Use of Airspace Control Data and GIS for assistance in road accidents - A case study

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Abstract. *Air transport can solve road traffic congestion problems in emergency situations in order to quickly and efficiently assist accident victims through solutions from transport policy makers. This work presents a prototype as a use case, to determine the main points of accidents on the federal highways of Paraná, as well as the main air resources and health units for caring for serious victims. In particular, as a methodology, we used an exploratory data analysis in conjunction with the KNN-based algorithm to define the main strategic locations and regions to allocate air resources to attend to the occurrences in the best possible way, as well as define the available hospital and the flight plan to proceed to the destination. The study also presents the top ten locations with the highest number of accidents, along with the three priority regions, in order to optimize care.*

Resumo. *O transporte aéreo pode resolver problemas de congestionamento do tráfego rodoviário em situações de emergência, a fim de ajudar de forma rápida e eficiente às vítimas de acidentes por meio de soluções dos formuladores de políticas de transporte. Este trabalho apresenta um protótipo como caso de uso, para determinar os principais pontos de acidentes nas rodovias federais do Paraná, bem como os principais recursos aéreos e unidades de saúde para atendimento a vítimas graves. Em particular, como metodologia, utilizamos uma análise exploratória de dados em conjunto com o algoritmo baseado em KNN, para definir os principais locais e regiões estratégicas para alocar os meios aéreos para atendimento às ocorrências da melhor forma possível, bem como, definir o hospital disponível e o plano de voo para seguir até o destino. O estudo também apresenta os dez principais locais com maior número de acidentes, juntamente com as três regiões prioritárias, a fim de otimizar o atendimento.*

1. Introduction

According to studies by the International Brazilian Civil Aviation Organization [ICAO 2021], the civil air traffic has grown significantly in recent decades, involving and currently influencing the lives of a large part of the world population using air transport. Similarly, technological advances, computer equipment, communication networks, sensors for target detection and systems for visualizing this information have also evolved in number and sophistication in recent times.

From an international perspective, this air traffic rate tends to increase exponentially and, in the future, could result in significant congestion, flight delays and high air pollution [ICAO 2021]. To keep this number of aircraft flying fluidly, efficiently and, above all, safely, with new technologies, control techniques and optimized methods to manage information from these critical systems must be employed. Although the use of airspace control to solve problems (such as assistance in accident victims, effective plans and impacted factors) is well consolidated in several countries around the world and also in Brazil, the national scientific literature and applications using real data in relation to the subject is still very rare. As an example, there is still no integration among road accidents, air and medical resources, in order to assist victims quickly. In this direction, this work presents an analysis with a use case using open data on traffic accidents, information on air support points and health units to assist victims, using data from the Paraná State, in Brazil. Within contributions, we can mention a KNN-based algorithm for air emergency care providers, three priority regions in terms of care in Paraná along with other essential parameters to be considered in air rescue. The work is organized as follows: Section 2 presents the related work, Section 3 presents the use case, followed by the conclusion in Section 4.

2. Related Work

The Brazilian Airspace Control has a complex system that connects organs, procedures, facilities, aircraft and people, whose components aim to provide regularity, safety and efficiency to the flow of traffic at airports and in airspace [DECEA 2010]. Air Traffic Services in Brazil are provided by the Airspace Control Department (https://www.decea.mil.br/), and the definition of each service is internationally standardized by the International Civil Aviation Organization (ICAO) (Communication, Navigation and Surveillance; Meteorological Services; Aeronautical Information Services; Search and Rescue Services; and Air Traffic Management[1]). In terms of legislation pertinent to Airspace Control, one of the main standards is the ICA Aeronautics Command Instruction 100-12 [DECEA 2016], defining the "Rules of the Air", or that which concerns the Regulations on Unmanned Air Vehicles (UAV or drones) - ICA 100-40.

