

Chapter 1

Risk Assessment, Methodology, Vulnerability, Impact and Importance

This chapter attempts to set the work on engineering lifelines in the context of risk management, and initially presents excerpts (in italics) from material published by two acknowledged experts in risk management — Patrick Helm and Janet Gough. What follows is a description of risk management considerations discussed at the time of the project workshop in October 1994, the methodology and the project structure. The various steps of the analysis are then described, which should prove useful for any group embarking on their own project. The way in which mitigation measure implementation was, and continues to be, undertaken is then discussed.

In the June 1996 volume of *Tephra*, the magazine published by the Ministry of Civil Defence, a comprehensive article dealing with “Integrated Risk Management for Natural and Technological Disasters” was written by Patrick Helm of the Department of Prime Minister and Cabinet in Wellington. The article introduces the concepts and principles of risk analysis and outlines a practical risk management strategy. Although the term ‘lifelines’ is not used, its equivalent term is ‘infrastructure’.

Patrick Helm’s article deals with disasters and their consequences, not only lifelines. The relevant portions of the article are set out below and very adequately introduces the theme of this book. The issues raised and the practical applications suggested are very similar to that developed in the Christchurch Engineering Lifelines Project.

Introduction

Risk assessment has been little used in New Zealand for the management of emergencies and natural disasters. At best, it has been regarded as a passive activity to help insurance companies set premiums for coverage of infrastructural damage.

Yet the techniques now becoming available for analysing and quantifying risk can prevent or minimise disasters, can improve safety, and can markedly reduce societal disruption following disasters. They have

much to offer those responsible for reacting to emergencies and dealing with the aftermath.

Government Perspective

Government’s interest in risk management in respect of dealing with emergencies and natural disasters began about ten years ago. With the transfer of responsibility that occurred through the reforms in local authorities in the 1980s, central government put in place policies designed to encourage more effective safety and loss prevention strategies. These were enunciated, for example, in a set of principles developed for the 1987 Recovery Plan for Natural Disasters which placed considerable emphasis on risk management and mitigation.

The essential idea was that central government would accept shared responsibility for the restoration of damage from natural disasters only if the local authority concerned had done its part to minimise, mitigate, and manage the risk to its assets. The expectation was that local authorities would not simply provide insurance cover, but would seek to protect life and property by managing all the risks they faced. That is, they were expected to take all reasonable steps to reduce the possibility of adverse events occurring (or follow-on secondary events), to put in place protection and damage limitation measures that would reduce the consequences, to examine the efficacy of response mechanisms, and generally to improve the way that emergencies and disasters were managed.

By obliging local authorities and other asset owners to accept a share of the responsibility for restoring damaged infrastructure, central government’s intentions were to transfer some of the risk, to limit its potential financial exposure, and to shift the focus to loss prevention and better overall risk management. As the “owners” of the assets, local authorities are best placed to identify local hazards and to implement strategies for ameliorating the consequences of any disasters. The outcome in the long run should be better protection of public assets, a safer environment for employees and society generally, less frequent interruption of essen-

tial community services, and a reduction in the financial impact of losses.

With time, however, some local authorities have started to acknowledge the wider benefits of pro-active risk strategies to eliminate or reduce potential losses. This is an encouraging trend. But it has also revealed the complexity of, and paucity of knowledge about, risk assessment involving disaster potential in New Zealand.

Risk Assessment

In New Zealand, those responsible for dealing with emergency and disaster situations have been slow to adopt risk control techniques. This is partly explained by the public scepticism that has developed over recent years in response to “expert” assurances about risks over which individuals have no control, or about which they hold different values (e.g. nuclear safety, mad cow disease, etc.). But it is also because the concept of risk can be difficult to grasp, dealing as it does with chance and uncertainty somewhere in the indeterminate future. At first sight, risk analysis seems to lack the rigour of some other disciplines and even as a process of applied science it appears to have methodological shortcomings.

Notwithstanding these perceptions, risk analysis can be a powerful aid in decision-making involving public safety or in dealing with potential emergencies and disasters. It forms an overlay on the emergency/disaster management process (i.e. the four phases of Mitigation, Preparation, Response and Recovery) which can help evaluate the contribution of each phase to overall safety management. Risk methodologies are useful not only for well-understood situations where good empirical evidence and statistics are available (bridge design, fire suppression, river control, etc.), but also for situations in which there may be inadequate direct experience (e.g. a large volcano, epidemics, or environmental issues such as stratospheric ozone depletion).

Its particular strength for analysing situations of uncertainty stems from the fact that it offers a structured, systematic and consistent approach that forces the analyst into understanding the total risk picture. Provided that hazards are identified with care and consistency, that causal models are analysed logically, and that data is subject to strict quality control, the results of risk analysis will make a practical contribution to public safety and loss prevention. Risk assessment may be defined and undertaken in many ways. Terminology varies among

different risk practitioners. This paper is most closely aligned with the definitions used in the Australian/New Zealand Standard Risk Management, AS/NZS 4360:1995.

Definitions

Risk Analysis

A systematic use of available information to determine how often specified events may occur and the magnitude of their consequences.

Risk Assessment

The process used to determine risk management priorities by evaluating and comparing level of risk against predetermined standards, target risk levels or other criteria.

Risk Management

The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring risk.

The essential idea is that it involves a formal, quantitative evaluation of potential injury or loss over a specified period of time, or the prospect of future mal-performance of a safety or security system.

Approaches to Assessment

Risk techniques do not eliminate uncertainty, but help put it in context. Provided there is some appreciation of the degree of uncertainty innate of the factors in a defined situation, risk assessment can make an important contribution to reducing potential adverse effects. In practice, there are usually no direct linear techniques for assessing risk. Experts tend to “gravitate” towards a conclusion through cyclical processes that may involve several independent approaches. For example:

- With natural hazards such as flooding, there may well be considerable local experience on which to base extrapolation to more serious risks.
- In some situations observed records and expert views will be highly valuable.
- In other situations where events are rarer (e.g. tsunami) it may be instructive to draw on experience and practices elsewhere.

