIT events have been a significant historical component of accidents in the 1960s. However, technological milestones achieved during the 1980s with the development of aircraft glass cockpit, satellite-based navigation systems, procedures, and warning systems have contributed to reducing CFIT accident rates, becoming a significant risk mitigation factor (ICAO, 2019).

Problem Statement

The Brazilian airspace management is under the sole responsibility of the Brazilian Air Force Department of Airspace Control (DECEA). DECEA's Aeronautical Cartography Institute (ICA) is in charge of conducting the analysis, development, and certification of visual and instrument navigation flight procedures, including those related to departure, approach, and landing (Brasil, 2010).

There is a long term perspective of growth in air traffic in Brazil, associated with the increasing quantity of airports planned to be operated by companies under RBAC 121 and RBAC 135 (*Regulamento Brasileiro de Aviação Civil*, Brazilian operational regulations, similar to the United States Code of Federal Regulations Part 121 and Part 135, respectively).

Therefore, that scenario suggests an increase in the demand for the development of instrument approach procedures for VFR-only airports, providing equivalent levels of safety associated with the approach and landing operations, and higher operational efficiency levels. Table 2 lists regional airports in Brazil with relevant commercial traffic volume and their current operations certification status.

Table 2

Regional Airports with Relevant Traffic Volume.

IATA / ICAO Code	**Condition**
GVR / SBGV	IFR
OPS / SBSI	IFR
TXF / SNTF	VFR
JPR / SBJI	VFR
PGZ / SBPG	IFR

OAL / SSKW	VFR
TJL / SBTG	VFR
BYO / SBDB	IFR
ROO / SBRD	IFR
LEC / SBLE	VFR
VAL / SNVB	VFR
DIQ / SNDV	VFR
FEC / SBFE	VFR
BRA / SNBR	VFR
PAV / SBUF	VFR
PIN / SWPI	VFR
RVD / SWLC	VFR

Note. Adapted from (DECEA, 2020).

Purpose Statement

This work provides evidence of the need for a ranking method to implement IFR approach and landing procedures, contributing to mitigating risks associated with unstable approaches on VFR-only airports.

The development process of instrument procedures is a complicated and time-consuming undertaking. It requires detailed analyses of the topographic characteristics of the regions surrounding the airport, the estimation of aircraft flight path within regulation-based terrain separation criteria, aircraft flight performance simulations, and flight tests to provide adequate compliance with certification regulation.

Therefore, adequate prioritization of those airports is a critical aspect to the safe and efficient development of Brazilian air transportation and is an essential topic in discussions held with significant stakeholders, including airline companies, airport authorities, and DECEA, in industry-level forums as the BCAST (Brazilian Commercial Aviation Safety Team), the Brazilian Chapter of CAST (BCAST, 2019).

Research Question

Several new potential flight network expansion VFR-only airports have observed flight diversions and cancellations, unstable approaches, and terrain proximity warning alerts. A research question to be addressed is, therefore, what prioritization methods could be proposed and applied to effectively contribute to ranking current VFR-only airports to be provided with instrument approach procedures, including non-precision, RNAV approach procedures, for instance?

Project Goals and Scope

This work's primary purpose is to conceive a method to produce a list of higher priority VFR airports, ranked by adequate metrics, to be presented to DECEA for analysis over the development of instrument approach procedures.

Once the procedures are developed and certified, accessibility to those airports is expected to increase over time, with significant improvements on operations' efficiency and reduced costs to airlines associated with fewer flight cancellations and diversions to alternate airports due to adverse meteorologic conditions.

Also, a decrease in unstable approach events and ground proximity alerts is expected. As a result, they are contributing to higher safety levels in operations to those airports.

The proposed approach contains an analysis of Terrain Awareness and Warning Systems (TAWS), or Ground Proximity Warning Systems (GPWS) alerts as possible adequate metrics. The analysis of TAWS alerts data related to landing procedures is provided by airlines, collected in local industry committees, as the BCAST. Combined with current, historical, and forecast traffic volume information over regional, VFR-only airports, a set of indicators and a ranking methodology are proposed to determine high-priority airports to receive instrument procedures.

Plan of Study

Chapter 2 is dedicated to the bibliography review, presenting the fundamental concepts and principles of terrain and ground proximity warning alerts in the context of the final approach and landing flight phases, along with the general regulatory framework. A discussion of the association of unstable approaches and VFR-only airports is also provided, covering the need to reduce the risk of Controlled Flight Into Terrain (CFIT).

Chapter 3 discusses the proposed research methodology. An overview of the research design is provided, covering TAWS data sources as a means of identifying potential CFIT "hotspots" related to the Brazilian airports' population and a sample of interest. The research method also discusses the classification and comparison of IFR and VFR airports by historical air traffic volume to be contextualized in the International Air Transport Association (IATA).

In Chapter 4, the data analysis results based on the proposed methodology are presented and discussed.

Finally, Chapter 5 brings the conclusions, limitations of this study, and suggestions for further research.

Definitions of Terms

Caution Alert	An alert is requiring immediate flight crew awareness. Subsequent corrective action usually will be necessary (FAA, 2000).
CFIT	Controlled Flight Into Terrain. An accident or incident in which the airplane, under the flight crew's control, is inadvertently flown into terrain, obstacles, or water without either sufficient or timely flight crew awareness to prevent the event, or both (FAA, 2000).
Warning Alert	An alert for a detected terrain threat requires immediate flight crew action (FAA, 2000).

