BAYESIAN BELIEF NETWORK OVER FATAL ACCIDENTS ON AVIATION OCCURRENCES IN BRAZIL

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ABSTRACT

Using public Data Banks from Brazilian Civil Aviation Agency on the national fleet and from Brazilian Center for Investigation and Prevention of Aeronautical Accidents over aeronautical occurrences, this paper presents a Bayesian Belief Network (BBN) able to manipulate conditional probabilities. The BBN correlates basic aircraft characteristics, including age, type of operation, number of engines, and others, to last ten years (2009-2019) descriptions of aeronautical occurrences, including accidents, major and minor incidents and ground occurrences. Among other possible results, the paper show that the probability of a fatal outcome on an aeronautical accident may be four or five times larger depending on the type of certification and the type of aircraft involved.

1. INTRODUCTION

Aviation has been expanding over last few decades, presenting a significative growth. Everybody is flying, and this is very much related to air tickets better prices during this period, according to Brazilian Civil Aviation Agency (ANAC, 2017). The growth on the aviation also corresponds to an absolute growth in aeronautical accidents and incidents yet flying is still the safest way to travel (STOOP and KAHAN, 2005).

As a result, news on aviation accidents with fatalities is also following the tendency. In São Paulo only, during 2018, the amount of aviation accidents increased 36%, totalizing 100 occurrences (VIANA e PAIVA, 2018). From 2008 to 2017, in Brazil, there were 1.187 accidents and 513 major incidents, according to the Brazilian Center for Investigation and Prevention of Aeronautical Accidents (CENIPA, 2019).

Fatal accidents were on headlines and main Brazilian TV news, like the death of journalist Ricardo Boechat, of singer Gabriel Diniz (from the hit "Jennifer") and of all Chapecoense soccer team, a little farther in time. For the two first accidents, it was demonstrated that operators were not certified to operate as Air Taxi (G1 SP, 2019; LOBEL e ZYLBERKAN, 2019), and for the Chapecoense Accident, a major case of imprudence was detected (MACIEL, 2018). Examples shown that pirate and clandestine operation also raised during last years, mainly on private contracts (RIBEIRO e CARVALHO, 2019), further encouraged by a weak oversight structure that has been going on for some years (GONÇALVES, 2011).

This aviation scenario served as a motivation to establish the objective of this study, which is to investigate the relationships between pre-flight identifiable factors and the risk of fatal accidents using Bayesian Belief Networks and Public Databases on air activity available from CENIPA and ANAC. Factors taken into consideration are the category in which the aircraft is registered, type of engine, type of aircraft (fixed wing or rotary wing) and year of manufacture. In addition to causal relationships, we can observe how

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a priori probabilities are updated with the database to, afterward, make inferences about the risk of fatal accidents according to the related factors, questioning the model and evaluating different scenarios.

2. Background

2.1 BBN on Aviation

Initially, the Scopus database was searched with aligned variations to understand which main researches used Bayesian networks applied to aviation. Thus, there was a consolidation of one variation in the database, examining documents published in journals and excluding book chapters, repeated documents and congresses. Therefore, an automatic search using the terms (“bayesian belief network*” OR “bayesian network*”) AND “aviation”) aimed at crawling articles by title, abstract and keywords returned 60 papers, from 1992 to 2018. 2018 shown the larger contribution, with eight papers with these keywords. USA, China and UK are more present on that area.

The study of keywords on these papers brought the keyword network graph of figure 1, where “Bayesian Networks” is frequently mentioned with “Inference Engines”, “Risk Assessment”; “Aviation Safety” and “Aircraft Accidents”.

