The Concept of Risk in Air Transport Operations

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Introduction

`When *I* use a word,' Humpty Dumpty said to Alice in rather a scornful tone, `it means just what I choose it to mean - neither more nor less.'

‘Risk’ is a Humpty Dumpty word. ‘Everybody knows what risk means’. The catch is that everybody knows something different, and sometimes the author intends it to mean different things at different times. This is not conducive to clear communication or thought.

Expressions like ‘risk management’, or ‘safety risk’, or ‘prioritising risk’ sound good, but on inspection it isn’t clear what they intend by ‘risk’. Perhaps they mean ‘hazard’, or ‘probability of harm’, or ‘loss’. So when making recommendations for avoidance of systemic failures, I would suggest that discussion of ‘risk’ should be carefully considered.

This paper deals with regular public air transport; some of the considerations would be different for other forms of transport, as we shall see. And we are talking about safety considerations – specifically, about the avoidance of harm to the travelling public. ‘Risk’ in this context does not necessarily have the same connotation as in risk to profitability, for example.

Dictionary

The obvious place to find out what a word means is a dictionary. When we look up ‘risk’ in the Oxford English Dictionary, we find (as with many words) that the meaning has changed over time. This can have important effects when we come to review legal implications, because we need to know what the word meant at the time a judgment was given, in order to understand the judgment.

In 1933, the Oxford English Dictionary, 1st Edition, defined risk as ‘hazard, danger, exposure to mischance or peril’, and in 1976, the Concise Oxford Dictionary, 6th edition definition of risk was ‘hazard; chance of, or *of*, bad consequences’. In other words, ‘risk’ was a synonym for hazard. Today, the definition is ‘Danger, (exposure to) the possibility of loss, injury or other adverse circumstance’. Additionally, there is ‘a chance or possibility of danger, commercial loss, or other risk’ (Shorter Oxford Dictionary (5th edition, 2002)).

AS/NZS 4360

Alternatively, we could look in the Australia and New Zealand Standard for Risk Management, AS/NZS 4360. From the Standard, we find that there is no one definition of risk. Risk is ‘The chance of something happening that will have an impact on objectives’ (i.e. the probability, a number), but ‘Risk is measured in terms of a combination of the consequences of an event and their likelihood’ (p. 4) (i.e. a cost of some sort, modified by a number).

The Standard has recently been re-issued (2004/05), and some limitations of the first version (1995) have been addressed. The earlier version dealt with commercial risk. While that remains the principal focus (see the companion handbook HB 436: 2004, pp. 7, 10) some safety issues are now covered. The ‘As Low As Reasonably Practicable’ (ALARP) principle is discussed (p. 65), although the question of the meaning of ‘risk’ in Lord Asquith’s judgement in Edwards v. National Coal Board, discussed later, is not considered. There are also a number of important reservations stated in the Handbook, which apply to safety risks.

Firstly, there is the matter of “rare but severe risks” (p. 71) that “may warrant risk treatment actions that are not justifiable on strict economic grounds. Legal and social responsibility requirements may override simple financial cost benefit analysis.” ‘Rare but severe risk’ is a reasonable description of an airline hull-loss accident.

Secondly, the definition

Risk = function {consequences, likelihood}

is only equivalent to

Risk = consequences x likelihood

if the level of risk is proportional to each of its two components (p. 49). The question of how non-linear functions will be discerned, or coefficients determined, is not addressed. However, Leveson has argued that, when considering political risks arising from an accident, the public’s reaction will be proportional to at least the square of the numbers of people killed. A Cessna 172 accident in which four are killed will rate a paragraph on an inside page of the paper; a Metroliner accident will be a nine day wonder; a Boeing 747 accident is likely to result in a Commission of Inquiry.

Thirdly, “high consequence outcomes may be so unacceptable that the frequency of occurrence is not a relevant factor” (ibid.). In other words, for rare but severe events (such as an aircraft accident) the hazard must be driven down.

Commercial Risk

Since there may be confusion between commercial and safety risks, commercial risks will be considered next. Commercial risk analysis started with insurance.

Insurance risk refers to ‘exposure’: how much the insurer may have to pay out. Both the probability of having to pay, and the magnitude, are relevant here, so ‘risk’ in these circumstances is taken to be the product of the potential financial loss and the probability of incurring the loss. This has a physical meaning: the ‘risk’ is the amount that, averaged over all the policies underwritten, will have to be paid out. This money must therefore be kept on call, while the remainder of the premiums can be kept in more profitable long-term investments.

