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Forecasting and assessing consequences of aviation safety occurrences

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ABSTRACT

Aviation safety is essential for the healthy growth and sustainability of the global economy. The implementation of Safety Management Systems to support safe service delivery has become one of the most important goals within the airline industry over the last years. However, in most cases the involved organisations use unsophisticated methods based on risk matrices for the development of such systems. In this paper, we present models to forecast and assess the consequences of aviation safety occurrences as part of a framework for aviation safety risk management at state level.

1. Introduction

Air transport is fundamental for the development of modern societies and safety is one of its key features: various organisations like the International Civil Aviation Organization (ICAO), the Federal Aviation Administration (FAA), the European Aviation Safety Agency (EASA) or EUROCONTROL have aimed at making aviation the safest transportation mode since their creation. As a result, the ICAO binds the 191 signatory states of the Chicago Convention to develop their national Safety Management Systems (SMS) aimed at properly managing aviation safety (AS) in their respective countries. Indeed, the viability of an aviation organisation depends largely on its ability to preserve the public perception of its safety. This requires a constant balance between service costs and safety goals, making risk management essential for sustainability.

Despite a high safety level in aviation worldwide, occurrences continue to take place. As an example, in our context, we need to consider 88 different types of occurrences, ranging from *bird strikes* to *runway excursions* going through *engine failures* and *loss of control*. As proposed by ICAO (2013), each of such occurrences is classified into one of five severity classes: *Accident* (1); *Serious Incident* (2); *Major Incident* (3); *Significant Incident* (4); and, finally, *Occurrence without safety effect* (5). Thus, we may talk, for example, about a severity 3 engine failure occurrence.

In earlier work, Rios Insua et al. (2016a), we have presented a framework to support AS risk management at state level. It employs decision analysis (French and Ríos Insua, 2000) and includes as stages: (a) providing forecasting models for the numbers of various types of occurrences; (b) forecasting models for the occurrence severity classes; (c) forecasting models for the consequences of occurrences; (d) the construction of a multiattribute utility model to assess such consequences; and, finally, (e) using such models to screen riskier occurrences and assign resources optimally to mitigate aviation hazards. In particular, the framework is used by an AS state agency to decide how to allocate their resources, specifically their inspection capabilities, to improve AS in a country taking into account technical and financial constraints. This facilitates the preparation of the national SMS and overcomes standard AS risk management practice based on risk matrices (e.g. ICAO, 2013; Ayres et al., 2009; FAA, 2007; McIntyre, 2002), with well known defects, Cox (2008). Netjasov and Janic (2008) provide a review of other AS approaches, including Bayesian belief networks (Ale et al., 2009). However, such approaches tend to be not integrated within appropriate decision making structures.

In this paper, we present in full detail stages (c) and (d). Besides being key ingredients for our risk management methodology, the models presented allow us to forecast and assess consequences of AS occurrences, thus being of interest not only for aviation authorities, but also for insurance companies, aviation operators and aircraft companies. Given the above mentioned emphasis on risk matrices in AS, which focus on qualitative global impacts in an ordinal scale (typically,

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1–5), it is no surprise that relatively little work on assessing AS consequences is available. Sobieralski (2013) provides a review of the scarce literature on the topic which we complement in Section 3.1 below. Our contributions include the identification and structure of objectives typically relevant in AS from a state perspective; the provision of models to forecast and asses such AS consequences; and, finally, a model to globally assess such consequences. We view all of the above models as templates, in the sense that an organisation could use them as starting points to be refined and adapted to their own data and circumstances.

In what follows, we shall make a distinction about various aircraft types: T1, general aviation, aerial works, or business aviation, with less than 19 passengers; T2, regional flights (<100 seats); T3, continental flights (<200 seats); T4, intercontinental flights (>200 seats). T2, T3 and T4 refer to aircrafts engaged in commercial aviation.

2. Aviation safety objectives and multiattribute evaluation

2.1. Objectives

AS occurrences may entail very negative consequences in terms of lives and costs. Through risk management, we aim at minimising them. Each organisation must determine their relevant consequences for risk management purposes. They will typically vary from private organisations, say an airline, to state organisations, like a national AS agency. They may also vary for different countries. We present here the consequences considered relevant in our case, which may serve as initial information for other organisations, specially if they are governmental. Recall that the context of our problem refers to an AS public agency that aims at introducing a risk management plan outlining a resource allocation procedure to improve AS in the corresponding country, as part of developing their national SMS.

After a brainstorming process and a literature review, in particular based on EUROCONTROL (2013), the incumbent organisation (the Spanish Aviation Safety and Security Agency, AESA) decided to focus on the objectives hierarchy in Fig. 1, which portrays the chosen objectives and subobjectives as well as the corresponding attributes. Clemen and Reilly (2013) and Keeney (2009) provide details on designing hierarchies of objectives.