In general, using a variety of approaches will yield a more robust assessment and help avoid problems of systemic bias. It will also increase the likelihood of

exposing rogue conditions or interrelationships. For effective risk management, these different techniques should be utilised in ways that lead to a quantitative outcome where possible. The better the quantitative base, the better will be decision making, resource allocation, mitigation success and, ultimately, public safety or loss prevention.

Measuring Risk

Quantitative risk assessment combines three key ideas:

- the chance of something going wrong;
- the consequences if it does; and
- the context within which the situation is set.

For any given set of circumstances, the level of “Risk” may be calculated as the product of the “Probability” of an event or adverse outcome (chance/likelihood/frequency, expressed as occurrences per unit time) and a measure of the “Consequences” of the event (damage/detriment/severity, expressed numerically as a specific value measure such as lives lost or financial damage per event). In symbolic terms, we can write the equation $R = P \times C$.

It has to be stressed that this simple product is not sufficient in itself to fully describe the real risk, but for a given situation in which the terms may be specified with reasonable accuracy, it provides an adequate basis for comparing risks or making resource decisions.

Tolerable Risk

Decisions on the appropriate level of investment for dealing with natural and technological hazards depend critically on judgements about the acceptability of risk. Strictly speaking, no level of risk is “acceptable” but, as a point of principle, risk can be considered tolerable when there are commensurate benefits. Safety does not require all risk to be eliminated: rather, that there be an appropriate balance among costs, risks and benefits. As in any analysis of this type, there will inevitably have to be value judgements made of one kind or another: what level of risk will individuals or society tolerate? What proportion of ratepayers’ funds should be invested in mitigation? What criteria should be applied?

In just the way that individuals tend to set themselves personal thresholds of tolerable risk, so too communities have informal but real perceptions of societal risk thresholds. Travellers the world over continue to fly in jetplanes notwithstanding the fact that, occasionally,

accidents occur that kill 200 to 300 people at a time. Society would probably not accept say, one jumbo jet crash per week, but seems to tolerate one per year. Clearly, when dealing with natural disasters in particular, it is not practicable to seek to achieve zero risk; the investment to make life totally safe would be beyond any government. This is more feasible when dealing with technological hazards but, even here, economics, risk acceptability, and the need for the technology have to be balanced carefully. Risk management experts recommend that, whenever feasible, those responsible try to eliminate high severity risks that might occur in a typical lifetime.

For any specific risk, they recommend trying to reduce dangers to just below a level commensurate with reasonable cost — the “As Low as Reasonably Practicable” (ALARP) principle. (Too conservative an approach to safety can easily end up costing more than the benefits.) A great deal of work has been done to try to devise standards of tolerability, but as yet they have not received universal acceptance. Desirably, risks associated with all hazards, natural and technological, should be reduced to the point where they are low compared with levels that are widely accepted by the community without concern.

Figure 1.1 brings together several different concepts to do with the tolerability of risk. Derived from risk guidelines developed in the United Kingdom, it depicts risk thresholds in terms of local acceptability of deaths from industrial and other accidents. Plotted as exceedance or disasters involving a given number (N) of fatalities. The “Local Tolerability Line” defines a region which is characterised by both high frequencies and severe consequences — the “Intolerable” region. The region between this line and the “Local Scrutiny

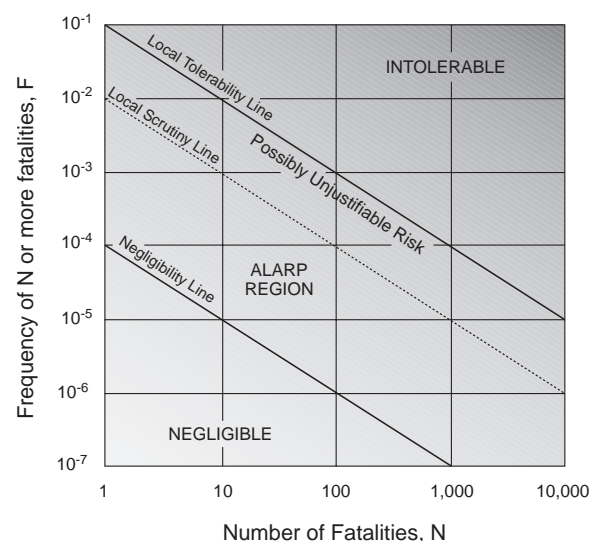


Figure 1.1: Indicative frequency-fatalities curve

Line” is a region of possibly unjustifiable risk. Between this latter line and the “Negligibility Line” is a region which is judged to be tolerable but for which all reasonably practicable steps should be taken to reduce the hazard further. This is the ALARP region (As Low As Reasonably Practicable). All combinations of frequency and number of fatalities which fall below the “Negligibility Line” are considered to be negligible.

Above a certain level, a risk is regarded as intolerable and cannot be justified in any ordinary circumstances (see Figure 1.2). Below such levels, an activity is allowed to take place provided that the associated risks have been made as low as reasonably practicable (ALARP). In pursuing ALARP, account can be taken of cost. It is, in principle, possible to apply formal cost-benefit techniques to assist in making judgements of this kind. [Source: *The Tolerability of Risk from Nuclear Power Stations*, Health and Safety Executive, London, 1992.]

Management Strategies

The risk equation ($R = P \times C$) points us to the two basic strategies for managing risk: we can try to lower the likelihood of an event happening; or we can try to reduce the consequences by putting in place suitable provisions for ameliorating the worst effects.