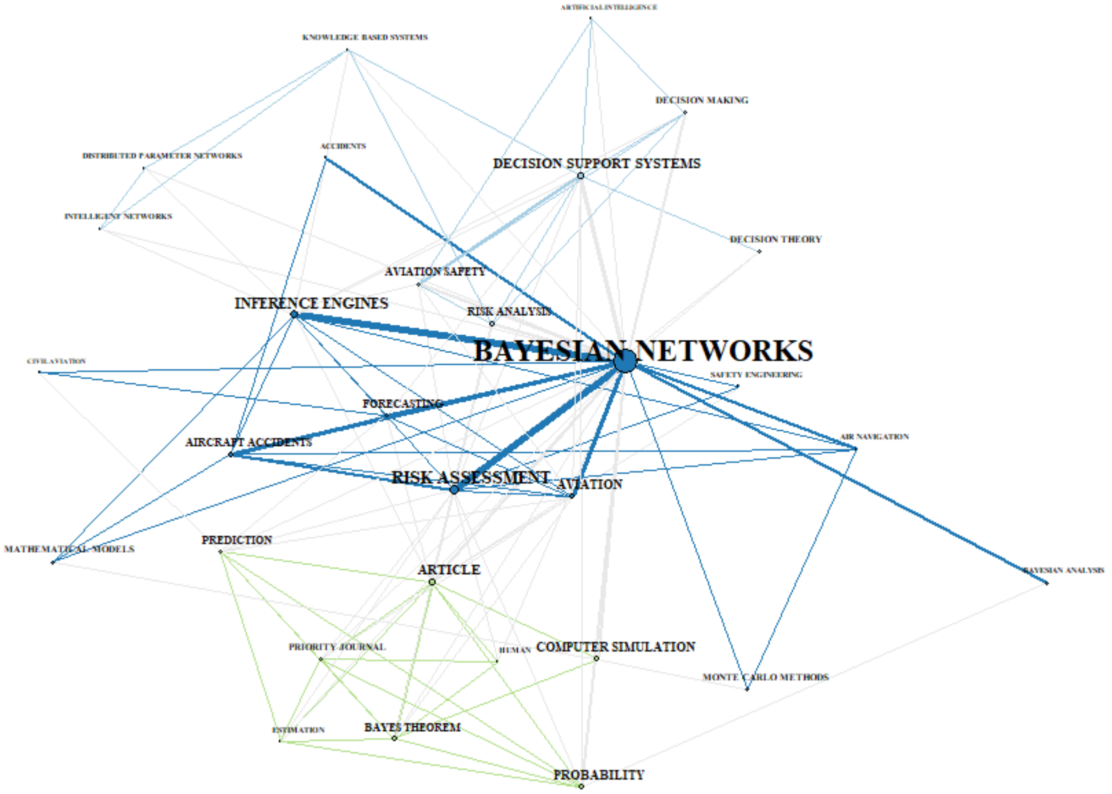

Fig. 1 – frequent connections between keywords.

2.2 Aviation Accidents

There are few scientific papers related to the Center for Investigation and Prevention of Aeronautical Accidents (CENIPA). The authors Fajer et al. (2011) analyzed a set of air accidents that were investigated by CENIPA and found a lack of inclusion of organizational aspects as influences to motivate causality.

From another perspective, Vieira and Santos (2010) indicated the need to work on communication skills in training aviation professionals to prevent future accidents.

Recently, Vasconcelos et al. (2019) sought to analyze the fatigue and drowsiness conditions of a pilot by checking his communication with the control tower. According to the Cenipa report, these conditions have increased fatality.

According to resolution no. 293 of 2013 of the National Civil Aviation Agency, CENIPA uses aviation segmentation according to the Brazilian aeronautical registry (Figure 2).

