Natural Hazard Risk Management for Road Networks

Part II: Implementation Strategies

Transfund New Zealand Research Report No. 222

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An Important Note for the Reader

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- Wellington City Council enabled development of some of the risk management approaches as part of the risk study for the Wellington City road network carried out for the Road Asset Management section. We thank Mr Deven Singh of Wellington City Council for this contribution, and also for his comments on the risk management approaches and peer review comments.
- Opus International Consultants facilitated development of some of the risk management methods using GIS, as in-house research.
- Participants in the workshop on risk management implementation held by Opus on 12 July 2001 and others in the road sector who made available time for discussion of the issues.

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Executive Summary

Road networks are lifelines for the community and are essential for the economic and social well-being of New Zealand. Natural hazard events cause significant and widespread damage to transportation networks, leading to significant repair costs to road controlling authorities, access difficulties for emergency services, and disruption to road users and the community at large.

The proposed Civil Defence and Emergency Management (CDEM) Act will place a responsibility on operators of lifeline utilities to be able to function after an emergency, and to demonstrate their capability of doing so. This requires comprehensive planning and action to achieve reduction of risk, together with readiness for, response to and recovery after emergency events.

A co-ordinated and systematic effort to manage the natural hazard risk to road networks is lacking. Current efforts have considered the risk associated with earthquake damage to state highway bridges only. Part I of this research study developed strategies to manage risks to road networks as a whole. Part II, which was carried out in 2000–2001, explored the implementation of these strategies, and the outcomes are presented in this report.

The research involved considering overseas approaches to risk management, review of recent New Zealand approaches, and consultation with stakeholders and road funding, planning and controlling authorities.

Effective management of natural hazard risk to road networks in New Zealand will require implementation at the following five levels:

1. national strategy,
2. regional land transport strategy,
3. local road network asset management,
4. emergency management planning,
5. project development.

The national strategy would be developed from the regional strategies and the national emergency management plan required under the proposed CDEM Act, with the assistance of Transit New Zealand (Transit), which manages the national state highway network.

The research also identified ways in which the road funding policy set by Transfund New Zealand (Transfund) could be modified to encourage and facilitate prudent risk

management by road controlling authorities. Suggested changes to the policy include:

1. Providing assistance for developing risk management plans and risk assessments.
2. Requiring a prudent level of mitigation as part of emergency repairs, consistent with the importance of the particular road link based on risk management strategies.
3. Enhancing preventative maintenance programmes, with appropriate criteria for funding based on the importance of the road.
4. Enhancement of Transfund's *Project Evaluation Manual* (*PEM*) by incorporating levels of risk for road projects depending on their location in the network and importance of the link.
5. Including guidance in the *PEM* on assessing risk, indirect benefits, and intangible factors such as the importance and lifeline status of the road.

Developing regional road risk management strategies and incorporating them in land transport strategies will help define the improvements necessary to increase the resilience of the road networks within a region. This will also identify roads significant to the region, providing an input to risk assessments at the local network and project levels.

Risk management studies by road controlling authorities will assist in the development of asset management plans that allow for actions to improve the resilience of the road network to natural hazards. The spatial GIS-based risk analysis developed in Part I of this study will help in developing suitable strategies based on risk analysis. Transit New Zealand's state highway strategy studies provide a basis for initiating risk assessments, which can then be combined to assess the risk for the network. Road network risk studies would be suitable for similar assessment for the risk management of local authority roads.

The network risk management assessments can also provide inputs for the emergency management plans required under the proposed CDEM Act. It is important to co-ordinate the emergency management plans for roads with regional emergency controllers and plans for other lifeline utilities.

To ensure that the road networks become more resilient to natural hazards over time, it is important that, in road project development, the performance requirements in terms of natural hazard risk are considered, according to the importance of the road link within the network. Inclusion of robust risk analysis in project evaluation will help justify the additional level of risk reduction that may be prudent. This is illustrated through examples of risk economic analysis at project and link levels.

Integration of the various levels of risk management by different authorities is important to ensure that a coherent approach to improving the resilience of road networks to natural hazards is adopted.

Abstract

Road networks are lifelines for the community and are essential for the economic and social well-being of New Zealand. Significant natural hazard events can cause widespread damage to transportation networks, leading to significant repair costs to road controlling authorities, access difficulties for emergency services and disruption to road users and the community at large.

To improve the resilience of the road network to natural hazards, risk management is required. This report, Part II of a research study, develops methods of implementing natural hazard risk management at five levels: national, regional, local network, emergency management and project development. The responsibility for implementation is discussed, together with the need for an integrated approach between the five levels. Project risk evaluation is illustrated through examples of risk economic analysis at project and link levels.

Road funding policies have a significant influence on risk management. Suitable amendments to funding mechanisms to encourage and facilitate risk management at all levels are discussed.

1. Introduction

Road networks are lifelines for the community and are essential for the social and economic well-being of New Zealand. Natural hazards such as earthquakes, storms, floods, volcanic eruption, snow, wind and slope failures are prevalent in New Zealand, and cause considerable damage to road networks from time to time. Significant natural hazard events can also cause widespread disruption to transportation, leading to significant repair costs to road controlling authorities, access difficulties for emergency services, and disruption to road users and the community at large. The consequential effects on businesses and the economy can be significant. Road networks are also crucial in enabling the community to survive in the aftermath of a major natural disaster, and to recover from it.

There are currently no systematic approaches to natural hazard risk management for road networks in New Zealand. The response is traditionally reactive, and involves cleaning up and reinstatement after natural hazard events. The potential damage to bridges from earthquakes is being addressed systematically through a seismic screening programme for state highway bridges, and risk mitigation has been carried out for some of the important bridges. However, these approaches do not consider the whole road network.

As Part I of a Transfund New Zealand-sponsored research project, Opus International Consultants developed strategies for the management of natural hazard risk to road networks (Brabhaharan et al. 2001). The research report identified approaches for:

- assessing the spatial risk to road networks using a geographical information system (GIS),
- considering risk mitigation,
- prioritising sections of road for management of the risk,
- considering intangible factors.

The study recommended further research into how these risk management strategies can be implemented by the various organisations involved in the planning, management and funding of road networks.

The proposed new Civil Defence and Emergency Management (CDEM) Act places a responsibility on lifeline and utility operators to manage the risks to their operations, so that they will be able to function during and after emergencies, including natural hazard events. The Act will require road controlling authorities to consider the risk to road networks under their control, and to demonstrate how the risk is being managed and that the roads will be able to function after an event.

This report is Part II of the Transfund-sponsored research project, and considers how risk management can be implemented for road networks. It was compiled in 2000–2001 from research into current practices, discussions with road controlling and funding authorities, and consideration of the methods and issues involved in implementing risk management. It presents different levels at which risk management should be addressed, and discusses how these may be integrated to achieve a resilient road network. The report also considers the current funding regime for roads, how this affects the management of risk, and what changes could facilitate a more proactive approach to risk management. Risk economic analysis at project and link levels is also illustrated through examples. In conclusion, the outcomes derived from this research are presented.

2. Research Objective and Methods

2.1 Objective

The objective of this research was to develop methods for incorporating natural hazard risk management into routine road planning, management and design practice.

The methods developed consider the application of natural hazard risk management to land transport strategies, road network asset management, and the design of specific roading projects.

2.2 Evolution of Research Methodology

The research methodology evolved as the project proceeded, to take into account the results of the information search and review. It became clear that little information was available on how natural hazard risk management is implemented in other countries, where the approach appears to be as reactive as it is in New Zealand. Most overseas research concentrated on seismic prioritisation and retrofit of bridges only. Contact with overseas authorities yielded little information.

The research therefore concentrated on recent approaches in New Zealand to deal with risk management issues, and discussion with parties in New Zealand. This included consideration of New Zealand influences on risk management and of barriers to effective management of natural hazard risk in the roading sector, focusing on ways to overcome the barriers and to apply the techniques developed in real roading-sector practice.

2.3 Outcomes

The research outcomes were:

- approaches to incorporating road network risk management into New Zealand roading-sector practices at various levels,
- consideration of the responsibility for the effective application of road risk management in New Zealand,
- consideration of risk analysis methods and issues in incorporating risk management into road projects, which may be used as a basis for Transfund to develop policy for project evaluation, and supplement the *Project Evaluation Manual* (Transfund 1997), and
- consideration of the barriers to effective risk management and of how to improve funding policies to encourage prudent road risk management.

3. Risk Management Framework

3.1 The Joint Australia/New Zealand Standard

The process of risk management was presented in Part I (Brabhaharan et al. 2001). The process as it applies to roads is presented again in this section, to provide the basic framework for the discussion later in this report.

The Joint Australia/New Zealand Standard on Risk Management, AS/NZS 4360:1999 (Standards Australia 1999), presents a useful framework for the management of risk, and provides some important definitions.

3.2 Definitions

Selected definitions from AS/NZS 4360:1999 follow.

Term	**Definition**
Event	an incident or situation which occurs in a particular place during a particular interval of time.
Hazard	a source of potential harm or a situation with a potential to cause a loss.
Likelihood	used as a qualitative description of probability or frequency.
Probability	the likelihood of a specific event or outcome, measured by the ratio of specific events or outcomes to the total number of possible events or outcomes. Probability is expressed as a number between 0 and 1, with 0 indicating an impossible event or outcome and 1 indicating that an event or outcome is certain.
Consequence	the outcome of an event expressed qualitatively or quantitatively, being a loss, injury, disadvantage or gain. A range of possible outcomes may be associated with an event.
Cost	of activities, both direct and indirect, involving any negative impact, including money, time, labour, disruption, goodwill, political and intangible losses.
Loss	any negative consequence, financial or otherwise.
Risk	the chance of something happening that will have an impact upon objectives, measured in terms of consequences and likelihood.

Term	Definition
Risk assessment	the overall process of risk analysis and risk evaluation.
Risk evaluation	the process used to determine risk management priorities by comparing the level of risk against predetermined standards, target risk levels or other criteria.
Risk acceptance	an informed decision to accept the consequences and the likelihood of a particular risk.
Risk avoidance	an informed decision not to become involved in a risk situation.
Risk treatment	selection and implementation of appropriate options for dealing with risk.
Mitigation	appropriate action for dealing with risk.
Risk management	the culture, processes and structures that are directed towards the effective management of potential opportunities and adverse effects.
Risk management process	the systematic application of management policies, procedures and practices to the tasks of establishing the context of, identifying, analysing, evaluating, treating, monitoring and communicating risk.

3.3 Risk Management Process

A structured approach will enable rational consideration of the risks and will facilitate making appropriate decisions. AS/NZS 4360:1999 presents a commonly used process for risk management, which is shown in Figure 3.1 on page 16.

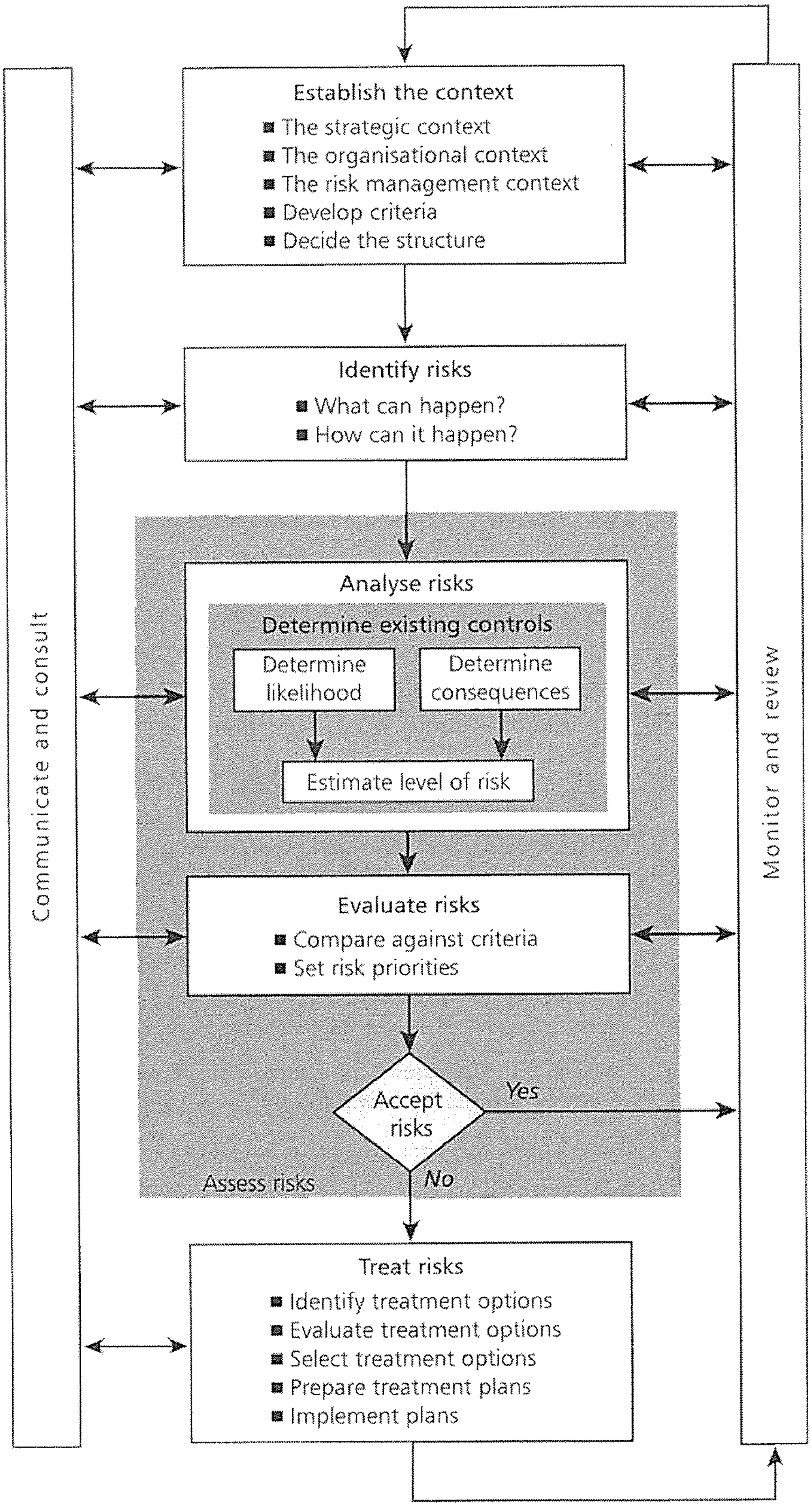
3.4 Derivation of Risk

The risk associated with any hazard is derived as a combination of the likelihood of a hazard and its consequences, that is:

