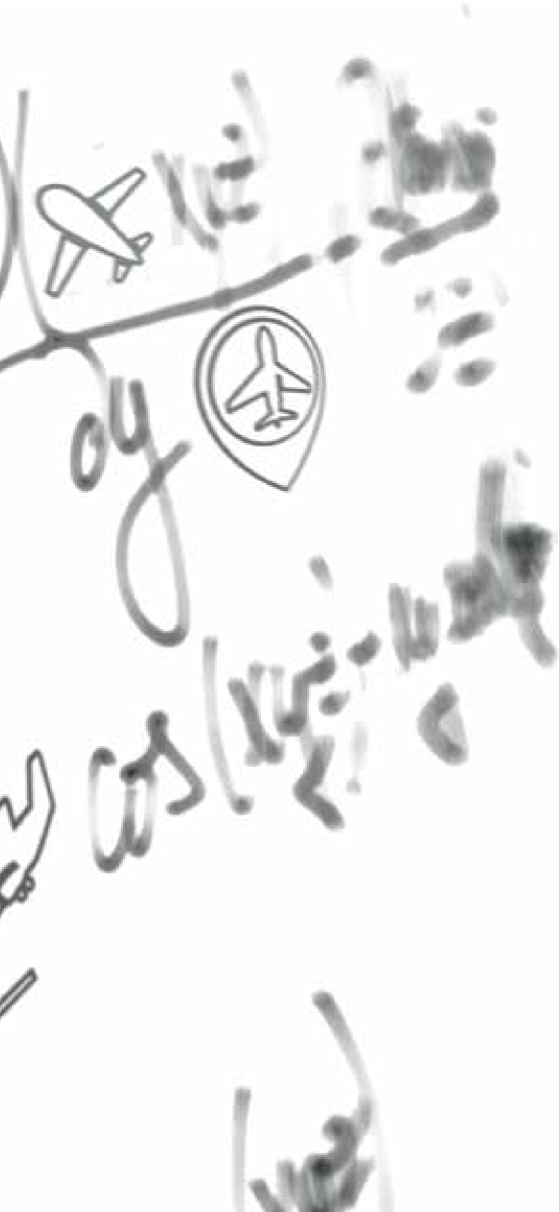
RUNWAY COLLISION RISK: WHAT DOES SAFETY SCIENCE TELL US?

by Dr Sybert Stroeve

The risk of a collision due to a runway incursion depends on many aspects, such as the situation awareness and performance of involved pilots, vehicle drivers and air traffic controllers, the size, weight and performance of involved aircraft, the layout and hold-short positions of intersecting taxiways, the availability and use of advanced surface movement guidance and control systems (A-SMGCS), and the prevailing weather conditions. This issue of HindSight focuses on the ways that these kinds of aspects can contribute to the collision risk, and what kinds of measures can most effectively reduce this risk.

When evaluating the collision risk in a particular context, it is a key insight from safety science that the risk contributions of these aspects are highly interdependent and non-linear. This implies that collision risk cannot be calculated simply using some constant probability factors for barriers against a collision, but that the risk calculation needs to account for the context-dependent interaction between the various aspects. This is of course no surprise for operational experts, who are well aware of the complexity and variability of day-to-day operations and who are the first to say "well, it depends...". The key question, however, is how the collision risk of such complex operations can be calculated in a valid way. This article provides some recent insights which safety science has contributed towards this end and it discusses how they can be effectively used to improve safety management of aerodrome operations.



Rather than trying to assess probability factors of safety barriers, agent-based Dynamic Risk Modelling (DRM) explicitly represents the processes, variability, dynamics and interactions of human operators and technical systems in runway incursion scenarios[1]. Next it uses dedicated computer simulation techniques (the rare event Monte Carlo simulation) to evaluate each particular scenario millions of times, accounting for the variations that exist in the interactions and dynamics of the involved humans and systems. Basically, in these Monte Carlo simulations the frequency of collisions between the aircraft (or vehicle) in each runway incursion scenario is used to estimate the probability of a collision occurring. For instance, the agent-based DRM of a runway incursion scenario between an aircraft taking off and an aircraft taxiing describes the aircraft dynamics during takeoff and taxiing, the situation awareness updating and aircraft manoeuvring actions of the pilots of both aircraft, the situation awareness updating and control actions by the runway controller, the functioning of surveillance and communication systems, the functioning of runway incursion alert systems, the aerodrome infrastructure and the visibility and wind conditions. These models represent the dynamics of these processes, such as the durations of task performance by the human operators, the acceleration of an aircraft during takeoff or the braking action during taxiing or rejected takeoff. The key point is that they also represent variations in these processes, such as the timing of a runway incursion with respect to a conflicting take off, variations in task duration, errors in task performance and system failure modes.