In practice we should do both. With natural hazards it is often difficult to do anything about modifying the likelihood of the primary event occurring, but we should be aware of possible problems from closely coupled systems and should aim to reduce the chances of further adverse events being triggered (i.e. secondary events such as flooding leading to dam collapse). By contrast, the likelihood of technological accidents

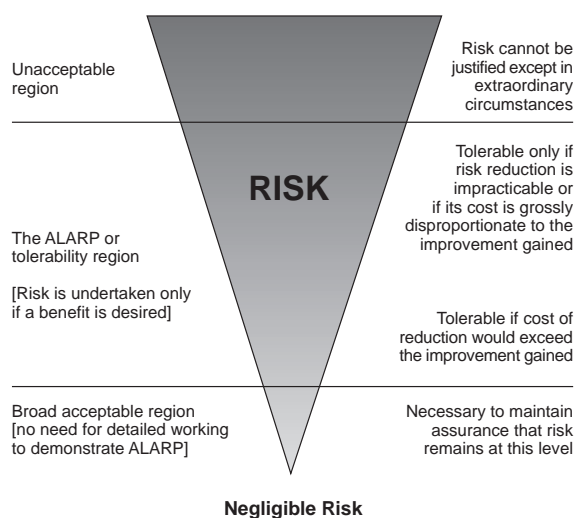


Figure 1.2: Risk tolerability levels

can be modified in many ways: by good safety engineering, redundancy in design, self-regulation, fail-safe mechanisms, defence-in-depth, and proper training, operations and maintenance, for example. In both situations we should also put in place protective or damage limitation measures, and other provisions (preparation and response etc.), to reduce the unpleasant effects should the event happen. The difficulty, of course, is in deciding on the balance of effort that should be applied to prevention (or reduction of likelihood) versus mitigation (e.g. containment, diversion, protection) or to any other aspect of damage limitation in the response and recovery phases. Low probability, high consequence events present the greatest difficulty. Some highly unlikely circumstances such as meteorite impact are most efficaciously dealt with simply by repairing the damage — the “do nothing” option.

Implementation Issues

In practice, the local authority risk manager has the difficult task of controlling the risks from all public hazards in ways that not only maintain community safety, but minimise physical damage, and reduce social and economic disruption. More than most, that person must understand the big picture and avoid excessive reliance on any one sector such as the monitoring of developments, response or insurance. Their task is to devise a management strategy that ensures every facet of the risk management process is understood, is operating well, and is in appropriate balance. They need to anticipate potential weak points since failure at a single point in the logic or practice of a safety process may jeopardise the success of the whole.

For example, where a known hazard exists (such as the possibility of a river control system failing catastrophically) the risk manager has to understand the importance of each and every factor in the risk equation, and the relative contribution each makes to saving lives and minimising damage. The following are some of the more significant considerations:

- Know what can go seriously wrong, when, and with what forewarning.
- Examine ways to reduce the chance of it happening.
- Put in place measures to contain the worst effects, divert them away from communities, or otherwise reduce the severity of the impact.
- Anticipate what might go wrong with the mitigation measures and any new risks they may introduce.

- *Test whether the warning time is sufficient to evacuate people (and decide whether the warning system and communications can be relied upon to work properly).*
- *Be familiar with all aspects of the response mechanisms (who, how, when, how reliable, contact numbers, availability, alternates etc.).*
- *Consider specific public education or training that might improve the community's reaction to the warning.*
- *Anticipate what might go wrong in the response phase, and what new risks it might introduce.*
- *Decide how the injured will be dealt with to minimise further loss of life.*
- *Develop plans for recovery (people, materials, finance, insurance, etc.).*
- *Look for opportunities to test and evaluate the entire system (especially with small events), and make adjustments.*

Resource Allocation

An important corollary is that there is no point in having any one step functioning excessively well. Each step should yield an outcome of equivalent quality in terms of its contribution to the overall safety process. Anything else represents a less than optimum use of resources. That is not to suggest that effort and resources should be applied uniformly to each step, but rather that each should receive support commensurate with its importance or potential for improving the outcome. Moreover, in complex situations involving many variables and uncertainties the precision with which the overall risk can be determined will be dominated by the most uncertain or crudely known factor.

Practical Application

It is not the intention of this paper to detail all of the steps used in developing risk strategies. That will depend on the risk being analysed. The process, however, typically involves three broad phases:

- *assessing the risks quantitatively;*
- *applying reasonable and effective safety and loss control measures; and*
- *evaluating the effects of the overall risk management programme.*

These are set out in greater detail in Table 1.1, which

represents the processes that a local authority might go through in doing a comprehensive risk study. For the sake of clarity, the sequence has been broken into five broad steps: analysis, estimation, evaluation, control and verification. Other approaches are possible depending on the nature of the risk, but the process of quantitative risk analysis would normally involve most of the steps detailed.

In an ideal world, a local authority or other risk manager would undertake a series of risk analyses covering all the risks falling within their jurisdiction in order to rank them in importance and to apportion funding for mitigation. In practice, experience and pragmatism would mean that only the most significant risks would be subject to comprehensive analysis of this type. The degree of analytical effort applied would tend to reflect the scale of risk, potential benefit, and familiarity with the hazard (e.g. expert judgement and experience might be given greater weight than other techniques in determining risks). But, regardless of the degree of formal evaluation, there are unquestionable benefits in knowing as much as possible about local hazards and in improving the understanding of risk and its control. Experience overseas has shown that risk management is most effective when those responsible for the risk fully accept ownership of the assessment and control processes. In particular:

- *Local authorities need to fully understand their local risks themselves. The practice of employing external contractors does not encourage those with the ultimate responsibility to gain the qualitative insights necessary for informed management. And, in-house knowledge is essential to understand the implications for safety under unusual circumstances or when elements of the hazard change with time.*
- *Assessment should be specific to a category of risk (e.g. flooding of a defined section of a lake or river) or to a particular facility or hazard (e.g. hydro-dam or volcano). Results from similar situations elsewhere may be relevant, but considerable care is needed in adapting from other experiences.*
- *Risk management can not be done purely on the basis of codes of practice or regulations. Risk managers need to take responsibility for the total risk situation, not merely demonstrate compliance with general safety regulations.*

Conclusion

Disasters can be difficult problems to address. They are inevitably complex and characterised by high levels of uncertainty. Typically they involve low probabilities and high consequences, making them difficult

ANALYSE

Understand the context of the hazard, existing controls, and safety objectives.
Treat all aspects of the hazard and its management as an integrated system.
Identify sources of all hazards, vulnerabilities, threats and potential losses associated with the event, activity or system.
Clarify potential problems, trigger mechanisms, and conditions of exposure.
Develop models, and establish relationships between cause and effect.
Analyse consequences of all possible outcomes, especially safety aspects.
Consider threats to life, property and environment separately.
Consider records, empirical evidence, experience elsewhere, and expert opinion.