$$\text{Risk} = \text{Likelihood of hazard} \times \text{Consequences}$$

Risk can be derived qualitatively or quantitatively, depending on the information available and the purpose. In a qualitative derivation, the likelihood is described in appropriate terms such as rare, unlikely, possible, likely and almost certain, and the consequences as insignificant, minor, moderate, major and catastrophic. Derivation of the level of risk (low, moderate, high and extreme) from such a qualitative approach is presented in AS/NZS 4360:1999.

Figure 3.1 Risk management process (after AS/NZS 4360:1999).



Risk can also be derived quantitatively, often using a probabilistic approach. In quantitative risk assessment, the likelihood can be specified in terms of the probability of the occurrence of the hazard over a specified period (say, design life) or as an annual probability. The consequences may be specified quantitatively, in terms of monetary loss (dollars) or as numerical factors to represent the consequences.

3.5 Risk Evaluation

An important step in risk management is the evaluation of the risk to assess whether it is acceptable or requires some form of risk treatment. Risk evaluation may be by comparison with specific criteria developed for the purpose or by prioritising the risks for treatment.

3.6 Risk Treatment

Once risks have been evaluated, various risk treatment options can be considered. These include:

- avoidance (e.g. relocate road to lower risk corridor),
- acceptance (e.g. decide that the likely frequency of damage is acceptable),
- transfer (e.g. insure for the risk, where the risk is transferred to the insurer),
- reduce likelihood (this is often not a option for most natural hazards),
- mitigation (e.g. strengthen bridge to reduce the consequences of an earthquake),
- preparedness (e.g. reduce the consequences of damage to a road through emergency preparedness, by enabling quick reaction to reinstate access).

4. Natural Hazard Risk to Road Networks

4.1 Natural Hazard Effects on Roads

The effects on roads of a range of natural hazards in New Zealand were discussed in Part I (Brabhaharan et al. 2001). The natural hazards and their effects are summarised in Table 4.1.

Table 4.1: Effect on roads of natural hazards.

Natural hazard	Hazard effects	Impact on roads
Landslides	Overslips, underslips, mudflow, overall slip	Closure of road by slip debris, removal of road platform, traffic safety hazard from slip materials or mud.
Earthquakes	Ground shaking	Damage or collapse of bridges and retaining walls; failure of steep embankment, particularly on soft ground.
	Fault rupture	Severe deformation of roads crossing faults, and possible misalignment due to displacements.
	Slope failures	A range of impacts from rock falls and slumps blocking the road to major rock slides or landslides removing the road corridor.
	Liquefaction	Deformation of the road due to subsidence of the ground or lateral spreading of road embankments on liquefiable ground or roads close to free surfaces such as river or coastal banks. Damage to structures such as bridges due to ground deformation and thrust.
	Collateral hazards	Collateral hazards, such as a building falling on the road or a damaged utility such as a gas pipeline causing a fire, could also cause disruption by blocking the road.
Storms	Flooding	Inundation of low-lying roads, erosion or scour by rivers or stream floods, damaging roads and blocking traffic.
	Wind	Blocking traffic along roads due to fall of trees onto road.
	Coastal erosion	Erosion of roads along the coast, leading to loss of road platform.
	Storm surge	Flooding of coastal roads and disruption due to storm surge and sea-spray.
	Slope failures	Closure of road by slip debris, removal of road platform, traffic safety hazard from slip materials or mud.

Natural hazard	Hazard effects	Impact on roads
Tsunami	Tsunami and seiche	Flooding of roads close to coastal areas and possibly erosion and scour of road due to tsunami or (to a lesser extent) seiche.
Volcanic eruption	Lava flow	Can completely cut off roads if lava flows across the road, as can happen from the small probability events that may be associated with the Auckland volcanic field.
	Ashfall	Most common volcanic hazard from eruptions in the Central North Island; can affect road surfaces, causing traffic hazards, and close roads affected by heavy ashfall.
	Lahar	Volcanic deposits washed down by heavy rainfall or overflow or break of crater lake, leading to large flow of volcanic mud which can remove roads and bridges along the way.
Snow and ice	Snow	Closes roads from time to time in the Central North Island, Rimutaka Hill and the South Island due to heavy snow. Poses traffic safety hazard during lighter snowfalls.
	Ice	Icing of road causes accidents and is a significant safety hazard in winter, in particular.
Soft ground		Deformation or failure of road embankments built on soft ground. Could be an ongoing maintenance cost.
Wild fire		Rural fires pose a risk to traffic and may require temporary closure of roads.

4.2 Likelihood of Impact

One of the difficult considerations in the assessment of risks is the likelihood of the possible impacts on the road network. The likelihood of the natural hazard impact on the road can be assessed as a combination:

Likelihood of natural hazard impact = Likelihood of hazard event x Likelihood of effects

In a quantitative analysis, the probabilities of the events and effects will be used to represent the likelihood. For natural hazard events, the likelihood of the events is often represented as a "return period" and may be converted to either:

- probability of exceedance over a period of time, or
- annual probability of occurrence.

4.3 Consequences

The consequences of the natural hazard effects on the roads are important in the assessment and management of the risk. The main consequences, as discussed in Part I, are summarised in Table 4.2.

Table 4.2 Consequences of natural hazards.

Consequence	Outline
Damage repair/ reinstatement cost	Damage to a road section from a natural hazard such as an earthquake-induced slope failure will need to be repaired. The repair cost could be significant, particularly in steep terrain and where the area is developed, requiring structural solutions.
Potential loss of life	Depending on the nature of the failure, the time of occurrence and the possible prior indication of failure, large failures could lead to loss of life – for example, a large overslip onto a road from an earthquake or avalanche when there is traffic. However, most failures are not expected to cause significant loss of life.
Loss of access for emergency services	Roads are important for emergency services access in the aftermath of a major event such as an earthquake. Loss of access can lead to consequential effects, such as impeding fire services to put out fires or the inability to transport injured people to hospitals quickly.
Loss of service	Road failures can impair traffic flow, leading to loss of the service provided by the road to the community. Where the community is completely cut off by the failure, there is a total loss of service, including loss of public transport using the route.
Impairment of road network	Failure along some sections of roads could impair the road network as a whole by diverting traffic onto other roads. The impact of failure on a road in the network is important from a network management perspective.
Disruption to community	Failures impeding or cutting off road links can disrupt the community by impeding the ability of people to go about their activities, possibly causing consequential costs to the community.
Economic loss from business disruption	When roads are impeded or blocked by failure, this leads to traffic delays, prevents people from going to work and can severely affect businesses that depend on the road network for transportation. This leads to economic costs to businesses.
Damage to adjoining property	This is particularly important in urban areas where there are properties close to road corridors. Slope failures affecting the road corridor can also cause severe damage to properties, e.g. failure of a road cutting could undermine properties at the top, leading to legal liability and costs.

Consequence	Outline
Damage to services along road corridor	Other lifelines and services such as gas, electricity, water supply and telecommunications are often located along roads. Failure of the road could also lead to failure of these services, with consequential disruption. Damage to sewers can give rise to environmental and public health concerns.
Traffic safety hazard	Snow, icing, flooding or mudflow slope failures may not close the road, but could lead to traffic safety hazards.
Intangible impacts	Roads are important lifelines for communities. Disruption to roads can lead to significant criticism and adverse publicity for road controlling authorities.

The relative importance of the various categories depends on the particular road network, its location and the emphasis placed on the various consequences. Road controlling authorities have a responsibility to provide road networks that meet the different requirements, and will have to consider these factors depending on their socio-economic perspective.

It is important to consider the consequences of the failures in prioritising any mitigation. It would be useful to consider the impact of any mitigation on the network as a whole, in addition to local effects. This is because, where a particular link has a number of vulnerable areas, the impact of mitigation of a particular section of road may have little benefit, whereas a similar mitigation at another location could lead to a significant reduction of risk for the network.

4.4 Derivation of Risk

The risk can be assessed by combining the likelihood of each hazard with the consequences of that hazard. The cumulative risk can then be derived by summing the risks from the various natural hazard events affecting the road.

$$\text{Risk} = \Sigma\ (\text{Likelihood of hazard} \times \text{Consequences})$$

However, some of the consequences are difficult to quantify and may be considered using a scoring system, as discussed in Part I.

Since road networks are geographically spread with lengths of tens of kilometres, it is difficult to assess the overall risk to the network. A risk assessment approach based on a geographical information system (GIS) can be used to derive the overall risk, as well as present the spatial distribution and variation of risk. Such an approach has been developed as part of a number of road network risk studies (Brabhaharan 2000) and is presented in Part I.

5. Road Management Structure in New Zealand

5.1 Road Authorities

Road controlling authorities (RCAs) have responsibility for the management of New Zealand's public road network. The current RCAs in New Zealand are:

- Transit New Zealand, and
- territorial authorities (including unitary authorities).

Other government agencies that have key roles in the management of New Zealand's public road network are:

- regional local authorities (including unitary authorities), and
- Transfund New Zealand.

5.2 Transit New Zealand

Transit New Zealand (Transit) is responsible for managing New Zealand's entire state highway network, including asset management, road improvements and maintenance. Transit operates under the Transit New Zealand Act 1989, and its entire operations are funded by central government. The funding is administered by Transfund New Zealand (Transfund).

5.3 Territorial Authorities

Territorial authorities are responsible for managing the local road networks in their district, other than state highways. They are responsible for asset management, improvements and maintenance. A variety of local government legislation governs their responsibilities to manage the local road networks, funding for which comes predominantly from local rates. However, Transfund provides a subsidy for road improvements and for repair of damage from natural hazard events.

5.4 Regional Local Authorities

Regional councils and unitary authorities are responsible for developing regional land transport strategies and co-ordinating the strategies of territorial authorities, Transit, Tranz Rail and bus operators to ensure that there is a consistent land transport strategy which meets the requirements of the community. They carry out research into community requirements and prepare regional land transport plans, which set out the strategies for the region.

5.5 Transfund New Zealand

Transfund, which was established by government legislation in 1996, is charged with allocating funds from the National Roads Account to provide a safe and efficient integrated road network for New Zealand. Transfund works in close collaboration with New Zealand's road controlling authorities and regional councils to evaluate and approve funding for road construction and maintenance, as well as providing funding assistance for passenger transport services.

Transfund sets criteria for funding road projects and provides funding for road maintenance and preventative maintenance. It provides 100% funding to Transit for state highways, and a subsidy for local roads.

6. Key Influences on Road Risk Management

6.1 Local Government Amendment Act 1986

The Local Government Amendment Act (No. 4) 1986 requires local authorities to have plans to manage their assets, including roads. The asset management requirements include risk management. Most local authorities have been preparing asset management plans for their assets, including roads, over recent years. While this has included valuation of their assets, few councils have systematically considered the risk management requirements which form part of their asset management.

6.2 Lifeline Groups

Lifeline groups are informal local groups which, supported by regional councils, have got together to assess the impact of natural hazards on lifeline utilities in their region. They have brought together the utility operators and considered the effect of natural hazards on lifelines at a broad-brush level. These groups have helped highlight critical hazards in the regions, and encouraged utility operators to undertake risk management actions.

Roads are one of the important utilities considered in lifeline studies. The critical nodes identified by lifeline studies have led to specific studies by road controlling authorities of key road structures, and in some cases to mitigation – for example, the Thorndon Overbridge and Aotea Quay bridge in Wellington. However, the risks to road networks have not generally been addressed at a network level.

Lifeline studies have also led to the consideration of emergency response and routes by some road controlling authorities.