List of Acronyms

AC	Advisory Circular
AIC	Aeronautical Information Circular
ANAC	*Agência Nacional de Aviação Civil*
BCAST	Brazilian Commercial Aviation Safety Team
CAST	Commercial Aviation Safety Team
CI	*Circular de Informação*
CFIT	Controlled Flight Into Terrain
CFR	Code of Federal Regulations
COMAER	*Comando da Aeronáutica*
DA	Decision Altitude
DECEA	Departamento de Controle do Espaço Aéreo
DH	Decision Height

EASA	European Aviation Safety Agency
EGPWS	Enhanced Ground Proximity Warning System
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FDM	Flight Data Recorder
FDX	Flight Data eXchange
FMS	Flight Management System
FOQA	Flight Operations Quality Assurance
GASP	Global Aviation Safety Plan
GPWS	Ground Proximity Warning System
IATA	International Air Transport Association
ICA	*Instituto de Cartografia da Aeronáutica*
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IOSA	IATA Operational Safety Audit
IS	*Instrução Suplementar*
LNAV	Lateral Navigation
LOC-I	Loss of Control In-Flight
MEL	Minimum Equipment List
PAPI	Precision Approach Path Indicator
PBN	Performance Based Navigation

RBAC	*Regulamento Brasileiro de Aviação Civil*
RBHA	*Regulamento Brasileiro de Homologação Aeronáutica*
RNAV	Area Navigation (Specification)
RNP	Required Navigation Performance
SE	Safety Enhancement
SID	Standard Instrument Departure
TAWS	Terrain Awareness and Warning Systems
TSO	Technical Standard Order
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation

Chapter II

Review of the Relevant Literature

TAWS and GPWS alerts

This chapter discusses the literature related to the TAWS and GPWS alerts in commercial aviation, with a brief overview of terrain avoidance and warning systems actuation modes. The regulatory framework and historical aspects of conventional and satellite-based navigation means are presented. A critical perspective of visual, non-precision, and precision approach procedures is also provided in Brazilian airports, along with the BCAST safety enhancement plans related to mitigating the risk of CFIT.

The Terrain Awareness and Warning System (TAWS) is a generic term that describes an alerting system designed to provide information to the flight crew to detect a potentially hazardous terrain proximity situation and avoid a CFIT accident (FAA, 2000).

Specific systems currently in use include the GPWS and the EGPWS. TAWS design, installation, and operation requirements are covered by several regulations applicable to avionics manufacturers to which TSO-C151c is applicable (FAA, 2012), aircraft manufacturers under FAR 23, FAR 25, and operators in general aviation (FAR 91), commuter and on-demand air transport (FAR 135), and commercial flag air transport (FAR 121). Brazilian regulations also address manufacturers and operators in a similar context for Brazil's cases (ANAC, 2005).

CFIT fatal and non-fatal accidents

In (IATA, 2018), CFIT accidents have accounted for 6 % of total accidents in commercial aviation during the period between 2008 and 2017, as illustrated in Figure 4.

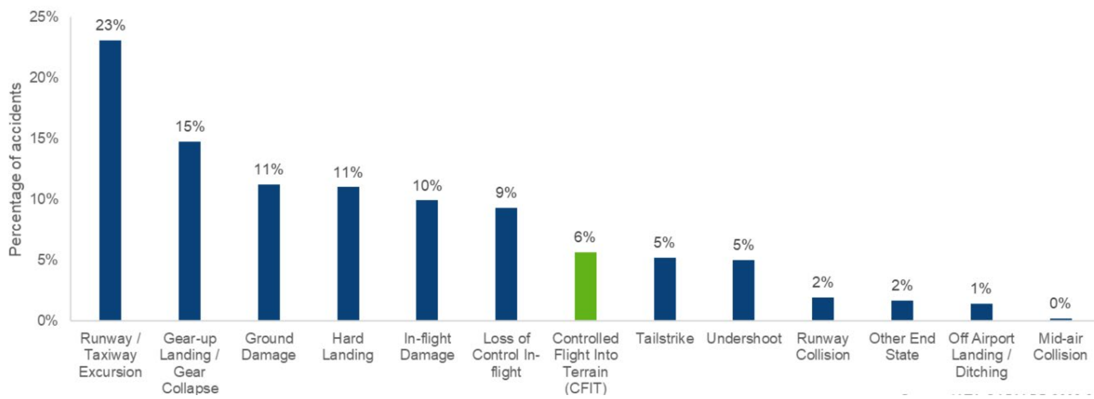

Figure 4 – Percentage of commercial accident categories to total accidents [2008 – 2017] (IATA, 2018)

Although CFIT accidents have shown fewer absolute numbers in the past decades, the outcomes are almost catastrophic and involve fatalities to passengers or flight crews, as depicted in Figure 5 (IATA, 2018). IATA and industry representatives have assessed CFIT as one of the highest priority topics for safety intervention in the face of the fatality risk.