One of the spatial algorithms that can be used to optimize transport dynamics, including air vehicles and airways, is kNN-Select (in queries as for example, find k-hospitals and k-aerodrome closest to my location). Another important spatial predicate is the kNN join (for example find the nearest k-fire departments for each gas station), which can also be useful when multiple kNN-Select predicates are to be executed on the same dataset [ALY et al. 2015]. Algorithms such as queries by similarity, and by Scope (Rq) and by k-Reverse Nearest Neighbors (RkNN - get all stored elements that have a given reference element as one of its k most similar elements) [JAMES et al. 2013]. An example of the application of kNN is shown in the case study on medical services through ambulances in Seoul, when the impact of traffic fluctuation on the availability of EMS first response in urban areas is evaluated, evaluating the coverage of k-minutes in various traffic scenarios. This also makes us reflect on the need to use air assistance as a complement to ground ambulances [YUHONG et al. 2015].

One of the major challenges encountered by emergency service providers is selecting the appropriate locations for ambulance stations. The important thing is to focus on locating ambulance stations using real traffic information to minimize the average travel time to handle emergency requests [YUHONG et al. 2015].

For different purposes, cars, trucks, buses, ships, trains, UAVs, planes and helicopters transport people and materials inside and outside cities. The logistics behind

[1] https://www.icao.int/safety/annexes_booklet_en.pdf

drones and the services they make up is also an optimizable and critical part of improving the city's efficiency [ANAC 2021]. Therefore, there is a need for a new generation of airspace control and management services, through the allocation of special routes, flight levels and reserved transponder codes (which individually identify the aircraft) and specific control consoles for this special category of unmanned aerial vehicles [FOINA et al. 2015].

Aeromedical transport consists of the rescue or removal of seriously injured people, by means of helicopters or aircraft, in places that traditional ambulances cannot easily or quickly reach. To meet these requirements, aircraft must undergo a major transformation, going from rudimentary equipment to helicopters, jets and planes with high-tech equipment, in order to be able to respond to any type of situation. According to data from ANAC, the private aeromedical service is currently operated in the country by around 44 companies. In Brazil, the free and humanitarian Aeromedical Transport System is closely linked to the military area, specifically to the Brazilian Air Force (FAB), the Military Police and the Fire Department. In parallel, literature already stated that studies of air medical rescue in Brazil are required due to the investments made in pre-hospital care in a country without an organized trauma system [CARDOSO et. al 2018].

Within the challenges in the area, we can mention: (1) Management and safety of air traffic in large urban areas; (2) UAVs: improvements in design, in the capabilities of these vehicles, in regulations, in tests, resulting in improvements in flight, control, monitoring, data processing and landing systems, in order to ensure their reliability , communication with ground control stations and integration with other systems [FOINA et al. 2015]; (3) Governance: standardization of data and a higher integration along different stakeholders [PRZEYBILOVICZ, CUNHA and TOMOR 2017]; (4) Security, (5) Management of natural resources, (6) Improvement of the quality of life, (7) Emergency transports, 8) Open data and 9) Sharing know-how about airspace control products and services. In this direction, this work contributes to items 7 (Emergency Transports) and 8 (Open Data), in order to assist air emergency care providers.

3. Use Case - Assistant to Accident Victims

A preliminary questionnaire was applied with 4 users, with an "in loco" visit to the hangars and facilities located at Bacacheri Airport, Curitiba - PR. The questionnaire had 19 questions[2], addressing the environment and conditions of the Aeromedical Transport sector, such as: number of companies in the sector in Paraná, air means used, conditions of support locations, adequacy of infrastructure, number and qualification of specialized personnel, number and conditions of Intensive Care Units (ICUs); types of victims served; among others. The participants included a manager and pilot, a pilot and two doctors, all of them working in Aeromedical Transport. Within the four users, three are male and one is female, with ages between 35 and 55 years.

Regarding the answers, we can mention that: 1) the suggestions were in relation to the need for more helipads close to the accident sites, the improvement of the conditions of the helidecks in terms of night operation and adequate lighting; 2) the majority considered the costs involved as “high”; 3) the main points of occurrence of

[2] https://forms.gle/LSNtzajXZ3VdATDD8

accidents are in the mountains; 3) 75% answered that there is no application that helps operations and 25% answered that there are only applications for air navigation; 4) Regarding the convenience and benefits of an application to point out the best conditions for service, 75% answered yes, and 25% said yes, depending on the aircraft/helicopter and the regulation of the sector.