ESTIMATE

Quantify all factors objectively, and determine uncertainty.
Carry out sensitivity analysis for the dynamic situation.
Consider physical limits and worst credible bounds (e.g. using statistical inference and scientific postulation).
Define character and magnitude (size or severity) of consequences.
Estimate chance (likelihood or frequency) of event or condition.
Calculate component risks and overall risk using Probabilistic Risk Assessment.

EVALUATE

Determine significance of estimated risks (in absolute and comparative terms).
Consider acceptability (in terms of both individual and societal tolerance).
Study economic impact and funding options for response and recovery.
Examine costs and benefits of control for most serious risks.
Assess cost risk benefit balance.
Decide to accept, reduce, or transfer risk.

CONTROL

Minimise, Mitigate and Manage risks, i.e.: develop ameliorative measures that:

- lessen likelihood of event and/or consequent system failure;
- lower magnitude of consequences;
- provide resources for response and recovery.

Consider all possibilities for risk reduction:

- design for safety, using prevention, protection, and damage limitation;
- reduce uncertainty, monitor constantly, maintain and upgrade systems;
- set standards and apply quality control at all steps;
- develop defence-in-depth (layered response) to counteract small failures;
- reduce likelihood of human error or perversity (training and safety culture).

VERIFY

Test effectiveness of risk reduction strategies.
Obtain independent safety audit and inspection.
Establish incident reporting methods that include responses etc.
Establish feedback mechanisms to learn from experience, then re-prioritise.
Develop compliance programmes covering management, training and procedures.
Assess cumulative system risk across all stages (including any additional risk introduced by intervention, i.e. mitigation, preparation, response and recovery).
Establish quality assurance mechanisms to have all parts optimally balanced.
Continually monitor, review and improve systems.

Table 1.1: Risk management strategy for natural and technological hazards

to analyse. The most serious events are (fortunately) the least likely to happen, but this also means there is often a lack of reliable data. Data that does exist may be held anecdotally or in a variety of forms by different agencies. And, not least, because of their potential to affect people adversely, they can end up being the subject of conflict or controversy.

The analytical techniques now becoming available for interpreting situations of this type have much to offer those responsible for public safety and loss prevention. Risk management strategies of themselves cannot guarantee better performance because of both the role that chance and uncertainty play, and the vagaries associated with human intervention. But the methodologies used for assessing risk can contribute to understanding where the most serious components lie. They can point to the more promising control options, assist policy development, and inform the allocation of resources. Risk analysis is therefore going to be used increasingly in the management of emergencies and natural disasters in New Zealand. The message from government is clear. Those responsible for public safety and for managing infrastructural assets in New Zealand are obliged to assume full responsibility for managing the risks, i.e. to identify the hazards, to assess the risks, and to take whatever precautions are required. Support from central government is conditional upon proper risk management having been demonstrated. These are not matters that can be regulated in Wellington. It is up to the local authorities or asset owners to take responsibility for balancing the costs, risks and benefits in the best interests of the communities they serve.

Relevant Quotations

The following quotations are from *Risk and Uncertainty* by Janet Gough (Information Paper No.10, Centre for Resource Management, July 1988).

Page 1

Risk is an important part of our everyday existence. We continually expose ourselves or are exposed to risk over which we may have little or no control. Our perception of the risks we encounter varies according to factors such as whether our exposure is voluntary or involuntary, how much control we feel we have over the risk, and whether or not we feel that the risk is 'fair'.

Increased knowledge, as well as technological and institutional changes are giving us greater control over our environment and at the same time allowing us to modify it at a much faster rate than previously. The number of risks involved is increasing and as greater knowledge does not necessarily reduce total uncer-

tainty, the magnitude of technological and environmental risk is also increasing. Man is now able to create his own catastrophic events, without the aid of God.

Some of the types of risks we encounter as a society include environmental, psychological, physical, future oriented and political risk. It is noteworthy too that as well as having varying perceptions as to the degree of risk involved in a particular activity, individuals and groups have different perceptions of the types of risks involved.

People concerned with the study of risk include philosophers, sociologists, business managers, economists, engineers and politicians. Of these, philosophers, sociologists and economists are concerned primarily with the characteristics of risk and choice under uncertainty, engineers are concerned with quantifying risk, while managers desire to manage and reduce risk. Politicians and decision makers rely on information obtained from the other groups to make decisions which will in part reflect the risks involved and in part be the result of other contributing factors.

Page 3

Risk-related problems tend to enter the public domain when the magnitude of the potential outcome is so great that it might have possible severe or even catastrophic consequences for large land or sea areas or big population groups. These population groups may be identified by geographic, demographic or other social boundaries.

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The decision-making process begins with the decision that a problem exists, and in any decision-making process there will be a number of value elements about which value judgements must be made. These judgements are necessary because there is seldom a commonly accepted 'correct' approach. Rowe (1977) divides these value judgements into three groups:

- (1) technical value judgements;*
- (2) social value judgements; and*
- (3) managerial value judgements.*

Technical value judgements are important, since very often the 'experts' who make technical risk estimates do not recognise that these estimates are in fact value judgements because of the uncertainties and assumptions involved in their calculation. Social and managerial value judgements are more readily accepted as such because they are generally more open to scrutiny by external observers.

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Statistical estimates of risk are used when there are sound statistical data available for the particular event being studied. In this way, we can make reasonable estimates of the risk to the child from a mother smoking during pregnancy (using long run average frequency estimates). The difficulties arise when, for example:

- (1) the historical data being used is not sufficiently specific for the purpose for which it is being used;
- (2) the data does not cover a sufficiently long period;
- (3) the estimate obtained is applied to a different population to that from which it was derived; or
- (4) the probability of occurrence is very low.

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Fischhoff (in Covello et al., 1981) lists six reasons why disagreements occur between the public and experts:

- (1) the distinction between 'actual' and 'perceived' risk is misconceived;
- (2) lay people and experts are talking different languages;
- (3) lay people and experts are solving different problems;
- (4) debates over substance may disguise battles over form and vice versa;
- (5) lay people and experts disagree about what is feasible; and
- (6) lay people and experts see the facts differently.

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Fischhoff (1978) defines acceptable risk in the following way: "The acceptable level is the level which is 'good enough', where 'good enough' means that you think the advantages of increased safety are not worth the costs of reducing risk by restricting or otherwise altering the activity."

