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Estimation of air traffic longitudinal conflict probability based on the reaction time of controllers

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A R T I C L E I N F O

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A B S T R A C T

To estimate air traffic longitudinal conflict probability influenced by human factors, an analytic model considering the reaction time of controllers is proposed. In the model, the decelerating process of two close flights is described, and the reaction time of controllers is considered a stochastic variable. Then one hundred data of the controller reaction time are collected and analysed. Maximum likelihood estimate is used for parameter estimation. The Anderson–Darling Goodness of Fit test is used for significance test. The results show that the reaction time of controllers fits lognormal distribution at levels of significance 0.05, 0.025, 0.01 and 0.005 respectively. Case study is then performed to certify the rationality of the model, and the impact of the controller reaction time on air traffic longitudinal conflict probability is shown.

1. Introduction

For the application of satellite-based CNS (Communication Navigation Surveillance) and the improvement of aircraft performance, air traffic management is more highly human-dependent for its safety. Human behaviour plays a key role in air traffic management safety. Previous work on air traffic risk assessment, including original Reich model (Reich, 1966) and some typical examples such as stochastic model (Bakker and Blom, 1993) and EVENT model (Brooker, 2008), mainly focused on conflict or collision risks in longitudinal orientation, lateral orientation and vertical orientation caused by system errors, navigation errors and weather factors. There are also some achievements considering human factors in air traffic risk assessment. DNV (1997) estimated the safe spacing of P-RNAV parallel routes taking ATC intervention into account. Brooker (2008) studied spacing safety taking account of human factors and non-human factors through accident analysis, and demonstrated that collision risks caused by human factors accounted for the proportion of about 85%. However, literatures on quantified human behaviour in air traffic risk assessment are still rare.

As one of the main aspects in human behaviour, human error is a major contributor to air traffic management incidents, with some reviewers suggesting that human error contribution is in the order of 90% or more (Isaac et al., 2002). Since the probability of the occurrence of the errors is small, the probability distribution is difficult to formulate in a model. As Brooker (2008) say, it is inherently difficult to produce estimation of event frequency for infrequent occurrences. Although it is difficult to model the errors or the reliability of controllers, Human Reliability Assessment (HRA) in air traffic management has been carried out (Isaac et al., 2002). Kirwan et al. (2008) collected Human Error Probabilities (HEPs) via analysing the results of a real-time simulation involving controllers and pilots with a focus on communication errors, and discussed options and potential ways forward for the development of a full HRA capacity in air traffic management. Nevertheless, the real-time air traffic risk is difficult to assess according to the errors of controllers. The detailed tasks to be carried out by controllers during detection of air traffic conflict and separation loss has been split up into tasks performed by the perceptual, cognitive and motor processors (Mosquera-Benitez et al., 2009). Mosquera-Benitez et al. (2009) estimated the collision probability based on controller reaction time for potential conflicts in the scenario that a pair of aircraft encounter in cross routes. Wicks et al. (2005) applied Operator Choice Model (OCM) to the research on the controller reaction time for potential conflicts in cross routes, and demonstrated that the distribution of controller reaction time followed the geometric distribution.

In fact, the controller reaction time in the two literatures above shows the controller performance in conflict detection in cross routes. In this research, the controller reaction time concerned is a kind of stimulus–response time, which has been an important measure in the investigation of cognitive processes. We study the probability distribution of the reaction time of controllers monitoring the operations of air traffic, and propose a new model to

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estimate longitudinal conflict probability. It is expected that the method would be useful as a reference for future theoretical research. The remainder of the paper is organized as follows. In Section 2, we formulate the model. In Section 3, we analyse the probability distribution of the reaction time of controllers. In Section 4, a case is studied, and we have a discussion. Finally, we conclude in Section 5.

2. Mathematical model

For the preferences of pilots and airlines or other reasons, aircraft may change their speed. Especially in route, there is less change in the altitude of a flight. When the leading aircraft decelerates, controllers need identify it and issue the instructions to the following aircraft in the same route and direction to decelerate. After certain delay which includes the time of identifying, thinking, determination, and communication, the following aircraft begins to decelerate. We define the time of identifying, thinking and determination as the reaction time of controllers.

The assumptions used for the model are listed below:

1. The change of the speed for each aircraft is allowed by aircraft performance and ensures that the altitude of each aircraft will not be changed.
2. Pilots execute the instructions of controllers immediately.
3. The decelerating process terminates when the two aircraft reach the same final speed, and the final speed is known.
4. Generally speaking, the time spent on decelerating in fixed altitude is short enough to make us believe that the deceleration of each aircraft is constant in the decelerating process.