6.3 Civil Defence and Emergency Management Act

Although a variety of legislation places a responsibility on road controlling authorities to manage the road assets, and good road asset management requires management of the risks, this has not developed sufficiently. The traditional approach to risk management by reactive measures has continued to be the dominant way of dealing with natural hazards risk. The current Civil Defence Act 1983 also focuses on reactive measures.

The proposed Civil Defence and Emergency Management (CDEM) Act, which is expected to become law later in 2002, will place a specific responsibility on lifeline utilities. These are specified in Schedule 1 of the proposed Act and include "an entity that provides a road network (including state highways)".

A lifeline utility must, under the proposed Act:

(a) Ensure that it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency;
(b) Make available to the Director in writing, on request, its plan for functioning during and after an emergency;
(c) Participate in the development of the national civil defence emergency management strategy and civil defence emergency management plans;
(d) Provide, free of charge, any technical advice to any Civil Defence Emergency Management Group or the Director that may be reasonably required by that Group or the Director;
(e) Ensure that any information that is disclosed to the lifeline utility is used by the lifeline utility, or disclosed to another person, only for the purposes of this Act.

The purposes of the Act are to:

(a) Improve and promote the sustainable management of hazards (as the term is defined in this Act) in a way that contributes to the social, economic, cultural and environmental well-being and safety of the public and also to the protection of property; and
(b) Encourage and enable communities to achieve acceptable levels of risk (as that term is defined in this Act), including, without limitation,
    i. Identifying, assessing, and managing risks; and
    ii. Consulting and communicating about risks; and
    iii. Identifying and implementing cost-effective risk reduction; and
    iv. Monitoring and reviewing the process; and
(c) Provide for planning and preparation for emergencies and for response and recovery in the event of an emergency; and
(d) Require local authorities to co-ordinate, through regional groups, planning, programmes, and activities related to civil defence emergency management across the areas of reduction, readiness, response, and recovery, and encourage co-operation and joint action within those regional groups; and
(e) Provide a basis for the integration of national and local civil defence emergency management planning and activity through the alignment of local planning with a national strategy and national plan; and
(f) Encourage the co-ordination of emergency management, planning, and activities related to civil defence emergency management across the wide range of agencies and organisations preventing or managing emergencies under this Act and the Acts listed.

The proposed CDEM Act will require the government and local authorities controlling roads (as a lifeline utility) to understand the hazards and their impact on utilities, actively reduce risk over time, prepare for emergencies, and bring roads into use and recover quickly after emergencies.

7. Review of Key Literature

7.1 Literature Search

A review of key literature was carried out for Part I of this research project, and the literature search for this second part focused on:

- any additional information that has become available since that study, and
- any information that may be available on implementation of risk management.

The search was carried out using the resources of the Technical Library and Information Service of Opus International Consultants, to obtain literature on risk management for road networks. Literature was sourced both locally and from overseas, and was reviewed.

7.2 New Zealand Information

In 1996, a study was carried out for Transfund and Transit to develop interim guidelines on risk analysis concepts and their practical application. These guidelines were included as Section 3.9 of the *Project Evaluation Manual* (*PEM*) (Transfund 1997). Further information on this study was not available.

The sections in the current *PEM* dealing with natural hazards risk were reviewed (the *PEM* discussion of risk analysis is reproduced as Appendix A). The current *PEM* provides a means for calculating the benefits from retrofit of nodal structures such as bridges. However, it does not consider the road network or link as a whole, nor the importance of the link in the road network. The current methodology provides no guidance on the assessment of the benefits from mitigation arising from a whole spectrum of natural hazard events with different magnitudes and return periods, and uses single or selected events only.

Taranaki Regional Council had a study done (BCHF 2000) to assess whether national strategic factors as identified in *PEM* apply to State Highway (SH) 3 between Taranaki and Waikato. SH3 is a particularly vulnerable link, which has suffered storm damage several times in the past five years. It is believed that this has led to significant losses to the community, and that the lack of a reliable road link to the north has retarded the economic growth of the Taranaki region. The study included a willingness-to-pay survey, which indicated that there are substantial benefits to the business community that are not captured by the benefits calculated in accordance with *PEM*. The study also noted that the actual cost of time loss due to traffic disruption related to road damage could be higher than the cost of time savings from road improvements.

Further work has been done on the seismic screening of state highway bridges, focusing on mitigation work that may be prudent. The lack of adequate linkages between spans was found to be a major deficiency in bridges identified as being vulnerable to earthquakes. Selected bridges were assessed in further detail, and an economic analysis was done of the benefits of a programme upgrading linkages for vulnerable bridges (Opus International Consultants 2001).

7.3 Overseas Literature

Basoz & Kiremidjian (1996) carried out further studies on the prioritisation and retrofitting of bridges, where they considered the impact of bridge failures on the road network as a whole. (Their studies incorporate the use of GIS.) However, they considered only the bridges in the transportation network.

Shinozuka et al. (1998) developed models to assess how earthquake damage to transportation systems affects the economy, so that the total losses due to the earthquake impact can be assessed. The model considers only bridges and the impact of bridge failure on the economy, taking into account the loss of production from predicted earthquake damage to buildings.

The Multidisciplinary Center for Earthquake Engineering Research (MCEER) in the United States is developing a *Seismic Retrofitting Manual for Highway Systems* (see Power et al. 1999). The series is expected to include bridges and other highway structures and slopes.

Prof. Amr Elnashai's seismic group at the Imperial College in London is reported (www.ic.ac.uk) to have developed a GIS-based software that can store information on the design, construction and maintenance of the various parts of a road network. It can estimate the relative risk for the whole network and give a visual and numerical picture to indicate where extra funding would be best invested to reduce earthquake risk to the network. It can also assess the relative risk of an earthquake or a hypothetical earthquake, and help target emergency response. The software is being applied initially to a 700 km expressway in Greece.

Sasaki & Kiremidjian (2000) have developed a simulation model using ArcView GIS to evaluate the performance of a road network during an earthquake, using a Monte Carlo simulation.

8. Risk Management Approach by Overseas Road Authorities

The risk management approaches used by overseas authorities were explored in various ways. Information was sought through a disaster e-mail digest run by the Natural Hazards Center of the University of Colorado. Only limited information was obtained from this query. A direct approach was also made to the California Department of Transportation (Caltrans) seeking information on natural hazard risk management, but no information was available. Information was also sought from a risk advisor and former head of emergency management at the City of Los Angeles, but no information was available.

The approach of overseas roading authorities has been surmised, based on the information obtained as above and the literature review. It appears that the overseas efforts, particularly in the US, have focused on the seismic screening and retrofit of bridges, which is similar to the past efforts in New Zealand. Basoz & Kiremidjian (1996) presents the approaches used by different US transportation agencies, such as:

- Caltrans,
- Federal Highway Administration (ATC/FHWA Guidelines),
- Illinois Department of Transportation (IDOT),
- Washington State Department of Transportation (WSDOT).

All these approaches deal with seismic prioritisation for retrofit of bridges, and lack consideration of the bridges as part of the road network.

GIS has been used to plan emergency actions in a few cases, and this points to the growing awareness of the powerful applications of this spatial system.

The MCEER study (Power et al. 1999) indicates that there is a growing awareness that non-bridge components of roads are also important if the risk to roads is to be managed effectively. This study deals only with the effect of earthquakes on transportation networks, and does not consider other natural hazards. A similar awareness in Europe is suggested by the GIS software developed by Elnashai's group in London.

A report by the Federal Emergency Management Authority (1997) in the US on the costs and benefits of natural hazard mitigation indicates that economic analyses are increasingly used there for deciding on risk mitigation.

Overall, very little guidance was available from overseas studies on methods for implementing risk management in practice.

9. Development of Framework for Implementation of Risk Management

9.1 Levels of Implementation

Effective management of natural hazards risk requires it to be addressed at all levels, from strategic planning to implementation, emergency response and recovery. It requires that risk awareness and assessment be built into the various levels at which roads are considered, and that risk management be implemented by the various organisations involved in the planning, funding, development, maintenance, management and repair of road networks, both state highways and local roads.

Five levels of implementation have been identified for effective management of risk to achieve a road network that is resilient to natural hazards. They are:

- national road risk strategy,
- regional transport planning,
- road network management,
- emergency management,
- project development.

The levels of risk management cannot effectively function in isolation, and it is envisaged that there will be interaction between the different levels and that outcomes from some levels will provide inputs to other levels. The different levels also facilitate inputs from different organisations involved in the management of road transportation in New Zealand, as described in the following sections.

The five levels are discussed below, followed by discussion of another important factor that influences risk management decision-making, the funding mechanism.

9.2 National Road Risk Strategy

A national road risk strategy could be formed by integrating the regional plans, which would ensure consistency across the regions. It would also facilitate risk management for larger hazard events that have an impact across more than one region.

9.3 Regional Transport Planning

Planning of transport at a regional level is done by regional councils, and to some extent by Transit. Transit can also consider its state highway network across regions and even nationally. Land transport strategies at this level deal with "the big picture": they involve consideration of the transportation needs of the wider community and ensure that transport solutions are consistent across local networks, helping to develop improvements and new infrastructure that are efficient and compatible.

At present, the regional strategies are based on current traffic patterns as well as growth in particular geographical areas and economic sectors (e.g. forestry and tourism). Different existing as well as potential routes have varying levels of risk arising from their vulnerability to natural hazards, and of accidents. Considering the risk at regional level would enable efficient management of the risk to road networks and hence to transportation. Natural hazard risk could be an additional characteristic of transportation networks to be addressed in regional land transport strategies.

A recent example of regional consideration of transportation reliability issues is the Taranaki Regional Council's willingness-to-pay study (BCHF 2000), although an assessment of the risks to the road network would have addressed the issues better.

9.4 Road Network Management

Road controlling authorities (RCAs) are responsible for the management of New Zealand's road networks. As outlined in Section 5, territorial authorities manage local road networks and regional offices of Transit manage the state highway networks. Natural hazards cause significant damage to road networks from time to time, and larger events (such as earthquakes or big storms) can cause even greater and more widespread damage, leading to significant disruption to communities. The RCAs spend significant amounts of their funds on maintenance and "flood damage repairs" to reinstate the roads after even modest hazard events. Additional funds are spent as "preventative maintenance".

Management of natural hazards risk at the local road network level will enable RCAs to better and proactively manage the reliability of their road assets, their maintenance expenditure and emergency responses. This may involve risk assessment, consideration of alternative methods of mitigating the risk, assessing the economics of risk reduction, and prioritising routes for risk mitigation. For example, when assessing future strategies for a road link, Transit could incorporate consideration of the risk to the network, and this could provide the basis for network strategies.

The Wellington City Council's recent study of risk management for its road network (Brabhaharan 2000) is a good example of a structured approach to risk management.

It is important to ensure that the risk management strategies developed at the local road network level are consistent with those at the regional level. Indeed, the process should be interactive, with local road risks contributing to the "big picture" and the regional strategies contributing to the development of local action plans.

9.5 Emergency Management

RCAs are responsible for the emergency management of road networks. RCAs currently have reasonably robust measures in place to respond to emergencies, either through their own staff or through consultants and contractors. While the staff involved have knowledge of their road networks, this is being compromised by both staff mobility and the method for procuring consultants and contractors, whereby the organisation responsible for emergency management changes regularly.

Some RCAs have a system for recording and monitoring hazard areas (e.g. slope check systems). A network-wide risk assessment programme and development of a database (possibly as a GIS) will help in identifying potential risk areas and in developing plans for dealing with them. A planned response to known hazard events will enhance emergency management and help to reduce the consequences.

The co-ordination of emergency responses with those of other utilities and civil defence staff is variable. A more co-ordinated approach will enable rationalisation of response and reinstatement measures. This will become mandatory under the proposed new CDEM Act.

9.6 Project Development

Road construction and improvement projects are regularly implemented by RCAs throughout New Zealand. Transit engages consultants to develop state highway projects. For local roads, projects are developed either by consultants or by in-house territorial authority staff.

The risk characteristics of the projects will change the overall risk to road links and the network as a whole. It is therefore prudent to develop and design projects in a manner that is consistent with the road link and the network, as well as meeting the requirements of the regional strategy. For example, the performance requirements of a section of road in natural hazard events may differ, depending on whether it is a regionally important lifeline arterial road, or a secondary road with secure alternative main roads. If such requirements are not considered in developing new projects, it may hinder the achievement of an acceptable level of risk in the regional and network strategies. This could lead on the one hand to building unacceptable risk into an important arterial route, or on the other to waste of resources in building a road section to an excessive standard not consistent with its use.

The *Bridge Manual* (Transit 1996) attempts to address this in the design of bridges for earthquakes by assigning risk factors depending on traffic volumes and whether the link is a motorway/national state highway or a provincial state highway. However, this does not apply to other hazards or to non-bridge sections, and does not take into consideration the importance of the road to the region or the network in hazard events. The discussion of "National Strategic Values" in the *PEM* (Transfund 1997) could be used to include the importance in terms of risk. However, a more explicit treatment of this issue would ensure that risk management is taken into account consistently.