Rowe (Goodman and Rowe, 1979) describes a set of conditions which he suggests support the existence of acceptable risk. They are:

- risk which is perceived to be so small as to be deemed negligible;
- risk which is uncontrollable or unavoidable without major disruption in lifestyle;
- acceptable risk levels established by a credible organisation with responsibility for health and safety;

- historical levels of risk which continue to be an acceptable one; and
- risk which is deemed worth the benefits by the risk taker.

He refers to these as the threshold condition, the status quo, the regulatory condition, the de facto condition and the voluntary balance condition. These are examples of risks which we argue should be termed **accepted risks**. We further contend that there is no such thing as acceptable risk, but only accepted risk, and that this is what is commonly meant by the term acceptable risk.

Risk management considerations and the community

The following discussion presents some issues of relevance to risk management beyond those specifically considered in the project work. To some degree, these are implicit in what has been done, however there are gaps in the work and these are recorded to qualify the results to date and to flag areas for attention in any future effort.

Risk acceptance criteria

In compiling mitigation measures, the project identified many things of modest cost that have already been adopted. Other sensible measures can be phased in through ongoing maintenance and replacement programmes, often with little or no extra cost. Where the requirement is costly, however, and may have some urgency, there is a need for a rational approach to decision-making.

The following discussion describes how decisions could be made regarding proposed mitigation measures in terms of the effects on the community of the particular hazard scenarios considered. Largely, the decision whether or not to invest in mitigation rests on the level of risk that is acceptable to those affected. The more risk that may be accepted, the less need there is for mitigation.

The perceived magnitude of risk consequences, and the probability of occurrence in relevant forward time frames, will determine acceptability or non acceptability to those affected.

In discussing the concept of risk, it is suggested that people are concerned about effects that may realistically occur within their "cognisant lifespan", say, 50 years. To the extent that people's views can be extended to society as a whole we should consider impact through loss of lifelines on that basis. So an imperative

for action is the likelihood or probability of the outcome of concern occurring, or, more properly, being exceeded within a 50 year period.

We therefore have the two-dimensional problem of selecting hazards that occur often enough, and which are severe enough in terms of the consequences of lifelines failure that we should do something about them.

Figure 1.3 illustrates this problem and proposes the existence of decision spaces which may assist in differentiating between acceptable risk and risk which may require action.

Obviously, if a frequently recurring event (lifelines failure) causes catastrophic effects in the community, the risk of failure is unacceptable and action is indicated. Conversely, if extremely rare occurrences result in only minor impact, the risk of failure will be acceptably low and no action would be required. In the range between these cases there will be a transition from “yes, we must act” through ambivalence to “no, we don’t need to act.”

The assignment of hazards to decision spaces is dependent upon the meaning of “frequent”, “remote”, “major”, “catastrophic”, etc. Some definitions of terms have been drafted and these are given below. These definitions, and the perception of the hazards issues, are then used to assign them to decision spaces.

Probability parameters definitions

Frequent

A 99.5% probability of the particular hazard scenario

being exceeded in a 50 year period. This is equivalent to a one in ten year occurrence event.

Reasonably probable

Probability of exceedance greater than 50% and less than 99.5% in a 50 year period.

Remote

Probability of exceedance greater than 5% and less than 50% in a 50 year period.

Extremely remote

Probability of exceedance less than 5% in a 50 year period. This is equivalent to a 1 in 1000 year event.

The problem with these definitions is that they place the majority of our hazards in only two classes. They do, however, reflect an intuitive understanding of the terms, “frequent” and “extremely remote” in particular.

The return period of exceedance and the probability of exceedance for identified hazard scenarios are given in Table 1.2. The relationship between return period of exceedance, and probability of exceedance for engineering lifelines is discussed below.

Effects Parameters:

The effects of lifelines failures on the community may be expressed in terms of inconvenience, economic cost, threats to life and health, social impacts, and threats to the natural environment. A significant factor will be recovery time.

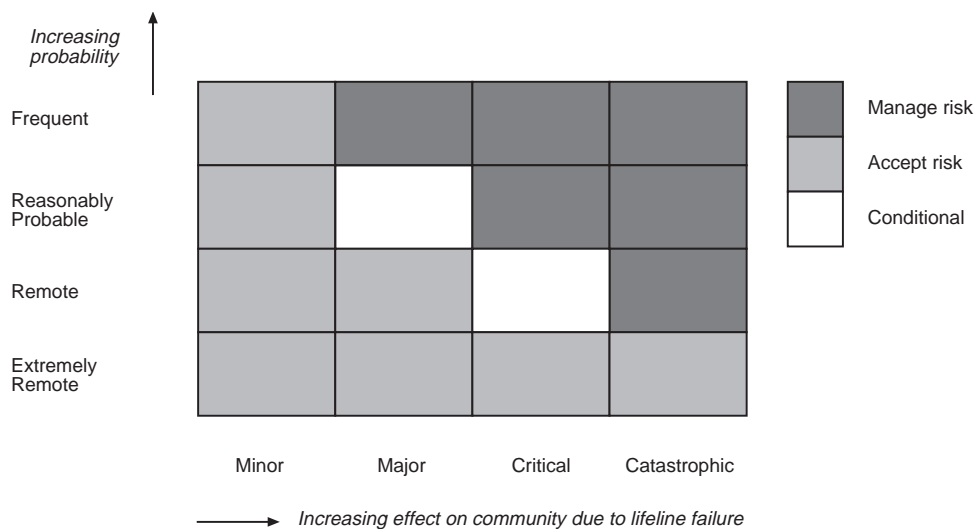


Figure 1.3: Risk acceptance criteria

Hazard	Return Period of exceedance (years) (indicative)	% Probability of exceedance	
		In 1 year	In 50 years
Local flooding	1000	0.1	5
Waimak flooding	500	0.2	10
Seismic	150	0.67	28
Wind	150	0.67	28
Tsunami	150	0.67	28
Snow	50?	2.0	64

Table 1.2: Probability and return period of exceedance for identified hazard scenarios

Minor effects

Temporary loss of one or more utility services, recovered generally (may be residual local loss) in less than one week with essential services restored in one to two days. Loss of life would be unlikely, however there may be freak accident scenarios. The well-being of people on life support or equivalent systems may be placed at temporary risk. Economic impact would be generally low but could be selectively significant for some businesses. Social impacts are largely of very temporary inconvenience.