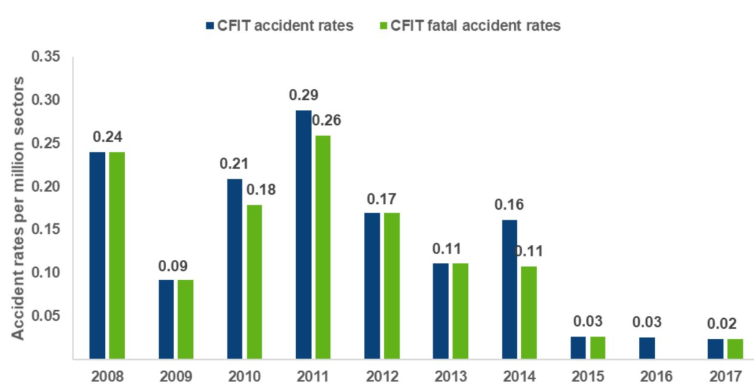

Figure 5 – Distribution of fatal and non-fatal CFIT accident rates per year (IATA, 2018)

Several contributing factors may occur individually and more frequently in combination to result in CFIT accidents. The analysis and assignment of contributing factors, classified as latent conditions, environmental, and airline threats, may help foresee the problem from a broader perspective and develop risk mitigation strategies. Table 3 lists some significant contributing factors related to CFIT accidents.

Table 3

Frequent Contributing Factors for CFIT (2008 – 2017).

Latent Conditions	**Percentage**
Regulatory oversight	72 %
Technology and equipment	54 %
Safety management	46 %
Flight operations	31 %
Environmental Threats	**Percentage**
Meteorology	51 %
Navigation aids	51 %
Ground-based navigation aid malfunction or not available	49 %
Poor visibility, IMC	46 %
The undesired Aircraft States	**Percentage**
Flight towards terrain	56 %
Vertical, Lateral, Speed Deviation	49 %
Unnecessary weather penetration	18 %
Unstable approach	10 %
Continued landing after an unstable approach	5 %

Note. Adapted from "IATA Controlled Flight Into Terrain Accident Analysis Report," 2018, p. 22. Copyright by International Air Transport Association.

The overall contributing factors indicated as latent conditions and environmental threats, in the form of low visibility, IMC, and lack of visual references, point to the need to implement instrument, precision approach procedures, or PBN approaches as an essential method to reduce the risk of CFIT accidents.

Likewise, unstable approaches are also essential components of CFIT accidents. They may influence the flight crew's attention and divert it away from the approach procedure to maintain better aircraft control that flight phase.

The most common definition of a stabilized approach, based on recommendations from ICAO and IATA's body of requirements under IOSA provisions, states that a safe approach requires the aircraft's flight path angle, landing gear and flaps configuration, and airspeed to be stabilized before a certain altitude threshold is reached.

Unless all the mentioned flight parameters are complied with, the approach becomes unstable and requires flight crew action. A go-around is then initiated.

The evaluation of airports with TAWS events history based on FOQA or other means provided by air transport carriers may prove an essential metric of risks related to unstable approaches and CFIT that affect candidate airports eligible for instrument procedures.

The implementation of PBN procedures has been considered an essential means to address unstable approaches in VFR-only airports. It may prevent the need to rely solely on the visual approach procedure (Brasil, 2020). Also, adequate obstacle separation areas corresponding to IFR procedures must be complied with by any PBN procedure designed for a given airport, as per ICAO Doc 8168 recommendations and DECEA regulations about instrument design approach procedures (DECEA, 2018; ICAO, 2007).

A report published by IATA about unstable approaches also addresses the benefits of PBN procedures as an effective technological measure to reduce inconsistent practices, as PBN provides flight crews with vertical and lateral guidance from the initial descent phase to the aircraft's touchdown on the runway, with defined descent profile and adequate terrain separation (IATA, 2017).

In specific locations with VFR-only airports, where there is no vertical or lateral flight path guidance chart or navigation database published to the flight crew, the implementation of instrument approach procedures is essential to provide higher safety levels in the landing operations (ICAO, 2019).

Moreover, cost-effectiveness can be attained by analyzing possible locations that can receive "RNAV Visual" procedures or the v-RNP (RNP APCH procedures for Visual Runways). Positive flight path guidance to the flight crew may offer safer operations than no guidance at all.

Therefore, for those airports where the only approach and landing procedure publication available is a Visual Approach Chart, the implementation of PBN instrument procedures such as the v-RNP may prove to be an effective means to improve operational safety levels, reducing the risks associated with unstable approaches and CFIT events.

Chapter III

Methodology

This study's nature involves basic and applied research, as fundamental air navigation concepts are discussed and applied to VFR-only airports' operational environments. A quantitative approach analyzes data about TAWS alerts and traffic volume figures (number of flight operations) into airports in the Brazilian landscape. Analyses of the significance of TAWS alert data in VFR-only and IFR airports are provided, along with the historical data of flight cancellations or diversions caused by adverse meteorological conditions.

Research Method Selection

In this study, technical research procedures cover the bibliography, applicable regulations, guidance material related to the topic, and experimental methods associated with collecting TAWS alerts data. This approach characterizes ex-post-facto, as data and other relevant information are based on past events.

CAST recommends that the evaluation of airports with the highest risks of unstable approaches, including those certified as VRF-only, be identified with a significant history of TAWS warnings from the Flight Data Monitoring database (CAST, 2018).

A preliminary analysis of airports based on TAWS alerts clusters are conducted, and data visualization software with geolocation tool (Tableau®) is used for visual identification of the TAWS "hotspots".

Graphic visualization of the identified "hotspots" may scale the problem's scope in the Brazilian scenario.

Airports' population covers the traffic volume observed in the operations of the most relevant air carriers in Brazil operating under RBAC / FAR 121. Sample delimitation considers TAWS alerts events time histories. Data is collected from the air carriers FOQA database in a 1-year timeline, from January 2019 to October 2019.