There is therefore a need to include the importance of the route to the network in project development and design. Another important issue is the inclusion of natural hazard risk reduction in the economic analysis of projects. The *PEM* provides a basis for this: the recent update (Amendment No. 2, effective from 1 September 1998: see Appendix A) contains a short section on including risk in the economic evaluation, with a simple example for a bridge subject to natural hazards. Better coverage of natural hazard risk reduction in the *PEM* would facilitate the incorporation of risk mitigation into the economic evaluation of projects. This in turn would encourage conscious consideration of risk management in project evaluation, and provide a better framework for justifying prudent risk mitigation.

9.7 Road Funding Mechanisms

Currently there are two sources of finance for road maintenance and development: Transfund; and local authority funds from ratepayers. The allocation of funds for roads in local authorities varies, depending on the particular approaches of individual councils and their historical expenditure.

As it funds all state highways and also provides a subsidy for some local authority road works, Transfund represents the major single source of funds in New Zealand. It funds roads through four different mechanisms, according to purpose:

1. road maintenance,
2. "flood damage" repairs,
3. preventative maintenance,
4. road projects.

The first three categories can be considered as funding for maintaining existing road networks, and the fourth as funding for improvements or new construction.

The criteria used to determine funding for 2, 3 and 4 have an influence on risk management. "Flood damage" repair funding is a reactive response to events, and is provided without meeting any economic criteria, as roads have to be fixed when they have been damaged by natural hazard events. Preventative maintenance is funded on qualitative criteria, and represents a relatively small amount of work. Road projects are funded on strict economic criteria, where the benefits of the work have to be more than three to four times the cost of implementation.

From the perspective of natural hazard risk management, the funding criteria encourage a reactive approach. Given that projects have to have benefits exceeding three to four times the cost, whereas after-the-event "flood damage" repair funds are provided irrespective of the cost, it may be expedient to build projects with a higher level of risk, to achieve a higher benefit/cost, and then repair any future damage from "flood damage" repair funds. This probably does not happen consciously, and such an outcome is not the intent of the criteria, but the effect is to encourage reactive risk management, which may be leading to a higher cost to the government, and higher costs to the community in disruption to road users.

The preventative maintenance category is possibly intended to redress this situation. However, given the qualitative criteria and limited funds, it probably does not have a significant impact on the response to natural hazards. Presumably, "flood damage" is funded on the basis that the road has failed and needs to be reinstated to maintain the existing road infrastructure and the service it provides to the community. On this basis, projects to prevent damage to roads and hence preserve the infrastructure could be considered separately from projects to provide a new road or improve an existing road. This issue warrants further consideration.

An improvement in the way funds are allocated for roads could be used to facilitate enhancement of road risk management.

10. Consultation with Road Stakeholders

10.1 Methods of Consultation

The consultation was carried out in several ways, but primarily by:

1. holding a road risk management workshop with representatives responsible for planning, development and maintenance of roads, and
2. discussions with representative staff of organisations with an interest in road risk management.

10.2 Road Risk Management Workshop

A workshop was held in Wellington on 12 July 2001, one day before the RCA forum, to facilitate attendance by participants from around the country. Invitations were sent to:

- Ministry for Emergency Management,
- Transfund New Zealand,
- Transit New Zealand head office,
- Transit New Zealand regional offices,
- regional and local authorities,
- territorial authority road asset departments,
- civil defence/emergency management offices,
- Ingenium (association of local government engineers),
- lifeline group co-ordinators.

Invitations were targeted to obtain representation nationally and from areas with significant natural hazards. There were 12 participants, representing organisations from Auckland to Dunedin and from all the above except for Transit New Zealand head office and lifeline groups (the workshop participants are listed in Appendix B.1).

The workshop agenda in given in Appendix B.2.

The issues raised for discussion by the participants, following the presentations by John Norton (Ministry for Emergency Management) and the principal author of this report, are summarised in Appendix B.3.

10.3 Outcomes from Workshop

10.3.1 Implications of Civil Defence and Emergency Management Act

The Director of Emergency Management, John Norton, outlined the implications of the proposed new CDEM Act for operators of lifeline utilities. Roads are one of the lifeline utilities included in the Act, and utility operators will have a responsibility to ensure that their utilities are able to perform to the maximum extent possible after an emergency, albeit at a lower level than usual. They must have considered the impact of events on their utilities and operations and be able to demonstrate that their utilities can continue to function. The Director of Emergency Management will be empowered to ask utility operators to show their plans for achieving this.

John Norton emphasised that RCAs should get together through such forums as the workshop to develop ways to address risk management. He noted that the emergency response measures of the Civil Defence Act will give way to a risk management approach, including risk reduction and planning before emergency events.

10.3.2 Interests of Stakeholders

The interest of different stakeholders in relation to the risk to road networks was discussed, and is summarised in Table 10.1.

Table 10.1 Interests of stakeholders.

Stakeholder(s)	Interests	Key issue
Road users	Access Safety Convenience Security (reliability) Value for money	Level of service
Adjacent people Utilities sharing corridor	Security to property (including impact on values) Access Environmental issues	Security to property
Road controlling authority	Level of service to public Minimise disruption Level of preparedness Value for money Risk management	Level of service to public Value for money
Transfund Ratepayers	Value for money Optimise use of limited funds Management of budgets Minimise funds for maximum benefit	Optimise use of limited funds

To ensure successful implementation, natural hazard risk management must take into account the interests of the different stakeholders.

10.3.3 Strategies for Implementation

The outline strategies for implementation developed by the principal author were discussed at regional, local network, emergency management and project levels. The contributions from the workshop participants are summarised in Table 10.2 overleaf.

10.3.4 Effect of Funding Mechanisms

The effect of funding mechanisms came up as an important issue during the workshop discussions. The participants had varying views on this issue, as summarised below.

Most agreed that, while it was prudent to fund emergency repairs (or "flood damage" repairs) without economic criteria, given the urgent need to reinstate roads, requiring projects that aim to mitigate the risk of damage in advance to achieve a high benefit/cost ratio tends to discourage proactive risk reduction.

Some expressed the view that it may be prudent to have different benefit/cost ratios for risk reduction work compared with road improvement or new projects. Others considered that it would be more productive to carry out the risk management work under the current system, e.g. by incorporating other benefits, rather than trying to change the existing system, which would be difficult. The authors' view was that this research project should identify any good ideas for changes in funding mechanisms and these should be put to Transfund and other authorities for consideration.

On the evaluation of projects, some thought that the current *PEM* could be modified to allow for easier incorporation of intangible factors. Others expressed the view that the current *PEM* does allow for inclusion of intangible benefits through the "national strategic factors" category, and that the benefits should be quantified and incorporated into the economic evaluation. It was commented that the *PEM* could be modified to clarify how risk analyses and intangible benefits can be incorporated into the evaluation of projects.

10.3.5 The Way Forward

The participants felt that the workshop was useful and provided feedback from practitioners on the risk management implementation being explored in this research project. It was felt that the research would provide useful guidance on the implementation of risk management for roads.

Table 10.2 Workshop views on strategies for implementation.

Level	Comments on implementation
Regional	Land transport strategies should consider natural hazards risk (proposed new CDEM Act may emphasise this). Risk strategies will enable achievement of a more resilient network (there is progress now, but this can be improved). The opportunity to plan new roads to manage risk should be part of the process now, but is applied at varying levels. Regional strategies will enable actions to feed down into network and project levels. Implementation could be through developing methodology for land transport strategies, driven by the proposed CDEM Act.
Local network	Risk assessment processes can help consider the risk to road networks. While effort may not give a return in some instances, road authorities need to know areas of the network of concern. Risk should be part of Transit strategy studies for links at individual level, and could also be part of emergency plans. Identification of the relative priority and importance of road links in a network would help road investment decisions. There is a need to include intangible factors (e.g. lifeline status), and there may be an opportunity for Transfund to include such intangibles in the *PEM*. Road asset management should include recording and maintaining knowledge of risk areas to ensure its availability. Preventative maintenance should be included in road asset management. But the funding criteria may not be correct where emergency work is funded but preventative maintenance has to meet or exceed a benefit/cost ratio to be funded.
Emergency management	Awareness of risks will help to achieve a better plan for responding to natural hazard events. Economic costs of response need to be taken into consideration in project evaluation. Response plans are in place, but their depth is variable. Response plans can be improved by considering risks. Local authorities and road controlling authorities co-operate well in some regions, but co-operation limited in others. There is potential to improve, particularly given the regional co-ordination that is being set up.

Level	Comments on implementation
Emergency management (continued)	Visual presentation of risks through GIS would be helpful in managing risks in emergencies. Existing plans may not be actively used.
Project	Project design should take into account prudent risk management. Transfund risk analysis guidelines provide some means of considering risk in design. If land transport strategies identify higher-level risk issues, these can be incorporated into the lower levels of risk management. *PEM* enhancements could include risk assessment. There is a need to review the benefits and costs, and this should not automatically affect the benefit/cost ratio that should apply.

10.4 Discussions

The principal researcher visited several key people to discuss risk management initiatives for road networks and to obtain feedback not captured at the workshop. Visits were made to:

- Transit New Zealand head office,
- Transfund New Zealand,
- Environment Canterbury,
- Canterbury Lifelines Group Co-ordinator.

In addition, telephone discussions were held with other people in different areas of the country. The key issues and comments emerging from this process are summarised below.

Key points made by David Bates, National Operations Manager at Transit head office, were:

1. He is interested in the risk assessment approach using GIS, and thought that it may provide a useful model for assessing the state highway network regionally, and eventually nationally.
2. It would be prudent for strategy studies to include the risk assessment for links and then this could be combined for the region. Transit has been trying to make that happen.

3. He considers that projects should incorporate a level of design appropriate in terms of risk, notwithstanding any pressures to meet benefit/cost ratio funding criteria.
4. The funding for roads comes under different allocations (as described earlier). At present the allocation for preventative maintenance is small and is prioritised according to qualitative criteria. There is the potential to seek an increase in this funding and allocate preventative maintenance funding based on a more robust risk analysis.
5. There is pressure for funding for different issues, such as reducing congestion, improving safety, risk reduction, etc., and natural hazard risk management is one of them. RCAs and Transfund have to balance the needs of different issues in managing the road assets.
6. He agrees that the risk management should be incorporated within the asset management of Transit's road network.
7. Where risk mitigation can reduce the greater costs of damage, there may be a case for funding the mitigation work even though benefit/cost does not exceed the cut-off for general project funding. He noted that Transit has funded bridge retrofit work, even though the benefit/cost ratios were low.

David Silvester, Evaluation Analyst at Transfund, indicated that the organisation was interested in the outcomes of the research. However, it considered that much of the implementation of risk management would be by RCAs.

Patrick Quinn, Regional Transport Planner at Environment Canterbury, noted that its land transport strategy, which does not specifically address the natural hazards risk, had just been completed. However, he considered that incorporation of risk management strategies was a good idea and could be considered in the next revision.

John Lamb, co-ordinator of the Canterbury Lifelines Project, has recently been implementing a broad-brush study of the risks to important road links in the Canterbury region. He considered that the proposed risk assessment methods were too detailed for the lifelines study, because it was being carried out without external consultants and no funds were available for more detailed studies. However, these risk assessment methods could be very useful for RCAs in considering how they manage their risk.

Allan McGibbon, Civil Defence Controller at Wairoa District Council, thought identification of the risks would help with emergency management, as would improving co-ordination between RCAs and local civil defence controllers.

11. Risk Management Implementation

11.1 Context

Natural hazard risk management strategies for road networks were developed in Part I of this research project (Brabhaharan et al. 2001). Such strategies, which would be implemented by those involved in road planning, development, management and funding in New Zealand, would also need to meet evolving legislative and funding requirements. Following the review of local and overseas practices and consultation with the relevant parties in New Zealand, as described in earlier sections, a strategy for implementation has been developed.

11.2 Levels of Implementation

Five levels of implementation are proposed, based on the existing road management framework, as summarised in Table 11.1.

Table 11.1 Levels of natural hazard risk management implementation.

	Description	Coverage
Level 1	National strategy	New Zealand
Level 2	Regional transportation risk management strategy	Region
Level 3	Network asset risk management plan	Road controlling authority
Level 4	Emergency management plan	CDEM group area
Level 5	Project risk analysis	New or road improvement project

11.3 Responsibility for Implementation

To achieve a robust and effective outcome, it is important that risk management be done by the various organisations involved in managing road assets. In the proposed strategy, the organisations responsible for implementation and their suggested roles are summarised in Table 11.2 overleaf. It should be noted that some organisations do not manage roads themselves, but have an indirect role through funding or planning roads. They too can contribute to effective management of natural hazards risks by providing a funding framework that encourages risk management, or by land transport strategies that take risk into consideration.

Table 11.2 Suggested responsibility for implementation of risk management.

	Description	Role	Organisations
Level 1	National strategy	National Road Strategy	Ministry for Emergency Management* and Transit NZ
		Funding/policy	Transfund NZ
Level 2	Regional transportation risk management strategy	Regional land transport strategy	Regional councils with Transit NZ
Level 3	Network asset risk management	Asset management	RCAs**
Level 4	Emergency management	Emergency response	RCAs**
Level 5	Project risk analysis	Project development	RCAs and Transfund NZ

Notes:

* Ministry for Emergency Management has a responsibility under the proposed CDEM Act to develop a National Emergency Management Strategy.