Considering the answers above, the first phase was to integrate open data in order to assist road accidents, as shown in Figure 1: 1) accidents on Federal highways in Brazil[3], from 2007 to 2018 (further details can be found at MATTOS et al. 2019), 2) data from public and private aerodromes[4] (298 helipads, 2476 private aerodromes and 508 public aerodromes), and 3) 9224 hospitals and clinics in the state do Paraná[5] (further details about the data can be found at CAVALCANTE, NETO e KOZIEVITCH 2018). Note that data from the flight plan along with the air ambulance occurrence is also stored within the data. The complete dataset was inserted in a PostGIS, along with respective indexes.

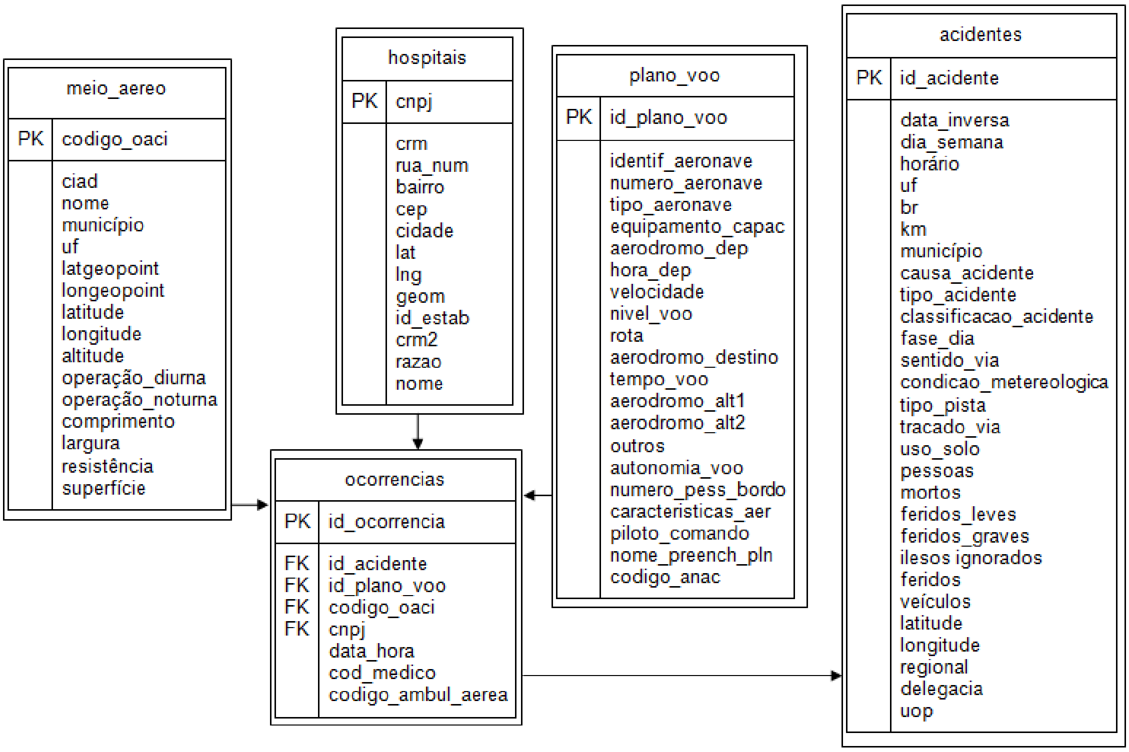

Figure 1. Data from the use case.

The air ambulance coverage area is calculated by comparing the initial accident data against the air ambulance locations along with the victim assistance process [CHO and YOON 2015]. The algorithm (Figure 2) uses the KNN-Select algorithm (find the k-aerodrome closest (origin, with the closest air ambulance) to the main historical accident sites on Paraná highways followed by the nearest k-hospitals (destination), calculating the best flight plan.

[3] http://vias-seguras.com/dados_da_prf
[4] https://sistemas.anac.gov.br/dadosabertos
[5] http://www.crmpr.org.br/

The main limitations regarding the use case are: (1) the data is limited to the state of Paraná/Brazil; (2) several geocoding problems occured, since accident data had errors with latitudes and longitudes in some points of the Brazilian Federal Highways; (3) there were structural differences among the accident data along the years; and (4) the traffic accident data range is between 2007 and 2018.

