

Air Traffic Control Safety Indicators: What is Achievable?

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Abstract

European Air Traffic Control is extremely safe. The drawback to this safety record is that it is very difficult to estimate what the ‘underlying’ accident rate for mid-air collisions is now, or to detect any changes over time. The aim is to see if it possible to construct simple ATC safety indicators that correlate with this underlying accident rate. A perfect indicator would be simple to comprehend and capable of being calculated by a checklist process. An important concept is that of ‘system control’: the ability to determine the outcome against reasonably foreseen changes and variations of system parameters. A promising indicator is ‘Incident Not Resolved by ATC’, INRA, incidents in which the ground ATC defences have been ‘used up’. The key question is: if someone says he or she knows how to make a good estimate of the underlying accident rate, then how could this claim be tested? If it correlates very well with INRA, then what would be the argument for saying that it is a better indicator?

1. Introduction

Should Europe’s airspace be safe? Should politicians keep their promises about improving European aviation safety? Some questions obviously need the answer ‘Yes’. But is it actually feasible for the air transport industry to demonstrate that European air traffic control (ATC) systems are safe? The European Union (EU) legislation setting up the Single European Sky states:

“Smooth operation of the air transport system requires a consistent, high level of safety in air navigation services allowing optimum use of Europe's airspace and a consistent, high level of safety in air travel...”

The aim here is to see if it possible to construct good ATC safety indicators.

The real problem – a very good problem to have – is that modern ATC systems in developed countries have very few accidents, of which a small fraction are mid-air collisions. Thus, attention has to focus on ‘incidents’ – safety occurrences somehow ‘near’ to accidents. Unfortunately, there are very many different kinds of incidents; and is it not always obvious which incidents are ‘near’ to accidents, for example see Spouge and Perrin (2005).

It is incredibly difficult to be confident that one understands the mechanisms that relate incidents to accidents. So what confidence can there be that an indicator is giving the ‘right’ answers? Confident predictions require strong evidence about the causation and measured frequency characteristics of that kind of event. This argues for as few assumptions to be made as possible, and for calculations that do not require arbitrary or judgemental assumptions.

The concern is not with the present, or rather recent history, but with what information such incidents convey about the risks inherent in the system, so as to enable predictions to be made about the future. How can incident information – supplemented by what other knowledge? – somehow be processed in a way that provides estimates of future system risk. Put bluntly: “What are the odds of a mid-air collision next year?”

For present purposes, the analysis is restricted to en route ATC, i.e. not including accidents operating at airports, and the focus is on mid-air collisions, but recognising that (e.g.) accidents on runways and taxiways can be equally catastrophic. This excludes, for example, accidents occurring if controllers were to provide incorrect information about severe weather conditions. Airborne accidents arising from e.g. terrorism or hijacking, i.e. where there is some intention to cause an accident, are also not covered.

2. ATC Safety Indicators: Purpose

Safety here will be taken to relate to the rate of mid-air collisions occurring over a given period. Usually, this period covers tens of millions of aircraft flight hours while under the supervision of controllers, during a particular year for the country or region in question. ‘Safe’ is usually a statement that this rate is less than some declared safety target (e.g. see Brooker, 2004).

Safety indicators are of two types: if safety targets are being met this year – absolute indicator; if safety is improving or not, year by year – relative indicator. The first is much more desirable – but also much more difficult.

A safety indicator must tell us about system performance. It should enable us to predict the future frequency of critical system failures. A perfect indicator should be:

- simple to comprehend;
- capable of being calculated by a checklist process;
- ‘obvious’, in the sense that people would agree that it was a sensible thing to measure – what the psychologists call ‘face validity’; and
- not require complex modelling calculations to be carried out in order to ‘weight’ the data appropriately

The quality of the prediction does not have to attain perfection, but it needs to be reliable in a statistical sense. A perfect indicator would consistently match the pattern of actual changes. A useful indicator might match the underlying patterns changes 80% of the time and fail to match 20% of the time.

Suppose that a collision could only be caused by one particular set of circumstances. Suppose also that near-collisions were a well-defined category that described events that could only happen in a finite limited number ($N - 1$) of occasions per collision. This would correspond to the picture in Figure 1. A collision is the dark hexagon, a near-collision is a lighter shaded hexagon, and all the situations with no risk are empty hexagons. In reality, there are an enormous number of empty hexagons, extending in all directions, because collisions and near collisions are rare.

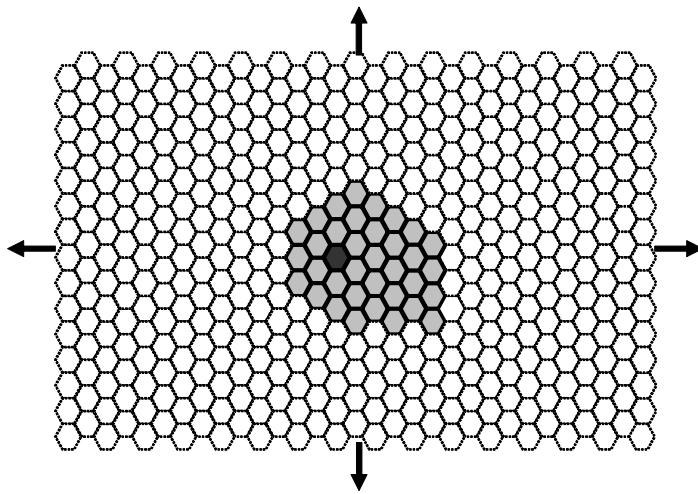


Figure 1. Idealised Accident/Incident Model – see text for explanation

Suppose that the probability of an event is represented simply by the number of hexagons, and that all hexagons, empty, shaded or dark, are equally likely to happen. This occurs in reality if impaired performance were caused by a single (detectable) failure in a piece of doubly redundant equipment, and total failure by an independently occurring second failure of this equipment.

