REPORT

Tonkin+Taylor

New Zealand Transport Agency National Resilience Programme Business Case

Risk Assessment Methodology

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1 Introduction

New Zealand faces a range of natural hazards and risks, which are increasing in complexity and uncertainty due to the effects of climate change. The New Zealand Transport Agency (the Transport Agency) is working to better understand the resilience of their network to withstand these increasing and ever-changing natural hazard risks through the development of their National Resilience Programme Business Case (PBC).

The intention is that this National Resilience PBC will then inform the systemic changes required to address resilience issues impacting the wider land transport system. The National Resilience PBC will aim to also act as the catalyst for the development of smaller scale Programme Business Cases to help address the identified geographical risks and improve overall network resilience. The National Resilience PBC aims to provide context, initial evidence, coordination, priority and initial direction to interventions and activities seeking to improve the New Zealand's land transport system's resilience.

At a high level, the approach involves:

- Completing a desktop evaluation of resilience related risks based on hazard and asset data. This generates a preliminary view of priority risks for the land transport network.
- Testing the preliminary analysis with stakeholders. This has been done on a regional basis but could also be undertaken on a corridor, journey or other basis through a portfolio risk assessment framework.

Developing 'strategic intervention' options with stakeholders for priority risks, drawing on stakeholder knowledge and a framework for identifying potential options. This report details the portfolio risk assessment framework and methodology for identifying full portfolio of natural hazard and climate change risks across the land transport network. For the purpose of the National Resilience PBC the PRA focused on state highways (SH), local roads which provide alternate routes to SHs, and the KiwiRail network.

1.1 Report structure

This remainder of this report comprises:

- Section 1 – Introduction: Brief overview of the wider National Resilience PBC in which this methodology sits.
- Section 2 – Background: Details the previous resilience work that has been carried out by the Transport Agency to reduce double up and address gaps.
- Section 3 – Risk assessment methodology: Detailed portfolio risk assessment methodology carried to identify the full portfolio of natural hazard and climate change risks across the land transport network.
- Section 4 – Summary: Provides summary comments and limitations of the portfolio risk assessment approach.

2 Background information

2.1 Review of previous resilience work

Previously completed resilience business cases were reviewed to provide useful context within the Portfolio Risk Assessment workshops. These included:

- The Transport Agency, 2013 – Strategic Resilience in the State Highway Network
- The Transport Agency, 2014 - State Highway Network Resilience National Programme Business Case
- Opus, 2016 - National State Highway Resilience: 9 Priority Programme Business Case Corridors
- The Transport Agency, 2019 - National Resilience Strategic Case

The National Resilience Strategic Case (2019) includes a review of the previous the Transport Agency business cases and is summarised below.

Previous the Transport Agency business cases on resilience have taken a narrower lens that is no longer considered fit-for-purpose in order to carry out a 'whole of system' approach across the land transport network[1]. The *2013 Strategic Case: Resilience in the State Highway Network* focussed on the legislative requirements of the Transport Agency in managing the state highway network to:

- Improve access to support disaster response and recovery
- Improve network reliability to support economic growth
- Reduce risk from rock falls and slips

The resulting *2014 National Resilience Programme Business Case*, directed investments to improve resilience in three areas:

- Priority corridors
- Critical spot treatments
- Improve management and preparedness

The *2014 Resilience PBC* identified that 'Priority 1' corridors should be assessed under a separate PBC. The *2016 9 Priority Programme Business Case Corridors* focused on addressing these 'Priority 1' corridors across the network[2].

The *2013 Strategic Case* also initiated the *2014-2017 Resilience Business Improvement Project* (Figure 2.1), which focussed on three work streams: business continuity plans; emergency response plans; and the business case process.

[1] 2019, The Transport Agency, National Resilience Strategic Case
[2] 2016, The Transport Agency, 9 Priority Programme Business Case Corridors

Figure 2.1: Resilience Business Improvement Project overview[3]

In preparation for the various engagement sessions all Corridor Management Plans[4] and the National Transport Planning Overview (NTPO)[5]were also considered to provide an overview of resilience issues along key regional routes. Appendix A provides a summary of other relevant reports that have also been reviewed.

2.2 Natural hazard and asset data collection and review

Appendix C presents an overview of the natural hazard and asset data collected and reviewed. Where possible hazard and risk information was collected for both natural and technological hazards. For the purpose of this project we have defined technological hazards as those hazards resulting from a failure of technology (failed traffic lights, operation centre outage, etc.).

