Chapter 2

What Is Risk?

Introduction

The antecedents of what has become risk analysis and risk assessment are intertwined in many different areas of science, engineering and technology. Because of this, important and helpful papers have appeared in a wide assortment of journals not easily accessible to all interested parties. Glickman & Gough (1990) produced a collection of readings that provides a useful overview of the topic.

The hazards of ionising radiation have been appreciated since early this century and it is therefore fitting that one of the earliest large-scale risk assessments was the Reactor Safety Study which used a team of about sixty people to undertake a quantitative study of the safety of light-water reactors (US Nuclear Regulatory Commission, 1975, Rasmussen, 1981). The health issues involved in the radiation area, where large doses of radiation lead to serious health problems, and the methods used to study them, helped to shape the tools involved in health risk assessment. Work on natural hazards, and the use of applied statistics in engineering design has come together in risk assessment methods to examine issues such as oil spills, accidental chemical releases and climate change.

The use of risk analysis by regulatory agencies in the United States was an outcome of the US prohibition on the use of food additives found to be carcinogenic. As recounted in the influential report of the National Research Council (1983), widely known as the red book because of the colour of its cover, the law was also interpreted as prohibiting approval of any drug, for use in animals produced for human food, that had been shown to cause cancer. In 1962 this requirement was relaxed so that a carcinogenic animal drug could be approved if the Food and Drug Agency (FDA) was convinced that, by using approved analytical methods, no residue of a drug would be found in edible tissues of treated animals. This proved unworkable for two reasons: firstly, progress in analytical chemistry was so rapid that approved methods of analysis quickly became obsolete and, secondly, improved detection methods showed that no drug administered to animals is ever entirely absent from animal tissues.

In an attempt to provide a consistent and predictable procedure for approving methods to search for drug residues, the FDA decided that, rather than gear criteria to an analytical technique, the standards would be defined in terms of risk, and they specified a 10^{-6} lifetime risk of cancer as a quantitative criterion of insignificance.
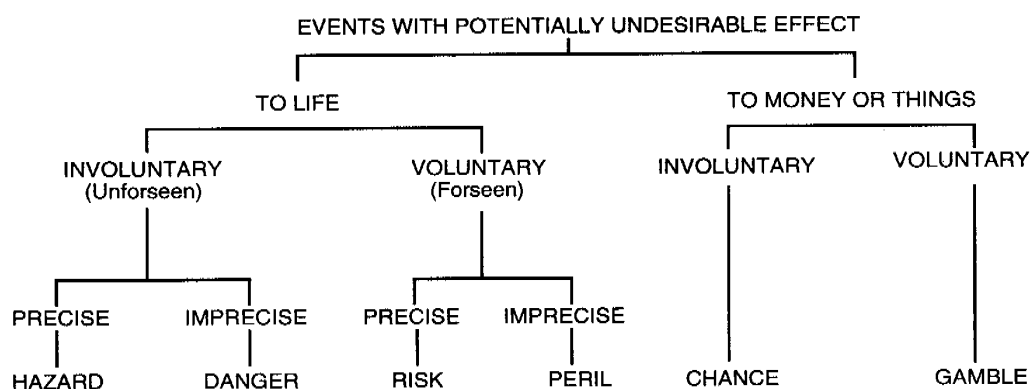
Risk and Hazard

There is a distinction between risk and hazard, but the nature of the distinction between the two varies depending on the discipline. Ingles (1991) considers the term hazard to refer to a precisely defined involuntary (i.e. unforseen) event with potentially undesirable effects on life, whereas risk refers to a voluntary event (i.e. foreseen). This is summarised in Fig. 2.1.

This is **not** the way that hazard and risk tend to be used in the literature related to technological risk. In these disciplines it is more usual to consider hazard to be an intrinsic property of a substance, which is activated upon an event. The term risk then tends to have a dual usage. It is sometimes used to refer to the probability of the event occurring; and it is sometimes used to refer to the combination of the probability and its consequences.

To be more specific. Consider the risks associated with diving into shallow water. The shallow water itself constitutes a hazard. The act of diving is the event that precipitates the risk. The consequences can range from severe, such as death by drowning to mild, such as cuts and scratches.

The concept of risk, and the idea of risk management, are used in many diverse fields. Sometimes, however, even though the words used are the same, their meaning differs in different disciplines. This section discusses the way in which different disciplines use the term risk.