Major effects

Short-term loss of more than one service (could be through interdependency), say, two to three weeks, which would require importation of resources to retain essential services. Possible loss of life, but low numbers (single figures?). Some at-risk people may die through loss of life support, etc. Social impact would largely be one of sustained inconvenience with associated stress and conflict. There would be a significant impact on the local economy, but this would be generally recoverable with local resources. There may be some business failure.

Critical effects

Medium-term (three to six months) loss of more than one service, which would require substantial assistance and temporary provision for meeting population needs (for example, evacuation, water delivery, temporary field hospital facilities, etc.). There would be moderate loss of life, say less than one hundred. Public health would be a serious management issue, people with marginal antecedent health likely to die. There would be major social and economic impact on the local community that would require large-scale relief from outside the region. This would provide difficult but manageable resourcing issues for central government.

Catastrophic effects

Total loss of most lifeline services would occur requiring major external support effort and emergency regulation for many months. There would be significant loss of life (one hundred to low thousands). There would be major social impacts both locally and probably New Zealand wide. Serious health issues would arise that could not be properly addressed. There would be a devastating impact on the local economy with very difficult consequences for the national economy.

On that basis the hazard scenarios could be plotted as shown in Figure 1.4.

The outcome of this provisional evaluation is that only seismic hazard is clearly out of the acceptable risk category, but it is still not clearly of the “definite action required” category in terms of fundamental community needs. That is not to say that action is not relevant to optimise the performance of utilities, or that co-operation between utilities owners in prioritising mitigation and recovery action is not of social benefit.

We may be looking at fine tuning rather than a need for a fundamental shift in policy in lifelines management.

Who defines acceptable risk

What is an acceptable level of risk depends upon who is affected by the hazard. Each community of interest will have different needs. Those concerned will include utility owners, utility operators, utility customers and the community as a whole. The wider community needs may be met to some extent by regulations (e.g. the Building Act), however, in this case, regulations do not fully cover the issues concerned. It is suggested that the lifelines participants can represent the interests of owners and operators reasonably well. The needs of customers and the wider community (is there a difference?) is something else again.

In applying the above method to assessing acceptable risk, the assignment of issues to decision spaces rests

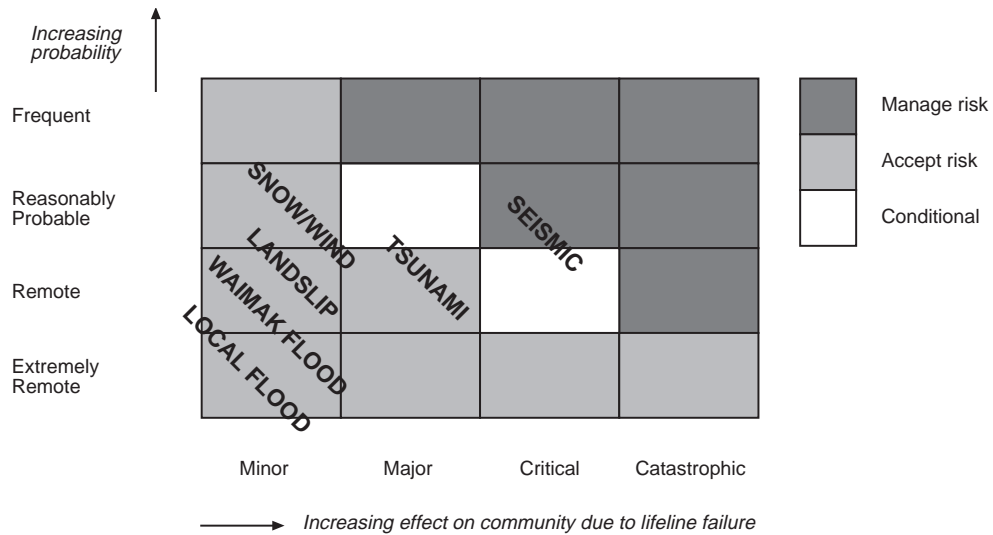


Figure 1.4 : Acceptability of lifelines hazards risk

heavily on the definition of terms and the individual perceptions of anyone brave enough to use it. The “right” decision would rely upon it being in accord with wider community perceptions. Failure of our system management will be signalled by adverse public reaction. Of course the wider community would have limited understanding of the effects of loss of lifelines until the hazard actually occurs. In the meantime, the best we can do is use our collective experience, and the experience of others, and propose a course of action given overt assumptions. This is what is being done in this project. The community at large should be consulted in some way to check the validity of these assumptions, which would in turn require public education to ensure consultation is informed. This is a job for the utilities owners over time, with appropriate technical input. However, it could also be considered in any future lifelines efforts.

Hazard scenarios

The project used discrete hazard scenarios selected on the basis of the knowledge and intuition of the hazards task group, as moderated by other participants in the project. There are some inherent difficulties in this approach; in particular, the single scenario may leave some surprises for us that a broader view may have avoided, and the single scenario may not be the optimum in terms of return on investment in mitigation.

By studying a range of scenarios the above difficulties can be overcome to some extent.

A plot of potential damage rate against probability of exceedance for a range of event scenarios typically takes the form shown in Figure 1.5. The area under the graph equates to the total unmitigated damage poten-

tial of all possible event scenarios for the period under consideration.

In theory, mitigation can be optimised by designing to a particular exceedance probability such that the damage potential saved divided by (the cost of mitigation plus the residual damage potential) is a maximum. (The cost of mitigation depends on probability as well.) This approach is routinely used for flood mitigation decision making in New Zealand. Also, by considering the full range of event scenarios, knowledge of the effects of super design events will be of value to preparedness and response planning, if not mitigation.