When identifying hazards of interest, we have:

- Considered the range of natural hazard events that occur within each region where appropriate data is available;
- Considered human – made hazards (technological and socio/political) where relevant;
- Identified exacerbating factors – factors that could amplify or exacerbate hazard magnitudes and frequencies should be considered. These include climate change effects, as well as other human-induced causes such as crashes.

Transport system/network/asset data was collected from the Transport Agency and publicly available data sources such as LINZ. This data primarily focuses on network infrastructure e.g. roads and rail, as well as critical infrastructure locations such as ports, bridges, airports, vehicle charging infrastructure and other utility infrastructure served by transport corridors.

Data has been gathered on key interdependencies, such as electricity, primarily within different elements of the transport system. Systems/networks/assets have been considered both individually by sector (e.g. road, rail, port) and in the context of a 'route' which may serve a community either in a business-as-usual or disaster situation, and considering multiple modes serving the same transport purpose.

This data review is summarised below and provides a first pass at identifying key risk areas which were discussed in engagement sessions with regional stakeholders.

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[3] 2019, The Transport Agency, National Resilience Strategic Case
[4] The Transport Agency, Corridor Management Plans
[5] 2015, The Transport Agency, NTPO Resilience Table

2.2.1 Asset data

Asset data as shown in Appendix C was obtained as it has potential to influence criticality, risk or resilience issues for the land transport network. Generally, asset data is readily available for the entire network for both roads and rail and work has been previously done to apply criticality ratings to some of these assets.

Key lifelines/utility locations have also been obtained. This is to identify which road elements services these key lifelines – and therefore have potential to create an interdependency (and increase the criticality).

It is noted that local road data has also been obtained, however this will be used only for understanding potential detour routes or access to critical lifelines/interdependencies.

2.2.2 Hazard and risk data

Information on hazard data coverage, return periods and limitations has been obtained, where applicable. Most of these datasets are at a national level, providing a consistent comparison across the country, and enabling identification of areas of higher hazard exposure and risk.

We note that national datasets are limited by their coarse resolution, and are appropriate for this National Resilience PBC level assessment, however, should not be utilised for detailed analysis. For example, the National Seismic Hazard Model provides a good understanding of impacts within proximity to fault locations, therefore can be used to indicate potential impacts for transport networks. National climate change data however has higher levels of uncertainty within datasets, and is usually presented at a regional scale, limiting detailed assessments of impacts.

2.3 Previous Transport Agency hazard/risk assessments

The Transport Agency have provided a dataset entitled "Natural Hazard Resilience Prioritisation" road asset information, which gives varying risk ratings including low, major, significant or vital. The dataset is intended to highlight the level of risk for SH segments (in relation to natural hazards) across the network. The effective risk rating within this assessment is derived from the following:

- Low frequency – high impact events (earthquake, volcano, storm, tsunami)
- Resilience costs related to network maintenance costs from key naturals hazards including slips, ice/frost, and floods (assumed that these costs are indicative costs which are inferred from the predicted degree of damage)
- The relative importance of the road segment based on the One Network Road Classification

For more information on both the natural hazard resilience prioritisation and bridge data, see the Transport Agency Resilience Hazard Maps[6]. As this dataset is currently the primary information source available for natural hazard risk across the Transport Agency network and is readily available, this information is useful to compare with the outcomes of the regional engagement sessions (refer Section 3.3).

[6] The Transport Agency Resilience Hazard Maps

3 Portfolio risk assessment methodology

This section details a portfolio risk assessment (PRA) methodology assessing risks to the land transport system. The intended use is to identify key risks across the land transport system. The PRA approach follows the guiding principles of ISO:31000, adapted to this project to allow for the broad scope and tight timeframes. A PRA is not a detailed risk assessment but an affordable and practical high-level assessment that enables the Transport Agency to better prioritise resilience works and develop investment strategies. In a PRA, the risk relating to different system elements in the portfolio is assessed based on historically available information as well as information gathered through elicitation workshops with informed stakeholders.

The PRA methodology adopts a *Likelihood* and *Consequence* approach to assess risk as outlined in ISO:31000 Risk Management Principles and Guidelines (ISO, 2009). This approach is considered good practice, simple to understand, and aligns with the current the Transport Agency approaches. The PRA approach was developed and refined with regional staff during workshops and engagement sessions. This ensured the criteria for assessing risk across the network was tailored to the Transport Agency context and purpose of the National Resilience PBC.

Ultimately, the PRA aims to identify risks, prioritising high and extreme risks, across the transport system with regards to natural hazards or 'shock' events, as well as slow onset and climate change induced hazards.