In Paraná, the main Federal Highways that cross the state are: BR 476, BR 376, BR 277, BR 116 and BR 369. In total, the state had in the last 13 years 169,787 accidents, with 26,979 unharmed people, 3,244 people with serious injuries (target of this study) and 7,012 deaths. Regarding the accidents, 52% is during the day, 41% is during clear weather, 17% is during cloudy weather, 48% is with vehicles and 71% have a male driver.

```
Air_Ambulance_Occurance (Accident, Hospital_Ocurrance, Ambulance_Ocurrance, Flight_Plan) (

  /* Select the best and available ambulance for the accident,
  considering factors such as location */
  If (obstructed traffic and  meteorological conditions){

        /* Select the best location for ambulance origin and best ambulance for
        attending  the occurrence */
        Ambulance_Ocurrance ←Knn_SelectAmbulance (Accident);

      /* Considering the Ambulance origin and the accident, calculate the
      best hospital as destination */
      Hospital_Ocurrance ←Knn_SelectHospital (Accident, Ambulance_Ocurrance);

     /* Having the data of the ambulance origin, the accident, and the hospital
      destination, calculate the best flight plan */
     Flight_plan_Ocurrance ←Calculate_Flight (Hospital_Ocurrance, Accident,
Ambulance_Ocurrance);
     }
)
```

Figure 2. The algorithm used for an Air Ambulance Occurrence.

Table 1. Main locations of accidents in Paraná.

id	uf	br	km	# of accidents	Altitude	Nearest Local point	Distance to the local Point (Km)
1	PR	476	124.0	994	2939	SSJF	3,22
2	PR	376	668.0	978	3061	SSIG	29,87
3	PR	476	125.0	888	2939	SSHI	3,26
4	PR	376	665.0	824	3061	SSIG	16,03
5	PR	376	176.0	782	1896	SSPX	12,33
6	PR	376	183.0	752	1804	SSPX	12,33
7	PR	476	138.0	672	2975	SSJF	3,21
8	PR	376	182.0	672	1890	SSPX	12,33
9	PR	376	666.0	670	3045	SSIG	16,03
10	PR	476	122.0	636	2975	SSJF	3,22

At each accident, kilometers of traffic jam can be present and, in fact, urgency, critical response time and weather factors can become favorable conditions to serve accident victims by air. In this direction, the ten main locations of BR with the highest number of accidents are illustrated in Table 1. A suggestion with ten priority locations, in descending order, is presented in Table 2, containing the geographical coordinates of the point, the air support base and the nearest health unit, for the purpose of air resources availability and installation of Medical Units with ICU or other medical services for emergency care for victims of road accidents.

In order to test our approach, consider the algorithm in Figure 2, along with the air ambulance coverage area approach [CHO and YOON 2015], the main historical accident sites (Table 1), the priority service locations (Table 2) and related data (Figure 1). For a first practical test, consider the following example (Fig.3): an historical area accident at Km 124 of BR 476, which might be attended by an helicopter at the Federal Police Headquarters (SSPF - located about 3.2 km from the location), with an estimated time of 3 minutes.

This solution is calculated and the trajectory and the respective flight plan are presented by the algorithm according to the initial conditions, such as location, obstructed ground ambulance traffic, meteorological conditions and available ambulance. In the same way, depending on the severity of the injuries, victims can be taken to the Hospital in Colombo, within 800 meters away (MAXIPAS COLOMBO), or transported to the ICU available at a Hospital in the City of Curitiba, or to Bacacheri Airport (SBBI) at 4.5 KM (4 minutes - which has a Mobile Air ICU already on standby at that airport, in case there is a need for transport to another capital).

Table 2.Priority Service Locations by Regions.