The proposed method to analyze FOQA data to capture unstable approaches is useful as is may provide precise means to breakdown essential flight parameters related to a "stable approach window" and the flight path along with the descent profile, such as descent slope, descent rate, airspeed, thrust setting and adjustments, terrain proximity warnings, and aircraft landing gear and flap configurations.

Current data related to 2020 may not prove useful due to the worldwide reductions in commercial flight operations caused by the covid-19 pandemic, causing air carriers to reduce or temporarily cease operations in several airports significantly.

Data collected contains airport identification, geographic location coordinates of TAWS alert events, the nature of TAWS alerts by type (Caution or Warning), and arrival runway designations.

The determination of VFR-only airports with a higher number of TAWS alerts, associated with a traffic volume history, provides a list of ranked candidates to receive instrument approach procedures.

Also, TAWS alerts observed in VFR procedures into IFR airports may even rank in the candidate airports list to receive a further analysis from implementing other instrument approach and landing procedures or the revision of existing procedures.

A list of the recorded TAWS parameters that compose the database is described in Table 4. This study's parameters of primary focus are the geographic coordinates of the TAWS alerts, destination airport, flight phase during which the alert is detected, and the type of landing procedure performed (VFR or IFR).

Table 4

TAWS: description of recorded parameters.

Parameter	**Description**
Event Date	Date of the year
Flight Phase	Flight phase during which the alert occurred
Alert Type	Warning or Caution
Departure Airport	(ICAO Code)
Departure Runway	(ICAO Code and RWY Code)
Destination Airport	(ICAO Code)
Flight Procedure	VFR or IFR
Landing Runway	(ICAO Code and RWY Code)
Latitude	Geographic coordinate
Longitude	Geographic coordinate
Altitude (QNH)	Altitude at which the alert occurred.

Note. It is extracted from the Brazilian Commercial Safety Team (BCAST), CFIT Working Group, under confidentiality and study purposes.

Chapter IV

Outcomes

TAWS events database is provided from the three currently most relevant Brazilian air carriers, considering the number of flight operations in one year from January 1st, 2019 to October 31st, 2019.

TAWS events

An overview of the number of TAWS events is described in Table 5, detailed by the flight phase. Most TAWS events are observed for the final approach, followed by landing and approach flight phases.

As expected, TAWS events during take-off and climb are commonly rare. The majority of initial climb and departure phases occur in normal conditions and are carried out in Standard Instrument Departure procedures.

Table 5

TAWS events per flight phase (January 2019 – October 2019).

Flight Phase	**Number of Events**	**Percentage**
Initial climb after take-off	2	0.17 %
Enroute climb after take-off	5	0.43 %
Descent	2	0.17 %
Approach	26	2.24 %
Final approach	1079	93.02 %
Landing	46	3.97 %
Total	1160	100 %

Note. It is extracted from the Brazilian Commercial Safety Team (BCAST), CFIT Working Group, under confidentiality and study purposes.

Therefore, the need to further study the approach and landing scenarios is highlighted as VFR and IFR approach procedures in the considered database may arise.

Table 6 details the contribution of TAWS alerts observed in VFR and IFR flight rules during the approach, final approach, and landing phases.

Table 6

TAWS events per flight rule: VFR and IFR (January 2019 – October 2019).

Flight Phase	**Number of Events**	**VFR**	**IFR**
Approach	26	0	26
Final approach	1079	976	103
Landing	46	46	0
Total	1151	1022	129

Note. Extracted from the Brazilian Commercial Safety Team (BCAST), CFIT Working Group, under confidentiality and study purposes.

As indicated in Table 6, the most significant contribution to the total number of TAWS alert events in VFR procedures is observed for the final approach and landing phases. The suggestion is coherent with the expectation that, as the flight progresses to land under VFR rules, the exposition to terrain clearance risk may increase during the visual traffic pattern.

It is important to note that the total number of TAWS alerts observations in VFR procedures covers all airports in the analysis database, including those that are IFR-certified but had received flights performing a VFR procedure to land.

The analysis is then detailed further to consider and separate the airports that are VFR-only from the entire airport database, described in Table 7.

Table 7

Airports in the database for which VFR landing procedures were performed.

IATA / ICAO Code	**Landing Certification**
AFL / SBAT	IFR
BEL / SBBE	IFR
BSB / SBBR	IFR
CGB / SBCY	IFR
CGH / SBSP	IFR
CGR / SBCG	IFR
CKS / SBCJ	IFR
CNF / SBCF	IFR
CWB / SBCT	IFR
CXJ / SBCX	IFR
FLN / SBFL	IFR
FOR / SBFZ	IFR
GIG / SBGL	IFR
GRU / SBGR	IFR
GYN / SBGO	IFR
IOS / SBIL	VFR
MAO / SBEG	IFR
MCZ / SBMO	IFR
OAL / SSKW	VFR
POA / SBPA	IFR
PVH / SBPV	IFR
RAO / SBRP	IFR
REC / SBRF	IFR
ROO / SBRD	IFR
SDU / SBRJ	IFR
SLZ / SBSL	IFR
SSA / SBSV	IFR
VCP / SBKP	IFR
VDC / SBVC	IFR
VIX / SBVT	IFR
XAP / SBCH	IFR

Note. Adapted from (DECEA, 2020).