3.1 Risk assessment for 'shock' hazards

'Shock' events such as earthquake, tsunami, rock-fall or storm-induced flooding and landslip require addressing slightly differently to that of climate-related hazards such as coastal inundation, coastal erosion and groundwater rise (influenced by sea-level rise, refer section 3.2).

This PRA approach uses combined *likelihood* and *consequence* parameters that influence the level of risk (refer Figure 3.1). The *likelihood* is addressed by combining the hazard frequency and the duration of outage which is indicative of the level of potential damage to the asset from its exposure to the hazard (i.e. the greater the damage the greater the duration of outage). The *consequence* is addressed by combining the criticality of the road and the availability of a viable detour.

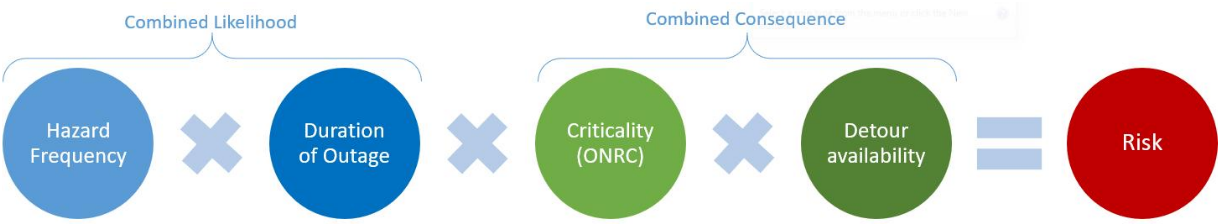

Figure 3.1: Risk assessment methodology/framework

3.1.1 Combined likelihood

In order to manage the key parameters within a '*likelihood* and *consequence*' approach, a *combined likelihood* parameter has been developed as a combination of the <u>hazard likelihood</u> and the likelihood of damage expressed as the <u>duration of outage</u>.

Table 3.1 details the criteria used to rate the hazard likelihood and the duration of outage in terms of low (1), medium (2) and high (3) combined likelihood. Table 3.2 details the matrix used to combine the hazard frequency and duration of outage ratings into a combined likelihood of damage rating of unlikely (UL), likely (L) or very likely (VL).

Table 3.1: Combined likelihood rating criteria

Descriptor	Hazard Likelihood/Frequency
Low (1)	Occurs approximately every 50 years or more
Medium (2)	Occurs approximately every 5-50 years
High (3)	Occurs approximately every 5 years or less

Descriptor	Duration of Outage
Low (1)	Less than 12 hours
Medium (2)	12 – 48 hours
High (3)	> 48 hours

Table 3.2: Combined likelihood matrix

		Hazard		
		Low (1)	Medium (2)	High (3)
Outage	Low (1)	1	2	3
	Medium (2)	2	4	6
	High (3)	3	6	9

Rating Key
Unlikely (UL)
Likely (L)
Very likely (VL)

3.1.2 Combined consequence

The *combined consequence* parameter is assessed by combining the criticality of the road network which has been based on the Transport Agency One Network Road Classification (ONRC) and the availability of viable detours.

Criticality

The ONRC is a classification system, which divides New Zealand's roads into six categories based on: how busy they are; whether they connect to important destinations; and if they are the only route available. Discrete categories include[7]: High volume, National, Arterial, Regional, Primary collector, Secondary collector, Access, Low volume.

Criticality should also consider the road interdependencies with essential services and lifeline utilities. During initial discussions with Transport Agency staff, it was highlighted that the ONRC does not always reflect the actual use of the road and its importance to the region/nation. To enable stakeholders to adjust for this, criteria has been included to enable the ONRC rating to be increased to reflect the appropriate risk to the Transport Agency network. Where increases to the ONRC rating are made, this needs to be documented. This may be due to the road being a key route for vulnerable/isolated communities or the region, but only has a low rating of primary or secondary collector. It therefore becomes hard or near impossible to obtain appropriate funding for upgrades to these roads even though they have significant resilience, safety and/or capacity issues.

An example of this is SH 7 through Lewis Pass in north Canterbury/West Coast. The route is one of three routes which provide access between the east and west coasts of the South Island, however it has a lower ONRC rating than the other two. It represents a key and high-risk area which impacts Canterbury, Top of the South and the West Coast but is not prioritised due to its low criticality. This was emphasised after the Kaikoura Earthquake when it became the primary route north from Canterbury.