Typical probabilities of a collision in such runway incursion scenarios are in the range of 1 collision per 100 to 1,000,000 take offs, dependent on the particular context. If we view these collision risk rates from a Safety-II perspective, they show that all but 1 event in up to 1,000,000 runway incursions, a collision is avoided due to the overall performance of the interacting human operators and technical systems in the runway incursion scenario. In agent-based DRM, such reasoning is not just playing with probabilities of events (collision) and opposite events (no collision), but ensuring that the performance variations leading to successful avoidance of a collision are truly reflected in simulation of the socio-technical system. So agent-based DRM is fully compatible with a Safety-II perspective.

Agent-based DRM has provided interesting results on the effectiveness of runway incursion alerting systems as part of A-SMGCS[2]. These results show that in a runway incursion scenario with good visibility and A-SMGCS level 1 (without runway incursion alerts), where pilots are lost and start crossing an active runway without appreciating it, the probability of collision with an aircraft taking-off is about 1 per 5,000 take offs. In the same scenario with A-SMGCS level 2, meaning that

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1- Stroeve S H, Blom H A P, Bakker G J. Systemic accident risk assessment in air traffic by Monte Carlo simulation. Safety Science. 2009;47:238-49.

2- Stroeve S H, Bakker G J, Blom H A P. Safety risk analysis of runway incursion alert systems in the tower and cockpit by multi-agent systemic accident modelling.
7th USA/Europe Air Traffic Management R&D Seminar, Barcelona, Spain, 2007.

the runway controller is supported by a runway incursion alert system, the collision risk is almost the same as in the A-SMGCS level 1 case. We can deduce that runway incursion alerting systems are not effective in good visibility because the pilots can very often recognise and resolve the conflict before they receive a warning from ATC. In the same scenario with A-SMGCS level 4, where the pilots in both aircraft as well as the controller are supported by their own runway incursion alerting systems, the collision risk is reduced significantly by a factor 2.8. This risk reduction is facilitated by the communication of a direct warning to pilots which is independent of both communication from the controller and any errors in controller clearances. In reduced visibility (with a runway visual range between 400 and 1500 m), very different collision risk results are achieved for this runway incursion scenario at the various A-SMGCS levels. With level 1, the probability of a collision is about 1 per 200 takeoffs, which is 25 times more than in good visibility. A huge increase, since the pilots are far less capable of timely visual recognition of the conflict. In A-SMGCS level 2, the risk is reduced significantly by a factor 3.8 and the ATC alerting is more effective because the visual recognition of the conflict by the pilots is less effective.

In A-SMGCS level 4, the risk is reduced by a factor 31, since the direct warning of the pilots is most effective and to a large extent compensates the lack of timely visual recognition by the pilots.

Apart from the key implications for the value of runway incursion alerting systems, the above results clearly show the non-linear and hard to predict interdependencies between the contributions of the different human operators and technical systems for reduction of the collision risk. Yet, many risk assessment studies use event sequence diagrams (ESDs) or barrier models, which look at the success or failure of the available barriers. My detailed comparison of two risk assessment studies for a same runway incursion scenario, where one study used ESDs and the other study used agent-based DRM, concluded that the collision risk was assessed to be considerably lower in the ESD-based study[3]. This was attributed to the absence in the ESD-based risk assessment of sufficient consideration of the interdependencies between the risk reduction contributions of the pilots, controller and runway incursion alerting system.

Another of my studies[4] has concluded that the results of agent-based DRM can be effectively used to strengthen safety management in aerodrome operations. This study noted that current severity categories (A,B,C,D,E) for runway incursions are based upon the outcomes of these events, in particular on the closest distance attained. 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. Lessons from incursions with less severe (C, D) outcomes may be undervalued and there may be an overreaction to severe (A, B) outcomes. It is proposed that the analysis of runway incursion events should not use an outcome-based severity category, but one which is strictly based on the collision risk of scenarios associated with runway incursions. It is shown that these collision risks for large sets of runway incursion scenarios can be effectively attained by agent-based DRM.

3- Stroeve S H, Blom H A P, Bakker G J. Contrasting safety assessments of a runway incursion scenario: Event sequence analysis versus multi-agent dynamic risk modelling. Reliability Engineering & System Safety. 2013;109:133-49
4- Stroeve S H, Som P, van Doorn B A, Bakker G J. Strengthening air traffic safety management by moving from outcome-based towards risk-based evaluation of runway incursions. Reliability Engineering & System Safety. 2016;147:93-108.