As Table 7 indicates, SBIL and SSKW are the first strong candidates to receive instrument procedures since they are VFR-only airports and are contained in the database of detected TAWS alerts.

The Tableau® visualization of geographic locations of TAWS alerts identified in the collected data is depicted in Figure 6. The "hotspots" indicate a scatterplot of TAWS alerts' geographic coordinates and may contain several superimposed points related to alert events detected in the database within the analysis timespan, as the examples highlighted by the numbered circles detail further.

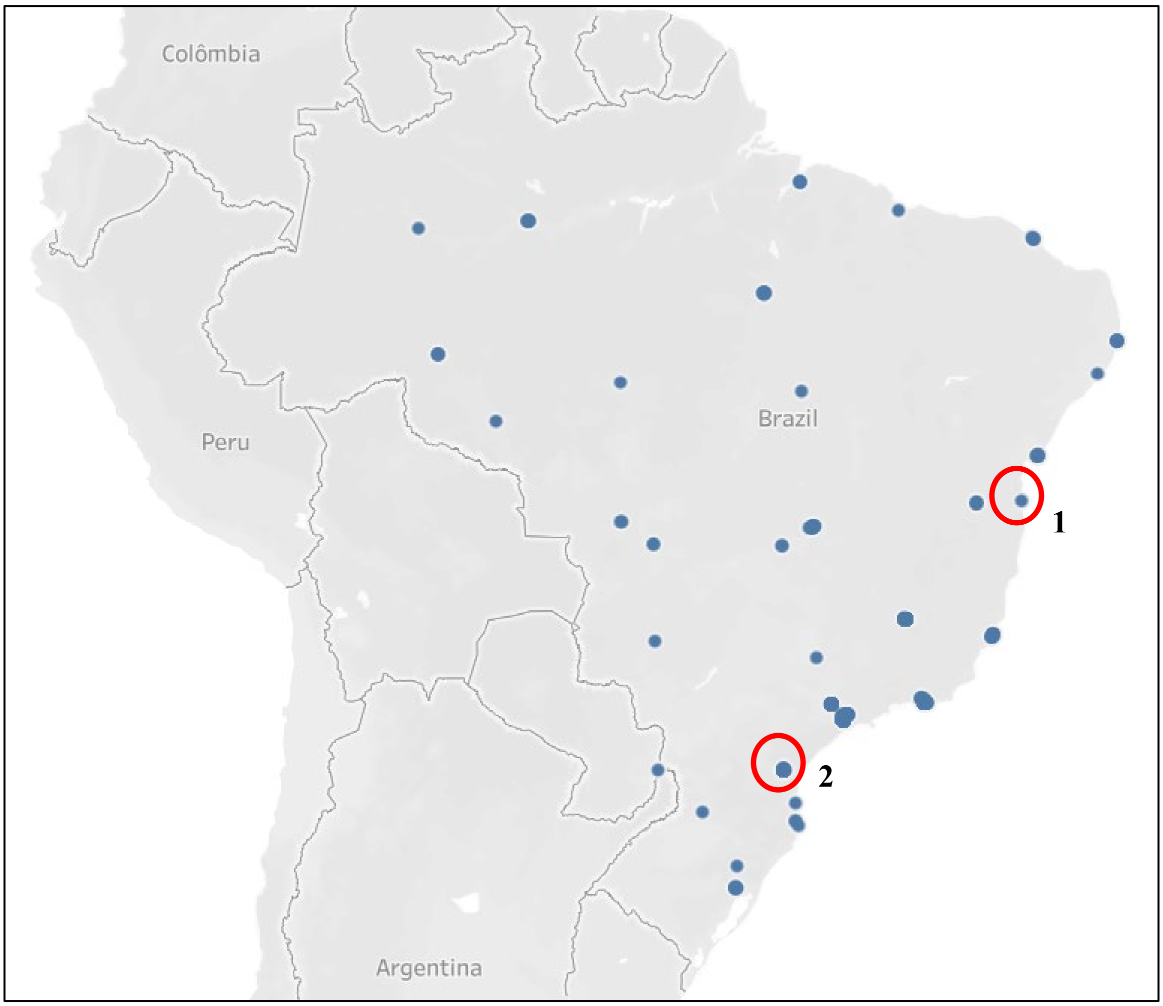

Figure 6 – "Hotspots" of TAWS alerts collected from the study database.

For example, in Figure 6, red circle #1 refers to Ilhéus Airport (IATA Code IOS) in Bahia State, and red circle #2 refers to Curitiba Airport (IATA Code CWB) in Paraná State.

Enlarged pictures of those locations with further detail are illustrated in Figure 7 for IOS and Figure 8 for CWB. While IOS presents one TAWS alert point detected in the analysis timespan, IOS is a VFR-only airport. Its candidacy to receive instrument procedures, therefore, remains relevant within the scope of this study.

The TAWS alert event location is identified by the blue dot in Figure 7. It refers to an alert detected close to the runway in the short final approach phase to land.

Figure 7 – TAWS alert identified for Ilhéus Airport (IOS), RWY 11.

The case for Curitiba shows in Figure 8 several TAWS alert events detected in various points along the final approach path, most of which for Runway 33. That characteristic indicates unstable approaches and suggests difficulties in maintaining the correct final approach glideslope to the runway.