Leaving statistical variations aside for the moment, and with ‘near collisions’ including any actual collisions, the picture says:

$$\text{Rate of collisions} = \frac{\text{Rate of collisions}}{\text{Rate of near collisions}} \times \text{Rate of near collisions}$$

Or:

$$\text{Rate of collisions} = \frac{1}{N} \times \text{Rate of near collisions}$$

So if collisions are not observed during some time period, their rate can be estimated by scaling down the rate of observed near collisions by the factor N . The three key elements for this to work satisfactorily are: that near collisions can be identified; that they are of equal value in predicting the collision rate, i.e. there is a single factor for doing this scaling; and that the size of this factor is in principle knowable. Unfortunately, this nice mental model is a wholly inadequate description of ATC incidents and accidents.

3. ATC Incident and Collision Equation

Figure 2 shows a basic ATC Incident and Collision Model equation to calculate the collision risk C_E in State E. As stressed in the figure, C_E is actually an abstraction, because collisions are so rare. The equation is necessarily true, simply because the definitions interlock, but if assessed over a finite time period, N_{ES} and F_{ES} in particular will be subject to considerable statistical variations.

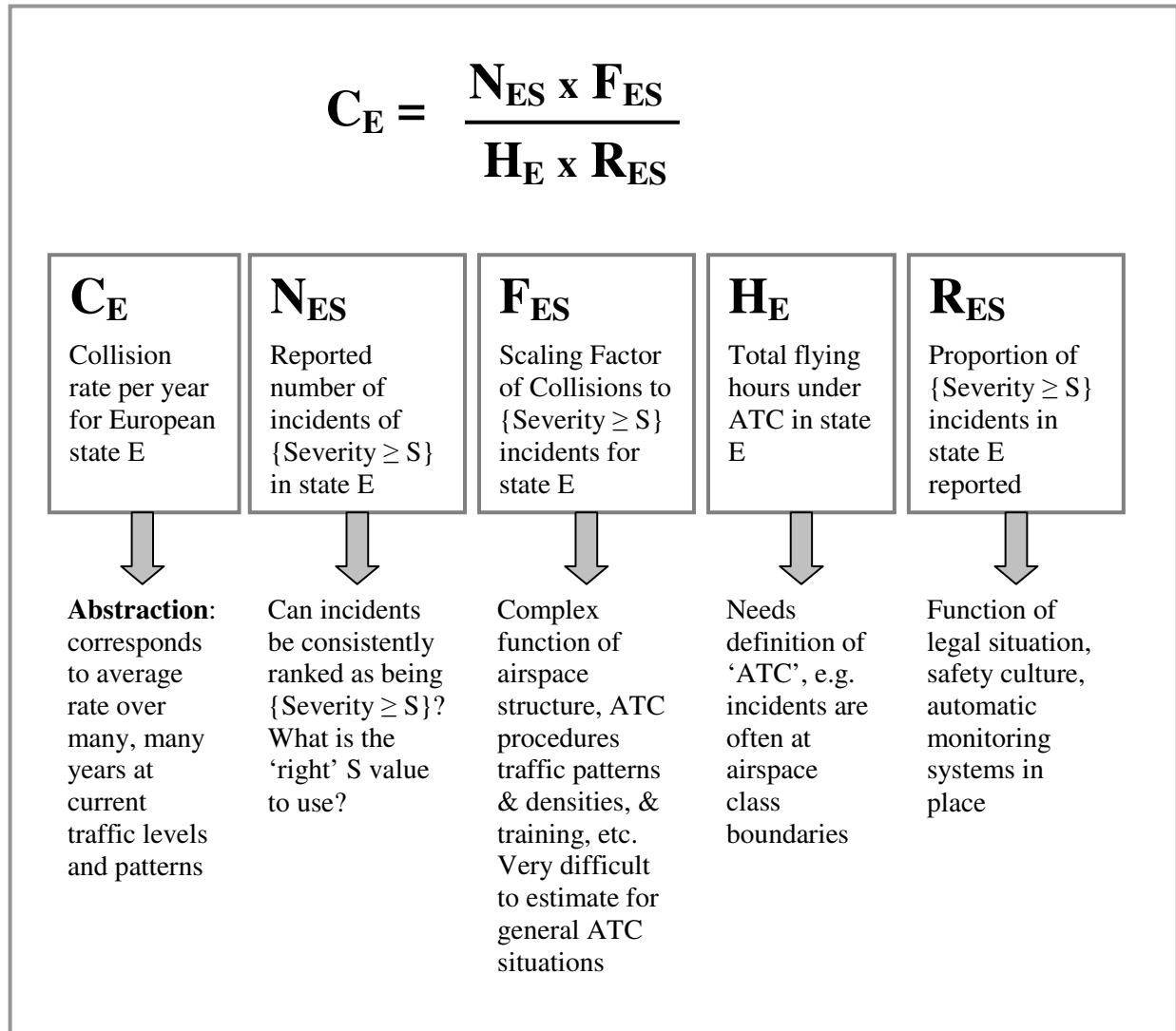


Figure 2. ATC Incident and Collision Model, plus a selection of issues

Every term in the C_E equation has definitional and computational problems, as shown by the issues listed at the bottom of the Figure. A different formulation of this equation could not eliminate such problems, because they are intrinsic to the estimation process. If the parameters in the equation are known, then it is possible to compare the estimated collision risk, and hence en route safety, across States (see discussion in Brooker (2007b)).

Safety targets place a maximum value on C_E across all States. But C_E is not directly measurable – ATC is extremely safe. F_{ES} , the scaling Factor of Collisions to $\{ \text{Severity} \geq S \}$ incidents for State E, is very difficult to estimate for general ATC situations, as distinct from special ATC subsystems. The temptation is to assume that it has about the same value across States, but this would be no more than an assumption about an unknown function.