** RCAs have a responsibility under the proposed CDEM Act to have plans to ensure that their lifelines can function after an emergency.

11.4 National Road Strategy

Under the proposed CDEM Act, the Ministry for Emergency Management (MEM) has to prepare a National Emergency Management Strategy. It is envisaged that this will include how the risk to national lifelines such as major roads will be managed during an emergency. Given the other emergency response requirements, there may be a need to establish the performance requirements for major roads. These could then be used to set the requirements for management of the risk to such roads at regional, network and project levels.

It is envisaged that these roads would be state highways, and that Transit as the operator would manage the risk to these lifelines as required by the proposed Act. Transit, with MEM, could develop strategies for these roads, based on their vulnerability assessed at regional and local network level. These strategies would then be incorporated into the requirements at other levels.

11.5 Funding Policies

Transfund is responsible for central government funding of transportation, and thus sets the framework for funding road projects. Funding issues have a significant effect on the response of RCAs to road issues, and natural hazard risk management is no exception.

Transfund influences investment decisions in road management and development through:

- funding provided for maintenance, emergency repair, preventative maintenance and improvement projects,
- criteria for funding and subsidies for local authority roads,
- policy on road projects, through the *Project Evaluation Manual*,
- review of the economics of projects submitted for funding.

Funding for road projects has evolved from historical funding by government through the National Roads Board and then Transit New Zealand. Given that natural hazards risk management has traditionally been reactive, the funding arrangements have also been based on this model of road maintenance. Transfund has recently moved to require financial and project risk assessment for road projects, and this has the potential to improve financial risk management in funding projects. It would be logical to extend the risk management into natural hazard risk management, which would improve the management of the risk to roads and reduce the consequential repair costs, as well as the wider cost to the community and the economy.

The current funding regime has a number of limitations. These, together with possible improvements, are summarised in Table 11.3 overleaf.

It is suggested that Transfund review its funding arrangements to facilitate and encourage proactive natural hazard risk management.

11.6 Regional Transportation Risk Management Strategy

Regional councils (and the unitary authorities) are responsible for developing land transport strategies for their regions. They consider the various factors that impact on the transportation needs of the community and develop broad strategies to cater for these needs, given the constraints. The strategies are developed in consultation with Transit and territorial authorities, who consider their respective road networks.

It would be prudent to consider the risk to the road networks at the same time, thus incorporating the risk management needs for transportation in the region. This risk

Table 11.3 Current funding regime and possible improvements.

Item	**Current policy**	**Possible improvements**
Emergency repairs (Flood damage repairs)	Emergency work is fully funded regardless of economic or social factors. This discourages prudent risk management of roads. Repairs may be vulnerable to future ongoing failures leading to ongoing costs. Repairs are done under emergency conditions and at significant additional cost and risk than under planned mitigation.	This is important for maintaining the road infrastructure. Improvements could be: • requiring RCA to ensure repair is consistent with a risk management strategy for that road, • requiring repairs to be carried out to mitigate future failures, rather than allowing continuing expenditure. This may facilitate a more resilient road network and reduction of future emergency funding in the long term. Modifying subsidy to encourage establishment of risk management plans.
Risk mitigation projects	Limited preventative maintenance funds, not based on risk analysis. Large mitigation or local authority risk reduction projects subject to benefit/cost cut-off as for new projects. This discourages proactive risk management.	Increasing amounts of separate funding for risk reduction work to reduce vulnerability of existing road network and hence reduce downstream costs. Funding based on risk management strategy for particular road network, requiring justification in terms of tiered benefit/cost ratio, depending on assessed importance and lifeline status of link. Risk analysis to justify projects considering performance, economic and strategic factors.
Risk assessment and development of risk management plan	No specific funds.	Provide funding to encourage risk management, required under the proposed CDEM Act, which would give long-term benefits in terms of resilient road network and reduced emergency repair costs. Provide subsidy for local authority road risk assessment.
Project funding	Controlled by evaluation according to *PEM* and funding subject to benefit/cost cut-off based on funds available.	Enhance *PEM* to incorporate level of risk for road based on risk management plans and importance or lifeline status of link.

Item	Current policy	Possible improvements
Project funding (continued)	Limited guidance on simple seismic risk analysis for bridges.	Incorporate guidance for inclusion of link reliability and multi-hazard road risk analysis in economic assessment.
	National strategic factors allow intangible factors.	Include guidance for consideration of strategic factors such as intangible lifeline status of road.
	Benefits of risk mitigation based on savings in otherwise increased travel-time costs, which are same as for road improvements giving travel-time savings.	Consider whether travel-time costs due to disruption are higher than savings from geometric improvements of the road, and if appropriate amend *PEM*.

assessment should be used as an additional characteristic of the network in deciding on transportation improvement strategies. It may lead, for example, to upgrading a key route in the region, or to developing any new routes in such a way as to reduce the vulnerability of the network to natural hazards.

The proposed CDEM Act stipulates that regional emergency management plans be developed, setting out risk management plans for the region as a whole. Utility operators, including RCAs, are also required to prepare plans for their assets and provide input into the regional emergency management plans. This gives additional impetus to management of risks at a regional level.

Ideally, regional transport strategies are developed by considering the risk first to individual local networks, then to the regional network as a whole. Transit could also consider its state highway network on a regional basis, for incorporation into the total regional network strategy. In some instances, regional strategies may be better developed by considering networks wider than those within one regional council boundary. For example, some important links, such as that between Blenheim and Christchurch, may span two regions.

The risk may be assessed using the methods developed in Part I of this study (Brabhaharan et al. 2001). The use of GIS would facilitate this. To assist with the emergency management plan, it may be prudent also to assess the impact on the network of important natural hazard scenarios. For complex networks, it may be prudent to incorporate traffic analyses into the road risk assessment.

11.7 Road Network Risk Management

Management of the risk to the road network is a prudent requirement for each RCA, as part of its asset management. The Local Government Amendment Act 1986 requires management of local authority assets, which includes management of risk. The proposed CDEM Act will place a specific responsibility on RCAs to implement risk management for their road networks as lifeline utilities.

The risk may be assessed using the methods developed in Part I of this study (Brabhaharan et al. 2001). The use of GIS provides a visual indication of the spatial risks along the roads in the network. Part I also presents a case study for a rural road as well as a state highway link. A road risk assessment and evaluation of mitigation was recently carried out for Wellington City Council's road network (Brabhaharan 2000).

Several risk management options that may be considered for the road network and specific vulnerable sections are outlined in the Part I report. The risk management evaluation should be tailored to the particular road network and may need to be more complex or simple depending on its characteristics.

Transit's strategy studies for state highway links could incorporate assessment of risks. These could then be brought together to develop risk management strategies for state highway networks within a region.

One issue requiring further consideration is the appropriate level of risk or the level of service that should be provided. It is suggested that further research be carried out into risk tolerance and appropriate levels of risk for different hierarchies of roads (e.g. state highways, arterial roads) in New Zealand. This will facilitate the making of risk management decisions.

11.8 Emergency Management

Emergency management would be part of any risk management strategy for road networks. In addition to traditional reactive measures, the Part I report discusses other measures, such as planned emergency reinstatement based on prior design, which may be prudent for some sections.

The emergency management should be co-ordinated with other utilities and the regional emergency controller. This will become more structured under the proposed CDEM Act.

11.9 Project Development

Road projects modify or extend the network. To achieve robust risk management and a resilient network, the projects should take into account the network's performance requirements, determined from the regional and local network risk management strategies. To ensure that projects are consistent with these, it is proposed that:

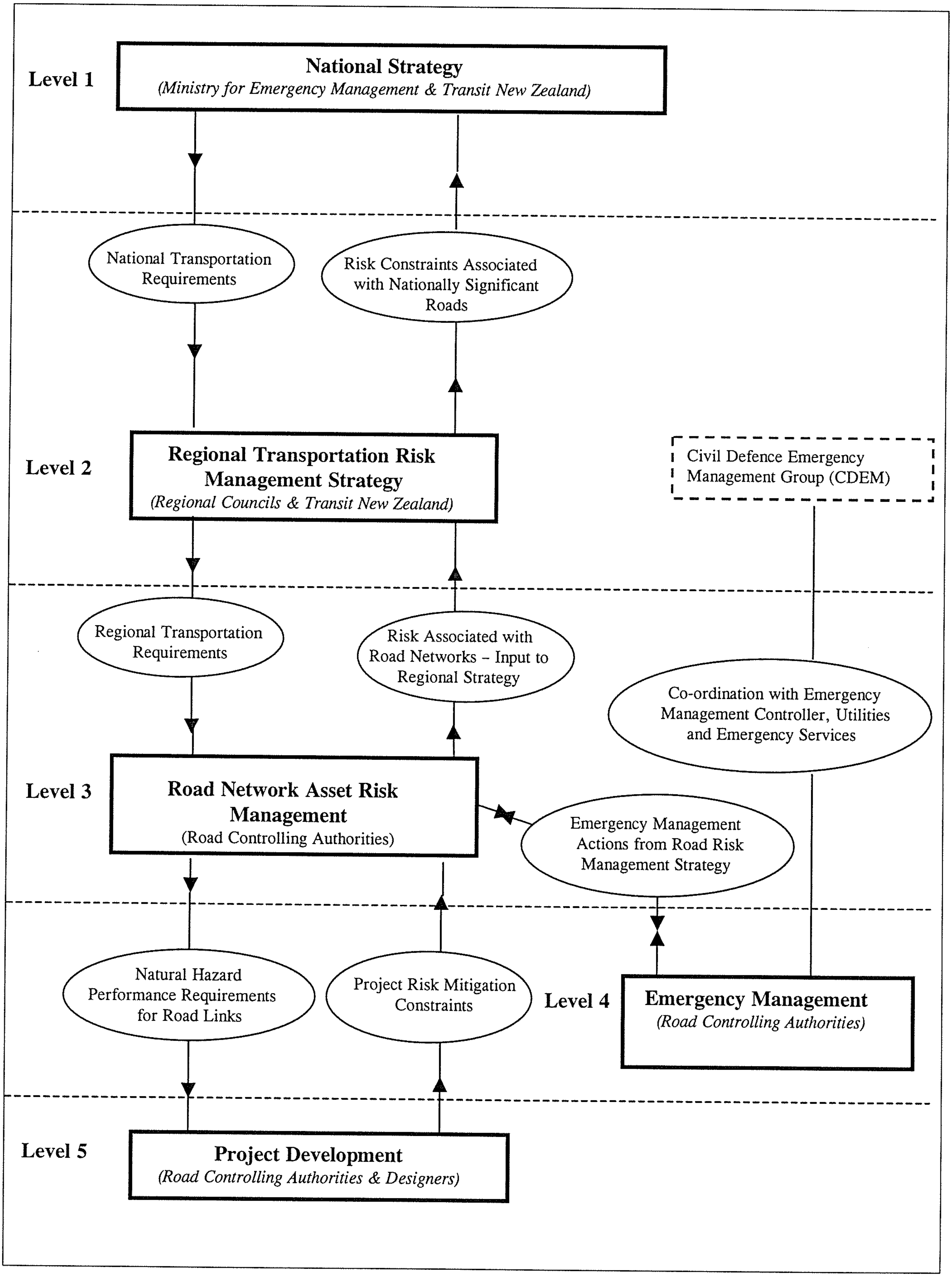
1. Projects should have a natural hazard risk performance requirement, consistent with the needs of the road network, and be developed to meet this requirement, which should be specified from the outset. For example, a project on an important lifeline route may require the project design to ensure that the road remains operational in particular hazard events, and the level of performance in larger events may be specified.
2. Project evaluation should incorporate the benefits of risk mitigation, by including a risk economic analysis and where necessary incorporation of intangible benefits.
3. The *PEM* could include guidance on these requirements, so that risk mitigation can be justified in the evaluation of projects. The economic analysis of projects is discussed in Section 12.

11.10 Integration of Risk Management

It is important that the various levels of risk management from national to project level are integrated, so that the strategies developed at different levels are consistent with other risk management actions, and provide inputs to projects.

The integration of the various project levels is illustrated in Figure 11.1 overleaf.

Figure 11.1 Integration of risk management.



12. Economic Evaluation of Road Projects and Links

12.1 Background

Traditionally, road projects have been evaluated on the basis of whether an element such as a bridge replacement, road improvement, by-pass road, etc., improves the level of service given. This approach has, however, ignored the presence of risk and the likelihood of future costs from a set of hazards that may differ among the options being evaluated. Only more recently has risk analysis been developed to the stage where it can be incorporated into project evaluation. Even then, the focus has tended to be on seismic damage to bridges, with little consideration given to other hazards and their impact on the wider situation.