Figure 2.1 Modern English Usage for "Events with potentially undesirable effects." (From Ingles, 1991)

EVENTS WITH POTENTIALLY UNDESIRABLE EFFECT

TO LIFE   TO MONEY OR THINGS

INVOLUNTARY (Unforseen)   VOLUNTARY (Forseen)   INVOLUNTARY   VOLUNTARY

PRECISE   IMPRECISE   PRECISE   IMPRECISE

HAZARD   DANGER   RISK   PERIL   CHANCE   GAMBLE

Risk in Financial Management

Imagine the situation where you wish to purchase 1000 shares of a company at $1 each. What is your risk?

When phrased like this, it begins to look as if the question is not adequately defined. One response is, risk of what? Risk of being run over by a car on the way to the stockbroker's office? Risk of financial loss? Risk of financial liability? Risk of legal liability? Or all of these?

Some of the possible answers that one could envisage are:

a)   You are risking $1000. This perfectly legitimate answer concentrates on the upper bound of financial loss. If you really believed that you were risking this money, with no possible compensating benefit, then you would not go ahead with the purchase. Many who never purchase shares must feel like this. But the many who do own shares must believe that the possible future benefits outweigh this particular definition of risk. Thus, a more sophisticated definition should capture this complexity.

b)   A statistically proficient stockbroker could prove to you that there is no risk. Consider that the shares move in $1 price increments. And let us assume that over the course of a year the probability of a $1 decrease is 0.1, the probability of no change in price is 0.6, the probability of a $1 gain is 0.2 and the probability of a $2 gain is 0.1. These are summarised in Table 2.1

Table 2.1 Hypothetical likelihood table for a share purchase

| Expected price movement	Probability
$2	0.1
$1	0.2
$0	0.6
-$1	0.1

The expected mean value of the purchase is then obtained by adding together the product of each price movement with its associated probability. The answer is

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then $0.30 per share. The expected return on the purchase is a gain, hence, one could argue, there is no risk.

Alternatively, one could argue that the risk is 0.1, namely the probability of a loss, or that the risk is $0.10 per share, the expected mean value of the loss.

c) The applied statisticians approach to the discussion so far would be to note that all of the information given in Table 2.1 could be expressed in a single function, the probability distribution function, that plots the probability on one axis and the consequences on the other axis. The dollar values such as the $1000 ($1 per share) given in section (a), or the $0.30 and $0.10 mentioned in section (b), are then particular estimates obtained from this distribution. This is depicted in Fig. 2.2

Figure 2.2 The probability distribution function for an assumed share purchase links the consequences (measured in terms of price movements) with their probability of occurrence.
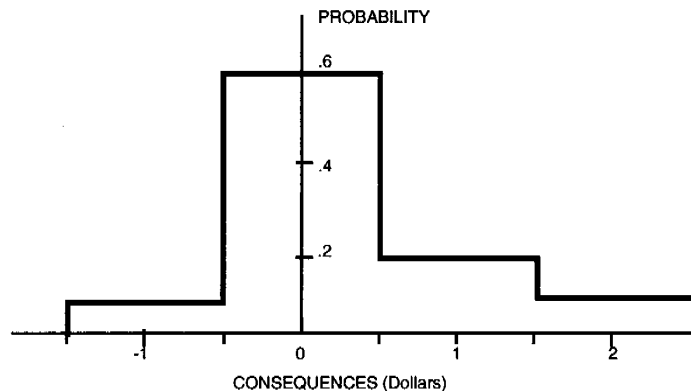
d) The original question posed in this section failed to specify the nature of the company in which one wished to purchase shares. Surely the purchase of $1000 worth of shares in a large, well-established company is less risky than the purchase of $1000 worth of shares in a speculative venture. This is true, and can be accommodated in Fig. 2.2 and Table 2.1 by changing the probabilities according to the type of company under consideration.

e) The term risk, when used in financial management, attempts to quantify the probability of loss as contrasted to the probability of gain. When used in connection with the stock market, risk is equated with volatility, which is defined as the standard deviation of the share price (Brearley, 1969). Thus, a share whose price fluctuates little is considered to be of lower risk than a share whose price fluctuates a lot.