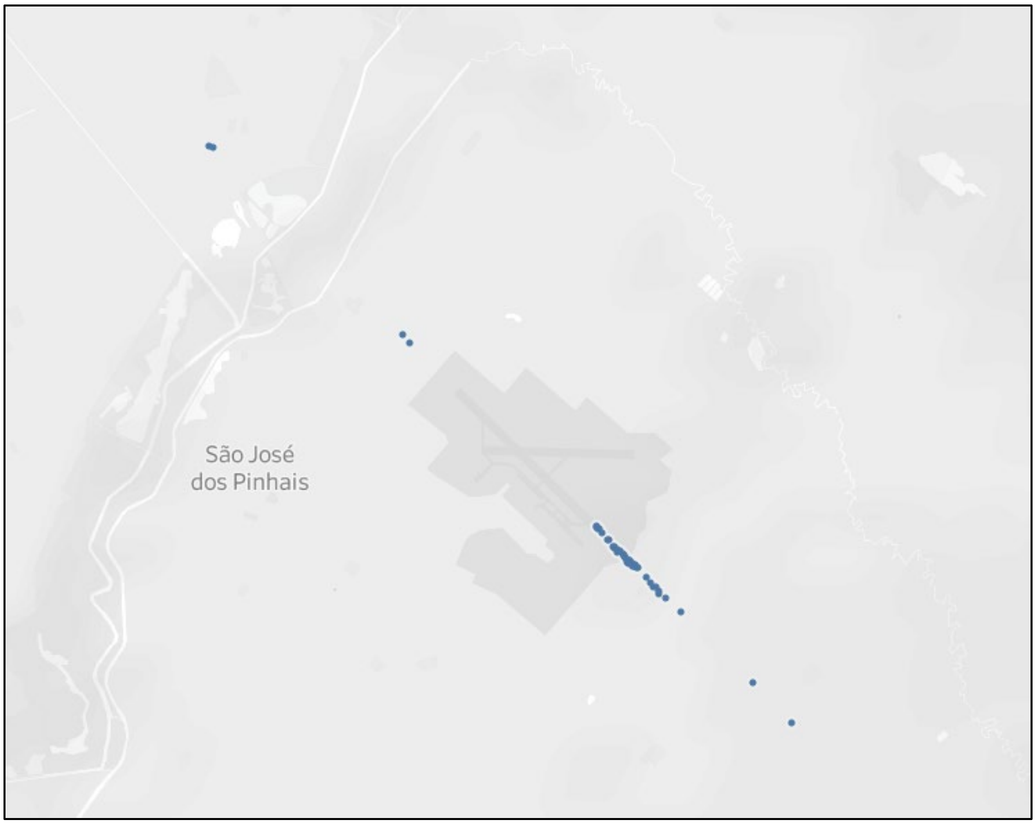

Figure 8 – TAWS alert identified for Curitiba Airport (CWB), RWY 15/33.

As discussed previously, the collected database contains TAWS alerts observed in VFR operations in destination airports that are IFR-certified. Figure 9 depicts the number of TAWS alerts during VFR operations, including IFR-certified airports, listed by IATA Codes.

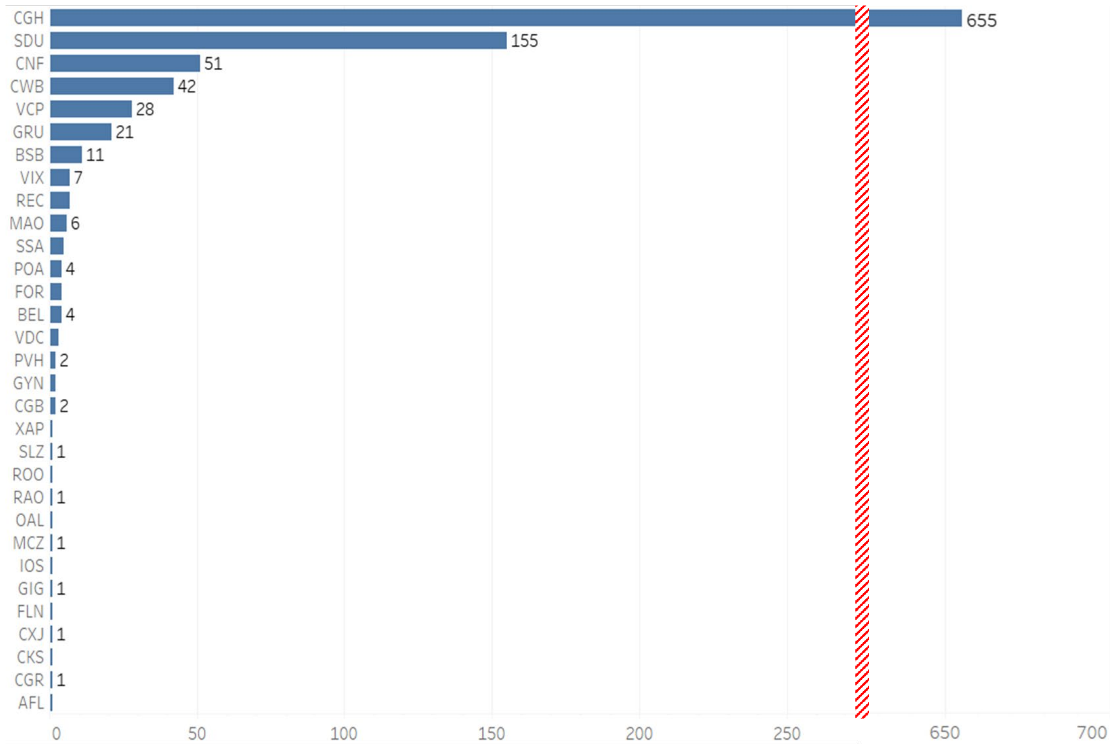

Figure 9 – Quantity of TAWS alerts in VFR operations, including IFR-certified airports (January 2019 – October 2019).