This is one version of the second meaning of ‘risk’ used in AS/NZS 4360.

This meaning is appropriate to the management of commercial risk generally. Suppose that the frequency of incurring a loss of one million dollars is once per year, this will attract attention. However, the loss of $10,000, twice a week, will have an equal priority in the mind of management. By contrast, if some other event leading to a loss of one thousand dollars will only occur once per year, this will be lower on the list of management priorities, and indeed management might decide to accept the risk, i.e. take no action to reduce the possibility or amount of the loss. Here, the use of probability times consequence is useful in deciding on the order of priority in dealing with potential losses, or in deciding to accept the risk of loss.

The use of a probability/consequence matrix is well-suited to commercial decision making; for example, deciding whether to accept a lower tender from a supplier who may not be able to deliver on time. Acceptance of commercial risks is essential to the success of a business enterprise. Concepts such as accepting risk in order to gain opportunities are valid in commercial operations.

Engineering usage

Engineering usage is different from commercial usage, because it is intended to facilitate finding numerical values for risk, in engineering design.

(Leveson, 1995) reviewed the use of ‘risk’ in systems safety literature. She arrived at the following definitions:

Hazard: a state or set of conditions of a system (or an object) that, together with other conditions in the environment of the system (or object) will lead inevitably to an accident. Note the reference to the environment: for example, a release of toxic gas would only be harmful to people if they are in the vicinity.

Risk: the hazard level, combined with (1) the likelihood of the hazard leading to an accident (sometimes called the *danger*) and (2) hazard exposure or duration (sometimes called the *latency*). She notes the usage of ‘risk’ as meaning the likelihood of the hazard leading to an accident, but prefers the wider term for engineering purposes.

Exposure is included in her definition of risk because an accident arises from a coincidence of conditions. The longer the hazardous state exists, the greater the chance that the other prerequisite conditions will occur. While “the coincidence of conditions necessary for an accident may be a statistically low-probability event, the probability of coincidence can be dramatically increased if the hazard is present for a long time" (p. 179).

With these definitions, 'risk analysis' and 'hazard analysis' are not synonymous. Hazard analysis is the identification of hazards and the assessment of hazard level, while risk analysis adds the identification of the environmental conditions, along with the exposure or duration.

The Relevance of Probabilistic Risk Assessment

The relevance of various concepts related to probability, in relation to aircraft accidents, has been questioned. The Chief Scientific Adviser, Human Factors, FAA, has expressed the view that Probabilistic Risk Assessment (PRA), a useful engineering concept, is an inappropriate approach to accidents where human factors are involved. Human error is not analogous to mechanical failure, for which PRA was designed (Abbott, 2006). Mechanical or electronic components often fail completely: they either work or they do not. Also, once they have failed, they stay failed. In principle, there can be reliable data about the probability of failure. By contrast, human performance may degrade progressively, but human error can be reversed and the system restored to normal working. There is likely to be wide variability in human performance, which can be predicted only in the most general terms. Since human error is generally considered to be responsible for about 80% of fixed-wing aircraft accidents (Zotov, 2000), PRA is, at best, of limited value.

Human Factors literature

Since we are concerned in aviation with accidents which stem largely from human factors, the usage of 'Risk' in the human factors literature may be relevant. Here, 'risk' has been used with the meaning of 'the probability of incurring some harm'. The word 'hazard' is used to mean the potential for the harm that may be incurred. (See, for example, (O'Hare, 1990)). Consider a path along the very edge of a cliff. The placement of the path is a hazard (a condition, or continuing state of affairs). The harm that may be incurred by a pedestrian is sudden impact with the terrain at the foot of the cliff. The risk is the probability that the pedestrian will fall from the cliff, so incurring that harm.

'Risk' in this connotation cannot be interpreted as the product of probability and consequence. Taking the above example, suppose that the terrain was such that a fall from the cliff would result in a broken leg, and the probability of falling was 0.5. The meaning of the product is 'half a broken leg', which is nonsensical. However, to say that the risk of a broken leg to someone walking along the path is 50%, has meaning: on half of the occasions that someone walks along the path, they will suffer a broken leg.

This meaning of 'risk' is akin to the second meaning of 'risk' given in the Shorter Oxford Dictionary, and is the first meaning given in the Standard. It is also the definition adopted by the (UK CAA, 2006), and by the International Atomic Energy Agency in considering harm to humans (IAEA, 2006): 'risk' is the probability of incurring some stated harm.

