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Sensitivity analysis of influencing factors in probabilistic risk assessment for airports

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ABSTRACT

Risk assessment methods in aviation greatly rely on the knowledge of the factors influencing risk and safety during daily operations. One of the weak points of the common approaches in aerodromes is the qualitative method to support decisions respect to quantitative evaluations. In this study, three airports with diverse characteristics (i.e.; aircraft annual movements, airfield geometry, and runway features) were selected for the analysis.

The RSARA© (Runway Safety Area Risk Assessment) software, which is based on the Aircraft Cooperative Research Program (ACRP) model, has been utilized as a starting point for further sensitivity analyses of probabilistic risk assessment of each airport's runway with determined casual factors, including runway geometry, traffic characteristics, and weather conditions. A comprehensive airports incident/accident database between years 2000 and 2015 was also used to perform the sensitivity analyses.

By providing different independent variables as input in the frequency model of RSARA, the outputs were useful to determine the influence of each of the casual factors on the accident probability of occurrence. Selected variables include: runway length in terms of declared distances, Runway Safety Area geometry, instrumental landing system category, weather operational data and annual traffic growth rate. The sensitivity analyses showed that the weather condition and runway related factors played a major role in increasing or decreasing the probability of the accident; the probability of landing overrun (LDOR) can be increased by four times, for instance, due to specific combinations of runway length and climatic conditions. Engineered arrestor beds such as EMAS also has the potential to decrease by 50% the risk of LDOR and can be selected as an effective choice compared to other pavement materials within the RSA.

Identifying critical variables on the occurrence of high-severity runway accidents could influence the aerodrome design, operating scenarios, regulations, emergency planning and risk management measures and techniques.

1. Introduction

Fatality, injuries, and damage are important topics of all transport safety policies; performing systemic risk assessment is therefore inevitable. In this regard, safety strategies are to be developed and applied on the system and frequent monitoring is needed to assist in developing comprehensive safety policies for various transport modes such as rail, road, air and maritime (de Castro Fortes and Correia, 2012).

Aerodrome is considered a complex system, assessing risk in aviation would thus use complex procedures. This assessment greatly relies on the acquisitive knowledge of the factors influencing the risk and the safety buffer that needs to be designed in order to achieve an acceptable level of safety in daily operations and movements. One of the weak points of prior approaches to manage risk in aerodromes is their large dependency on judgmental and qualitative decisions. Less subjectivity can be obtained by evaluating the direct and indirect impacts of different factors affecting both the airport and the aircraft.

Aviation performances can be divided into two categories of operation; normal operation with stochastic variations in performance and abnormal operation (Trucco et al., 2015). Measures to be employed for increasing safety could be categorized as passive or active measures. Passive measures may stand for taking care of more extreme and unpredictable hazards, in contrast active

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measures cover the expected stochastic variations in normal operations.

The International Civil Aviation Organization (ICAO) has strengthened its standards and recommendations for the geometry of the Runway Safety Area (RSA) in airports (Annex 14, ICAO 2013). The surface beyond the end of a runway which is available to protect an overrunning or undershooting aircraft consists of a 60 m strip plus the Runway End Safety Area (RESA). Prior ICAO standard accepted smaller RESA but this was extended in current regulations (Annex 14, ICAO 2013). Although newer standards can have positive impacts on increasing safety, implementing them can cause significant costs to the airport authority. In some cases extending the RSA is not even possible for airports which are landlocked or face challenges due to terrain or environmental restrictions, such as wetlands. A greater knowledge about the analytical assessment of the probability of possible hazards and corresponding consequences is thus fundamental.

Landing and take-off phases of flight are experienced as including the major portion of air accidents (Guerra et al., 2008). The reason behind these events is mainly loss of aircraft control and surpassing the designated thresholds and safety areas. In general, common possible accidents that occur during these flight phases can be categorized as landing overrun (LDOR), landing undershoot (LDUS), landing veer-offs (LDVO), take-off overrun (TOOR), and take-off veer-offs (TOVO).

Regulations and requirements (Valdés et al., 2011) for designing safety areas in the proximity of the runway aim to decrease the probability of these types of accidents and mitigate their possible consequences. In this study, a set of influencing factors which would affect the probability of risk related to associate types of events was investigated.