[7] The Transport Agency, One Network Road Classification https://www.The Transport Agency.govt.nz/roads-and-rail/road-efficiency-group/projects/onrc

Detour availability

It was also clear that the availability of viable detour routes plays a key factor in the consequence of hazards impacting the land transport network. For example, a national road has a high criticality rating however if there is a short detour for all vehicle types, the disruption to the network is limited compared to that of a regional road with a significant or no detour for the same combined likelihood.

Table 3.3 details the criteria used to rate the combined likelihood in terms of the ONRC (from 1 – 6) and the detour issues as low (1), medium (2) or high (3).

Table 3.4 details the matrix used to combine the ONRC rating and detour issues into a combined consequence rating of 1 – 5.

Table 3.3: Combined consequence rating criteria

Descriptor	ONRC Banding
1	Access/Low Volume
2	Primary/Secondary Collector
3	Regional/Arterial
4	National
5	High Volume
6	High Volume increase

Descriptor	Detour Issues
Low (1)	Short (<1hr) and easy to manage detour for all vehicles
Medium (2)	Moderate detour (<3hr) OR shorter hard to manage detour and no HPMV option
High (3)	Long detour (>3hr), hard to manage AND no HPMV option

Table 3.4: Combined consequence matrix

		Detour		
		Low (1)	Medium (2)	High (3)
ONRC + weighting	1	1	2	3
	2	2	4	6
	3	3	6	9
	4	4	8	12
	5	5	10	15
	6	6	12	18

Rating Key
1
2
3
4
5

3.1.3 Risk rating

The *combined consequence/criticality* is combined with the *combined likelihood* to assess the overall risk to the asset or section of network as minor, moderate, major or extreme (refer Table 3.5).

Table 3.5: Risk matrix

		Combined Likelihood		
		UL	L	VL
Combined Consequence	1	1UL	1L	1VL
	2	2UL	2L	2VL
	3	3UL	3L	3VL
	4	4UL	4L	4VL
	5	5UL	5L	5VL

Rating Key
Minor
Moderate
Major
Extreme

3.2 Risk assessment for climate hazards/stressors (time bound)

As mentioned, a slightly modified methodology is adopted for climate related hazards (coastal inundation, coastal erosion and groundwater rise) as the risk generally increases over time or are *time-bound*[8]. Hazards already affecting the Transport Agency land transport network are identified and worked through the same process as outlined above to provide a risk score for present day. These are also given a risk rating for the expected likelihood and consequence in 2050 based on the current projections under Representative Concentration Pathway (RCP) 8.5 (median value) for New Zealand. RCP8.5 was selected as this is considered a reasonable worst case and corresponds to the current warming trajectory with insufficient reduction in GHG emissions. Typically, this means increasing the hazard likelihood/frequency and/or the duration of outage to increase the climate risk over time.

For the hazards/risks that are not currently affecting the transport network or unknown, a high-level exposure assessment is carried out to identify areas of potential future risk to climate change induced hazards. The exposure assessment is a desk-top based assessment which utilises geospatial information systems and available hazard and asset datasets to identify areas where the asset intersects or is exposed to the relevant hazards. This was carried out for coastal erosion and sea level rise.

3.3 Workshops and engagement sessions

3.3.1 Risk assessment - desk top evaluation and stakeholder testing

Prior to the workshops and engagement sessions, hazard and asset information is used to identify initial risk areas. An initial list of risks guides the workshop discussion and helps to set the scene in terms of the high-level assessment. The initial risk areas are discussed with each group as the workshops/engagement sessions being a challenge-based stakeholder elicitation process. Stakeholders then work through their network area, working through the PRA methodology detailed above to identify key risk areas.

Workshops focused primarily on corridor grouping of resilience related risks and should involve a range of the following stakeholders:

- The Transport Agency Regional Managers/key identified staff;
- Network Outcomes Contract (NOC) key staff;
- Regional Transport Committee members (including local Councils);

[8] 2017, MfE, Coastal Hazards and Climate Change: Guidance for Local Government

- Regional and/or strategic planning staff from KiwiRail, Ports, Airports, and commercial road user groups;

The workshops and engagement sessions should cover the following broad topics:

- A discussion around the context and background to the National Resilience PBC.
- Presentation of existing knowledge around natural and human-made hazards (including climate change), previous work and document known gaps. This includes all information presented in the sections above.
- A discussion around 'criticality' in the context of the local transport system and identify critical routes.
- Discussion and elicitation of key known weaknesses (vulnerabilities) within the system (in relation to specific hazards), documented geospatially in a web viewer. This includes understanding failure modes, where relevant.
- Assess and rank risks (using hazard, vulnerability and criticality information) and prioritise within the group based on the PRA methodology set out in Section 3.1.
- Developing a series of possible alternatives and options to address those risks identified.