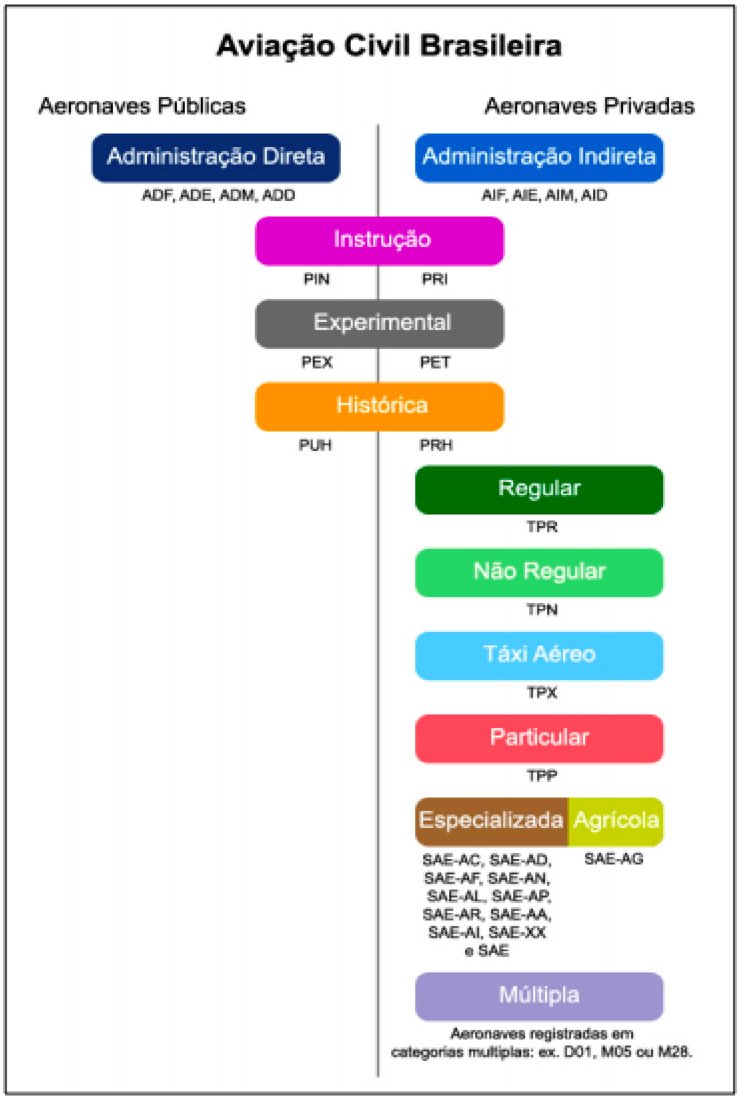

Fig. 2 - Aviation segmentation according to the Brazilian aeronautical registry

The three most cited problems identified by CENIPA in the occurrence of accidents were: Flight engine failure, loss of ground control and loss of flight control, which account for more than half of all accidents. Among serious incidents the most frequent were loss of ground control, landing gear and flight engine failure, characterizing most serious incidents.

Accidents occurred from 2008 to 2017 had 45.33%of TPP (private), followed by 18.33% of SAE-AG (agricultural) and 15.22% of PRI (instruction), being these the categories that had the most accidents occurrences between these years. There were on average 57 fatalities per year during this period, totaling 567 fatalities.

3. METODOLOGY

3.1 Used Databases

The main source of publicly available data is the website www.dados.gov.br, from which full databases (BD) of the Brazilian fleet and the occurrence of Aeronautical Accidents and Incidents in Brazil were extracted.

To determine the Brazilian fleet of interest, we used the bank “Aircraft - Brazilian Aeronautical Registration” (http://dados.gov.br/dataset/aeronaves-registradas-no-registra-aeronautico-brasileiro-rab).

According to Law 11.182/05, ANAC is responsible for administering the Brazilian Aeronautical Register (RAB), identified as Technical Management of the Aeronautical Register. (GTRAB) under the Airworthiness Superintendence (SAR). GTRAB has, among others, the function of registering civil aircraft subject to Brazilian law.

This database provides complete, periodically updated information about each aircraft of the national fleet, its characteristics and its state of operation. The database used was updates on November 23, 2018, and was filtered for aircraft in normal operating conditions, according to the condition of the registered aircraft. The field “Code of Prohibition” contains codes that indicate if the registered aircraft is banned (without authorization to operate) or in normal condition (N).

RAB has data from 29,667 aircraft records, 9,458 of which refer to aircraft in normal operating condition.