We started with a generic objective, *optimise AS*, which we specified through four sub-objectives:

- *Minimise health impacts*, associated with aviation induced deaths and injuries;
- *Minimise the operational impact* produced by unsafe aviation operations;
- *Minimise material damages* caused by safety occurrences; and, finally,
- *Minimise country image loss* associated with the lack of AS.

The first sub-objective was further decomposed into two referring to *minimising fatalities* and *injuries*. The attributes chosen to evaluate them were natural and correspond, respectively, with the number of fatalities and injuries in two categories, severe and minor, as defined by EUROCONTROL (2013). In AS, ICAO (2013) describes a fatality as *any person who suffers a fatal injury, resulting in death within thirty days of the date of an accident*. It is the most feared consequence in AS occurrences. An important example refers to the 583 dead in 1977 at the Tenerife North Airport (Spain) after the collision of two aircrafts. Similarly, ICAO (2013) defines an injured as *any person who suffers a non fatal injury as a result of: being in the aircraft; or in direct contact with any part of it, including parts which have become detached from the aircraft; or direct exposure to jet blast*. A relevant example refers to 64 injuries, including 7 severe ones, in 1988 due to a detachment of the ceiling of the cabin of an airplane during takeoff, forcing the pilot to make an emergency landing at Kahului.

The second sub-objective was also broken down into two, referring to *minimising delays* and *cancellations* induced by occurrences. Indeed, one of the associated negative consequences are the delays in takeoff or landing after the expected scheduled time (above 15 min, according to the FAA), which may induce significant costs to individuals and airlines and, in general, the aviation system in a state. As an example, Cook and Tanner (2011) report that around 750.000 flights in 2009 suffered some kind of delay in the European Union (EU), with an approximate associated cost of 1.25 M€. We shall estimate the delay induced by AS occurrences in minutes. On the other hand, when a flight is cancelled we must assume costs such as accommodation, transport or catering. The chosen attribute for this consequence was the number of cancellations due to such occurrences.

The third sub-objective referred to *minimising material damages* induced by occurrences. To reflect this, two subobjectives and their attributes were proposed: the number of destroyed aircrafts and the number of aircrafts requiring repair during the corresponding management period. For certain occurrences, and depending on their severity, it will be necessary to inspect the damaged parts and repair the aircraft cell. Moreover, after several accidents, repair might not be possible and it would be necessary to replace the aircraft. In terms of AS risk management, both destructions and repairs entail considerable costs that a state should take into account and promote their minimisation.

Finally, we did not need to further decompose the fourth sub-objective, *minimisation of image loss*. Image costs would be based on the media coverage that occurrences receive. In general, we assume that the more severe the occurrence is, the higher the image loss will be. This should be taken into account, as we are focusing on risk management at state level, and image may affect key economic sectors such as tourism. However, a natural attribute that allows us to evaluate this consequence was not readily available. One alternative would be to construct an artificial ordinal scale, say from 1 to 10. Level 1 would be associated with a situation of minimal image impact (for example, a severity 5 occurrence with no consequences that would not appear in the media); similarly, level 10 would be associated with a maximum impact accident with total destruction of the aircraft and numerous fatalities (for example, the Germanwings 2015 case that led the world press for several weeks), with a very negative image for a country. Henceforth, we would associate each of the levels with a qualitative description of severity with respect to image. However, as described in Brownlow and Watson (1987), we prefer to adopt a proxy variable that mitigates the ambiguities in such constructed scale. Thus, we shall use the number of accidents (occurrences of severity 1) suffered by commercial aircraft transport as a proxy for country image loss. These are the occurrences which will make it to the media and, presumably, are highly correlated with negative image impact.

In summary, through an AS risk management plan, the initial aim of the organisation would be to minimise over the relevant planning period the number n_F of fatalities; n_{H_1} and n_{H_2} of minor and severe injuries, respectively; the minutes t_D of delays and the number n_C of cancellations induced by occurrences; the numbers n_R of damaged and n_{HL} of destroyed aircrafts; and, finally, the number s^1 of commercial aviation accidents.

2.2. Multiattribute evaluation

We describe now the preference model agreed with the organisation to assess the consequences of AS plans. Among other things, this will allow us to forecast the costs associated with AS over the planning period as outlined in Section 4.8. If these are deemed high, we should look for appropriate risk management interventions, whose impact would again be evaluated with the aid of the proposed preference model. Thus, we need the regulator utility function, modelling its preferences and risk attitudes. For this, we use the concepts of measurable multi-attribute value function (Dyer and Sarin, 1979) and relative risk aversion (Dyer and Sarin, 1982).