When identifying the high-risk areas, stakeholders should be asked to determine the approximate cost of physical works needed to minimise or eliminate the risk. Where physical works were not viable, alternative responses can be considered including BAU/Ongoing maintenance/Reactive works and/or Enhanced preventative maintenance through the NOC contracts.

3.3.2 Developing potential solutions

Once risks have been analysed and evaluated, major and extreme risks are prioritised and taken forward. For each risk identified consideration is given to both the approach to develop a response and options for responding, referencing ISO 14090 Adaptation to climate change — Principles, requirements and guidelines:

The potential approaches to developing a response include:

- The risk is current and requires a response now.
- The risk is current but can be addressed as the opportunity arises e.g. during projects undertaken for other purposes (safety, efficiency) or as part of emergency response and recovery.
- The risk will emerge in future so a response can designed and implemented at a later time.

The options for responding include:

- Defend - develop solutions to mitigate the risk of disruption, for example flood protection or slope stabilisation.
- Accommodate - plan for periodic disruption, for example providing for rapid reinstatement, detour routes and/or timely information.
- Retreat - re-route journeys away from the impacted corridor.

The benefit of this approach is that it will quickly and transparently provide a shortlist of options in a qualitative manner - allowing appropriate effort to be focussed on those alternatives/options, which merit more detailed development through subsequent business case phases, thereby eliminating options that are unlikely to meet investment objectives or alleviate problems.

3.3.3 Systemic risks

Systemic or operational management type risks and issues, which hinder the ability to respond to natural hazard events or build resilience across the land transport network, should also be discussed and captured in the workshops/engagement sessions. Examples include limitations and complexity around funding for improvements, limited river catchment monitoring and management or other operational or management issues across multiple organisations.

3.4 Desktop vs. workshop analysis - cross referencing

Following the engagement sessions/workshops to elicit natural hazard information, identified risks, their corresponding risk ratings and possible solutions are then cross referenced and reviewed by key stakeholders. The purpose of this process is to confirm the risk ratings and ensure key risks are not missed and the appropriate ratings are been applied and agreed upon.

The results are also compared geospatially against available natural hazard information such as tsunami inundation/evacuation zones, flood hazard maps, coastal erosion, sea level rise and previous resilience and natural hazard data held by the Transport Agency including the Resilience Prioritisation[9] and Resilience hazard[10] maps. This is done to cross reference the engagement session and workshop information against existing data held by the Transport Agency and others. Through this process, it is possible to identify sections of the network where there is a disparity between existing hazard information and those hazards identified during the workshops. It is likely that sections will be identified as high hazard but no hazards are documented during the workshop. there are also likely to be sections of the network where hazards are identified during the workshops but not identified in existing datasets as having existing associated hazards.

Capturing and sharing risks on a geospatial basis allows sharing of workshop outputs in a geospatial viewer. This is an effective approach to seeking feedback from workshop participants and other stakeholders. Data is captured in a way that allows risks to be considered on a regional, corridor, journey and/or hazard basis.

It is important to note that this process is dependent on the availability and associated quality of the supplied hazard datasets. For instance, no coastal inundation hazard dataset is currently available, therefore any workshop identified hazards associated with coastal inundation cannot be cross-referenced through this process. Furthermore, the methodology used to develop each dataset vary and have not been considered in putting together the evidence base for this process. Given that the cross-referencing process is designed to further identify any areas of missing hazard identification, and not remove any identified hazards, this is seen to be acceptable.

[9] 2017, The Transport Agency, State highway resilience prioritisation maps
[10] 2017, The Transport Agency, Resilience hazard maps

4 Evidence base

In completing an assessment of risk, it is important to use appropriate evidence to inform the process. The information presented in Section 2 provides background on both previous assessments and available datasets. The methodology set out in Section 3 requires a range of data 'inputs'. These comprise an agreed evidence base that is used to inform and test discussions with stakeholders about priority risks at a regional or corridor level.

It is important to note that information on natural hazards, the impacts of specific events and the condition of assets is constantly changing. This means the evidence base will evolve over time and should ideally be maintained in a way that provides for quick and simple integration of new information.