The data on accidents and incidents in Brazil come from the Center for Investigation and Prevention of Aeronautical Accidents (CENIPA) and were also copied on the open data site (http://dados.gov.br/dataset/ocorrencias-aeronauticas- Brazilian Civil Aviation).

The database of aeronautical occurrences has 5,396 records, since January 1, 2009, of which 3,038 incidents, 648 serious incidents, and 1,710 accidents, of which 403 accidents had fatalities.

That way, we might say that 8,98% of all occurrences in Brazil resulted on fatal accidents for the last ten years.

3.2 Discussions over fatal aeronautical accidents

Within the universe of the national fleet, the proportion of fatal accidents can be studied according to each characteristic of the involved aircraft.

For example, the ratio of fixed-wing to rotary-wing aircraft is currently about 85.6% x 14.4%. The proportion between fixed and rotary-wing aircraft in fatal accidents in Brazil since 2009 is 81.11% x 18.89%. Taking these numbers as significant, it can be inferred that given a specific occurrence, the probability of fatalities is higher for rotary-wing operations than fixed-wing operations.

To establish a relationship between the aircraft type against fatalities, a Bayesian Belief Network was developed, connecting the characteristic fractions of the current national aircraft fleet with the proportions of the same characteristics in fatal accidents in Brazil since 2009.

For this network, some characteristics available in both BD RAB (Database from the RAB) and BD CENIPA (Database from CENIPA) were listed.

In the physical characterization of the aircraft, the type of wing, the number of engines and the year of manufacture were chosen. The cause-effect correlation between these characteristics is not direct, but they are factors that influence the risk level of each type of operation.

As for wings, an aircraft can be Fixed-Wing when its wings do not move relative to the fuselage to generate lift or Rotating-Wing when sustaining lift depends on the rotation of its wings over an axis. Popularly, the classic example of Fixed Wing is an airplane, and the classic example of Rotary Wing is a helicopter.

As for engine, an aircraft may have between none (for example, gliders) and three (maximum number of engines on one aircraft found in Brazil up to this date).

As for the year of manufacture, ten years were taken as reference, and the national fleet was divided between aircraft with more than ten years of manufacture and aircraft with less than ten years of manufacture.

In addition to the physical characterization, it was also possible to determine a characterization related to the type of operation and certification of aircraft operation, according to its registration category. In this case, five category types were grouped based on the categories already shown in Fig. 2 and detailed on table 1.

Tab.1 – Type Categories

Category Types	Description
TPP	Private Aircraft
TPR	Includes all aircraft on public transportation, regular or not, operating under certification by ANAC (RBAC 121 or 135, similar to FAR 121 or 135)
TPX	Includes all On Demand transport aircraft (Air Taxi), operating under ANAC certified operators (RBAC 135, similar to FAR 135)
SAE	Includes all aircraft operating under na Special Operations Authorization (like, agricultural, air-photo, external cargo, between other)
OTR	All other aircraft not included on other categories, like Private Training, public administration, Police, Firefighting and other.

3.3 Bayesian Belief Network (BBN)

Based on previous section discussion, the following BBN was developed, with only one Directed Acyclic Graph (DAG) level. Characteristics (factors) Level 1 brings the proportion values on the national fleet universe and Level 2 corresponds to the proportions between occurrences and accidents with fatalities according to each characteristic raised.

Ratio values can also be referred to as the probability of a single sample within the fleet universe.

For the elaboration of this BBN, the proportion values were used according to table 2.

Table 2 – Input for BBN: Proportions on occurrences with fatalities

Category Type	Engine	Wing	Year	Fatalities yes %	Fatalities no%
OTR	MON	ROTAT	ovr2009	8,0	92,0
OTR	MON	ROTAT	und2009	5,8	94,2
OTR	MON	FIXED	ovr2009	14,5	85,5
OTR	MON	FIXED	und2009	3,4	96,6
OTR	BIM	ROTAT	ovr2009	0,0	100,0
OTR	BIM	ROTAT	und2009	0,0	100,0
OTR	BIM	FIXED	ovr2008	0,0	100,0
OTR	BIM	FIXED	und2009	2,7	97,3
OTR	More	ROTAT	ovr2009	0,0	100,0