Where earthquake effects on a bridge are being considered, this is generally with a view to minimising damage to the structure, and to reducing costs to the user through road or lane closure. For the wider picture, however, it is necessary to look first at the link on which the bridge is located. A project that aims to reduce disruption and delay by carrying out seismic damage mitigation works to the bridge will not be successful if the same seismic event produces a large landslide further along the link. Certainly, there are advantages for repairing the landslide damage in having the bridge remain intact, but the overall objective of saving detour and disruption costs will not be achieved. The link then becomes the element of importance, with a range of possible risks that includes landslides and flood damage, as well as bridge damage in its various forms and likelihood. There are issues relating to the period of closure for repairs to the bridge and for repairs to the landslide, but if the landslide takes longer to repair than the bridge it may have been more economic to omit the bridge retrofit.

When an analysis is made at the project or even link level, it is common to assume that traffic disruption costs are approximated by evaluating the additional costs of making a detour. In a more sophisticated analysis, some consideration may be given to the number of people who are deterred from travelling by the detour cost, at a loss in benefit, as well as the remainder who are willing to accept the extra cost. In either case, however, it is assumed that the chosen detour route will always be open, and will not have been affected by the same or even an entirely separate damaging event. This may not be the case, producing a situation that requires further analysis at the network level.

Such analysis may not be warranted for smaller projects, but where large volumes of traffic are involved, or the link and its assumed detour comprise a lifeline for a large community, the analysis may be essential. This could well be the case, for example, with the proposed Transmission Gully link north of Wellington, where one stated benefit and reason for providing the link is to increase the reliability of the northern transport link from Wellington. The desired outcome should not be presumed without further study of the new and existing links.

12.2 Current Evaluation Requirements

The *PEM* covers project risk analysis in two places. Section 3.9 (see Appendix A) states that a detailed risk analysis shall be considered for all projects of capital value exceeding $10 million and for all projects which have as their principal objective the reduction or elimination of risk. Risk costs are also to be included in other projects where these are significant. The manual details the steps to be taken:

- Identify uncertain elements in the project and the chain of consequences.
- Determine project costs and road-user benefits/disbenefits for each possible outcome.
- Identify annual probability of occurrence.
- Determine the expected costs and benefits by combining values and their probabilities.

Appendix A9 of the *PEM* deals with national strategic factors, where there is a need to include benefits to the community that are not covered in the standard project analysis. Security of access is noted as an example, and A9.2.2 states that projects covering the seismic strengthening of bridges, slip prevention work, and improvements to a busy route prone to closure may come into this category.

The process set out in *PEM* Section 3.9 is described in general terms, and covers the range of hazards associated with roads. The example given is of a bridge requiring replacement in five years' time, and the analysis considers whether the risk of seismic damage over the intervening period outweighs the additional cost of replacing the bridge immediately. While the example concerns a bridge, the method and the principles set out are universally applicable. There is no reason, given the right data, for not applying the method to other hazards.

12.2.1 Analysis at the Project Level

The approach described in the *PEM* covers a simple case where there is a single hazard. This needs to be extended to the case where there are a number of hazards with different probabilities of occurrence, and to the case where a prior occurrence can reduce or remove the damage costs in subsequent events. This type of analysis has already been carried out for the seismic retrofitting of bridges, where a bridge can fail or be significantly damaged in a number of different ways.

It is important to consider all the hazards which may have an adverse effect on a particular structure or section of road. This will ensure that any mitigation measures are appropriate to withstand the effects of different hazards (e.g. earthquakes and scour of river bridges), and also that the economic analysis of mitigation is robust. For example, if a single hazard is considered, the economic analysis may show the retrofit to be economic, but in reality, if the bridge may be damaged by scour, the analysis considering both hazards may indicate otherwise. Such analyses have been carried out for earthquake and storm effects on the slopes and retaining walls (Brabhaharan et al. 2001).

The underlying methodology of the risk economic analysis, as with all benefit/cost analysis, is to evaluate quite separately the different scenarios. The first scenario is the base case, where there will be no intervention to improve matters and the structure will continue as it is now. In this case there are likely to be costs through direct road or structure damage, and through road closure, causing delays and detours. The second and subsequent scenarios are the proposed project alternatives where intervention is contemplated, in which there will be an intervention cost but a reduced damage and delay/detour cost. These cases are then evaluated for all costs if they are implemented, and are then compared with the base case.

Risk is taken into account through the use of "expected values" for the costs associated with damage and traffic disruption. These are derived as the summation over the evaluation period of the expected value of the damage and traffic disruption cost in each year. Within any year, the damage and traffic-related cost comprises the sum of the damage and traffic costs associated with each threshold level of return period at which a different form of damage is sustained, each multiplied by their respective probability of occurrence.

Costs are assumed to include the costs of the erection of temporary works, the costs of repair, diversion to a detour route and, where applicable, change of vehicles' average speed. Indirect costs, such as the impact of disruption on business, may also be included.

The assumption can be made that, when damage occurs in an event (storm, flood, earthquake), it will be repaired in such a way that this damage will not occur again, or will occur only at a lesser level. This outcome can be built into the analysis. For example, if Event 3 occurs (where Events 1 to 3 are in ascending order of magnitude) there are three possible damage cost cases, as shown in Table 12.1.

Table 12.1 Cases where repair in an event precludes further damage.

Case	Event occurrence	Damage to structure
Case 1	No prior events	Event 1, 2 and 3 damage occurs.
Case 2	Event 1 has occurred previously	Event 2 and 3 damage occurs. Event 1 damage is reduced or zero.
Case 3	Event 2 (which includes Event 1) has occurred previously	Event 3 damage only occurs. Event 1 and 2 damage is reduced or zero.

In each of these three cases it is possible to assign damage cost and a traffic disruption cost, giving a total cost for each. The analysis then determines the most likely or expected value of Event 3 damage as the risk-weighted sum of all three possible outcomes.

Using the following definitions, and assuming for simplicity that damage is not repeated after a repair,

C_1 = total cost of Event 1, 2, and 3 damage
C_2 = total cost of Event 2 and 3 damage
C_3 = cost of Event 3 damage
p_1 = probability of Event 1 being equalled or exceeded in any year
p_2 = probability of Event 2 being equalled or exceeded in any year

then the expected damage if Event 3 occurs in Year 2, for example, is:

C_1 x (1-p_1) x (1-p_2) (i.e. C_1 x probability neither of Events 1 or 2 occurred in Year 1)

\+ C_2 x (1-p_2) x p_1 (i.e. C_2 x probability Event 2 not in Year 1 x probability Event 1 already in Year 1)

\+ C_3 x p_2 (i.e. C_3 x probability Event 2 occurred in Year 1).

The above process is expanded to cover each possible event, and to give expected event costs for Years 1, 2, 3, 4 … etc.

The cost determined for each event for each year is termed the risk-weighted cost for the event for the year (i.e. the cost weighted for the range of possibilities of lesser events having occurred, or not occurred, previously). For a particular event, the risk-weighted cost decreases with time as the probability of lesser events having occurred already increases.

The analysis then evaluates the total expected cost in any year as the sum of the costs expected from each possible event. The expected cost of an event in any year is the risk-weighted cost multiplied by the probability of that event occurring in the year, further multiplied by the probability that it has not occurred in prior years. This analysis may seem complex but is in fact readily amenable to spreadsheet evaluation, and has been applied to bridge evaluation (Opus International Consultants 2001).

The above process has been applied to the evaluation of bridge retrofitting options for the mitigation of seismic damage. In this case the analysis is relatively simple, as it is reasonable to assume that no damage occurs before a threshold level of seismic force, at which point an element such as a linkage bolt or a bearing gives way. Again, no further damage takes place until a higher level of force occurs, when a pier may be damaged. At a higher level still, the abutment may collapse. This produces a force/damage curve that is a step function, making for easy evaluation. It also gives a well-defined set of failure modes and associated probabilities.

The situation is different, however, for a landslide or a wall failure. These are characterised by a continuous force/damage curve where there is likely to be a certain level of damage for a low level of earthquake (for example), a slightly higher level of damage for a slightly larger earthquake, and higher damage again for a higher level of earthquake (see Figure 12.1 overleaf). The continuous curve makes computation more difficult, but again is amenable to spreadsheet analysis. This type of evaluation has already been done in determining benefit/cost ratios for mitigation of potential road damage from slope failure (Brabhaharan et al. 2001).

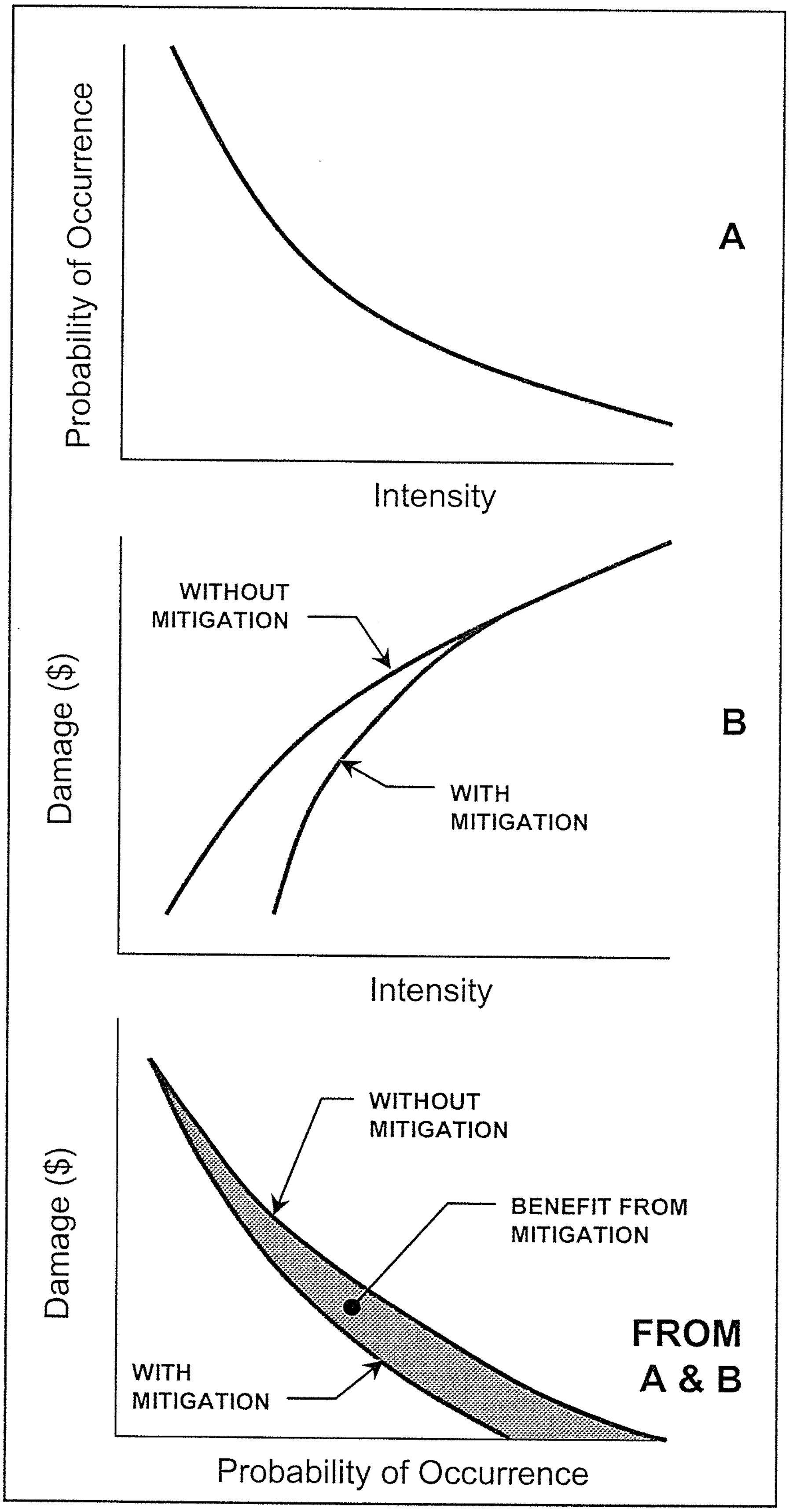
12.3 Evaluation at the Link Level

The stepwise and continuous types of analysis described above create no difficulty when considered at a project level. At a link level, however, they have to be combined.

Combination is easily done when, for example, two or more bridges on a link are being analysed as a link-level project for improving link reliability under seismic loading. In this case, say, if three bridges each have four failure modes, all differing in the threshold at which they occur, there are twelve possible interventions to be evaluated. For purposes of analysis, the three bridges can be considered as a merged single bridge with all the problems of each.

The problem comes if there is more than one type of hazard on the link – say, a bridge that is vulnerable to seismic loading and a potential landslide area that is vulnerable to very heavy rainfall. This requires a combination of stepwise and continuous damage types. However, it would be possible to overcome the problem either by reducing the continuous curve to a stepwise function with a small number of steps, or by doing the same with a very large number of small steps. The latter,

Figure 12.1 Derivation of benefits of mitigation.



which is more accurate, gives a large number of possible interventions and would be more suited to full programming rather than spreadsheet analysis in determining the optimum level of intervention.

As discussed in Section 12.2 for the project case, it is important to consider the effects of multiple hazards, where applicable, on each of the structures or sections of road. For example, earthquakes as well as storms can trigger slope failure. Such consideration is essential for the analysis to be robust. This has been done on road risk analysis projects, and a summary of the methods is included in the report on Part I of this research study (Brabhaharan et al. 2001).