The red marking in Figure 9 indicates the brake on the horizontal axis scale to accommodate the significantly higher number of TAWS alerts related to CGH airport in comparison to the other airports.

In this sense, based on the absolute numbers of TAWS alerts observed in this study's timespan, Figure 9 indicates the stronger candidate IFR-certified airports for detailed analysis to receive instrument approach and landing procedures.

The results indicated in Table 7 and Figure 9 shall be crosschecked with flight operations traffic volume related to those airports in the timespan of study.

The total number of the Brazilian main carriers' flight operations into those airports is described in Figure 10, considering both VFR and IFR procedures.

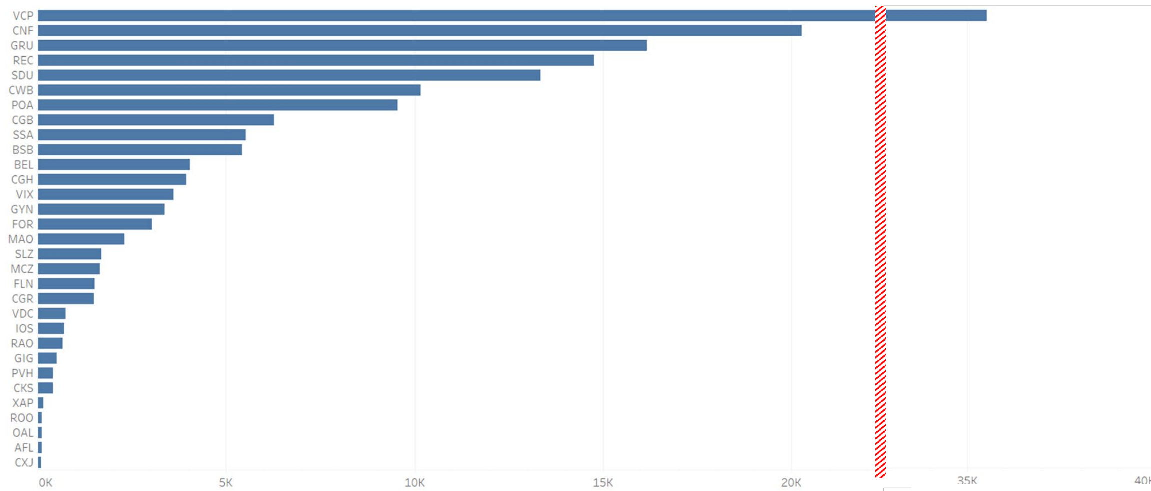

Figure 10 – Traffic volume: quantity of flight operations - VFR and IFR - (January 2019 – October 2019).

A relation between the results presented in Figures 9 and 10 can be established using the application of metric criteria (Index) to indicate the number of TAWS alerts per number of flight operations, illustrated in Equation 1.

$$Index = \frac{number\ of\ TAWS\ alerts}{number\ of\ flight\ operations}\ x\ 1000 \qquad \text{Equation 1}$$

The Index receives a dimensionless number as a correction factor (1000) to provide an exact comparison between airports to be ranked in the priority list to receive instrument approach and landing procedures.

Therefore, the index factor application provides the results presented in Figure 11, indicating the airports showing a higher number of TAWS alerts per thousand of flight operations in the study period.

