



The risk of an air accident as a result of a serious incident of the hybrid type

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ABSTRACT

Safety in air traffic is a multilayered concept and consists of many safety barriers. The practical side of increasing safety is mainly based on analysing the causes of accidents and incidents. This analysis leads to finding gaps in the safety structure and to developing corrective recommendations in order to eliminate them. In this paper we indicate that this practice is insufficient. Most incidents could transform into accidents with fatalities. The standard method of investigating incidents does not answer the question as to whether safety barrier is permanent or whether it was activated accidentally. This paper proposes a new method for analysing incidents aimed at finding their consequences rather than their causes. This makes it possible to find areas that need improvement. Stochastic, timed, coloured Petri nets were used for the analysis. There are three types of air traffic incidents, distinguished according to events that lead to a transformation of an incident into an accident: causal and temporal. The hybrid case, in which both types are important, has been discussed in detail. The method is useful in evaluating the current level of safety in air traffic. Applicability of this method has been shown on the example of the runway incursion problem.

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1. Introduction

Safety in air traffic is a multilayered concept and consists of many safety barriers: organisational, technical and procedural barriers. Their task is to protect participants of the transport process from events with potentially catastrophic consequences. Traffic accident investigations are conducted in terms of searching for the reasons and circumstances that were favourable for these events. The present studies were carried out within the existing organisational structures that make use of well-established and legally sanctioned methods and procedures ([20,32]), which are directed at determining the causes of accidents and making preventive recommendations aimed to eliminate them, and indirectly to prevent the occurrence of analogous events in the future. Of course, incidents (serious incidents) are also examined in the same way. This examination of incidents, as is the case for accidents, is focused on searching for the reasons why they occurred.

In this paper a new method of traffic incident analysis is proposed. This method is based on an exploration of the possible scenarios for the development of an incident and on checking what other effects it

could bring about. This approach allows us to evaluate and to verify whether any particular case of an incident that did not transform into an accident was the result of hedging activities or whether this was pure coincidence. In the latter case one should suggest preventive recommendations relating to those scenarios that did not actually occur. In other words, there is a common belief that safety barriers will work forever and that they will work in slightly different circumstances, such as worse weather conditions or worse technical conditions of the vehicle, etc. However, the fact that the safety barriers worked during a particular incident does not guarantee that they will work in any other case. This applies especially to complex systems working in the long time horizon, assuming that they can be subjected to threats which we are currently not even able to imagine. A similar approach is presented in works on resilience engineering [30,11]. A somewhat similar approach was recently presented by Khakzad et al. [38].

In this paper we propose a quantitative analysis of scenarios in which serious incidents could have transformed into accidents but did not do so. The proposed approach is illustrated by air traffic examples. Due to the special role of airports in logistics chains, the analysis was carried out for an aerodrome traffic incident. The studied case belongs to the class of so-called Runway Incursions (RIs). The International Civil Aviation Organization (ICAO) defines these as “any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a

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surface designated for the landing and take-off of aircraft” ([33]). The most common RI types are:

- take-off without the air traffic controller’s (ATC) permission
- aircraft runway crossing after landing contrary to ATC clearance
- issued ATC taxi clearance in conflict with other ATC clearance
- unauthorised runway incursion of people, vehicles or animals.

There are many factors that affect this type of event, e.g. weather, the airport’s configuration, conditional control clearances, simultaneous use of intersecting runways, phraseology, the use of several languages for controller-pilot communication, workload, etc. It constitutes a broad class of occurrences, with possible consequences of a most serious nature, thus much attention in the activities of organisations responsible for the safety of air traffic is devoted to it. According to Eurocontrol statistics for the period 2008–2011, the number of RIs was close to 0.06 per 10,000 flights [18,19]. According to the U.S. FAA (Federal Aviation Administration) ([23]), in the airspace of the United States from 2004 to 2007, 1353 RIs were recorded for about 248 million take-offs and landings, which gives an average of $5.46 \cdot 10^{-6}$ per flight, i.e. a similar likelihood of this phenomenon as in Europe.

The current strategy of the European Aviation Safety Agency (EASA) is to focus on five key operational problems in air traffic—the so-called “top five”. These also include runway incursions (RIs). The analysed incident that is a typical representative of the RI category applies to taxiing against ATC permission along with crossing a runway that is in use. Contributory factors are also typical, such as outdated maps, poor situational awareness and communication errors. The proposed method can be applied to a whole runway incursion class of occurrences. It can be used not only for error detection but also for error recovery [40].