The financial management definition of risk emphasises the statistical nature of risk categorisation. Though it is easy to criticise the process as being one in which a future, unknown standard deviation (the future risk) is estimated from historical data, it is also true that the definition is simple and allows an analyst to compute the risk of a particular share rapidly, and also the relative risk between them.

The problems of allocating financial priorities (i.e. investment decisions) solely on the basis of financial risk should be evident. It is a valid technique only if the past continues to be a guide to the future, and this cannot, in general, be guaranteed. An investment decision based solely on risk minimisation will give first priority for investment to a stock whose price has remained steady for as long as possible. Conversely, a risk-based strategy designed to offer the greatest probability of profit (but also the same probability of loss) would give first priority for investment to a stock with the most volatile share price. Yet in both cases the strategy could be flawed because of future changes. The apparently risk-free strategy (based on risk defined as the standard deviation of the share price) has a real risk attached to it that a change in

circumstances (e.g. death of a key executive) will alter the hitherto unalterable share price. And the high risk strategy designed to offer the maximum potential for profit can come adrift not just because the profit could turn into a loss, but also because a previously volatile stock could suddenly become quiescent.

Earthquake risk and insurance

Brillinger (1993) deals with the statistical issues involved in using financial insurance to protect against natural catastrophes such as an earthquake. The problem of risk within the insurance industry focuses on two crucial components:

- calculation of a premium commensurate with the risk;

- estimation of the size of the probable maximum loss resulting from a potential catastrophe.

To be specific, consider a time period of one year and suppose that the yearly possible loss is a random amount U. The pure risk premium for a year's insurance is given by the expectation value of U. Other premium formulas have been suggested that take note of random fluctuations by incorporating the standard deviation or the variance of the random distribution of U.

Yet another procedure for determining premiums is to select some acceptable probability of financial ruin and determine premiums such that the probability of financial ruin is less than the probability that the total of claims paid out exceeds the income plus reserves of the insurance company.

Application of the above concepts combined with probabilistic modelling of the spatial and temporal aspects of earthquakes may be found in Brillinger (1993).

Bushfire management

Australian fire-fighting authorities have long made a distinction between fire danger, fire hazard and fire risk. Of these, fire danger is the one most commonly used and disseminated to the community through boards in country areas warning people that the fire danger is low, medium, high, very high or extreme. These five categories are actually based on a complicated formula that combines meteorological information (wind, relative humidity, temperature) with information on the fuel dryness to produce a number between 0 and 100, known as the Macarthur Fire Danger Index. This is then divided into five categories such that 50-100 is extreme, 25-50 is high, 12-25 is high, 6-12 is medium and less than 6 is low fire danger.

Fire hazard is normally considered to be measured by the intensity of a fire once it is alight. This can be calculated as a function of the fire danger and the quantity of fuel. Fire risk, by contrast, needs to incorporate some measure of the probability of ignition actually taking place. In practice, this is correlated with the fire danger. Days of extreme fire danger have a higher probability of ignitions taking place than days of lower fire danger. But it is also true that days of extreme fire danger can exist with no fires during the day.

Defining risk

The above discussion illustrates the many problems facing a definition of risk. One particular problem, mentioned by White (1995), is that a perfectly sensible definition of risk within a specialised area may be ludicrous when applied to another area. His example is, that if risk is defined solely in terms of uncertainty, then playing Russian Roulette with six bullets in the chamber has a zero risk associated with it, because there is no uncertainty about the outcome.

The US Society of Risk Analysts set up a definitions committee in 1985 to consider the issue. After two years of work they produced the following list of thirteen possible definitions:

1. Possibility of loss, injury, disadvantage or destruction; to expose to hazard or danger; to incur risk of danger.

2. An expression of possible loss over a specific period of time or number of operational cycles.

3. Consequence per unit time = Frequency (Events per unit time) x Magnitude (Consequences per event)

4. Measure of the probability and severity of adverse effects.

5. Conditional probability of an adverse effect (given that the necessary causative events have occurred).

6. Potential for unwanted negative consequences of an event or activity.

7. Probability that a substance will produce harm under specified conditions.

8. Probability of loss or injury to people and property.

9. Potential for realisation of unwanted, negative consequences to human life, health or the environment.

10. Product for a probability of an adverse event times the consequences of that event were it to occur.

11. Function of two major factors: (a) probability that an event, or series of events of various magnitudes, will occur, and (b) the consequences of the event(s).

