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Strengthening air traffic safety management by moving from outcome-based towards risk-based evaluation of runway incursions

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ABSTRACT

Current safety management of aerodrome operations uses judgements of severity categories to evaluate runway incursions. Incident data show a small minority of severe incursions and a large majority of less severe incursions. We show that these severity judgements are mainly based upon the outcomes of runway incursions, in particular on the closest distances attained. As such, the severity-based evaluation leads to coincidental safety management feedback, wherein causes and risk implications of runway incursions are not well considered. In this paper we present a new framework for the evaluation of runway incursions, which effectively uses all runway incursions, which judges same types of causes similarly, and which structures causes and risk implications. The framework is based on risks of scenarios associated with the initiation of runway incursions. As a basis an inventory of scenarios is provided, which can represent almost all runway incursions involving a conflict with an aircraft. A main step in the framework is the assessment of the conditional probability of a collision given a runway incursion scenario. This can be effectively achieved for large sets of scenarios by agent-based dynamic risk modelling. The results provide detailed feedback on risks of runway incursion scenarios, thus enabling effective safety management.

1. Introduction

The safety of runway operations is one of the key focus points of Air Traffic Management (ATM). Runway incursions ("any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft" [1]) are to be avoided for the sake of safety of runway operations. Major accidents such as at Tenerife in 1977 (583 casualties) [2], Omsk in 1984 (178 casualties) [3], and Linate Airport in 2001 (118 casualties) [4] are sad reminders of the deadly consequences that runway incursions may have.

Safety programs such as [5,6] support the development of procedures, training and technical systems to reduce runway incursion risk. Considerable research has been done on human factors in runway incursion [7,8] and on the development of runway incursion prevention systems in the aircraft, air traffic control (ATC) tower, ground vehicles and aerodrome [9]. All such procedures, training programs and technical systems intend to improve runway safety by reducing the risk of runway incursions, either by reducing the probability of their occurrence, or by mitigating their potential consequences (most prominently, preventing a collision).

Monitoring and controlling the safety of runway operations is part of the safety management system (SMS) of the stakeholders of aerodrome operations. A safety management system includes goal setting, planning, measuring and feeding back of operational safety in a plan-do-check-act cycle [10]. For safety management of runway operations, runway incursions need to be reported and analysed [1,11].

As part of such analysis of runway incursions, the International Civil Aviation Organization (ICAO) recommends to classify their severity by one of the following severity categories [1]:

A. A serious incident in which a collision was narrowly avoided;
B. An incident in which separation decreases and a significant potential for collision exists, which may result in a time-critical corrective/evasive response to avoid a collision;
C. An incident characterized by ample time and/or distance to avoid a collision;
D. An incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and takeoff of aircraft but with no immediate safety consequences;

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E. Insufficient information or inconclusive or conflicting evidence precludes a severity assessment.

In the USA, the Federal Aviation Administration (FAA) uses the ICAO recommended severity categories A to D to classify runway incursions. FAA does not apply category E for insufficient information, since a decision about the severity is always made. Statistics on runway incursions and the associated severities are regularly published in runway safety reports and runway safety plans [5,12]. In addition to such reports, FAA publishes the details of runway incursions, including their severity categories, in a publicly accessible on-line database system, called FAA Aviation Safety Information Analysis and Sharing (ASIAS) [13]. In Europe, the European Aviation Safety Agency (EASA) provides statistics of safety occurrences, including runway incursions, in its annual safety review [14]. EASA uses generic severity categories (serious incident, major incident, significant incident, no safety effect, not determined) for all safety occurrences. In this paper we use data of runway incursions in the USA from the ASIAS database.

The current severity categorization of runway incursions (A, B, C, D, E) is to a large extent based on the particular outcome of a runway incursion. In particular, the closest distance attained by the entities (aircraft/vehicle/person) in a runway incursion is a main driver of the severity determination. This closest distance attained depends to a considerable extent on uncontrolled random circumstances, such as another aircraft being nearby at the time of the initiation of the runway incursion. In incursions that are judged as being less severe (C, D) typically the same types of errors or misunderstandings by pilots or controllers lead to initiation of runway incursions and the distinction with more severe (A, B) cases is primarily due to some uncontrolled circumstances. The consequence is that current safety management is driven largely by random outcomes, wherein lessons from incursions with less severe (C, D) outcomes may be undervalued and there may be an overreaction to severe (A, B) outcomes.