There has to be some specific value or consistent assessment corresponding to the severity S. Without a bottom limit, then, in theory, controllers and pilots could report all incidents, even those with minuscule safety impact – which in reality would probably tend to lead to massive under-reporting. There are good arguments for taking S values of high severity (Brooker, 2007a). The basic idea is that mid-air collisions will be most highly correlated with the occurrence of events which are closest in nature to collisions, and much less correlated with initiating precursor events. A non-safety analogy is scoring goals in football matches: goals scored will be better predicted by the number of shots at goal rather than the amount of possession of the ball.

Eurocontrol has recognised that there are serious problems with severity assessment, even when examined by genuinely expert groups. But what is an incident – or a severe incident? Traditionally, the severity of an observed event is defined by its ‘degree of risk’ – but this replaces one abstraction with another. Often, assessments are made by an expert group – so how is consistency to be assured between States and over time? The Netherlands safety experts, de Jong and van Es, recently commented:

“...a uniformly applied severity classification for air traffic occurrences in Europe appears unfeasible. There are too many different views, ideas and desires to make this possible...it is questionable whether these [proposed classifications] are going to work...”

Incidents are not always reliably reported, let alone sufficiently investigated, so severity is therefore often not classified, and there is not even consistency when just one severity classification scheme is used.

A critical problem is with the parameter R_{ES} . In 2006, the Eurocontrol Performance Review Commission (PRC) expressed concern that collection and communication of safety information Europe-wide is currently restricted by the publication and confidentiality policies. In the PRC’s view: “Achieved levels of safety and their trends remain opaque”.

4. ATC System Defences

ATC does not fail because of an evil opponent. All the controllers and pilots are on the same safety-enhancing team. Incidents and accidents occur because people are fallible :incidents and accidents are in essence ‘own goals’. Everyone makes mistakes, fails to remember some things, sometimes mis-estimates what is likely to happen, etc. Controllers and pilots are carefully selected and trained for their jobs, but still make these

kinds of errors – albeit at a very low frequency. ‘System control’ covers all the means by which the system is defended against potential negative and serious consequences of ‘own goals’. As system control is rarely lost in practice, the proportion of time that the ATC system is under threat from even these ‘root cause’ precursor events is very low (for a discussion, see Corcoran (2004)).

ATC has highly structured processes and safety defences. Figure 3 is a simplified version of the control processes ensuring safety, in reality there is a very complex set of probabilistic feedbacks and interactions. Explanations of separation minimum, STCA (Short Term Conflict Alert) and ACAS (Airborne Collision Avoidance System) can be found in Brooker (2005a) and its references; the symbols ① and ② are covered in a later section. The existence of STCA – plus help from colleagues – means that the controller is warned about potential separation breaches, even if he or she does not notice them. Note that a separation breach can occur because the pilot deviates from the safe plan; or when the safe plan was not in fact safe, in terms of the required minimum separation between aircraft. The existence of ACAS means that the pilot is warned about possible collisions, and told what ascent or descent flightpath should remove the risk.

Note that these defences allow for error corrections to be carried out before any separation is breached, i.e. the error would not be detected just from records of separation breaches alone. Remedial action in the ATC system is therefore diverse and in depth. Complex combinations have been observed in UK airspace, from an examination of Airproxes (Brooker, 2005; UKAB, 2006).

5. Closest Point of Approach Modelling

To reiterate, the ATC Safety Indicator problem is that of estimating the frequency of (almost completely) non-observed catastrophic occurrences from the frequency of related observed occurrences. Good predictions necessarily rely on regularity and consistent patterns.

A key question to ask is: “If things are the same next year, will there be an accident?” But they will not be the same next year. If one could be sure that things would be exactly the same, then there would obviously be no accidents next year. But empirically there are changes in the number and types of incidents observed from year to year, even if the total traffic/ATC environment were to be exactly the same. There will be a variation in the number and characteristics of initiating factors, and in the relative orientation and timings of the aircraft flightpaths concerned. If there were to be a near-repeat of an incident’s characteristics, there would still be variations in how the controller and pilot involved, aided by colleagues and the alerting systems, would handle such an occurrence. This means that the parameters for C_E in Figure 2 should actually be interpreted as statistical variables from underlying probability distributions: thus, the number of incidents N_{ES} of severity S would vary even for the same total traffic and a constant ATC environment.