12.4 Case Study of Link Analysis

A hypothetical case study of the link analysis is now considered, for a link comprising a bridge, retaining wall and a landslide. Table 12.2 gives an example of the approach and analysis of a highway link with three hazards considered.

Table 12.2 Multi-hazard road link analysis.

Hazard item	Failure type	Return period	Traffic delay (days)	Total user costs ($)	Repair cost ($)	Prevention cost ($)
Bridge	Earthquake – pier failure	40 yrs	60	1,100,000	500,000	100,000
Retaining wall	Earthquake – slumping	20 yrs	20	400,000	200,000	30,000
Landslide	Earthquake 5% damage	15 yrs	5	80,000	100,000	10,000
Landslide	Earthquake 15% damage	70 yrs	40	700,000	250,000	15,000
Landslide	Storm 2% damage	5 yrs	2	30,000	20,000	5000
Landslide	Storm 20% damage	75 yrs	45	750,000	300,000	50,000
Landslide	Storm 80% damage	100 yrs	50	800,000	400,000	150,000

In this example, only the landslide is considered to have a range of possible outcomes, but the method can be expanded to deal with multiple outcomes for all the hazard items and for multiple landslides, etc. It is also assumed that repair works, once required, will prevent all subsequent occurrence of damage at that level of event.

The economic evaluation has been done in accordance with the *PEM* requirements PFM2. Time Zero was assumed to be 1 July 2002, with construction of the improvement options taking place within a short timeframe centred on 1 July 2003, and benefits occurring continuously from this date onwards. The analysis period was assumed to extend 25 years beyond 1 July 2003, giving a 26-year project period in total. Construction costs were discounted one full year to Time Zero, and the discounting of the benefits, which were assumed to be centred on the middle of the year, were adjusted to bring these also to Time Zero.

The earthquake and storm outcomes can be analysed separately, as these are independent of each other. Consideration first of the earthquake situation gives the results of the economic analysis seen in Table 12.3.

Table 12.3 Results considering bridge only and earthquake hazard alone.

Improvement cost	Damage cost (no improvement)	Damage cost (with improvement)	Benefit (saved damage)	Benefit/cost ratio
$100,000	$319,169	0	$319,169	3.2

The option of improving the bridge appears well worth carrying out when this element is considered in isolation. However, consideration of the whole link gives the results of the economic analysis seen in Table 12.4.

Table 12.4 Results considering link but improving bridge only and considering earthquake hazard alone.

Improvement cost	Damage cost (no improvement)	Damage cost (with improvement)	Benefit (saved damage)	Benefit/cost ratio
$100,000	$478,133	$285,936	$192,197	1.9

If the bridge alone is improved, much of the savings supposedly achieved is negated by damage elsewhere on the link.

The addition of $45,000 of improvements to the rest of the link raises the benefit/cost ratio to 3.3, as seen in Table 12.5.

Table 12.5 Results considering link and all hazards.

Improvement cost	Damage cost (no improvement)	Damage cost (with improvement)	Benefit (saved damage)	Benefit/cost ratio
$145,000	$478,133	0	$478,133	3.3

The storm situation can be viewed as one hazard with three possible levels of improvement. Analysis of these three cases gives the results seen in Table 12.6.

Table 12.6 Considering three levels of improvement for storm hazard.

Improvement cost	Damage cost (no improvement)	Damage cost (with improvement)	Benefit (saved damage)	Benefit/cost ratio
$5,000	$180,646	$149,722	$30,924	6.2
$50,000	$180,646	$99,427	$81,219	1.6
$150,000	$180,646	$ 0	$180,646	1.2

The first alternative, at a cost of $5,000, is highly worthwhile, whereas neither of the other two would meet a benefit/cost ratio cut-off of 3.0.

12.5 Analysis at the Network Level

Koorey & Mitchell (1999) give an approach for considering link and network reliability. Their methodology deals with the situation where there are several hazards with different probabilities of damage on a link or on a set of links forming a network. In the first instance, they evaluate the probability of a link being closed by considering the probabilities of closure of all the individual hazards on the link. These can be combined using the formulae in the report to give a single probability of closure for the link.

The next step is to consider the reliability of the combined set of links forming the network. Again, formulae given in the report can be used to combine groups of hazards into a single probability of full network closure. At this stage it is possible to consider whether a proposed project has improved the network reliability or not.

This approach is possible if it is assumed that each hazard is characterised by the failure probability where significant damage first occurs, and if it is also assumed that the days of closure in any of the possible failure locations are not greatly different. This is not unreasonable for road works, and could be the case, for example, for the Transmission Gully project. There would be little point in taking account of an event, for example, that closed either the existing or new roads for two or three days. The focus would be on an event that produced major damage and disruption to the region, with a view to determining whether the new link provided greater reliability of access, or instead presented a greater liability. Sensitivity could be determined by considering a range of event levels about this mean.

If it could not be assumed that the timing of disruptive events on each of the links would be similar, i.e. one link might be closed for five days whereas another might be closed for five months, the evaluation could be made in other ways. It is likely that the study of the hazards and the subsequent analysis would lead to a solution that would be readily evident using common sense – a reasonable outcome in any event.

13. Conclusions

The principal conclusions of this research study are:

1. Systematic management of the risks is essential to achieve road networks in New Zealand that are resilient to natural hazards.
2. The key influences encouraging risk management are:
   - the Local Government Amendment Act (No. 4) 1986, which requires asset management of local authority assets, including management of the risk,
   - lifeline groups, who have highlighted the importance of lifelines and the effect of hazards on them,
   - the proposed Civil Defence and Emergency Management Act, which treats road networks as lifeline utilities and requires operators to ensure that lifelines are able to function to the fullest possible extent during and after an emergency.
3. The risk assessment methodologies presented in Part I of this study provide systematic approaches to managing the risks.
4. Effective and robust management of the risks should be implemented at the following five levels:
   - national strategy,
   - regional transportation risk management strategy,
   - local network asset management,
   - emergency management,
   - project risk,

   with an integrated approach to provide consistency between them.
5. A national strategy for the natural hazard performance requirements of major roads is appropriate as part of the national civil defence emergency management plan, and could be developed by Transit New Zealand and the Ministry for Emergency Management.
6. Regional councils should consider the natural hazard risks to the road network as part of their regional land transport strategy, especially when developing strategies for improving or developing the roads. This should also identify a hierarchy of regional roads reflecting their importance.
7. Prudent management of local road assets requires an assessment of the risks and formulation of risk management plans, which should include prioritisation of links, maintenance strategies and an action plan.

8. Emergency management should be part of the risk management strategy for the road network and this should be co-ordinated with other lifeline authorities, and the emergency management controller.

9. Development of road projects should reflect the relative importance of the link and its performance expectations. Robust risk economic analysis could be used to justify the level of design for natural hazards, and should consider the link or network as a whole and the effect of all natural hazards on both bridge structures and other sections of the roads.

10. Transfund's *Project Evaluation Manual* should include more guidance on risk analysis for natural hazards, to reflect the project's risk requirement and to incorporate consideration of indirect benefits, intangible factors and national strategic factors.

11. Some aspects of the current road funding mechanisms discourage natural hazard risk management by requiring a high benefit/cost for risk mitigation and providing funding without any economic criteria or risk robustness for emergency repair or "flood damage" reinstatement.

12. Road funding could be used to encourage robust risk management. Prudent measures would be:
    - requiring risk management to be considered in flood damage repair funding,
    - providing more significant preventative maintenance funding,
    - incorporating allowances in project funding for the importance or lifeline status of the roads,
    - providing direct assistance or subsidy for developing risk management plans and strategies.

14. Recommendations

On conclusion of Part II of this research study, we recommend that:

1. This report be published and made available, particularly to all participants in the road sector.
2. Transfund review the *Project Evaluation Manual* and incorporate amendments on the issues identified in this report.
3. Transfund consider the changes to the funding mechanisms suggested in this report.
4. Regional councils and road controlling authorities consider the recommendations on road risk management initiatives in this report.
5. Further research be carried out into the acceptable levels of risk and levels of service for different types of roads in New Zealand.
6. Additional research be carried out to incorporate traffic analysis into the risk assessment and management analyses developed in Part I of this study.

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Schedule of Appendices

A. "Risk analysis" extract from Transfund's *Project Evaluation Manual* (1997), Amendment No. 2

B. Road Risk Management Workshop at Wellington, 12 July 2001

- B.1 Participants
- B.2 Format and Agenda
- B.3 Issues and Questions

C. Case Study: Risk Management for Wellington City Road Network – Prioritisation of Road Links

Appendix A

"Risk Analysis" Extract from Transfund's *Project Evaluation Manual* (1997), Amendment No. 2

3.8 SENSITIVITY ANALYSIS

All project evaluations involve making assumptions and estimates which are subject to uncertainty. Assessments of the sensitivity of evaluations to critical assumptions or estimates shall be undertaken, and Worksheet 7 is provided for this purpose.

Sensitivity analysis involves defining a range of values for an uncertain variable in the evaluation and assessing the effects on the project evaluation of assumptions or estimates within the defined range. This will highlight those variables for which a change in the input value has a significant effect on the project evaluation.

For the significant factors the following shall be listed:
- assumptions and estimates on which the evaluation has been based
- an upper and lower bound of the range of critical or particularly uncertain estimates and the assumptions on which this range is based
- the resultant B/C ratio at the upper and lower bound of each estimate.

Significant factors where uncertainties are likely to occur include:
- maintenance costs, particularly where there are significant savings
- traffic volumes, particularly model results, growth rates, and the assessment of diverted and induced traffic
- travel speeds
- road roughness
- accident reductions.

3.9 PROJECTS INVOLVING RISK

A detailed risk analysis shall be considered for all projects of capital value exceeding $10 million and for all projects which have, as their principal objective, the reduction or elimination of an identifiable risk. For other projects which involve some significant element of risk, costs shall be included (as expected values) from an analysis of probabilities and costs of occurrence. Sensitivity analysis can also be used to test the effect of variations in input assumption for these other projects. The risk analysis procedures set out below are not intended for projects subject to minor risks such as occasional small slips from adjacent hills onto the road, etc.

Detailed treatment of risk may require a numerical simulation approach in cases where the number and interaction of uncertain variables makes an analytical approach impractical. Advice on this topic will be given in future revisions to the Project Evaluation Manual.

A general procedure for evaluating risk by an analysis of probabilities and expected values should comprise the following steps:

a) identify the uncertain elements in the project and the chain of consequences for any unpredictable events.

b) determine the costs to the project and the benefits or disbenefits to road users for each possible outcome.

c) identify an annual probability of occurrence and the period of years over which this probability applies, for each uncertain element.

d) compute the expected values of costs and benefits for the uncertain elements in each year as the product of the costs and the annual probability of occurrence. Include these in the project cost and benefit streams when carrying out the discounted cash flow calculations.

The following worked example illustrates the application of these general procedures.

3.9.1 Example - Replacement of a Bridge Due to Premature Failure

In this example, a minor bridge structure has been assessed to have a limited residual life and has been tentatively programmed for replacement after 5 years. However, the design of the bridge pre-dates modern earthquake design codes and the bridge would be damaged to an extent requiring replacement in an earthquake of return period of 200 years or more.

The annual probability of the bridge being destroyed by earthquake in any one year, denoted as p, is 1/200 = 0.005. The probability of the bridge surviving for 5 years and then being replaced as programmed, is calculated as follows.

a) The probability of an earthquake in the first year = p = 1/200 = 0.005

b) The probability of the bridge surviving for one year is therefore

c) (1 - p) = 0.995

d) The probability of the bridge being destroyed in year 2 is the probability of it surviving through year 1 multiplied by the probability of an earthquake in year 2
= p. (1 - p) = 0.005 x 0.995 = 0.004975 and so on for five years.

In the general case, the probabilities of the bridge being destroyed in each year are:

year 1	p
year 2	p(1-p)
year 3	p(1-p)2
....	
year n	p(1-p)n-1

and the probability of the bridge surviving to n years and then being replaced is therefore:

$$1 - p - p.(1-p) - p.(1-p)2 - \quad .p(1-p)n-1 \quad = \quad (1 - p)n$$

The probability of survival to the end of year 5 is therefore (1-0.005)5 = 0.97525

In the event of earthquake damage, a temporary Bailey Bridge would have to be erected while a new permanent structure was being built. This would impose an additional cost on the road controlling authority which would not occur in the case of a planned replacement. There would also be disruption to traffic at the time of the earthquake.

Assume that the bridge replacement cost is $2.5 million over 2 years. Making the assumption that an earthquake, if it occurred, would on average occur mid-year, it is then assumed that these costs are distributed $1.5 million in the first year, and $1.0 million in the next year.

Assume that the cost of erecting a temporary Bailey Bridge is $0.2 million spread over six months, the disruption cost during planned replacement of the bridge is zero (the old bridge remains open), and the disruption cost of unplanned delays while the Bailey is being constructed is $0.5 million and disruption during Bailey use (during the 2 years it takes to construct the new bridge) is $0.2 million per year.

