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Decision support for risk assessment of mid-air collisions via population-based measures

Neale L. Fulton [a,*], Mark Westcott [a], Stephen Emery [b]

[a] Mathematical and Information Sciences, Commonwealth Scientific and Industrial Research Organisation (CSIRO), GPO Box 664, Canberra, ACT 2601, Australia
[b] School of Civil and Environmental Engineering, University of the Witswatersrand, Johannesburg, South Africa

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ABSTRACT

Specifying proximity warning functions for aircraft in managed airspace has received considerable attention. However, similar functions for aircraft operating in unmanaged airspace have received comparatively little analysis despite the fact that these functions are stressed to a greater physical degree, and perhaps more frequently, than in managed airspace. The mid-air collision hazard and its associated risk are re-examined from both an historical and a systematic engineering modelling viewpoint. Historic measures of this transport risk in managed airspace have been based on fatalities normalized by flight hours or flight movements. However some of these data may not be available in unmanaged airspace. Another approach to measurement directs attention to populations at risk where several measures are now well known: collective risk, individual risk and the frequency of occurrence of the hazards that give rise to such risk. A decision support methodology is presented that relates both transport and population-based approaches. A cohesive and consistent set of aspired goals for various stakeholder groups can be set taking into account the different stakeholder needs. A case study is drawn from historic mid-air collision data to illustrate the process. A consistent basis for national-level policy decisions harmonised with proactive engineering design requirements is achieved. The strengths, limitations and implications of this approach for engineering design purposes are discussed.

1. Introduction

The risk of mid-air collisions has been studied over many decades, principally through a measure called target level of safety (TLS) – the number of flights (hours) per fatal accident.

The method of measurement of TLS presupposes that the number of flights over the period of measurement and the number of fatalities due to mid-air collisions are recorded. Both of these presuppositions are appropriate in the case of managed air space. However, in the case of unmanaged airspace, the situation is different because the number of flights undertaken over a given period of measurement may not necessarily be recorded. Thus, whilst TLS may be taken as an appropriate risk assessment measure in managed air space, the same cannot be said about its suitability in unmanaged airspace and, therefore, there is need to investigate alternative measures.

One alternative is to use a population-based measure and it is known that various decision making policies follow such an approach. These population-based measures are categorised as: collective risk, individual risk, and survival functions (that are closely related to societal risk paradigms). In observing actual practice of this approach, we have recognised two major problems. First, measures have been treated as essentially disparate by policy makers when in fact they are related

* Corresponding author.
E-mail address: neale.fulton@csiro.au (N.L. Fulton).

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Nomenclature

i	index for people flying per annum $i = 1(1)I$
j	index for number of movements (flights) $j = 1(1)T$
k	index for different aircraft types $k = 1(1)K$
m	index for different population categories $m = 1(1)M$
α_m	linear multiplier for the mth population
λ_m	normalised population multiplier for the mth population
κ	[mean number of fatalities per accident]
ΔF_A	sign of incremental change in collective risk for a specified time
ΔIR_A	sign of incremental change in individual risk for a specified time
ΔI	sign of incremental change in population at risk for a specified time
ENFY, $E(F_A)$	[expected number of fatalities per year (annum) in a specified population]
$E(IR_A)$	expected [proportion of deaths in a specified population per annum]
$E(L)$	expected [number of individuals per movement]
$E(X)$	expected [number of movements (flights) made by an individual] within a population
f, $f(N)$	frequency of accidents with precisely N fatalities
F, $F(N)$	frequency of accidents with N or more fatalities
F_A	number of fatalities per annum
$\bar{F}_A$	average [number of fatalities per annum]
$F_A(m)$	number of fatalities per annum in mth population
I	[population at risk]
I_A	[total number of individuals who flew per annum]
$I_A\ (m)$	[total number of individuals who flew per annum in mth population]
K	[total number of types of flight]
IR	individual risk [proportion of a specified population at risk that die per unit time]
IR_A	individual risk [proportion of a specified population at risk that die per annum]
$IR_{aggregate}$	Individual risk aggregated over M population groups
IR_{Aest}	estimated [probability of death per person per annum]
IR_i	[individual risk per annum for individual, i]
$\bar{L}$	mean [number of individuals per movement] as measured
L_j	[number of individuals (load)] on the jth flight
M	[total number of population categories]
N	number of fatalities in an accident
P_i	[chance of an individual, i, avoiding death per annum]
p	[probability of collision]
p_k	[probability of collision when a flight is flown in aircraft type-k]
P_i	[probability that the ith individual will die in a mid-air collision]
S	the total number of occupied seats per annum
$S_{i,j}$	a binary variable: $S_{i,j} = 1$ if the ith person is a passenger on the jth flight, 0, otherwise
X_i	the total number of seats occupied by the ith individual per annum
$X_{i,k}$	the total number of flights of type k that individual, i, makes per annum
$\bar{X}$	mean [number of movements (flights) made by an individual] as measured
X_K	mean [number of flights of type k per person per annum]
T	[total number of movements per annum] stated as a design bound
T	[period of time in Poisson model]
T_M	[total number of movements between mid-air collisions] stated as a design bound

mathematically. Second, no explicit account is taken of the fact that different stakeholder groups act independently accepting different levels of risk yet their activities in airspace may be associated by very close proximity that raises the instantaneous risk of each participant's activity.

In this paper, we put forward three propositions in addressing these problems. The propositions are:

1. Population models can be used to augment TLS for situations where flight hours and/or movements are not systematically or completely recorded.
2. The relationship between collective risk (CR), the number of fatalities per annum, and individual risk (IR), the fraction of a population to die due to a specified accidental cause per annum, may be used to form an effective harmonious decision aiding tool for assessing risk associated with mid-air collisions and thus provide a guide to both policy making and engineering design.
3. The relationship between collective risk and individual risk provides further insight for guiding the engineering design and implementation of airspace rules and procedures, inclusive of communication requirements.