Priority	Local	(lat, long)	Nearest Local Point	Health Unit
1	Km 122, 124 and 125 from BR 476	-25.3812036, -49.1992531	SSJF Helipad	Maxipas Colombo
2	Km 664, 665, 666, 667, 668, 669, 671and 672 from BR 376	-25.7719713, -49.1220803	Private Aerodrome from Tijucas do Sul	N.S. Das Dores Hospital
3	Km 175, 176, 182 and 183 from BR 376	-23.4321609, -51.8868065	SSPX Helipad Paraná Moda Park (Maringá)	Medical Clinic at Maringá
4	Km 130, 133, 135 and 138 from BR 476	-25.3811267, -49.1993532	SBBI Public Airport from Bacacheri	Via Saúde Medical Clinic
5	Km 584 from BR 277	-25.0241695, -53.5510039	SBCA Public Airport from Cascavel	Mascarello Health Unit
6	Km 728 from BR 277	-25.5097394, -54.5734450	SJPF Helipad	MMM Medical Clinic
7	Km 17 from BR 116	-25.1047699, -48.7388109	SNBB Helipad BMR Medical	Regional Hospital of Litoral
8	Km 156 from BR 369	-23.3584242, -51.3965981	SSOG Public Airport of Arapongas	Ass. Rolandense E.C.
9	Km 1 and 5 from BR 277	-25.5062701, -54.5874904	SJPF Helipad	Bianco F. Eireli - ME
10	Km 84 from BR 277	-25.4627246, -49.9191415	Private Aerodrome from Serrinha	Maternity Hospital Menino Jesus

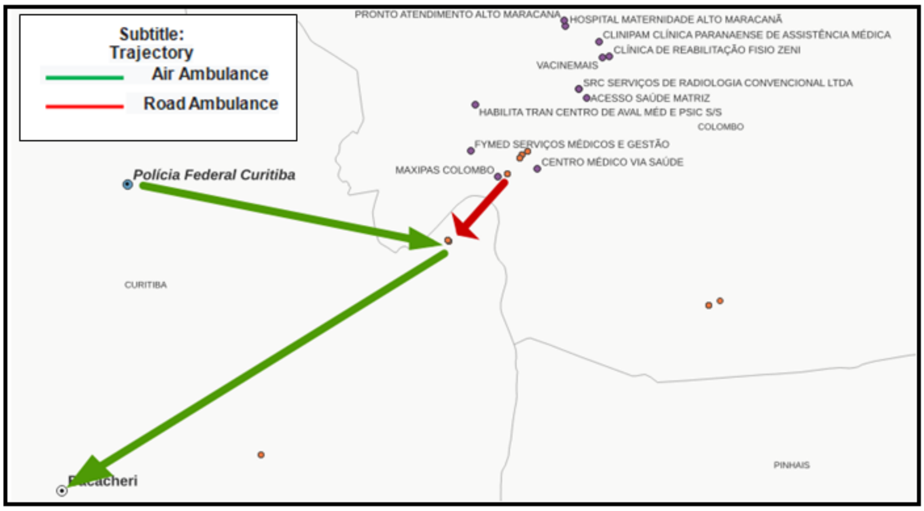

Figure 3. An occurrence which is attended by SSPF at KM 124 of BR 476.