In this paper, we present a new framework for the analysis of runway incursions, which does not use an outcome-based severity category, but which is strictly based on the risk of scenarios associated with runway incursions. Such a scenario describes the state at the initiation of the runway incursion, e.g., a small aircraft enters a runway near the runway start while its pilots are lost and it comes into conflict with a large aircraft landing in good visibility conditions. A main step in the framework is the assessment of the probability of a collision due to a runway incursion, which accounts for a variety of probabilistic circumstances that influence the collision probability. The results provide detailed feedback on risks of runway incursion scenarios, wherein similar kinds of errors or misunderstandings leading to runway incursions in similar conditions give similar risk values. This provides a basis for risk-informed rather than coincidental safety management.

The paper is structured as follows. Section 2 sets the stage by introducing states and events in the evolution of runway incursions and by providing a number of illustrative examples of runway incursions. Section 3 describes and discusses the current severity-based approach for assessment of runway incursions, including an analysis of the relation between shortest distances and severity categories. Section 4 presents the development of an inventory of runway incursion scenarios, which forms the basis of the new framework. Section 5 presents the steps in the new risk-based framework and provides illustrative results. Section 6 discusses the framework and describes future research opportunities. Parts of this research were also presented in a conference paper [15].

2. Many ways for evolution of runway incursions

There are many ways in which a runway incursion can arise and given its initiation there are many ways in which it can develop next, up to an accident as the most severe consequence. In line with the argumentation on accident precursors of [16], Fig. 1 illustrates relations between states X_t (circles) and events E_t (arrows) before and after the initiation of runway incursions. The states describe sets of variables that are relevant for taxiing and runway operations, such as the type of operation (e.g. takeoff, land, taxi), the position of an aircraft, and the situation awareness (SA) of pilots. The events are occurrences during taxiing and runway operations, such as acts of observation or communication by pilots/controllers, and aircraft manoeuvring. Following a particular state, there is a multitude of possible events, which is indicated by the dashed arrows in Fig. 1. These events may occur in various orderings and in a continuum of times.

In Fig. 1 we consider, as a leading example, potential runway incursions between an aircraft A_1, which taxies from a gate for departure, and an aircraft A_2, which approaches a runway for landing. An initial state X_{t_a} describes the states of the aircraft before (ante) any precursor of a runway incursion occurred. For instance, this state may include the sizes of aircraft A_1 and A_2 and their positions at the gate or along the approach path.

We denote the time of the initiation of a runway incursion as t_0. For times $t_a < t < t_0$ there can be various events that are precursors of a runway incursion, e.g. the pilots of aircraft A_1 make a wrong turn such that they have a wrong SA about their own position, or the pilots of aircraft A_1 forget an ATC instruction such that they have a wrong SA about the ATC instruction. Such inflicted states may lead to a runway incursion event $E^{RI}_{t_0}$ wherein aircraft A_1 passes the hold-short line of the runway and comes into conflict with aircraft A_2 that is about to land. Often, however, these kinds of inflicted states do not lead to a runway incursion, as there are various events that can prevent the progression to a runway incursion event, such as the pilots recognizing that they are at a wrong position, or being warned by ATC. In the scheme of Fig. 1, the state X_{t_0} that is attained at the start of the runway incursion depends on the initial state X_{t_a} and the events that occurred for $t_a < t \le t_0$.

Following the initiation of a runway incursion there may be a variety of events occurring for $t > t_0$, e.g., pilots recognize the conflict with the other aircraft, ATC warns pilots, aircraft A_2 initiates a go-around, or aircraft A_1 stops. All these types of events, their orderings, and timing have impact on the kind of final state in the evolution of the runway incursion at time t_f, when the entities involved are closest. For instance, final states may be aircraft A_2 flies over aircraft A_1 at 100 ft, aircraft A_2 goes around at 1 mile, aircraft A_1 stops at 10 ft before the runway edge while aircraft A_2 passes, or the aircraft are collided.

As an illustration of the ways that actual runway incursions evolved, Table 1 shows descriptions of some runway incursions in the FAA ASIAS RWS database [13]. For each of these incursions we added key features of the states X_{t_0} and X_{t_f}. Cases 1 to 5 all consider conflicts between an aircraft that is about to land and an aircraft taxiing on the runway without permission. In cases 1, 3 and 5 the taxiing aircraft lined up on the runway erroneously, either because the pilots seem to have thought to be allowed to do so (cases 1 and 3), or the pilot took a wrong turn and was lost (case 5). In cases 2 and 4 the taxiing aircraft crossed the runway, although in both cases the taxi instructions to hold short of the runway were read back correctly. A reason for the erroneous crossing is not provided in the descriptions. Maybe the pilots did not know that they were already at the runway crossing when they were, or they had forgotten or misinterpreted the hold-short instruction. In case 6 an aircraft lined up and took off without clearance, thus creating two types of runway incursions, wherein it (luckily) did not come into conflict with other traffic. The final states achieved in these incursions are varied, ranging from a fly over with 15 m vertical separation to a go-around at 1 mile from the runway. It can be observed in Table 1 that also the severity evaluations for these