2. Literature review and reference model selection

Nowadays, the definition of safety gets more comprehensive and it is described as the decreasing likelihood of harm to properties or persons which has to be kept under an acceptable level through a continue process of hazard identification (ICAO, 2013).

From previous studies and recorded accident data, it can be interpreted that LDOR, LDUS, LDVO, TOOR, and TOVO formed the major portion of the accident that occurred in the surrounding areas of the runway. Statistical records from 1959 to 2009 shows that 55% of world-wide aircraft accidents occurred during landing and take-off phases (Boeing, 2016). It is obvious that human and organizational errors play a big role in occurrence of these types of accidents but airport and runway conditions also contribute significantly to generate potential risk.

According to the Federal Aviation Administration, "The runway safety area (RSA) is a graded and obstacle-free rectangular-shaped area surrounding the runway that should be capable, under normal (dry) conditions, of supporting airplanes without causing structural damage to airplanes or injury to their occupants" (AC 150/5300-13, 1989). RSA can be divided into three sections depending on the type of accidents that may occur in the proximity of the runway. Two sections are located at the runway ends; these sections would help to mitigate the possible consequences of aircraft overrunning and undershooting the runway. The third RSA section is located in the lateral areas of the runway. This area should reduce the severity of aircraft veer-off incidents.

Assessing risk required both specific tools, which need to assign probability values to specific accidents, and models, which are able to estimate consequences of such events. Several accident probability models have been developed in the last decades. Eddowes et al. (2001) published a report concerning risk analysis in support of aerodrome design rules. Kirkland et al. (2003) focused on incident data collection and normalization to develop estimation of probability of occurrence, location of wreckage and assessment of the consequences. However, those studies suffered from the same limitation due to the database restriction, which only included the Historical accident Operational Data (HOD). In fact, in order to understand the effects of different variables on occurrence frequency of the accidents, sensitivity analyses should be performed on both accident database and non-accident flights movements. This latter is feasible only in existence of Normal Operational Data (NOD), not commonly available.

In 2008, the Airport Cooperative Research Program (ACRP) published the "Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas" (ACRP report 3, 2008). The report investigated the average probability of accident occurrence during landing and take-off; more influencing factors on risk probability calculation were taken into account compared to previous models, thus increasing the accuracy of this procedure. Normal operational data was also included besides accident/incident database.

In 2009, (Wong et al., 2009) used a frequency model based on specific accident types providing a comprehensive database of all possible accident types. Furthermore, the wreckage location model was developed based on cumulative recorded accidents location frequency, instead of on the actual landing and take-off kinetic energy modeling.

In 2011, probabilistic and risk models related to historical accident operational data have been proposed by (Valdés et al., 2011). Moreover, two studies on runway excursions were conducted by ACRP (ACRP, 2008, 2011), which applied traditional logistic regression to predict the probability of occurrence of runway excursion.

In 2014, (Wagner and Barker, 2014) used logistic regression and Bayesian logistic regression to model runway excursions. The authors of this study focused more on predicting the possibility of generating fatalities as a consequence of excursion occurrence more than predicting the type of runway excursion. Their effort aimed to model fatal airport runway excursions, define mitigation measures to accidents occurrence and their severities, and verify the efficacy of risk management strategies that were employed.

In 2013, a study from (Roelen and Blom, 2013) analyzed the evolvement of safety performance regards to runway airplane maneuver over the period 1990–2008. Statistical data records of worldwide accidents of commercial flights by fixed-wing aircraft with a maximum take-off weight of more than 5700 kg were selected as the boundary conditions. The output showed that the accidents occurrence rate related to Take-Off and Landing does not identify a clear positive or negative trend over the period 1990–2008.

While most of the previous models gave single probability values as the output, in 2015 Trucco et al. proposed a methodology which contains a two-step procedure and returns probability and severity results in the form of a topological grid as output. Therefore, by superimposing this topological risk grid on the terrain surrounding the runway it would have been possible to plan the mitigation measures, reduce the probability of occurrence and the possible consequences; these, in one word, correspond to the risk of accident on the infrastructure (Trucco et al., 2015).

Based on the strength and weaknesses of prior models, the ACRP accident formula is used for this study as the reference base model. This preference is related to the large amount of data upon which this model was built. Using normal operation data allowed to quantify the importance of each factor and the way it specifically influences the final accident probability. Several influencing factors were considered both from traffic characterization and impact of weather conditions on the runway (NTSB, 2005).