If the bridge is destroyed before planned replacement, then the costs at the start of the year in which the earthquake occurs are:

Roading Costs:	$million
Bailey Bridge	$0.1 x 0.9535 (SPPWF 0.5 yr)
	$0.1 x 0.9091 (SPPWF,1 yr)
Permanent replacement bridge	$1.5 x 0.9091 (SPPWF 1 yr)
	$1.0 x 0.8264 (SPPWF 2 yr)
	$2.376 million
Road User Costs:	
initial disruption costs	$0.5 x 0.9535 (SPPWF 0.5 yr)
ongoing disruption costs	$0.2 x 0.5 x 0.9091 (SPPWF 0.5)
	$0.2 x 0.8668 (SPPWF 1.5 yr)
	$0.2 x 0.5 x 0.8264 (SPPWF 2 yr)
	$0.83 million

where SPPWF is the Single Payment Present Worth Factor.

The probability of the bridge being destroyed by an earthquake in each of 1, 2, 3 and 4 are then multiplied by the above costs and benefits to give expected values in each year. The same is done in year 5 for the costs of planned replacement of the bridge. The expected values of costs and benefits in each year are then as follows:

Year	Probability	Costs	Benefits	EV (Costs)	EV (Benefits)
1	0.005000	2,376,000	-830,000	11,880	-4,150
2	0.004975	2,376,000	-830,000	11,821	-4,129
3	0.004950	2,376,000	-830,000	11,761	-4,109
4	0.004925	2,376,000	-830,000	11,702	-4,088
5	0.004901	2,376,000	-830,000	11,645	-4,068
	0.975250	2,190,000		2,136,000	

The above costs and benefits are effectively discounted to the start of each year and each must be further discounted by the SPPWF factor for (year -1).

The example does not take account of any benefits which may arise from bridge replacement such as a reduction in annual maintenance costs, road user benefits from improved alignment or reduction in bridge loading restrictions. These should be dealt with in a similar way, by discounting future costs and benefits to the start of each year 1 to 5 and then multiplying by the probability of loss of earthquake occurrence to give expected values, which should then be further discounted to time zero.

Appendix B

Road Risk Management Workshop at Wellington, 12 July 2001

B.1 Participants

Participant	Position	Organisation
Adam Ashford	Senior Evaluation Analyst	Transfund New Zealand
Pieter Besuijen	Roading Engineer	Dunedin City Council
Anthony Brennand	Manager, Transportation Planning & Policy	Wellington Regional Council
P. Brabhaharan	Principal, Geotechnical Engineering & Risk	Opus International Consultants, Wellington
Graeme Brown *(part-time)*	Logistics Co-ordinator, Emergency Management Office	Wellington City Council
Doug Mitchell	Senior Engineering Advisor	Manukau City Council (representing Ingenium)
Steve Moynihan	Senior Engineering Economist	Opus International Consultants, Wellington
John Norton *(part-time)*	Director	Ministry for Emergency Management
Mike O'Cain	Regional Manager	Transit New Zealand, Dunedin
Deven Singh	Roading Asset Engineer	Wellington City Council
Wayne Stewart	Business Manager	Opus International Consultants, Wanganui

B.2 Format and Agenda

The workshop was facilitated by Dr Wayne Stewart from Opus International Consultants, Wanganui, with the following agenda:

1. Introductions.
2. Presentation on the influence of the proposed Civil Defence and Emergency Management Act (John Norton, Director, Ministry for Emergency Management).
3. Presentation on road risk management strategies (P. Brabhaharan, Opus International Consultants, Wellington).
4. Establishing the context – what do participants want to achieve?
5. Review of stakeholders and their interests.
6. Group session: brainstorming work sessions to consider implementation at:
   - regional level,
   - local network level,
   - project level,
   - emergency management.
7. Discussion of funding mechanisms.
8. The way forward.

B.3 Issues and Questions

The following issues and questions came out of the workshop discussions.

1. The priority that natural hazard identification should be given compared with other outcomes (e.g. safety, congestion management, asset management), given the resource and funding constraints.
2. How can the risk management research be used effectively in the future?
3. Understanding the national, regional and local responsibilities for planning.
4. The responsibilities of different agencies in risk management.
5. How to incorporate risk management processes into the asset management plan.
6. Expansion of "risk procedures" in asset management.
7. Justifying risk reduction projects and the importance of emergency access.
8. Understanding the incentives and barriers to using risk management procedures.
9. How robust is the risk assessment methodology?
10. What is the appropriate level of service to be provided by roads and hence the risk?
11. How to achieve value for money – best investment.
12. How to achieve a cost-effective risk management process, considering the:
    - risk to the road network
    - risk management process at individual sites
    - acceptable/consistent level of risk
    - overall activities and achievement of risk management nationally.
13. Transfund funding issues for lifeline projects.
14. Views on benefit/cost ratios vary for new projects and risk management initiatives.
15. How processes could be implemented:
    - at regional level,
    - at network level,
    - at project level,
    - for emergency preparedness.
16. Incorporation of risk assessment in the *PEM*.

Appendix C

Case Study: Risk Management for Wellington City Road Network – Prioritisation of Road Links

Risks to the road network under consideration may be widespread, and it will be difficult to assess and undertake risk management for the whole network. Prioritisation will determine the order of importance of road links to the road network, and hence target assessment and prioritisation of risk management measures. This would help in implementing risk mitigation measures to reduce the vulnerability of the network where that is most beneficial.

The factors which influence the prioritisation of the links are:

1. **Route class factor** (F_c): whether the link is principal, arterial, collector or local.
2. **Traffic volume factor** (F_t): based on the annual average daily traffic (AADT).
3. **Importance factor** (F_i): whether there are any alternative routes, and whether the alternatives are close or distant.
4. **Emergency services route factor** (F_e): whether the route is important for emergency services access after a major event.
5. **Public transport route factor** (F_{pub}): whether the route is important for public transport facilities.
6. **Commercial use factor** (F_{com}): the importance of the route to commercial use that is vital to the functioning of the economy, including tourism.
7. **Overall risk factor** (F_{risk}): whether the road link has high or widespread risks (difficult and costly to mitigate), localised risks (where a small investment significantly improves security) or low risk (which may be acceptable and has limited impact on the road).

Hence the road link priority rating (F_P) is:

$$F_P = F_c + F_t + F_i + F_e + F_{pub} + F_{com} + F_{risk}$$

The factors that may be appropriate for road link prioritisation are presented in Table C.1 opposite. These are indicative only and subject to consideration by each RCA. A weighting may be applied to give greater or lesser prominence to certain factors. The weightings and factors will depend on the relative importance that the RCA wishes to place on different issues, and may vary according to the particular road network and the community it serves.

Using weightings, the priority ratings can be derived as:

$$F_P = F_c.W_c + F_t.W_t + F_i.W_i + F_e.W_e + F_{pub}.W_{pub} + F_{com}.W_{com} + F_{risk}.W_{risk}$$

Table C.1 Road link prioritisation factors.

Factor	Categories	Factor value	Weighting
Route class factor F_c	Principal/State Highway	2	W_c
	Arterial	1.5	
	Collector	1	
	Other local roads	0.5	
Traffic volume factor F_t	AADT greater than 16 000	2	W_t
	AADT 8000 – 16 000	1.5	
	AADT 2000 – 8000	1	
	AADT 200 – 2000	0.5	
Importance factor F_i	No alternative access	2	W_i
	Distant alternative access	1.5	
	Close alternative access	1	
	Close secure alternative access	0.5	
Emergency services route factor F_e	Primary emergency service route	2	W_e
	Secondary emergency service route	1	
	Not critical for emergency services	0.5	
Public transport use factor F_{pub}	Primary public transport route	2	W_{pub}
	Secondary public transport route	0.5	
	Not a public transport route	0	
Commercial use factor F_{com}	Heavy commercial use	2	W_{com}
	Moderate use	1	
	Mainly non-commercial use	0.5	
Overall risk factor F_{risk}	High localised risks	2[#]	W_{risk}
	High widespread risks	1[#]	
	Low widespread risks	0.5	
	Low localised risks	0	

A higher factor is applied for high localised risks where mitigation would be more practical, in contrast to high widespread risks where mitigation would be expensive and alternative routes may be more prudent.

The road link prioritisation using the scoring system in Table C.1 has been applied to the Wellington City road network, comprising the principal and arterial streets. The factors have been mapped using a GIS. The ratings are based on traffic volumes from the National Traffic Database and other factors based on judgmental assessment.

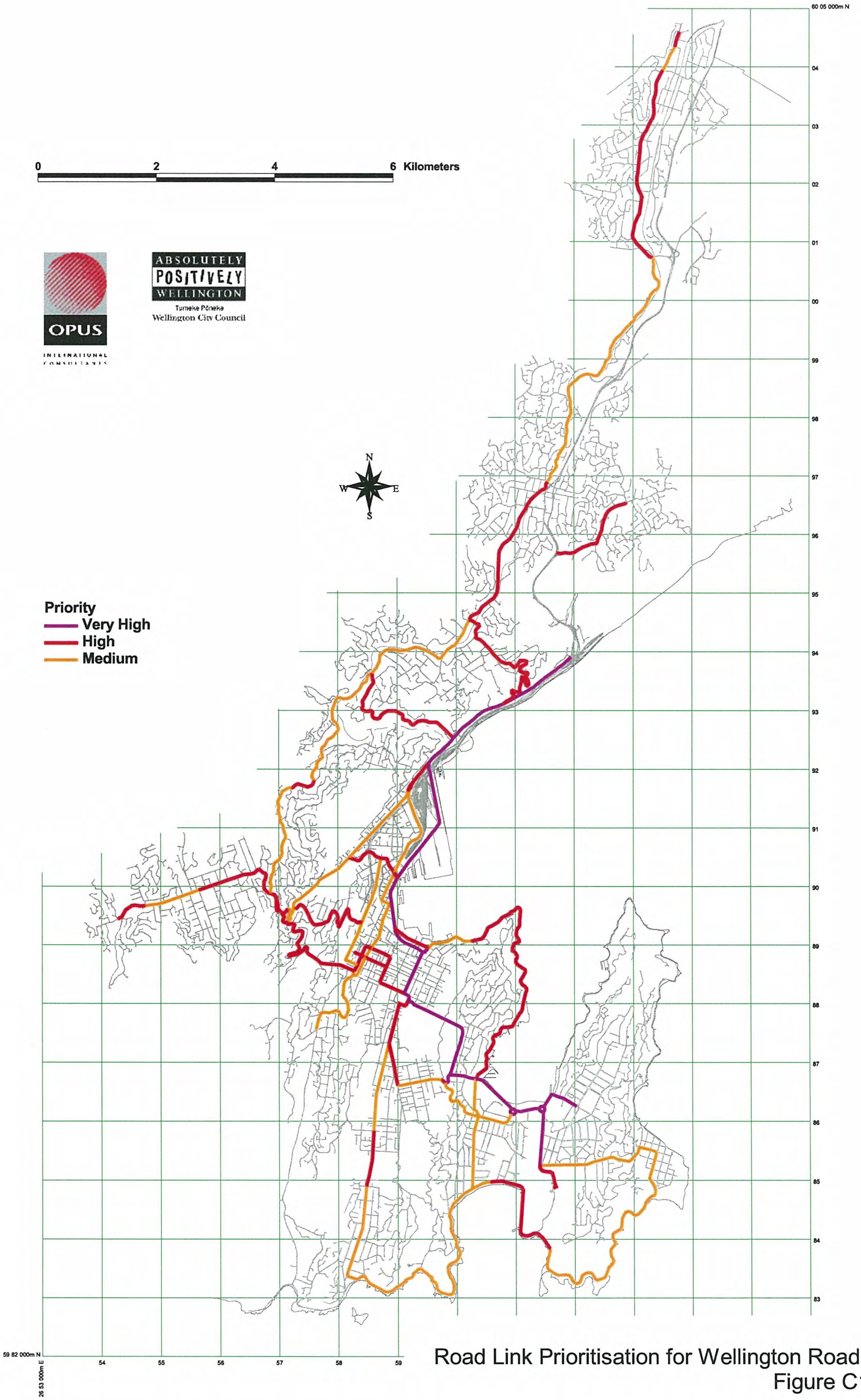
The following weightings for the factors have been chosen based on discussions with Wellington City Council staff, and used to derive a road link priority rating:

$$F_P = F_c.W_c + F_t.W_t + F_i.W_i + F_e.W_e + F_{pub}.W_{pub} + F_{com}.W_{com} + F_{risk}.W_{risk}$$

Table C.2 Weightings for road link prioritisation factors

Factor	**Weighting**
Route class factor (F_c)	$W_c = 8$
Traffic volume factor (F_t)	$W_t = 7$
Importance factor (F_i)	$W_i = 6$
Emergency services route factor (F_e)	$W_e = 10$
Public transport use factor (F_{pub})	$W_{pub} = 7$
Commercial use factor (F_{com})	$W_{com} = 7$
Overall risk factor (F_{risk})	$W_{risk} = 5$

The road link priority rating was derived using GIS, and the ratings are presented visually over the network map on Figure C.1 opposite.



Road Link Prioritisation for Wellington Roads
Figure C1