The evidence (data sets) that should be used to inform the Portfolio Risk Assessment includes:

Table 4.1: Asset data evidence base

Asset Data	
Category	Asset
Roads	The Transport Agency Roads
	Local Roads
	Bridges
	Operation centres
	EV Charging stations
Rail	Rail
	Bridges
	Critical functional elements
Airports	Airports
	Oceanic Control Centre
Utilities	Telecommunications
	Water
	Fuel
	Gas
	Electricity
Ports	Ports

Table 4.2: Hazard data evidence base

Hazard Data	
Category	Hazard
Geophysical	Landslide
	Liquefaction
	Seismic
Low Probability	Tsunami
	Volcanic
Hydrometeorological	Coastal Erosion
	Coastal Inundation
	Fluvial/River Flooding
Technological	Crash information
	Outage Data (TREIS)
Climate	Extreme Temp
	Wind

Outputs from the PRA process include:

- A list of risks based on 'desktop' analysis of the available datasets (Refer Section 3.1 and 3.2)
- A list of prioritised risks identified by stakeholders, informed by the desktop analysis.
- A note of systemic risks that have an impact on location/corridor-based risks.
- High level options for addressing priority risks.

5 Limitations

The following details limitations to consider regarding the PRA methodology and accompanying results:

- Due to the nature of the workshops and the National Resilience PBC which is focusing on Major and Extreme risks only, there is likely to be a bias towards higher risks in the regional results.
- Issues that have no real option for mitigation such as Alpine fault EQ or tsunami may not be captured in detail through workshops, although they are present in the available data which was collected and detailed in section 2.2.
- Datasets used for cross referencing were not verified as part of this process. Furthermore, only available hazard datasets were used to cross reference identified hazards. Where there were no specific hazard datasets, these were not cross referenced.
- The resilience prioritisation[9] data for low frequency hazards has been pulled from RAMM which indicates that the Transport Agency has spent money on responding to a certain hazard. This means the data misses any sections of road or bridges which are affected but have to has any response. It also means that any sections of road which have had a significant amount of resilience or response work done may now no longer be exposed or at risk but are showing as the highest risk.

6 Applicability

This report has been prepared for the exclusive use of our client New Zealand Transport Agency, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

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Appendix A: Key terminology

Key to any discussion, study or project is a common understanding of taxonomy. Below are established definitions based on existing literature across the climate change and natural hazard risk space:

Adaptation: The process of adjustment to actual or expected climate and its effects.

Adaptive capacity: The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Asset: The physical hardware (e.g. pipes, wires), software and systems to own, operate and manage Lifelines Utilities (energy, transport, telecommunications, water).

Climate Change[11]: A change in the state of the climate that can be identified by changes in the mean variability of its properties, and that persists for an extended period.

Criticality: informed (defined) by the consequence of the asset failing. That is if there is an unacceptable consequence should a particular asset fail, then that asset would be classed as highly critical.

Collective Risk[12]: is a measure of the total number of fatal and serious injury crashes per kilometre over a section of road. Collective Risk highlights which road links have a high number of fatal and serious crashes on them – which can be used to help determine where the greatest road safety gains can be made from investment in engineering. Collective risk is of most interest as this highlight where infrastructure improvements are most likely to be cost effective.

Exposure: The location of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Hazard: The potential occurrence of a natural or human-induced physical event that may cause harm. Harm can be both physical and non-physical, such as economic, social and/or cultural.

Mitigation (of climate change): A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Personal Risk[12]: is a measure of the total number of fatal and serious injury crashes per kilometre over a section of road. Personal Risk takes into account the traffic volumes on each section of state highway. Personal Risk shows the likelihood of a driver or rider, on average, being involved in a fatal or serious road crash on a particular stretch of road. Personal Risk is of most interest to the public, as it shows the risk to road users, as individuals. Personal Risk is typically higher in more difficult terrain where traffic volumes and road standards are often lower. In many cases infrastructure improvements on these roads are unlikely to be cost effective and other Safe System interventions such as safer road use and safe speeds need to be explored.

Resilience[13]: The transport system's ability to enable communities to withstand and absorb impacts of unplanned disruptive events, perform effectively during disruptions, and respond and recover

[11] IPCC, 2013 Motu Paper
[12] For more information see NZ Road Assessment Programme
[13] Derived and aligned with resilience definitions from the Sendai Framework for Disaster Risk Reduction, draft National Resilience Strategy (CDEM, Nov 2017) and The Transport Agency's Four-Year Excellence Horizon.

functionality quickly. It requires minimising and managing the likelihood and consequences of small-scale and large-scale, frequent and infrequent, sudden and slow-onset disruptive events, caused by natural or man-made disasters.

Risk: Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.