12. Probability distribution over all possible consequences of a specific cause which can have an adverse effect on human health, property or the environment.

13. Measure of the occurrence and severity of an adverse effect to health, property or the environment.

The unifying thread is that the definition of risk involves one or more of three essential elements:

• a time frame over which the risk or risks are being considered;

• a probability of the occurrence of one or more events; and

• a measure of the consequence of those events.

As a general definition we would therefore postulate a set theory definition (Kaplan & Garrick, 1981) that treats risk over a given time as the union of the set of possible consequences and their associated probabilities. However, the exact implementation of this definition is going to depend on the particular discipline. Kaplan & Garrick (1981) specifically include the choice of scenarios as one of the sets under consideration, but it seems more sensible to consider the range of scenarios as defining the universe of discourse. They also fail to consider time explicitly within their definition, though it can appear implicitly when the probabilities are determined on the basis of recurrence intervals. As a general definition we therefore suggest that:

RISK DURING A GIVEN TIME   = {CONSEQUENCES} U {PROBABILITIES}

of the scenarios under consideration

but will use specific definitions appropriate to the sub-fields of interest.

Risk in toxicology

Hazard assessment is the most commonly used methodology for analysing the effects of chemicals on the natural environment. Klöpffer (1994) formalises the definition of hazard with:

HAZARD = EXPOSURE X EFFECTS

The multiplication sign in this case is taken to indicate that there should be no hazard if there is no exposure or if there is no adverse effect. There is some concern, noted by Klöpffer (1994) that the above concept of hazard may not be applicable to extremely toxic and persistent chemicals. For example, polychlorinated dibenzodioxins and

dibenzofurans are examples of a rare group of products (xenobiotica) that are both extremely toxic and persistent. This is the worst possible combination of properties. Substances such as these pose a hazard even if their exposure is zero because of the potential for future exposure. Similarly, persistent chemicals do not fit the above definition because even if their effects are believed to be zero, it may subsequently emerge, as in the case of DDT, that this is incorrect. Persistent chemicals that are currently perceived as benign need to be viewed as having potentially hazardous effects.

The distinction that is usually made between risk and hazard is, then, that hazard is an intrinsic property that becomes a risk only when there is a finite probability of a manifestation of the hazard. Within this framework, one would then define risk as the product of a hazard and its likelihood of occurrence

RISK = HAZARD X LIKELIHOOD OF OCCURRENCE

This definition has widespread acceptance within toxicology. To make it easier to remember, Environment Canada use a definition based on the letter 'e', in which likelihood of occurrence is replaced by entry into the environment so that:

RISK = HAZARD x ENTRY = EXPOSURE x EFFECTS x ENTRY

References

Brearley, R.A. 1969, *An introduction to risk and return*, MIT Press, Cambridge, Mass.

Brillinger, D.R. 1993, Earthquake risk and insurance in *Environmetrics* , 4, 1-21.

Glickman, T.S. & Gough, M. 1990, *Readings in Risk*, Resources for the Future, Washington DC.

Ingles, O. 1991, A linguistic approach to hazard, risk and error in *New perspectives on uncertainty and risk*, (eds. Handmer, J. et al.), 66-78, Centre for Resource and Environmental Studies, Canberra and Australian Counter Disaster College, Mt. Macedon.

Kaplan, S. & Garrick, B.J. 1981, On the quantitative definition of risk, *Risk Analysis*, 1, 11-26.

Klöpffer, W. 1994, Environmental Hazard — assessment of chemicals and products, Part I: General assessment principles, in *Environmental Science and Pollution Research*, 1, 48-53.

National Research Council 1989, *Improving Risk Communication*, National Academy Press, Washington DC.

Rasmussen, N.C. 1981, The application of probabilistic risk assessment techniques to energy technologies, in *Ann. Review Energy*, 6, 123-138.

US Nuclear Regulatory Commission 1975, *Reactor Safety Study: an assessment of accident risks in US commercial power plants*, Report NUREG-75/014 (WASH-1400), Government Printing Office, Washington DC.

White, D.H. 1994, Concepts of risk management, *Agricultural Systems & Information Technology*, 6, 7-8, 1994.