This definition covers adverse consequences that may arise from an individual hazard alone. However, air transport accidents often arise from the unforeseen interaction of apparently minor hazards. The probability is unknowable; so are the consequences. Take for example the Ansett accident near Palmerston North, where an undercarriage hang-up led directly to a CFIT hull-loss accident with multiple fatalities. A hang-up is classified as of nuisance value only, because the crew can use the emergency procedure (ICAO, 2006). The probability that it would result in a hull-loss accident would be regarded as very remote. In reality, the accident occurred on the 11th occasion on which a hang-up occurred, and led ultimately to the destruction of a major airline. Nuisance is not quite the right word. So, when considering airline operations, the concept of 'risk' has limitations.

Legal Usage: the ALARP Principle

Our operations must of course comply with the law, and this applies as much to the way in which we deal with risk, as to our compliance with aviation regulations.

The common law principle that a risk to safety must be reduced until it is 'As Low As Reasonably Practicable' (ALARP) was laid down in a mining case, Edwards v National Coal Board. ALARP does not require hazards to be reduced to zero: it means 'until the cost of further improvement is entirely disproportionate to the safety benefit gained.'

In examining the meaning of 'risk' in this judgement, it is necessary to look at a contemporaneous dictionary definition. The older version of the Concise Oxford Dictionary, quoted earlier, gives the principle meaning of 'risk' as "Hazard; of harm, or the chance of harm". Accordingly the Rule in Edwards' case requires an operator to drive down hazard, the potential for harm, until it is as low as reasonably practicable. It is quite unacceptable for an operator's management to decide, on behalf of the public, to 'accept' a risk, to the operator's enrichment, by exposing the public to an avoidable hazard.

The Rule in Edwards' case was followed in the Longford trial (Hopkins, 2002) and is therefore part of Australian case law.

The Rule in Edwards' case was amplified in Marshall v Gotham, where it was held that quantitative risk assessment and compliance with rules and 'good practice' is not enough to qualify as a defence (per Lord Keith). In other words, one cannot hide behind the rules. It is still necessary to identify hazards and drive them down.

Finally, in the recent case of R v F Howe and Son, it was held that

"The size of a company and its financial strength or weakness cannot affect the degree of care that is required in matters of safety".

Accordingly, it will not do to say that limited resources had to be prioritised, and so some apparently less likely hazard had not been addressed. You may not seek to make a profit by exposing your employees or the public to avoidable harm.

In the Longford disaster (Hopkins, 2000) Esso had prioritised the No 1 plant as being low risk, because it had been operating 30 years without an accident. Accordingly, they had deferred doing a Hazard and Operability evaluation (HAZOP) on this plant – an expensive process - in favour of addressing more frequently recurring problems. Had the HAZOP been performed, it is highly probable that the hazard of supercooling would have been found and addressed. Civil and criminal penalties imposed on Esso have been of the order of $1,000,000,000.

The Longford case also illustrates the difficulty which people have in estimating very low probabilities. Longford No. 1 was considered ‘safe’ because it had been operating for 30 years without a disaster. However, one disaster in 30 years was not considered ‘safe’ when it happened. This illustrates the desirability of getting away from considerations of probability, and concentrating on the hazards.

Risk in the Context of Aviation Safety

Common Usage

It could be argued that there is a general acceptance within the aviation industry that risk is the product of likelihood and consequences. This acceptance may have come about because of the definition in the (obsolete) 1995 version of AS/NZS 4360. But the mere fact that an interpretation is widespread does not make it valid, in a particular usage. Before Columbus’ voyage to America in 1492, there was a general acceptance that the earth was flat, but that acceptance did not make it a useful concept for long range navigation. What is needed, in aviation safety, is a definition which is valid in the context of the problem at hand.

Flight Operations

The concept that risk may be thought of as a combination of probability and consequence can be used for commercial cost-benefit analysis, to see where resources can best be used. If the chance of something undesirable happening is high, then the risk is said to be high. Likewise, if the consequence is severe, the risk is said to be high even though the probability is low. However, the concept has limitations in the context of airline operations.

First, in the case of rare but severe risks, the Australian and New Zealand Risk Management Standard points out that actions may be required even if not justifiable on strict economic grounds. Legal and social responsibility requirements may override simple functional cost-benefit analysis. A hull-loss accident comes into this category. In considering probability, the UK CAA (2006) has stated that the only level at which a hull-loss accident might be considered acceptable is 1 in 10^9 hours of operation, a figure already in use for structural failure, in the airworthiness standards (see, e.g., JAR 25.1309). (While this figure may seem high, the global B777 fleet has already exceeded 10^7 hours of operation).