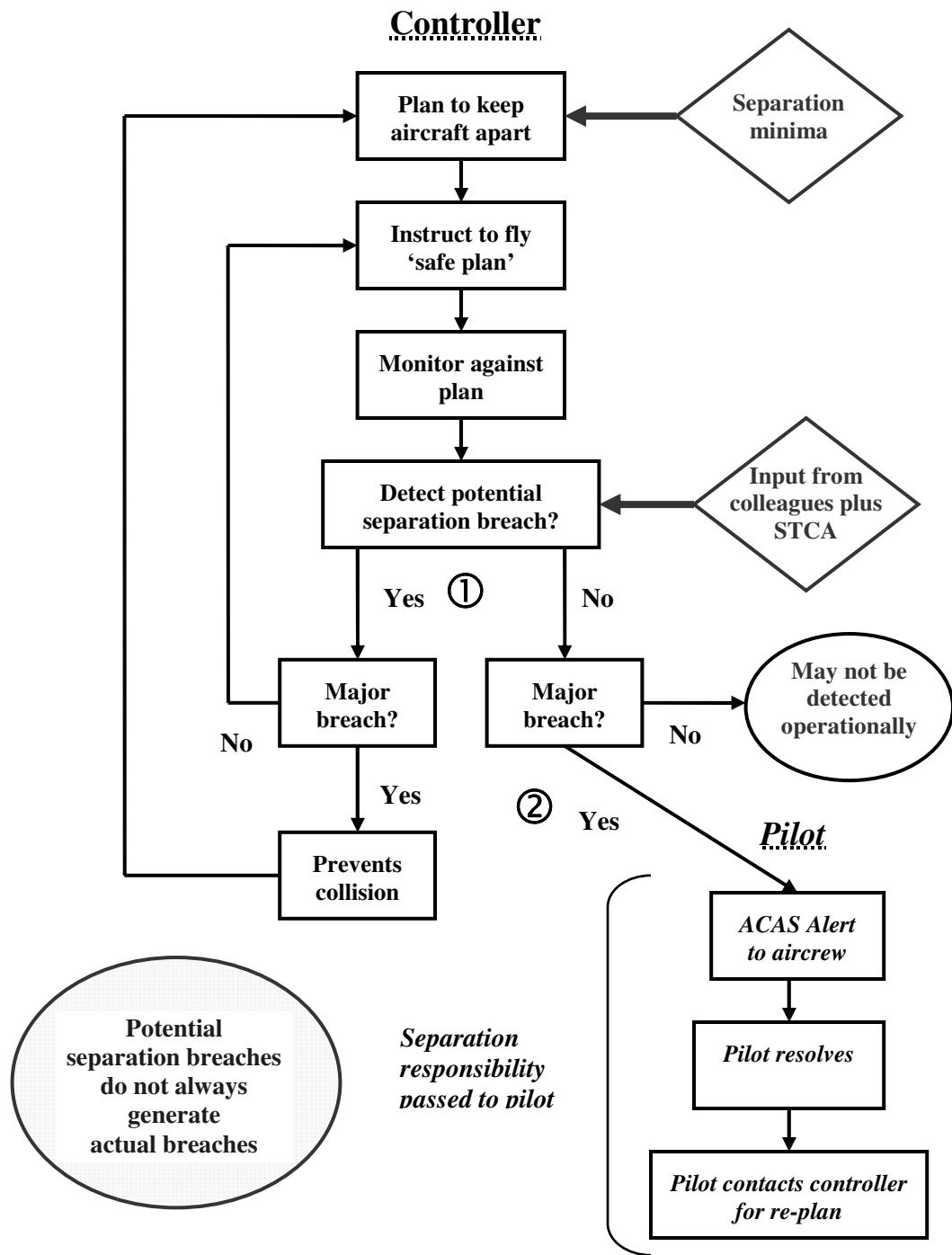


Figure 3. Simplified controller and pilot processes to prevent mid-air collisions

To represent variations in observed incidents, a simple characterisation of incidents is into Circumstances and Performance:

'Circumstances' describes the differences in the initiating event and flightpaths that lead to a breach of separation. Circumstances covers variations in the physical parameters, such as take-off time and entry to an airspace sector.

'Performance' is what the system defences of Figure 3 do about those Circumstances. Performance covers variation of humans and equipment in generating, detecting, and resolving the problem.

Thus, the incident data provides a particular set of Circumstances followed by a particular set of Performance actions dependent on those particular Circumstances. Incident data – notably the Closest Point of Approach (CPA) between the aircraft – generally correspond to some kind of intervention.

As regards predicting next year's incidents and the probability of an actual accident, the modelling difficulty is that both the Circumstances and the Performance are essentially samples from an unknown statistical distribution. This distribution corresponds to the coming year's traffic volume and general pattern repeated many, many times, with all the variations of real life, producing different incidents and accidents, both in terms of Circumstances and Performance. What are the general characteristics of the frequency distribution – and is knowing something about them actually helpful?

The first step is to simplify incident CPA descriptions by using a method previously introduced in studying Airproxes, STCA and ACAS (Brooker, 2005). Define H (Nm) and V (feet) to be the miss distances at the CPA. From Airprox data, H and V appear to be statistically independent variables, i.e. high values of one are not associated with either high or low values of the other. This offers the opportunity of combining the H and V values – a single indicator of close proximity is much easier to deal with analytically than a two-dimensional array. What should be the relative weightings in such a combination?

The simplest thing is to assume that the weighting should be based on the proportional deviation from the separation minimum, and to use terminal airspace criteria (because the great majority of Airproxes occur in TMAs). Thus, as the horizontal minimum is 3 Nm and the vertical minimum is 1000 feet, a 1 Nm horizontal CPA can be taken to be equivalent to 333 feet CPA. The simplest combination of the weighted H and V is just to add them together, i.e.:

$$CPI = (333 \times H) + V$$

Here CPI stands for Close Proximity Indicator. There are obviously variants on this: for example, the H value of en route incidents could be scaled down by the ratio 3 to 5, to reflect the difference in minima.

It cannot be emphasized enough that the CPA parameters and the CPI value are measured after intervention. The CPI does not provide information on how close the aircraft would have been had there been no intervention or a 'standard intervention'.