In Europe, EUROCONTROL Safety Regulatory Requirements (ESARRs) have been developed which discuss various aspects that affect the overall level of safety in air traffic. The European Organization for the Safety of Air Navigation EUROCONTROL has undertaken efforts to develop standardised methods and tools of risk management, particularly to determine the acceptable (tolerable, target) level of safety [16]. At present, the ESARR regulations are a part of the European Community Law, thus they have increased legal effect. This has been possible thanks to the Single European Sky (SES) initiative and to transposition works performed mainly in the years 2007–2011. The European regulations [21] divide events with the participation of ATM (Air Traffic Management) into five categories:

- accidents, which include: mid-air collisions, collisions on the ground, controlled flight into terrain (CFIT), total loss of flight control
- serious incidents: a significant loss of separation (separation of less than half the allowable minima), and neither the crew nor the air traffic controller is able to recover from the situation, cases when the aircraft changes its flight path in such a way that in order to avoid a collision an abrupt manoeuvre is required
- major incidents: a significant loss of separation, but with the crew or the ATC controlling the situation, a minor loss of separation (separation greater than half the minima), with the crew and the controller unable to recover from the situation
- significant incidents: an increase in the workload of air traffic controllers and flight crew, a minor loss of separation, with the crew or ATC controlling the situation and fully able to recover from the situation
- incidents without direct impact on safety.

Regulations [21] require that member states determine the current level of safety (CLS) and then make their evaluations by comparing them to the target level of safety (TLS). TLS and CLS are

usually defined as the quotient of the number of accidents divided by the number of flight hours or, simply, the number of flights [17]. These regulations define the tolerable level of risk just for the “accidents”. If the current level of safety is worse than the TLS, one must propose solutions to improve it. At the moment, TLS is understood as the maximum value of the probability of an accident; for commercial aircraft it was adopted as being equal to $1.55 \cdot 10^{-8}$ accident on a flight hour, or $2.31 \cdot 10^{-8}$ accident on a flight [17]. CLS forecasts should be made with respect to any change (technical or organisational) in the air traffic management system. The task of determining the current level of safety can be difficult in practice. For small- or medium-sized countries the annual number of operations is small and the number of accidents per year is often zero (or at most a few). This prevents accurate determination of CLS.

One method of solving this problem is to determine the level of safety on the basis of data on air incidents which are obviously more frequent than air accidents [14]. Unfortunately, the target level of safety for that category of events has not been specified. It has been planned that the standard will be defined in the future, but it is not certain whether such a standard could be practically accepted as air traffic incidents are very different in nature and the severity of effects is also different. Also, the combined examination of all incidents prevents one from understanding the real causes that led to them.

Another method is to treat a serious incident as “a partial accident”. By knowing the number of serious incidents and the likelihood of their transformation into accidents we can estimate the number that might be called the expected value of the number of accidents. The method of incidents analysis as proposed in this paper allows one to estimate the probability of the transformation of an incident into an accident.

The latter method is based on the number of serious incidents and the likelihood of their transformation into accidents. The objective of this paper is to develop a new method for the analysis of incidents—focused on exploring the consequences and not the causes. An accident model is created based on the model of a real incident and by taking incident development scenarios into account. Its analysis allows us to estimate the probability of the conversion of an incident into an accident as well as the probability that the scenario will take place.

The work is structured as follows: Section 2 briefly presents the specificity of the problem of air traffic safety in the vicinity of an airport. Also, some works on the modelling of traffic safety in the airport area are discussed. This section provides a classification of major incidents in transport into three groups along with references to literature and a selection of serious incidents with hybrid characteristics as the object of interest in this work; Section 3 presents an overview of the Petri nets; Section 4 describes the method of analysing the likelihood that a serious incident will turn into an accident; Section 5 presents a comprehensive example of applying the proposed method of analysis. Real data from a serious air traffic incident which occurred in 2006 at Warsaw Chopin Airport was used for this purpose. Petri nets modelling the actual incident and also the accident into which the incident could be transformed were shown. Results of the simulation research of the model is discussed; Section 6 provides a summary and the conclusions.

2. Airport traffic safety modelling—Literature review

2.1. Airport operations and air traffic control

The airport is a separate area on land, water or another surface which is intended for the arrival, departure and surface movement

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