Second, the characteristics of an aircraft, from the operational safety perspective, are high energy, fragility and usually, much highly inflammable fuel. These are different, in degree, from other forms of transport. A ship, for example, has large momentum but relatively low energy, and it has a strong structure to withstand the unforgiving nature of the sea. It is quite possible to visualise accidents which could not develop into catastrophes, though they might be embarrassing and expensive. (A fully-laden bulk carrier grounding in the entrance to a port would be an example). By contrast, the high energy, fragility and inflammable fuel of an aircraft mean that, in the worst case, *any* airline mishap may end in disaster. It is not a good idea, therefore, to think of aircraft mishaps of varying levels of severity.

Thirdly, the severity of the outcome is not a useful measure. It is dangerous to consider ‘incidents’ as being at a lower level of severity than ‘accidents’. While the actual outcome is indeed less severe, it is accepted that the difference between an incident and an accident is random chance: that is the reason for investigating incidents so as to avert accidents. The random chance of a less-severe outcome is not a ground for according lower priority to hazards which may lead to an incident.

In aircraft accidents, apparently trivial hazards can combine in completely unknowable ways, to bring about dangerous situations which can end in disaster. This is analogous to chaos theory in the study of meteorology. Who would have thought that an undercarriage hang-up could result in a controlled flight into terrain? Alternatively, if the possibility of a hull loss accident arising from a hang-up had been considered, it might have been thought unlikely in the extreme.

Since the severity of the consequences of an air transport accident, and its probability, are essentially unknowable, the consequences cannot usefully be ranked in order of severity. A probability-consequence matrix therefore has little meaning. In order to achieve safe operation, we need to minimise all hazards, whether seemingly trivial or not, so that interactions cannot occur.

There is one context in which a reasonable probability can be estimated, and that is the statistical probability of a hull-loss accident, either by type of aircraft (a jet airliner has about a thousand-fold less likelihood of being involved in an accident than a small commuter aircraft) or by airline, in the case of well-established airlines which have a sufficiently long safety record that probability can be expressed with some confidence. Where one major airline has never had a hull loss accident, and another has had an accident every few years, it is reasonable to say that the risk of flying with one is less than the risk of flying with the other.

Summary

There are a number of contrasts which we must keep in mind, between commercial risk management and safety risks in airline operations.

- The use of a probability/consequence matrix is well-suited to commercial decision making. However, it may not deal with interacting hazards whose probability and consequences cannot validly be estimated, and may not be useful in considering the safety of airline operations.

- Acceptance of commercial risks is essential to the success of a business enterprise. Concepts such as accepting risk in order to gain opportunities are valid in commercial operations. However, they have no place in consideration of safety. It is unacceptable to impose safety risks on the public, in order to make a commercial gain. For example, keeping aircraft in service at holiday time, with Airworthiness Directives overdue, should not be permitted.

- Commercial and safety risk concepts are significantly different, and should not be confounded. Examples of the conflict that can arise are the statements that ‘risk management should not be seen as an obstacle to taking risk’, and ‘accept risk when the benefits outweigh the cost’. ‘Taking risk’ and ‘accepting risk’ mean, in the context of RPT, imposing avoidable hazards on the travelling public: this is unacceptable.

There are many definitions of risk, some of them contradictory, and this can lead to unclear communication. The Standard has no one definition; it is concerned primarily with commercial risk, and as it notes itself, a different approach is needed for safety risk, where consequences are unacceptable, or where legal requirements dictate. Both of these considerations apply to air transport accidents.

A reasonable approach would be to adopt the UK CAA approach, and use the terms hazard and risk as they are used in human factors literature, where ‘risk’ means the probability of incurring some harm, while ‘hazard’ means ‘the potential for that harm’. This approach has also been adopted by the International Atomic Energy Agency for considering harm to people. It is simpler than any alternative approach, and the more complex approaches are inappropriate for occurrences with severe consequences.

It is inappropriate for operators to attempt to prioritise hazards. Apparently inconsequential hazards can combine with others in unforeseeable ways, to produce catastrophes. Operators should identify hazards, and reduce them to ALARP as quickly as possible.

Adopting formal definitions for risk and hazard should assist us in promoting industry understanding of the need to assess hazards, irrespective of the apparent probability of harm.

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