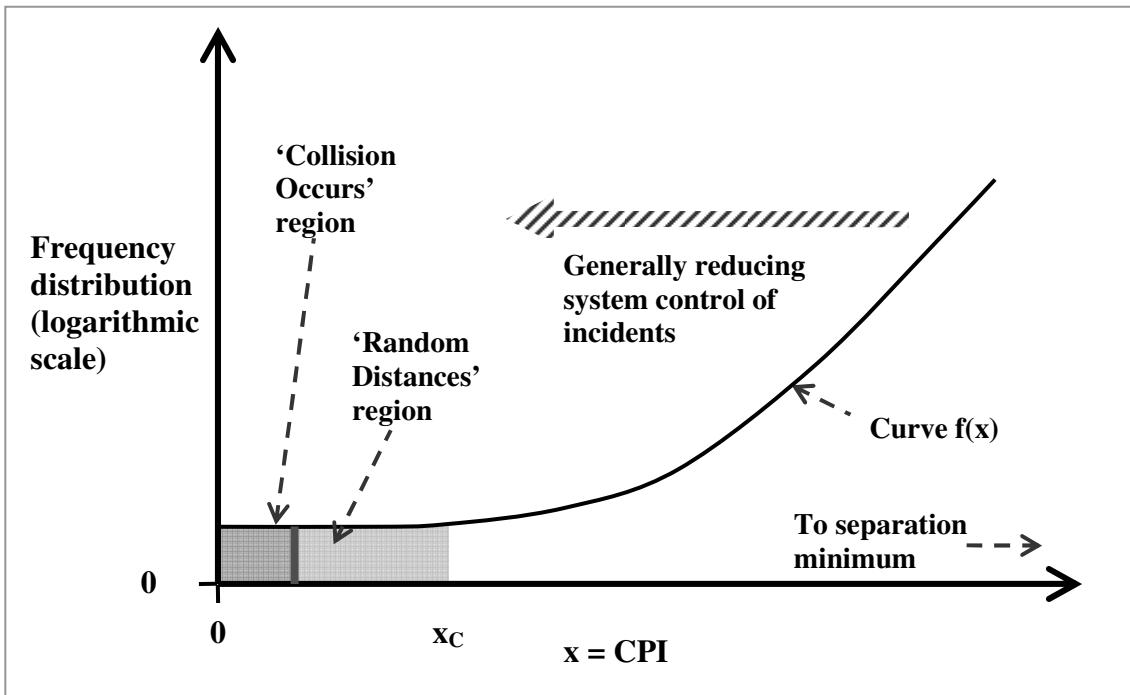


Figure 4. Schematic frequency distribution for CPIs

Figure 4 is a schematic picture – note the non-linear scale – of the unknown frequency distribution describing the proportion of incidents with a particular CPI value – the x-axis. The actual number of incidents in a particular ‘constant traffic’ year will be sampled from some other kind of distribution, probably more Gaussian in shape. The distribution in Figure 4 is a very long-term average, i.e. would be observed over a very long period of operation of the current year’s traffic, repeating the year almost endlessly. Why should the distribution have this kind of shape?

Why is the distribution drawn as monotonic increasing? The empirical reason is that data such as Airproxes do show this form: smaller CPI values are less likely than larger ones. In abstract terms, potentially small CPI values can be detected by the controller, STCA, the pilot, and ACAS; so there will be strong safety defences in place to prevent them occurring. Remember also that the CPI can be viewed in terms of the deviation from the separation minima.

Why is the region from origin to x_C flat and marked as ‘Random Distances’? This is because these small CPIs will represent incidents in which ‘system control’ has been largely lost. The relative distances between the aircraft when they pass will be a function of the chance orientations of their flightpaths, even if modified by ATC. For such an occurrence, is there any reason to believe that a CPI of 100 feet is more or less likely than one of 200 feet or 300 feet?

Formally, the phrase ‘system control’ in Figure 4 is intended to mean something like:

‘System control’ – the ability to determine the outcome against reasonably foreseen changes and variations of system parameters, such as the abilities of the participant(s), the environment (in the largest sense), and the safety mechanisms in place.

So where exactly does the flat region start to turn upwards? This is a very difficult question to answer, because it is essentially asking about the degree of control that a controller or pilot has about the flightpaths of aircraft.

What is the ‘Collision Occurs’ region? This represents the CPI values that are less than the aircraft dimensions. Thus, these CPI values are collisions not incidents. The key fact about the frequency distribution is that the flat shape near the origin, which includes collisions, cannot simply be extrapolated from the increasing section of the curve – note again the logarithmic scale. Simple extrapolations from the observed part of the CPI distribution are likely to be very cautious – e.g. see Brooker (2005). Knowledge of the distribution of CPIs for regions where there is a substantial degree of system control cannot then be extrapolated with great confidence to estimate the shape – more importantly the height – of the curve $f(x)$ in the ‘Random Distances’ region. To be useful in estimating $f(x)$ for x values near zero, i.e. to provide evidence about the flat section of the curve, it would be necessary to eliminate incidents from consideration that had any degree of system control. These kinds of arguments return to the discussion earlier, i.e. that the best estimates of the rate of critical events are likely to be made from indicators that are very near to those events and which differ from them largely through geometrical factors.

Does Figure 4 show the full structure of incidents? No, it does not: the full picture cannot be mapped onto a simple two-dimensional diagram. The degree of system control tends to be higher for the higher CPI values, but there is not a one-to-one relationship. Incidents with the same CPI value can represent widely differing degrees of system control: thus, a large CPI value might merely indicate that the aircraft were on widely separated flightpaths rather than being the consequence of a swift control action to keep them apart.

6. Incident Reporting

Incident reporting is a very large subject, and there are many possible ways of classifying incident reports. For present purposes, a division into three schemes is useful:

Individual reporting means an operational person detects something that is unsatisfactory in safety terms and reports this to a central monitoring body. The likelihood of someone reporting an incident very much reflects the ATC provider’s organisational safety culture.

Event-related reporting is triggered by automatic system warnings or alerts. The main examples are STCA and ACAS – other systems are in use for different phases of flight, e.g. Ground Proximity Warning Systems.

In *Post-processed reporting*, radar and related data are examined some time after actual operations, to determine if (e.g.) separation minima have been significantly breached (e.g. the UK's Separation Monitoring Function – SMF).

The combination of all the data from these three varieties of incident reporting system, enhanced by the pilot/controller recollections and other data (e.g. communication recordings), mean that a good picture can usually be obtained of the nature of any incident in controlled airspace. The exceptions are where there are equipment failures – this is very rare for UK Airproxes.

A reasonable ATC indicator must indicate something about ATC safety or the performance of the ATC system's safety defences. For a collision to occur, there must have been:

- separation breach – the aircraft was not flying to a safe plan or the plan was not in fact safe;
- failed or non-existent intervention(s) to remedy, even with assistance from colleagues and warning systems;
- the 'right' (post any intervention) flightpaths: traffic density, route/airspace construction are factors.

There are two obvious places for safety defence indicators in Figure 3, indicated by the symbols ① and ②. The first covers initiating events that produce a separation breach, and the second covers situations where the ground-based part of the system, i.e. ATC, has not resolved an incident. The first indicator, at about ① in Figure 3, counts 'Actual Separation Breaches' – ASB. The second indicator, at about ② in Figure 3 counts 'Incident Not Resolved by ATC' (INRA). Remembering an earlier comment, a key point in favour of INRA is that it represents a definite 'severity' benchmark, because it focuses on incidents in which the ground ATC defences have been 'used up'.