OTR	More	ROTAT	und2009	7,1	92,9
OTR	More	FIXED	ovr2009	0,0	100,0
OTR	More	FIXED	und2009	7,1	92,9
SAE	MON	ROTAT	ovr2009	15,0	85,0
SAE	MON	ROTAT	und2009	15,0	85,0
SAE	MON	FIXED	ovr2009	4,2	95,8
SAE	MON	FIXED	und2009	16,8	83,2
SAE	BIM	FIXED	ovr2009	0,0	100,0
SAE	BIM	FIXED	ovr2009	0,0	100,0
SAE	BIM	FIXED	und2009	0,0	100,0
SAE	BIM	FIXED	und2009	0,0	100,0
SAE	More	FIXED	ovr2009	100,0	0,0
SAE	More	FIXED	ovr2009	100,0	0,0
SAE	More	FIXED	und2009	100,0	0,0
SAE	More	FIXED	und2009	100,0	0,0
TPP	MON	ROTAT	ovr2009	23,1	76,9
TPP	MON	ROTAT	und2009	18,3	81,7
TPP	MON	FIXED	ovr2009	8,8	91,3
TPP	MON	FIXED	und2009	13,4	86,6
TPP	BIM	ROTAT	ovr2009	23,1	76,9
TPP	BIM	ROTAT	und2009	9,1	90,9
TPP	BIM	FIXED	ovr2009	1,2	98,8
TPP	BIM	FIXED	und2009	5,4	94,6
TPP	More	ROTAT	ovr2008	Não há	Não há
TPP	More	ROTAT	und2008	0,0	100,0
TPP	More	FIXED	ovr2008	0,0	100,0
TPP	More	FIXED	und2009	6,7	93,3

TPR	MON	ROTAT	ovr2009	0,0	100,0
TPR	MON	ROTAT	und2009	0,0	100,0
TPR	MON	FIXED	ovr2009	0,0	100,0
TPR	MON	FIXED	und2009	0,0	100,0
TPR	BIM	ROTAT	ovr2009	0,3	99,7
TPR	BIM	ROTAT	und2009	0,0	100,0
TPR	BIM	FIXED	ovr2009	0,3	99,7
TPR	BIM	FIXED	und2009	0,0	100,0
TPR	More	ROTAT	ovr2009	0,0	100,0
TPR	More	ROTAT	und2009	0,0	100,0
TPR	More	FIXED	ovr2009	0,0	100,0
TPR	More	FIXED	und2009	0,0	100,0
TPX	MON	ROTAT	ovr2009	33,3	66,7
TPX	MON	ROTAT	und2009	12,8	87,2
TPX	MON	FIXED	ovr2009	0,0	100,0
TPX	MON	FIXED	und2009	7,8	92,2
TPX	BIM	ROTAT	ovr2009	0,0	100,0
TPX	BIM	ROTAT	und2009	1,4	98,6
TPX	BIM	FIXED	ovr2009	0,0	100,0
TPX	BIM	FIXED	und2009	2,8	97,2
TPX	More	ROTAT	ovr2009	0,0	100,0
TPX	More	ROTAT	und2009	0,0	100,0
TPX	More	FIXED	ovr2009	0,0	100,0
TPX	More	FIXED	und2009	0,0	100,0

Fig. 3 shows the BBN Scheme, as well as the proportions (assumed probability related to each factor applied on BBN. Software NETICA(R) was used to describe BBN.