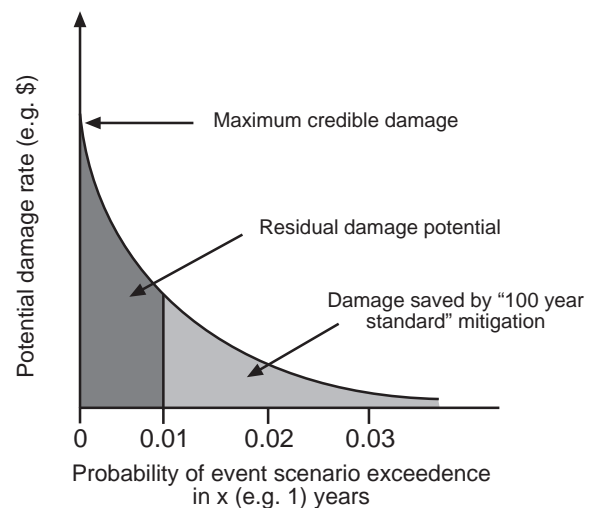


Figure 1.5: Hazard damage/probability relationships

But an approach of this type would have required immensely more work (on a component by component basis) which could have been unsustainable in terms of utilities support for the project. Moreover, an exhaus-

tive approach of this type would not be appropriate given the high levels of uncertainty involved in our knowledge of the hazards, and the network responses to them.

It is therefore considered that the approach taken — the selection of a realistic scenario and mitigating its effects — is a reasonable first step. One thing that would be of value for future study would be to put the work in the perspective of possible super design events. The historical experience in flood mitigation is that design standards are regularly exceeded in nature and it is now common practice to at least consider the effects of maximum credible events, rare though they may be.

Project Methodology

Introduction

Earthquakes and other natural hazards can damage the utility networks that provide essential support to human life and well-being. Severe social consequences can arise through network failures. Network owners need to allow for appropriate levels of hazard mitigation in their asset management strategies. They also need to consider how they will respond to disasters when they occur and it is useful if network owners collaborate in this. Resources can be shared in the definition of hazards, and in working through their implications. But, most importantly, in most cases there is a high level of interdependency between lifeline services. Each lifeline generally needs the others in some way. Collaboration in mitigation is therefore essential if the best results are to be obtained.

A key function of the project was to provide hard information to facilitate hazard mitigation measures which meet the needs of each network and the lifelines system as a whole.

It recognised that natural hazards form only part of the overall concerns relating to network vulnerability. Other hazards include human error in operation, defective plant, fire, chemical spills and sabotage. Budget decision makers will also consider factors such as operational costs, service demands, wear and tear, etc. Often factors other than natural hazards will prevail in the work and purchase programme, but even so it will often be a simple matter and relatively inexpensive to incorporate mitigation measures to avoid the worst effects of hazardous events.

This section outlines the methodology adopted for the project and places it in a context of risk management. Limitations of the approach are discussed and suggestions are made regarding any possible future work.

It is acknowledged that the methodology closely follows that adopted for the Wellington Earthquake Lifelines Project (Centre for Advanced Engineering, 1991), to which we are greatly indebted.

Risk management

In its pursuit of more resilient networks, any lifelines project is essentially an exercise in risk management. Because we have no uniquely defined problems in front of us (an actual disaster) we have to deal in possible disaster outcomes which we hope will bear some resemblance to events when they do occur in the future. Experience elsewhere, and our knowledge of the Christchurch networks and likely hazards, was combined to forecast, with no little uncertainty, what can go wrong and from that what may be done to prevent or mitigate it.

Risk is often expressed numerically as the product of quantified outcomes (e.g. \$ damage) and probability of occurrence. Outcomes can then be compared and the preferred one chosen.

As in most risk situations, the definition of natural hazards risks to Christchurch lifelines is fraught with uncertainty. Numerical methods of risk assessment therefore have their limitations. They are, however, a useful aid to decision making, as long as uncertainty is taken into account.

The project used a broad-brush approach to quantifying risk. This provided useful comparative information, but it did not promote absolute figures for damage which could be related to cost of mitigation. Utilities operators need to do that for themselves. Risk management may be considered to include the following steps:

- definition of the system at risk, in this case a utility network, and its components;
- description of the hazards faced by the system, and its vulnerability to those hazards, in this case natural hazards;
- description of the damage which may be sustained by the system and its wider impacts;
- identification of appropriate mitigation measures; and
- preparation and implementation of an action plan.

While the lifelines project broadly followed this process, there are some areas of acknowledged weakness which have been accepted for expediency, and practicality. These are discussed in “Risk management considerations and the community” (page 8).

Project structure

Project participants were structured into task groups firstly to identify the hazards and then representing network types:

- hazards;
- civil services;
- electrical and communication;
- transport;
- buildings; and
- fire.

The hazards group defined the natural hazards to the networks, such as seismic, flooding, tsunami, landslip, etc., and provided ongoing advice as the networks task groups worked through the detail of their assessments.

The networks task groups were responsible for describing the networks considered to be critical to delivery of lifeline services, and for working through the risk management process to the action phase.

The project organisation is shown in Figure 1.6.

Hazard scenario selection

A disaster scenario was described for each natural hazard under consideration. The approach taken was to select a scenario which, on the one hand could be considered to pose a significant hazard, but on the other had some realistic probability of exceedance in forward planning timeframes.

Wherever possible, the hazard was represented in a hazards map, otherwise the hazard was described as a scenario, e.g. wind and snow.

Some limitations of this approach are discussed in “Risk management considerations and the community” above (page 8).

Risk analysis

Each network was broken up into components, which were then assessed for their vulnerability to each hazard scenario. This was done by overlaying electronically the networks over the hazards map which was then examined to determine importance, vulnerability and impact of damage.

A scale of 1 to 3 was used to define component vulnerability: 3, 2, 1 corresponding to high, moderate, or low probability or distribution of failure. (“Probability” relates to components that are discrete elements, “distribution” relates to components that are grouped elements, (e.g. networks)). ‘0’ indicates no susceptibility to damage.

The consequences of failure of each network component were then assessed, taking into account its importance to the network concerned, and the wider impact of its being damaged.

Importance was ranked 1 to 5, with 5 being most important. A component’s importance would be ranked highly if it were essential to the function of the network as a whole. It would be ranked low if it could be bypassed.

Impact related to the degree of disruption caused or the effort required to reinstate it. Impact was consequently assessed for three timeframes:

- immediately after the hazard event;
- the period following the hazard event; and
- the time for return to normality.

“Immediately after the hazard event” covers the period for recovering a minimum emergency service by backup, bypass or temporary repair.