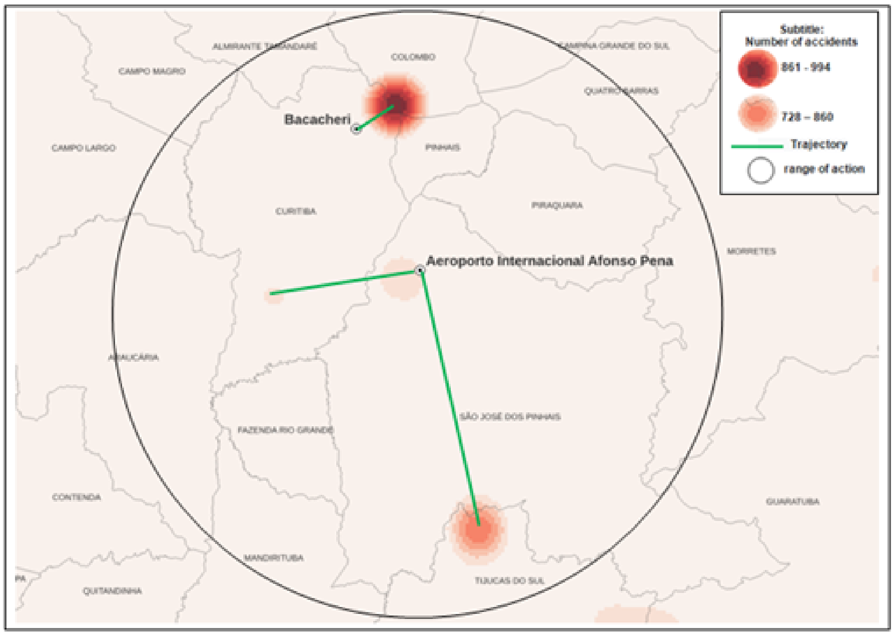

Figure 4: Region located between Curitiba and Tijucas do Sul.

As a second practical example (Fig.4), consider the areas (in red), which historically concentrate the accidents between Curitiba and Tijucas do Sul. Note that in this case, the Bacacheri Airport along with Afonso Pena International Airport should be used. Given that resources are limited (it is not possible to place aircraft and Intensive Care Units at all points closest to all accident sites), another strategy suggested is to define three priority regions in terms of care, which contain the main accident sites. Region 1 is between Curitiba and Tijucas do Sul (circle in Figure 4), Region 2 is between Maringá and Jandaia do Sul and Region 3 is between Foz do Iguaçu and Cascavel.

The same methodology could also be used for optimizing medical repatriations and emergency transfers along different locations. In addition to this analysis, in a real simulation, other items are essential, such as: (i) pre-existence of an ambulance and ground medical team at the site, (ii) the type and altimetry of the terrain at the site of the accident, (iii) the existence of high voltage lines within the path, (iv) updated air navigation maps of the area, (v) current weather conditions and (vi) characteristics of support points in terms of altitude, type of day/night operation, approach ramp shape, dimensions, strength and surface of the Helipad or Aerodrome.

About the main factors that influence the planning to support local and Federal Governments, we can list: (i) Costs: high cost to maintain air resources at support points, ICUs, ambulances, medical teams; (ii) Presence of an adequate ICU; (iii) Meteorology, terrain altimetry and flight time; (iv) Analysis of points on the possibility of hybrid assistance (an ambulance takes the injured to a point where the helicopter can safely land); and (v) preventive measures (traffic awareness campaigns, overt road policing in the main known accident sites). In particular, the state government of Paraná has the Air Operations Military Police Battalion (BPMOA), which currently has six aircraft for air medical care and other types of services, including four helicopters and two planes: a Bell 206 Jet Ranger Helicopter III (Falcão 01), two Eurocopter EC130 B4 Helicopters (Falcão 03 and Falcão 04), one Robinson R44 Helicopter (Falcão 7), one Cessna Skylane Airplane (Falcão 05) and a Beechcraft Baron BE58 Airplane (Falcão 06). The suggestions in the use case could still be optimized for the available fleet.

Therefore, the use case of this study made it possible to use the data and the KNN-Select algorithm to define the main strategic locations and regions to allocate air resources to attend to occurrences in the best possible way, as well as to establish the best hospital to transport victims and the flight plan to proceed to the destination. In addition, with the pre-established flight plan, it is possible and desirable that the air traffic control unit prioritize this service, reserving the most adequate flight level and air trajectory for the aircraft involved in this mission, as is already done with the transplantation of vital organs.

4. Conclusion

The movement of air traffic worldwide has grown significantly, implying the need for new technologies, software and information systems in this sector. A practical case using air traffic services, such as Aeromedical Transportation and flight plan, and exploratory analysis was presented using real data from road accidents, support information from air points and health facilities to help victims of road accidents on Federal Highways in the State of Paraná. Within contributions, we can mention a KNN-based algorithm for assistance in road accidents, three priority regions in terms of care in Paraná along with other essential parameters to be considered in air rescue. A questionnaire was previously applied in order to understand the use case. Therefore, the work contributes by supporting transport policymakers and managers in the decision-making process and in dealing with information as a way to save lives.

Regarding future work, we can mention the expansion of the model on the means of assistance to victims of traffic accidents to other states in Brazil, interface development for data access, the calculation of the numerical result in terms of gain in coverage area and population through the comparison between the initial data, among others.

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