Sensitivity: The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Appendix B: Summary of previous risk/resilience projects

Appendix B Table 1: Summary of previous risk and resilience projects

Resilience of State Highways: Lessons from the 2016 Kaikoura Earthquake, OPUS, 2017

Overview

This project aimed to assess the resilience of the state highway network at a broad national level and develop a methodology for implementation at regional level. The Kaikoura EQ then provided an opportunity to calibrate the resilience studies against observations from this earthquake and bring together key learnings for future resilience studies. Resilience of roads has been defined as being dependent on the loss of quality or serviceability, and the time taken to bring the road back into its original usage state:

Resilience State	Description of State
Availability state	Availability State indicates whether the road section would be able to be used either at full level, at various reduced levels or not at all. This gives an indication of the degree of access on a link after an event.
Outage state	Outage State indicates the duration over which the road will be in the Availability State above. This gives an indication of the duration of loss or reduced access in links along the road network.

Methodology included:

1. Characterisation of the 14 November 2016 Kaikoura earthquake.
2. Review of previous work
3. Gathering of earthquake damage data
4. Mapping of the availability state of the Kaikoura section of State Highway 1 after the earthquake.
5. Gap analyses by reviewing and comparing the previous resilience assessments with the observed post-earthquake resilience of SH1 in the Kaikoura earthquake, subsequent after-shocks and storm events.
6. Preparation of report with observations and recommendations for future resilience assessments

Prior to this a more detailed corridor level resilience study was carried out. This was also calibrated against the observations of resilience after the Kaikoura earthquake. It allowed comparison between the expected performance and the actual damage from the Kaikoura earthquake in discrete sections.

Overall, the national resilience study predicted the outcome of a large earthquake to close the highway both north and south of Kaikoura and the 2016 Kaikoura earthquake has validated this. The route was closed over most of the coastal sections of the highway, as predicted in the 2001 resilience study as well as the 2016 national state highway resilience study.

A key observation by Brabhaharan et al (2006) that was reinforced following the Kaikoura earthquake was that the restoration of access following an event occurs in stages rather than as a linear process from loss of service to full. In many instances particularly following a large event, access may be restored to restricted access, single lane and full access in several stages.

It should be recognised that safety hazards such as potential for rock fall could compromise availability of the route, even when the route is not closed, until the source areas for rock fall can be made safe, by scaling, sluicing or rock anchoring. This needs to be considered in response planning.

NZ Lifelines Infrastructure Vulnerability Assessment, NZ Lifelines Council, 2017

Overview

This report is a first pass at collating and summarising key findings from regional lifelines studies and other major national hazard studies such as DeVoRA, AF8 and WENIRP1. It aims to provide insights on New Zealand's critical lifelines infrastructure and its resilience (and conversely its vulnerability) to major hazards and several knowledge gaps in our understanding and mitigation of New Zealand's critical infrastructure vulnerabilities.

The longer-term goal, to be delivered through Stages 2 and 3 of this project is to provide government and industry with a strategic understanding of nationally significant infrastructure, its vulnerability and resilience to hazards, and strategies to mitigate risks to a nationally agreed 'acceptable' level.

Recent lifelines projects have followed a criticality assessment approach, which identifies lifelines infrastructure within the region as nationally, regionally or locally significant. Nationally significant infrastructure assets are often where there are 'pinch points' in the supply chain – sometimes these are single sites which would cause a significant loss of national service.

Along with key sector pinch points such as those described above, many regional lifelines projects look at risks associated with infrastructure 'hotspots' where critical assets from a number of sectors converge with a high consequence of failure associated with cumulative loss of services at that site.

The aim of this Stage 1 assessment is to provide a national view of critical infrastructure and vulnerabilities. It is intended to inform a range of activities, including:

- Regional lifelines projects, to provide an understanding of the cross-boundary issues that need to be considered in regional vulnerability assessments (impacts within the region impacting outside the region and vice versa).
- Lifeline utility resilience planning (e.g. support prioritisation of resilience projects with consideration of wider infrastructure impacts).
- National policy and strategy setting, such as the National Disaster Resilience Strategy and future review of the National Infrastructure Plan.
- Future infrastructure and hazard research priorities

A number of knowledge gaps have been identified and suggested projects to support ongoing resilience improvements are presented in Section 7. Coming out of work in the 'lifelines' sector, these projects are focussed on aspects such as improving our understanding of critical infrastructure, major hazards and the intersection between the two. Further work is also needed to understand the dependence of critical community sectors (health, emergency services, Fast Moving Consumer Goods, etc) on lifelines services and backup arrangements if those services fail.

Resilience of State Highways: Recommended Regional Assessment Methodology for Low Frequency Hazard Exposure, The Transport Agency, 2016

Overview

This report presents the methodology developed for the regional level assessment of the resilience exposure of the state highway network for low frequency, high impact natural hazards. This framework is consistent with the national approach but uses more detailed regional information, and therefore allows the resilience of the state highway assets to be assessed at a more detailed regional level. The results of these assessments informed the development of Programme Business Cases.