There are of course many other potential indicators, but these two represent decisive points in the safety defences, are very simple to understand, and can be measured reasonably consistently. This is because they correspond to measurable events or system states, rather than complex judgemental assessments of what might have taken place, i.e. judgements about severity. To find another simple indicator of specific severity in the flow chart between ① and ② is extremely difficult, given the variability and complexity of what can happen when ATC's defensive mechanisms restore full system control (e.g. see Spouge and Perrin (2005), SRC (2005a)).

ASB and INRA need definitions covering both typical and 'pathological' cases:
e.g.:

Actual Separation Breach This counts post-processed incidents that breached the appropriate separation minimum. It excludes incidents for which the breach was 'small', e.g. a 2.8 Nm horizontal closest approach when the minimum is 3 Nm. It might also exclude situations which ATC management declare to be 'acceptably safe', e.g. a special operating procedure that breaches a minimum slightly, to cope

with tight airspace constraints in the terminal area. But such exceptions must be documented in the ATC unit safety case or similar document.

Incident Not Resolved by ATC A count of Individual and/or Event-related reports in which the ground-based part of the system, i.e. ATC, has not resolved an incident. Was an ACAS Resolution Advisory (RA) then necessary to resolve the incident safely? The simplest incidents to count in this category are those in which an ACAS RA is deemed by ATC to be ‘justified’. But note – and this example shows the care needed – that if the incident were so very short-term that an RA was not generated, e.g. a very rapid descent to a small closest point of approach, then that obviously would have to be included under this heading.

Thus, the second indicator does require an assessment to be made by expert controllers, that the pilot action following the RA is justified. But it is an assessment which is restricted to the kinds of things that controllers actually experience, rather than an extrapolation beyond that. The current low reporting rate of this judgement is of serious concern, and so will in any case need to be tackled as a part of continuing efforts to improve European safety culture. To resolve the issues about safety culture in States, a specialist European body could be set up – based on successful State-based ‘peer review’ models for incident assessment.

ASBs provide an indication if the rate of ‘initiating events’ is changing. ASBs are in fact used by the Eurocontrol Safety Regulation Commission [SRC], although it is not obvious from its reports if some ‘acceptable’ varieties of separation infringement are filtered from the counting (SRC, 2005b)

The ratio of the counts INRA to ASB is a measure of the effectiveness of the ground ATC system in resolving initiating events. An improvement in this ratio would therefore demonstrate an improvement in ground-based ATC.

There are good grounds for believing that INRA would be a good indicator of the underlying collision rate, because the INRA would be scaled down by the proportion of ACAS RAs that did not successfully resolve the situation. In other words, that scaling-down would not be strongly dependent on the nature of the State’s ground ATC operation and airspace structures. Thus, the value of F_{ES} in Figure 2 would not be strongly dependent on which State E was being examined.

7. Indicator Data and Risk Estimates

From the argument in the previous Section, it appears that the simplest indicator of collision risk would need to use data from incidents in the ‘Random Distances’ region. Leaving aside for the moment how one might identify the extent of this region, how could an estimate of collision be made from such data?

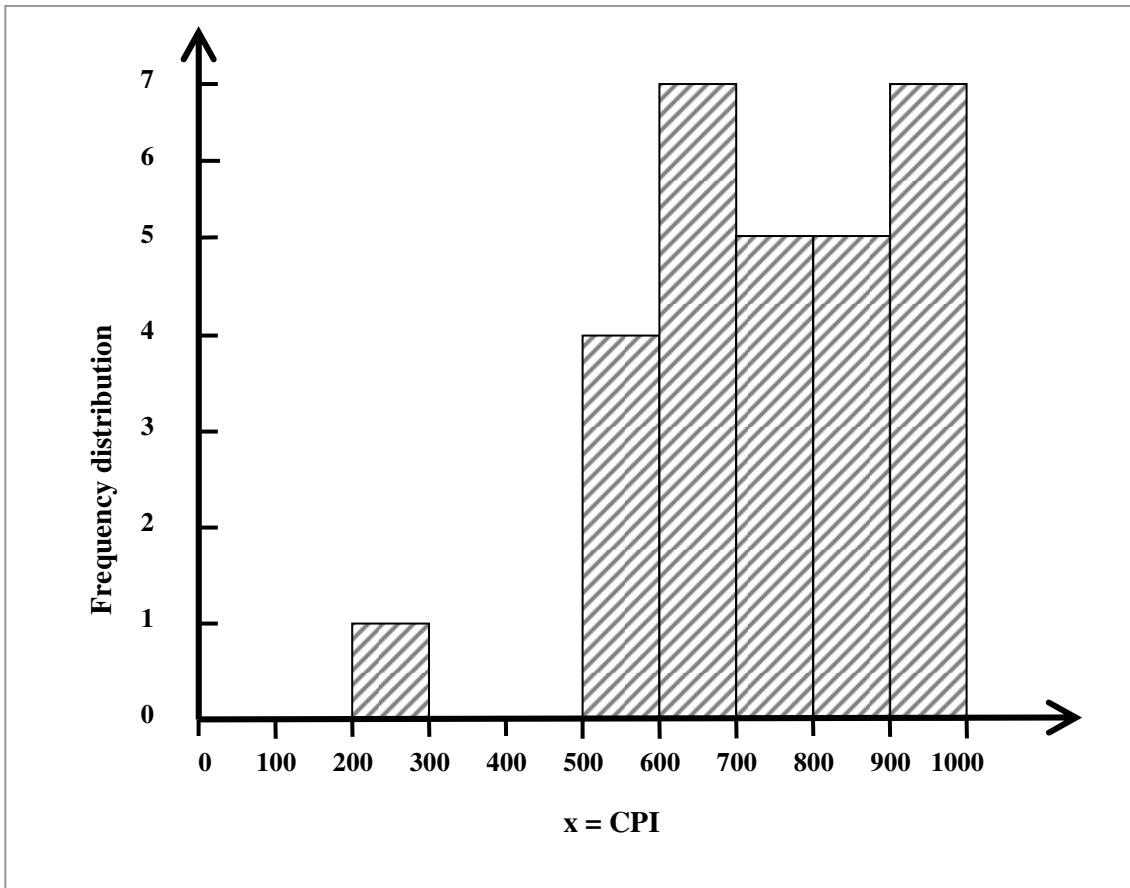


Figure 5. Five Year's actual frequency distribution for CPIs
 (From Brooker (2005): UK Airprox involving CAT aircraft, with STCA and ACAS indications, 1999 - 2003 inclusive)