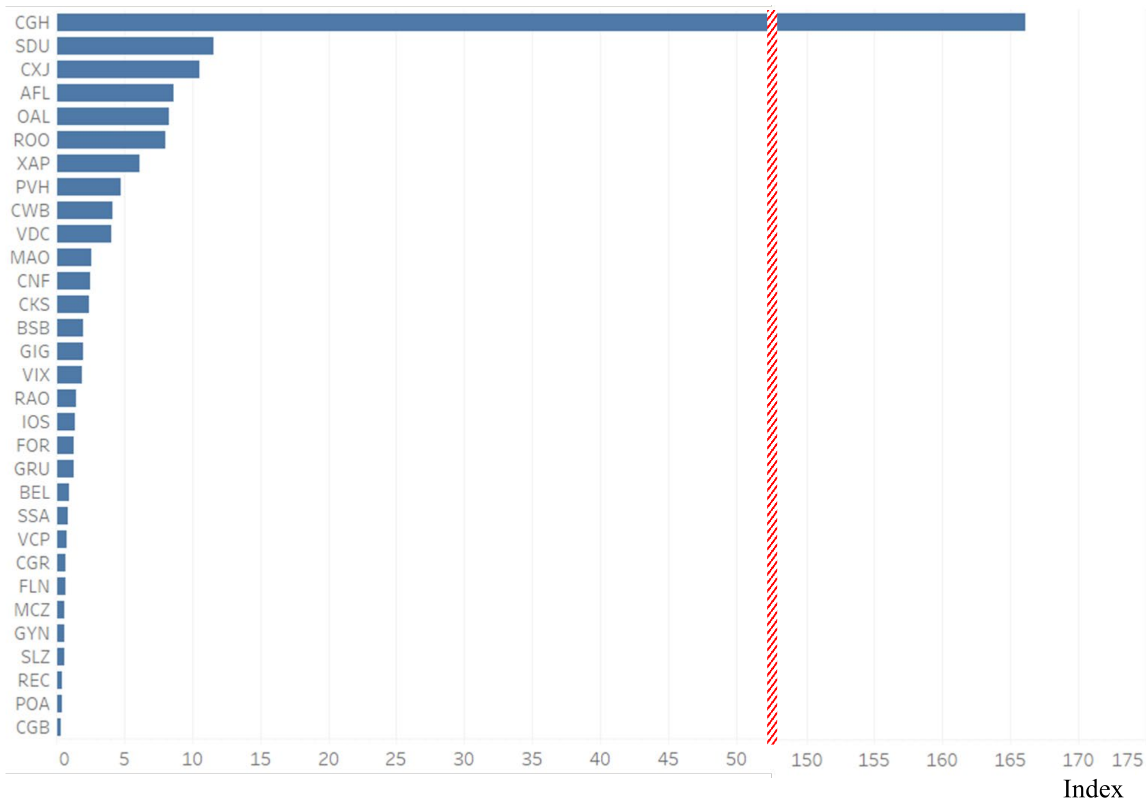

Figure 11 – Index: Number of TAWS alerts per flight operation [x1000].

For prioritization purposes, the results are shown in Figure 9 already indicate the airports of more significant concern to receive instrument approach and landing procedures. The application of the Index criteria, therefore, refines the rank of airports to be further analyzed by DECEA and ICA as its institute in charge of developing and implementing navigation procedures.

Regarding the frequency of diversions due to weather, for example, as discussed previously, the most significant causes for flight cancellations and diversions in VFR airports are adverse weather conditions at the destination. Therefore, the underlying condition may already be addressed in the TAWS alert analysis for those airports.

Nevertheless, an evolution of the ranking method may include a detailed analysis of possible correlations of TAWS alerts and weather diverts in a given set of VFR airports.

As for IFR airports that make up the ranking list, existing IFR procedures may have limited room for further improvements to address meteorological minimums, as RNP AR procedures, for example, would require additional certification to aircraft as well.

For the cases of VFR-only airports, RNP procedures for Visual Runways can be applicable. For IFR-certified airports, revisions of current instrument procedures or implementing the v-RNP type's additional procedures can also be applicable.

The 20 airports of primary concern, ranked by the Index criteria, are summarized in Table 8.

Table 8

Candidate Airports to receive a further analysis of instrument procedures.

# Rank	Airport (IATA Code)	# Rank	Airport (IATA Code)
1	CGH	11	MAO
2	SDU	12	CNF
3	CXJ	13	CKS
4	AFL	14	BSB
5	OAL	15	GIG
6	ROO	16	VIX
7	XAP	17	RAO
8	PVH	18	IOS
9	CWB	19	FOR
10	VDC	20	GRU

Finally, it is essential to notice that the ranking method also captured OAL and IOS airports. They were previously mentioned as potential candidates to receive instrument procedures since they are VFR-certified only.

Chapter V

Conclusions and Recommendations

This study examined the most significant aspects of the safe and efficient operation of landing procedures to airports in the Brazilian landscape by analyzing TAWS alert events collected from the central Brazilian air carriers operating domestic flights.

A ranking method is developed based on the identification of "hotspots" of TAWS alerts, evaluated for IFR and VFR-only airports. The prioritization of airports eligible to receive instrument approach and landing procedures also considers the history of traffic volume, in terms of the number of operations into those airports, to provide useful metrics of comparison between candidate airports.

The implementation of instrument procedures is an effective measure to provide appropriate separation with ground terrain and lateral and vertical guidance to maintain stable approaches, reducing the risk of CFIT.

As an additional result, PBN procedures improve meteorological minimums, providing higher accessibility to those airports, and reducing the number of flight cancellations and diversions to alternate airports caused by adverse meteorological conditions. That is also a significant economic benefit to increased connectivity and expansion of the national commercial air transportation network.

This study's limitation is the unavailability of traffic volume information detailed by type of operation (VFR or IFR). A more sophisticated method may consider separately the number of VFR operations about the candidate airports identified by the TAWS alert events.

Recommendations

The method may be presented to DECEA as a systematic process to identify, analyze and rank airports, in terms of TAWS alerts by the number of operations, to be provided with PBN procedures for approach and landing and, more specifically, the viability of the application of v-RNP (RNP APCH for Visual Runways).

For Future Research

Future research may include a more detailed analysis of TAWS alerts for each runway at a given airport. Since the TAWS "hotspots" are related to approach and landing procedures to a specific runway, the ranking method may be refined with the analysis to prioritize specific runways of interest.

Additional concerns to the TAWS alert event analysis also include the flight crews' measures to perform appropriately and promptly a missed-approach procedure or evasive maneuver once a TAWS alert is detected during approach or landing.

For airports with more complex surrounding terrain environments, evaluating the feasibility of a go-around maneuver under VFR rules may become a significant contributor or even dictate a given airport's priority to receive an instrument approach procedure.

Therefore, further research may also include analyzing the complexity of existing missed approach procedures considered in the ranking method.

Key Lesson Learned

The analysis of TAWS alert events in an appropriate timespan constitutes an important risk assessment method in evaluating improvements in safety for airports' operations.

This study highlights the importance of adequate analysis of the Brazilian airport systems in light of the need to assure safety, accessibility, and efficiency as a proving ground for expanding commercial air transportation network.

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