The “period following the event” is the period to restore a full service, albeit perhaps on a temporary basis.

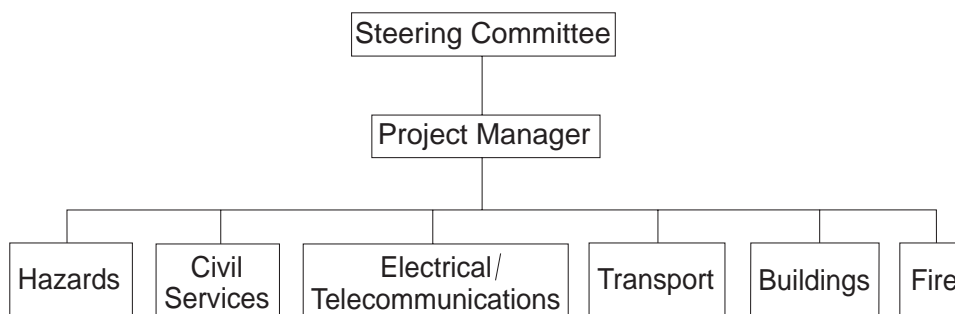


Figure 1.6: Project organisation chart

Mitigation measures

The vulnerability charts were then used for identification of the need for mitigation measures. Any measure that would reduce importance (e.g. by redundancy), reduce vulnerability (e.g. by strengthening), or reduce impact (by alternatives or contingency planning), would mitigate the impact of the disaster. The rankings provide a basis for prioritising action where budgets may be a limiting factor. In many cases, however, mitigation measures identified were very inexpensive, or could be easily integrated with ongoing maintenance and replacement programmes.

An holistic approach embodying all opportunities for mitigation will include strategies at the asset planning, engineering and operational levels.

Utility service provision can be planned to encompass:

- hazard awareness programmes;
- planning for redundancy;
- locating to avoid hazards;
- review of alternatives for critical components; and
- systems monitoring and response planning.

Engineering design and detailing can include:

- hazard-wise layout and conceptual design;
- hazard-wise design standards;
- hazard-wise code levels;
- hazard-wise procedures and practices;
- hazard-wise detailing; and
- special measures for critical components.

Each utility's operations management can incorporate:

- preparedness and response planning;
- appropriate spares holdings;
- equipment inventories;
- rerouting options;
- damage assessment; and
- planning staff training and exercises.

Interdependence

The methodology described above was carried out network by network. The interdependence of networks, both in operation (if A fails, B fails), and in response (need to fix A to get to B) can be a critical

factor. It is no good for the wider community if individual utilities go their own way in ignorance of the impacts of other utilities on them, and vice versa. Interdependencies are discussed further in Chapter 10.

Risk in Relation to Mitigation

The ultimate measure of the success of the whole project was the extent to which budget provision was made for the various mitigation measures that have been identified. To assist in this it was necessary to attempt to translate the technical assessments undertaken into understandable information so that the decision-makers (which includes the public) can themselves have some conception of the risk involved and the justification for any expenditure.

It is important that as a result of publicity regarding the project, people do not become unnecessarily concerned. It has to be remembered that the work was essentially an engineering lifelines project, the result of which will mean improved security of the engineering lifelines after some catastrophic event. It does not attempt to address Civil Defence concerns. (Nevertheless the whole project will be of inestimable value to Civil Defence in the event of an emergency.)

The public sometimes have such a perception of a risk that, however unlikely the event is to occur, they are prepared to pay for the mitigation of the hazard producing that risk. For example, the people of Christchurch have always been concerned about flooding from the Waimakariri and although it would appear the likelihood of Christchurch flooding from the Waimakariri is very much less than the risk from the other hazards identified, the public of Christchurch still want the city protected from the Waimakariri River flooding.

Reference to some of the quotations on pages 7 and 8 draws attention to the different way in which risks are perceived by different people, and concern could be expressed that those involved in the lifelines project are mainly engineers or managers. Although these people are decision-makers in their own right, most ultimately report to Councils or Boards of Directors whose members are most often non-engineers. It was thus necessary to attempt to express the likelihood of the various events and the justification for the mitigation measures in understandable terms for the decision-makers, which include the Councils, Boards of Directors, and ultimately, of course, the public.

In endeavouring to tease out proposed mitigation measures in one of the Task Groups, one engineer made his own value judgement to the effect that "the (decision-making body) would never give us funds for those sorts

of measures. It is a waste of time identifying them. We are much better to recommend something that may be financially viable". In the context of the lifelines analysis this should not be the approach. Ultimately, someone has to take the various recommended mitigation measures from the report and recommend their adoption in an environment that at budget time was almost inevitably one of pruning desirable works. The person making those recommendations, who is part of the decision-making process, has a very real responsibility to understand what is involved and be best able to assist the decision-makers.

The real test as to whether or not a community is prepared to accept the risk occurs at budget time, when the authorities decide whether or not to allocate money for mitigation measures. It is therefore most important that the decision-makers have the risk assessment expressed in understandable terms.

Budget needs by public authorities are assessed often with little flexibility because of the fixed charges that have to be met and the maintenance requirements, so the "spare money" is very small and there is a lot of competition for the discretionary budget.

Some decisions may be made simply in a hard

commercial light and the impact of being unable to operate a business for some time may warrant expenditure that could be said to be in the form of an insurance. However, in some cases there will not be a commercial loss but a very great inconvenience and, in fact, even danger to the public. It should be possible to distinguish between these — it is not simply an engineer's decision as to what work will be done.

In effect, the project drew to the attention of the participants in the project the risks that existed. The extent of investigation and funds allocated is left to the individual authorities. Problems may arise when these authorities take decisions that affect the interdependence of other lifelines. Interdependence issues must be taken into account when budget allowance is made. It is also important to regularly review progress on the mitigation measures and this alone would justify a continuing lifelines group.

Those involved in Civil Defence are aware of the general "motherhood" status of Civil Defence in that everybody agrees that it is necessary but very few do anything actively about it. An engineering lifelines investigation must not have that same status.

The investigation associated with this project was technically very interesting but would have failed in its objectives if the work on the project was not translated into budget provision for mitigation measures to be undertaken (see Chapter 11).