Figure 5 shows a real-life frequency distribution histogram of Airprox incidents recorded in UK airspace. [Note that the vertical scale here is linear not logarithmic.] This data is taken from Brooker (2005). It covers five years from 1999 to 2003. In this data set there were 29 incidents with $\text{CPI} < 1000$, of which one could well have had a CPI small enough to fall into the 'Random Distances' region. That incident was Airprox 2001/052, in which a pilot took a wrong instruction to descend, which was undetected by ATC because of simultaneous transmissions; its aircrew then ignored RA and used 'visual' avoidance action. The aircraft in this incident were surely 'at best' on the borderline of system control.

What would be a possible cut-off value for the 'Random Distances' region of x_C ? It might be derived from an analysis of many incidents, or it might be chosen by safety managers/regulators as a standard value. For illustration, assume it is 500 feet. The CPI value for the size of an aircraft might be of the order of 50 feet. As $f(x)$ is a flat distribution for values up to x_C , this implies that the CPIs for incidents within the range zero to x_C are equally probable. Thus, the probability of a CPI value falling within the 'Collision Occurs' region would be approximately 50, the aircraft dimension, divided by 500, the size of the 'Random Distances' region, i.e. 1/10. If it were believed that the risk

of a collision is constant, and there have been (say) ten years without any other incidents in the ‘Random Distances’ region, then the probability of a collision in the next year would be estimated about 1/100.

Whilst well founded in statistical and modelling terms, this Random Distances Estimate (RDE) is a disappointing calculation. The collision probability cannot be calculated without several years’ data, and this data will be subject to the typical large fluctuations to be expected from Poisson-distributed events. How is one to know quantitatively if the system is ‘safe’ now (i.e. for the next year), and if it is getting safer or less safe?

In an ideal world, the form of $f(x)$ would be known on a yearly basis. Consider Figure 6 (based on Figure 4, but with a magnified vertical scale). The Figure shows two possible curves A and B, one of which might be the correct form for $f(x)$ in a particular year. Estimating collision risk essentially means estimating the intercept on the vertical axis. Could this be done by measuring the size of the curve at some x -axis distance markedly above the value x_C , e.g. at x_I – where system control is weak but not wholly absent, thus benefiting from the accumulation of considerably more incident data? While it might not be possible to prove that the absolute estimate of the intercept was perfectly accurate, it might potentially be a very helpful way of monitoring relative collision risk. In other words, would a count of the annual frequency of small and medium-sized CPI values lead to a good indicator of collision risk in each year?

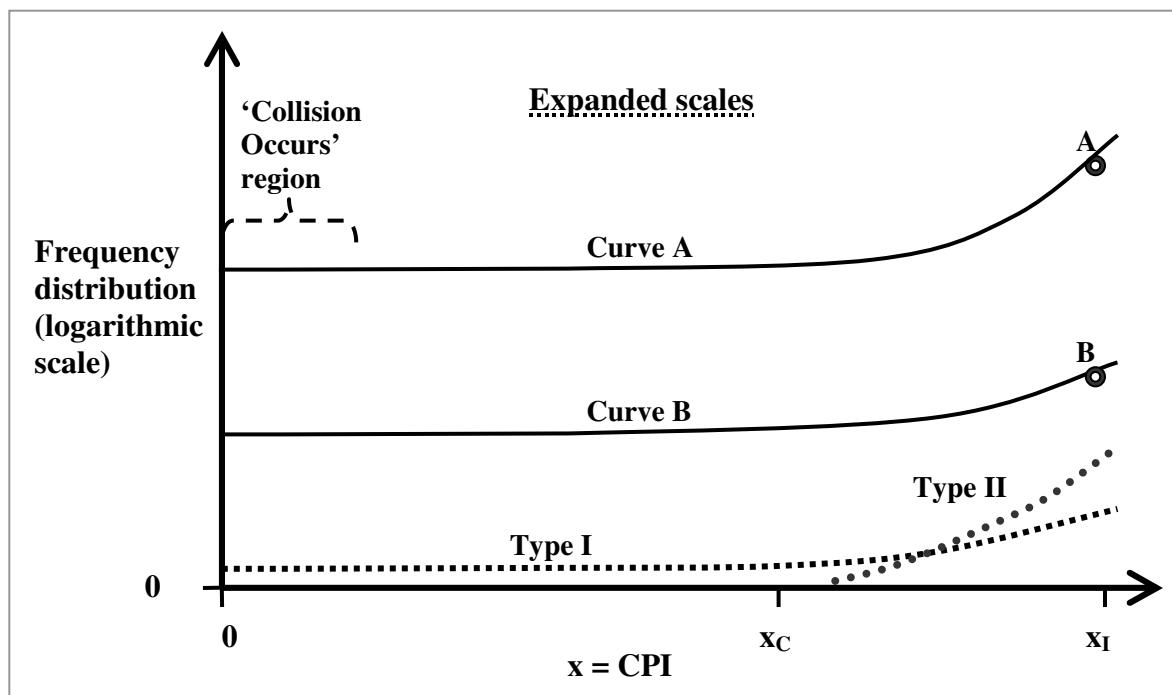


Figure 6. Possible frequency distribution for CPIs plus Accident/Incident components

To explore this, define an incident Type as a specific set of necessary conditions sufficient to produce a particular incident (see Brooker (2006) for discussion and

references on necessary and sufficient conditions). Each one of this set of causal factors, using the phrase loosely, can have a set of parameters associated with it. Thus, there could be a set of broadly similar incidents involving aircraft on converging routes; but some of them might be two commercial aircraft, whilst others would involve two executive jets, so that the speeds and climb performances would be different.