Fig. 1 shows the decelerating process. At the time when the leading aircraft at the initial ground speed of v_l began to decelerate with the deceleration a_l, the separation between the leading aircraft and the following aircraft was s_0. Then the following aircraft began to decelerate with the deceleration a_f after the controller reaction time T and the communication time C, during which the following aircraft had advanced for a distance of s_1 at the initial ground speed of v_f. After having advanced for s_2, the two aircraft reaches the same ground speed v_t when the following aircraft has advanced for s_3. Now the decelerating process terminates, and the separation between them is s. The time spent by the leading aircraft on decelerating is t_l, and the time spent by the following aircraft on decelerating is t_f.

Then we can formulate relative equations as follows:

$$s_1 = v_f(T + C) \tag{1}$$

$$t_l = (v_l - v_t)/a_l \tag{2}$$

$$t_f = (v_f - v_t)/a_f \tag{3}$$

$$s_2 = \begin{cases} v_f t_f - \frac{1}{2} a_f t_f^2, & t_f + T + C \geqslant t_l \\ v_f t_f - \frac{1}{2} a_f t_f^2 + \\ v_t(t_l - t_f - T - C), & t_f + T + C < t_l \end{cases} \tag{4}$$

$$s_3 = \begin{cases} v_l t_l - \frac{1}{2} a_l t_l^2, & t_l - T - C > t_f \\ v_l t_l - \frac{1}{2} a_l t_l^2 + \\ v_t(t_f + T + C - t_l), & t_l - T - C \leqslant t_f \end{cases} \tag{5}$$

$$s = s_0 + s_3 - s_1 - s_2 \tag{6}$$

Define the longitudinal separation minima as *sep*. The longitudinal conflict probability p_c can be written as follows:

$$\begin{aligned} p_c &= P\{s < sep\} \\ &= P\left\{T > \left[s_0 + \left(v_l t_l - \frac{1}{2} a_l t_l^2\right) + v_t(t_f - t_l) - \left(v_f t_f - \frac{1}{2} a_f t_f^2\right) - sep\right] / (v_f - v_t) - C\right\} \\ &= 1 \\ &\quad - P\left\{T \leqslant \left[s_0 + \left(v_l t_l - \frac{1}{2} a_l t_l^2\right) + v_t(t_f - t_l) - \left(v_f t_f - \frac{1}{2} a_f t_f^2\right) - sep\right] / (v_f - v_t) - C\right\} \end{aligned} \tag{7}$$

3. The probability distribution of controller reaction time

If sufficiently good models of system processes and human observation, decision and response are available, then fast-time computer simulation is also an option, and is normally much cheaper than Human-In-The-Loop (HITL). However the literature supports relatively few areas amenable to quantitative dynamic models of human performance. Among these are visual and auditory signal detection, continuous control, statistical decision-making, and information processing. One particular issue that arises in Next Generation Air Transportation Systems (NGATS) is the fact that human decisions take time, and when humans are called upon to evaluate complex situations that are unexpected and off-normal the response time may be quite long. It is well known that the distribution of human response time fits a lognormal model quite well (Sheridan, 2006). For example, Taoka (1989) applied an analytical model using the lognormal probability density function to publish driver response time measurements, and close agreement was obtained when this function was fitted to the measured responses of drivers to the onset of the amber signal as they approached signalized intersections. Van Der Linder (2006) found that the lognormal model showed an excellent fit to the response time of a person on a set of test items.

It is known that lognormal distribution has been widely applied in many fields such as economics, biology, medicine, and materials. Suppose that there is a sample, of which every datum is larger than zero and could be very small positive value. When the number of the sample is large enough, that is, fifty or more, it could be assumed that the natural logarithm values of the sample fit or

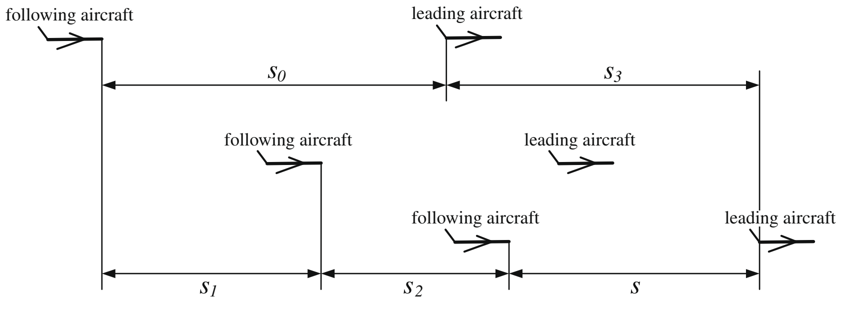

Fig. 1. The decelerating process of two close flights.