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FAST-TIME SIMULATION FOR EVENT SEQUENCE DIAGRAMS IN AVIATION SAFETY

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ABSTRACT

The Integrated Safety Assessment Model (ISAM) is being developed by the FAA to provide a baseline risk assessment for the National Airspace System. The model consists of a set of event trees, each describing a set of possible event sequences occurring following an initiating event, such as an engine failure. Probabilities associated with the initiating events and end events of the trees are typically quantified via historical incident and accident data. However, the intermediate branching probabilities are not quantified directly, but rather indirectly assumed. This case study provides a physics-based simulation of an aircraft taking off to help quantify the branching probabilities in the trees. The simulation consists of a continuous-time aircraft dynamic model and a discrete-event simulation of the event tree. Results show that accident probabilities are sensitive to a number of parameters that are not directly captured in the original event trees.

1 INTRODUCTION

The Integrated Safety Assessment Model (ISAM) (Borener, Trajkov, and Balakrishna 2012) is being developed by the FAA to provide a baseline risk assessment for the National Airspace System. One purpose of the model is to evaluate the safety implications of proposed operational improvements to the system under future traffic scenarios. The ISAM risk model includes a set of event-sequence diagrams (ESDs) and supporting fault trees to estimate aviation accident probabilities. An event-sequence diagram starts with an initiating event, such as an engine failure during take-off. The initiating event is followed by branching events which define the set of possible event sequences. An example of a branching event is whether or not air-traffic control resolves a conflict in which two aircraft are on a collision course. The end states of the tree include safe outcomes (e.g., avoidance of a conflict) and accidents of varying severity (e.g., a midair collision or a runway overrun). In total, ISAM contains 35 distinct event-sequence diagrams each with a different initiating event. The event-sequence diagrams are based on the Causal model for Air Transportation Safety (Ale et al. 2009) and the Integrated Risk Picture (Spouge and Perrin 2006), and are modified to represent scenarios in the United States.

To quantify risk, ISAM is populated with incident and accident data from a variety of sources. Data sources include the National Transportation Safety Board, the Accident / Incident Data System, Service Difficulty Reports, and post-hoc analysis of radar surveillance collected by the FAA. An inherent challenge is that accidents are extremely rare so there are limited data to quantify all the events in the trees. Typically, the initiating events and end events can be quantified with data, but not the intermediate branching probabilities. Instead, the intermediate probabilities are inferred by choosing values that make the initiating and end-event probabilities consistent. However, because there are more unknowns than constraints, additional assumptions must be made to quantify these values.

This case study provides a physics-based Monte-Carlo simulation to estimate the intermediate branching probabilities for an event-sequence diagram in ISAM.

2 METHODOLOGY

We consider an event-sequence diagram in which an aircraft system failure occurs during take-off. The intermediate branching points include events like whether or not the flight crew rejects the take-off, whether or not a take-off occurs at high speed, whether or not there is sufficient runway length following a rejected take-off, and so forth. There are five possible end states - the aircraft stops on the runway, the aircraft veers off the runway, the aircraft runs past the end of the runway, the aircraft continues flight, and the aircraft collides with the ground.

The simulation model consists of two parts - an event-sequence model and an aircraft state model. The event-sequence model replicates the branching events in ISAM. The state model tracks variables in continuous time such as acceleration, speed and aircraft position. The state model uses physical constants for specific aircraft, such as a Boeing 737, including maximum thrust, aircraft weight, and drag coefficients. The main idea is that relationships between the intermediate branching events can be obtained by integration of the event-sequence model and the state model. The overall model contains two main types of stochastic variables: Stochastic inputs and derived variables. Stochastic inputs are randomly chosen at the start of each replication. One example is the time of the aircraft system failure during the take-off roll. Another is the time for the flight crew to make a decision after the system failure. Derived variables are calculated via simulation of the aircraft state model. For example, one derived branching variable is whether or not the aircraft speed at the time of a rejected take-off is high. This can be determined from (a) when the system failure occurs, (b) when the flight crew makes a decision, and (c) the speed of the aircraft at the time the decision is made. The simulation model is executed by randomly generating the stochastic inputs, simulating the aircraft dynamics in continuous time, and then choosing a random path through the tree. In some cases, the branching paths are randomly chosen based on the probabilities given in ISAM. In other cases, the branching events are determined by the previously generated results of the aircraft state model.

3 SAMPLE RESULTS

Simulation experiments are conducted with different aircraft types and runway lengths. Several differences emerge between the simulated results and the original ISAM model. For example, the probabilities for over-run and veer-off are greater in the simulation models than in ISAM. This is because, historically, there have been no cases of over-run observed during an engine failure on take-off. The simulation model, on the other hand, presents this as a non-zero probability due to the random nature of the decision time and aircraft speed. A sensitivity analysis shows how the runway length changes the end-state probabilities for different types of aircraft. As might be expected, as the runway length increases, the probabilities of stopping on the runway and veering off increase, while the probability of over-run decreases. Larger aircraft and shorter runways result in a bigger discrepancy between the simulation output and the original ISAM model. Overall, the results provide more fidelity on the quantification of the intermediate probabilities. Results indicate that a random distribution in which system failures occur early during the take-off roll, rather than uniformly throughout, is more consistent with the quantified values in ISAM.

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