Figure 6 shows two incident Types that contribute to curve A, marked I and II. The curve will be made up of a large number of different incident Types. Every observed incident is a sample from all the ‘similar’ items, i.e. from that incident Type’s probability distribution. Type I incidents are those in which, for some rare combinations of parameters, correspond to loss of system control; which implies that very small CPI values – less than x_C – can occur, and hence there is a risk of collision. Hence, Type Is have collision potential. In contrast, incident Type II can never lead to a collision: there is always some system control and CPI values never get as low as x_C . Hence, Type IIs have no collision potential. An examination of Airproxes shows that the bulk of them probably fall into this second category: separation has been lost for some reason, but is then restored through normal processes; that being one of the characteristics of that incident Type. Thus, no reasonable combination of parameters could produce a collision for this specific variety of incident.

Of course, an additional contributory factor could be seen as turning a Type II incident into one with collision risk potential; but this extra factor would then mean that the incident should be categorised in another (Type I) family. Data on Type II incidents does have safety (i.e. collision risk) value if the probability of such additional contributory factors can be estimated in some way. But this is leading to complex risk modelling rather than the creation of simple ATC safety indicators.

On what basis would the curve A and B values, measured at x_I , i.e. the points A and B, be a good estimate of the relative y-axis intercepts of the two curves? Do the curves have the same shape? A thought experiment shows this is a hard question. Do curves such as A and B retain their shape for increased traffic volumes, given exactly the same ATC system, controllers, pilots etc? Suppose traffic numbers increase by a factor k , but that all strategic traffic patterns over time and space remain the same. A given aircraft will encounter k times as many aircraft and hence potentially k times as many incidents. Thus, the total number of incidents will be expected to increase by a factor k^2 . So will the collision risk and the number count for $CPI = x_I$ both increase by a factor of k^2 ? They might do – but they might not. A simple confounding element could be that, with an increased traffic volume, more ATC sectors would be ‘above capacity’ for short periods. This could increase the likelihood that controllers might be distracted and hence not remember that particular aircraft flightpaths had to be revised on their progress through the sector (e.g. see Loft et al (2004)). This could increase the number of Type I incidents in comparison to Type II incidents, i.e. increase the likelihood of incidents with collision potential. This kind of change would mean that curves such as A and B would have different shapes for increased traffic levels, rather than being simply scaled-up. The values A and B would not therefore be in proportion to the y-axis intercepts.

The fact that something might happen does not mean that it occurs in practice. It might be that the value at x_I is generally a good estimate of relative collision risk. Two factors that might make it so are:

- that Type II incidents are systematically excluded in this calculation – because they are in themselves irrelevant to collision risk and cloud the Type I incident picture;
- that x_I is not too far from x_C – because the further the extrapolation from x_C the less reliable will be any quantitative predictions.

ATC Incidents can be categorised in other ways. One example is the risk-bearing categories for Airproxes (UKAB, 2006). Another is the ‘risk of collision/severity’ scores proposed by the SRC (2005a). . The first has gaps, because it (intentionally) does not consider variations in circumstances compared the observed incident. The second is more promising conceptually, but the existing scoring system has not been demonstrated to have the properties necessary to match the underlying risk level. Details of this analysis are set out in Brooker (2007a).

8. Conclusions

ATC in developed European countries is extremely safe. The drawback to this safety record is that it is very difficult to estimate what the ‘underlying’ accident rate for mid-air collisions is now, or to detect changes over time. The rate cannot be observed directly. Is it possible to construct simple ATC safety indicators that correlate with this underlying accident rate, to indicate whether safety targets are being met and/or if safety is improving?

Can ATC safety indicators be constructed from the performance of ATC safety defences? Two are examined. The first counts initiating events that produce a separation breach and the second covers situations where the ground based part of the system, i.e. ATC, has not resolved an incident. The first indicator is a count of what is termed here an ‘Actual Separation Breach’ – ASB. The second indicator counts ‘Incident Not Resolved by ATC’ – INRA: this focuses on incidents in which the ground ATC defences have been ‘used up’.

An important concept here is that of ‘system control’: the ability to determine the outcome against reasonably foreseen changes and variations of system parameters. ASBs are a useful measure for the frequency of initiating events for incidents, i.e. where full system control needs to be re-asserted. The statistical distribution of incidents has been examined by focusing on an index – the CPI – of separation at the Closest Point of Approach. INRAs measure the number of times when safety is reliant on its final safety defensive layer, ACAS. There are good grounds for believing that INRA would be a good indicator of the underlying accident rate. This is because, by definition, these events are deemed ‘justified’ by controllers (and hence should generally be incidents with collision potential); have low CPI values; and reduced levels of system control. However, issues

about European safety culture in reporting incidents need to be addressed, and/or a specialist UKAB-like body might be needed to ensure complete coverage of such incidents.

The key methodological question is: if someone says he or she knows how to make a good estimate of the underlying accident rate, then how could this claim be tested? In particular, if it correlates very well with INRA counts, then what would be the nature of any quantitative argument for saying that it is in fact a 'better' indicator?

Indicators are valuable things to have – and it is very important to have systems that collect comprehensive data on incidents – but they are not in themselves solutions to safety problems. Accident rates will decrease because organisations and the people in them understand the causes of the full range of potential accidents, and can think of ways of reducing the frequency of or eliminating these causes. Voltaire said “Le mieux est l’ennemi du bien” – “The best is the enemy of the good”. So: identify good, simple indicators, based on significant kinds of events or states of system control, and focus effort and resources on trying to ensure that automatic systems are in place and reporting rates are high.

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