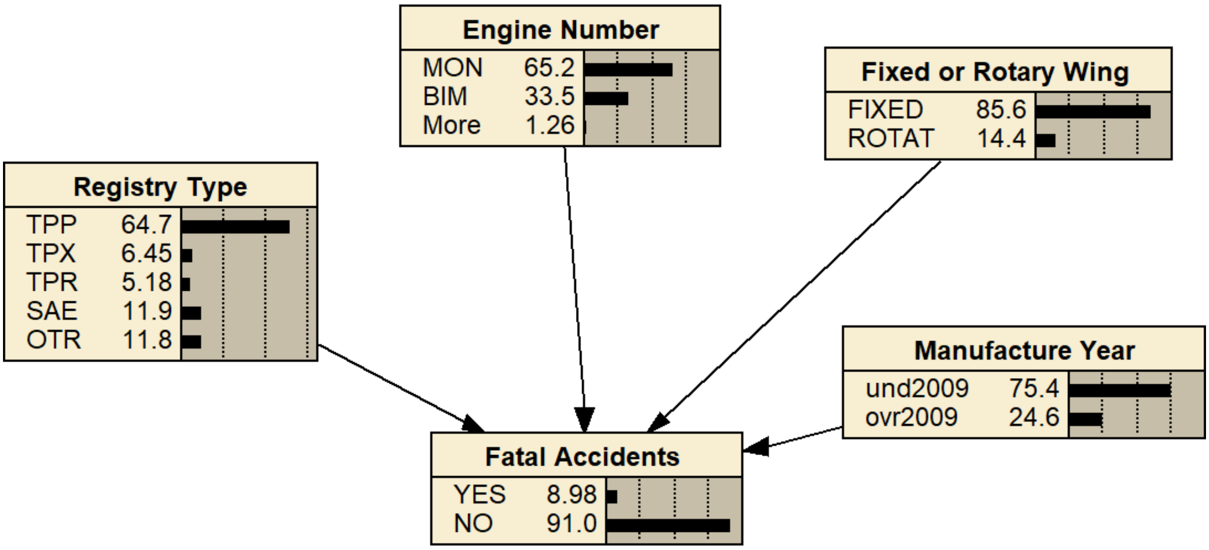

Fig. 3 – BBN Scheme

From this BBN, it is possible to check the fatality occurrence probability for each analyzed factor or set of factors.

4. RESULTS

4.1 Initial Setting

Initial Setting is presented on Fig. 3. All accidents with national aircraft on BD CENIPA were considered for the study.

For the whole BBN, it is possible to observe that TPP national fleet (private aircraft) is much larger than the sum of all other categories. It is important to remember TPX and TPR are aircraft that operate under certified operators, based on confirmed minimum technical requirements.

4.2 Sensitivity on Category Type

Table 3 shows BBN results for each Category Type, ordered by proportion of fatal accidents. This is the proportion of fatal accidents for each Category Type once all other factors are kept unchanged.

Table 3 – resultant BBN for each Category Type

	%(fatality)	
CAT 100%	YES	NO
TPR	0,22	99,78
OTR	4,68	95,3
TPX	5,61	94,4
SAE	10,3	89,7
TPP	10,6	89,4[1][2]

As might be expected, the TPR category accidents, which features public transport aircraft (scheduled airlines, or charter companies) have the least fatal accidents. These are the most controlled and certified companies. BBN translates exactly this point.

Next, the OTR category, which includes mainly aircraft devoted to instruction and aircraft used by state governments (eg police and fire brigade) carry a very low proportion of fatalities. This is a point that deserves attention. In a closer look, it is seen that only 2.9% of PRI (Instruction) aircraft accidents have fatalities, but the number of occurrences is quite high (14% of all occurrences in Brazil happens on PRI aircraft operations). Other category nested on OTR is State Aircrafts (ADE), which account for only 2.3% of national occurrences. It should also be noted that PRI and ADE aircraft tend to be more controlled and tracked. The conclusion is that OTR category is very heterogeneous and in other study could be divided on more categories.

Going forward, TPX aircraft also bring average below the national scenario (8,98%), what justifies, once these aircraft fly under a certification flag.

Categories TPP (private) and SAE (Specialized Services) resulted on similar numbers. These categories, in general, have less monitoring of their conditions by the State. In both cases, the average fatality is above the national average (around 20% higher).

4.3 Sensitivity on Number of Engines

Table 4 shows BBN results according to number of engines, ordered by proportion of fatal accidents.

Table 4 – resultant BBN for each Engine Mounting

	% (fatal accidents)	
ENG 100%	YES	NO
Twin	3,93	96,1
Sing	11,4	88,6
Other	15,3	84,7

BBN analysis reveals what is already a ditto, a single-engine aircraft "is always flying in emergency". On the other hand, analysis shows that for twin-engine aircraft, the proportion of fatal accidents is lower than the national average, less than 45%.

"Other" category is mostly fulfilled by gliders, and, for this type of aviation, most of occurrence reports are only made when something serious happened. That explains the high resultant proportion.

4.4 Sensitivity on Wing Type

Table 5 shows BBN results according to Wing Type, ordered by proportion of fatal accidents.

Table 5 – resultant BBN for each Wing Type

	% (fatal accidents)	
Wings 100%	YES	NO
Fixed	8,21	91,8
Rotary	13,5	86,5

Looking through the Wing Type perspective, BBN shows that rotary winged aircraft are riskier than fixed winged.

4.5 Sensitivity on Manufacturing Year

Table 6 shows BBN results according to manufacturing year, ordered by proportion of fatal accidents.

Table 6 – resultant BBN for Manufacturing Year

	% (fatal accidents)	
Year 100%	YES	NO
Before 2009	9,5	90,5
After 2009	7,3	92,7

According to the expected, the newer group favors survival of occupants, but the difference is small on national scenario.

4.6 Sensitivity on Manufacturing Year

Once the BBN network learning phase is over, the system allows various combinations of the chosen factors. Thus, a combination of characteristics can be elaborated to make some comparisons with specific situations.

An interesting example to be studied, quite prominent in the media during the beginning of 2019, is the case of aircraft in clandestine commercial operation, the so-called “Pirate Air Taxi”.

One description that may be appropriate to frame this type of operation is that they are driven by generally older (pre-2009 manufacturing), private (TPP), largely helicopter (rotary wing) and twin-engine (Twin) helicopters, most attractive to customers.

In contrast, an aircraft operating under ANAC standard air taxi certification (TPX registration) would have some similar characteristics, being also twin-engine helicopters (Twin & Rotary) but normally operating newer aircraft (aft-2009).

Table 7 shows the proportion of fatal accidents for clandestine (Pirate) and regularized (R135) air taxis.

Table 7 – resultant BBN for Pirate Operators compared to regular ones

	% (fatal accidents)	
Pirate 100%	YES	NO
Pirate	23,1	76,9
R135	1,41	98,6

Analysis makes clear the difference in proportion between a clandestine operation and a regularized one.

While on every 100 occurrences in regularized operations, little more than one result in a fatality, one in four occurrences in clandestine operations results in a fatality.

5. CONCLUSION

From the analysis performed, it can be observed firstly that the proposed BBN proved to be effective in identifying factors that separately contribute most to aircraft occurrences, incidents, and accidents. One of the relevant factors for the analysis applicability is the fact that there is an extensive record of both aircraft in operation and their characteristics, as well as incidents and accidents, and that these data are periodically updated.

Thus, it is possible to isolate operation aircraft characteristics that are strongly linked to aeronautical occurrences and, consequently, establish a hierarchy of factors that must be addressed during safety audits by regulatory authorities, seeking to reduce accidents and incidents.

Likewise, it is possible to evaluate the effectiveness of actions taken over time by assessing the effect 'a posteriori' through the built BBN network.

Also, we can highlight the relevance of some specific aspects of the study in question, which characterize categories of operation with very different safety indexes, especially when comparing clandestine and regulated operations, allowing users to make a decision based on quantitative risk analysis, as to the type of operation to be contracted.

Finally, we must highlight the opportunity to expand the evaluation through future studies, including other factors that may be relevant and that were not in the object of this study, to generate evidence for the strategic planning of the regulatory authorities regarding prevention and mitigation programs for aircraft incidents and accidents. Yet, taking the same BBN but specifying the Type Category on all types present on BD ANAC could bring light to other important conclusions on the Brazilian Aviation Safety Scenario.

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