The approach to assess the resilience exposure of state highway routes at a corridor or regional level is summarised below:

- Identify corridor for resilience assessment
- Determine scope/& assessment level
- Collate data
- Develop characterisation scheme
- Carry out site reconnaissance
- Characterise the road corridor
- Assess the hazard impacts
- Apply resilience metrics
- Capture into GIS

This is based on the approach developed by (Brabhaharan, et. al., 2001 & 2006), and is consistent with the approach developed for the national level resilience assessment (Brabhaharan & Mason, 2016)

The objectives of the regional assessment process are:

- Enable assessment of the resilience exposure of state highway corridors to low frequency, high impact natural hazards at a more detailed level than the national assessment, so that it can be used for the development of programme business cases for corridors and for planning resilience enhancement and network asset and emergency management;
- Provide a consistent basis for assessment of the resilience for the state highways in all the regions;
- Enable detailed understanding of the resilience of the network, particularly sections of corridors with poor resilience;
- Underpin the evaluation of gaps in resilience (desired resilience vs current resilience);
- Provide outputs suitable for the development of strategic responses and be able to be used for development of resilience enhancement measures (including emergency response planning);

- Provide a toolkit, including a process map and appropriate evidence/references that could be used in the process, and which has flexibility for adaptation/innovation for specific issues.

These objectives have provided the basis of the development of the regional assessment methodology for resilience exposure to low frequency, high impact events.

National State Highway Resilience: 9 Priority Programme Business Case Corridors, OPUS, 2016

Overview

The national level resilience assessment of the 9 priority corridors has identified sections of the state highways that are vulnerable to failure from a variety of natural hazards. The project involved collection of national data on natural hazards for use in the assessment of the resilience of the state highway network, and existing assessments of the vulnerability of components of the state highway (e.g. bridge seismic assessment or scour).

The national level resilience assessment has been initially carried out for 9 priority programme business case corridors, located throughout the country.

The outcomes of the national level resilience assessment are:

- Maps showing the resilience states for the state highways, presented as availability, outage and disruption states, and highlighting key areas of vulnerability of the SH
- Map showing prioritisation of the state highway network.
- A brief report summarising the results of the assessment.

This report presents the maps and summarises the results of the assessment.

The national resilience assessment methodology addresses the following objectives:

- Enables assessment of the resilience across the whole state highway network.
- Assesses at a broad-brush high level, efficiently and quickly.
- Assesses resilience to large natural hazard events.
- Uses a consistent basis applied across the country.
- Assesses to screen and understand the resilience of the network, to appreciate differences, and identify areas of concern.
- Enables further consideration of areas with poor resilience and inform and link with more detailed assessments at corridor levels by regional Agency teams.

These objectives have been the basis of the development of the national assessment methodology for resilience.

resilience metrics have been used to represent these two dimensions, through the resilience states developed by (Brabhaharan, Wiles, & Freitag, 2006) of:

- Availability state – level of access after the event, representing the level of service.
- Outage state – the duration of reduced access at the above availability state.

The report recommends that:

- A regional level resilience screening methodology be developed, and then implemented for the 9 Priority Programme Business Case Corridors. This will enable the resilience to be assessed with a better definition of local level hazards and the hazards (e.g. local flooding, liquefaction) in more detail. This will also provide insight into whether some of the PBC corridors would need to consider alternative alignments and identify which sections of the corridors are more critical from a resilience perspective.
- The national level resilience screening be continued for the remaining state highway network, after completion of the regional level resilience for the 9 priority corridors. This will enable the programme business cases to proceed but will also allow testing the methodology for the regional level assessment, and this may provide insights to refine the national resilience screening methodology.
- The identified national level critical resilience issues be used in asset and emergency management planning for these routes that have been assessed.

State Highway Network Resilience National Programme Business Case, The Transport Agency, 2014

Overview

The approach taken in this PBC assumes that resilience is concerned with any event, natural or man-made, which could disrupt our customers travel plans. The definition of resilience used in the development if this Programme Business Case (PBC) is taken from the National Infrastructure Plan (NIP) which states:

'The concept of resilience is wider than natural disasters and covers the capacity of public, private and civic sectors to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and grow over time'. A Strategic Case for the NZ Transport Agency, Highways and Network Operations (HNO) was developed late in 2013. It identified three problem areas, which would result in significant benefit when effectively addressed.

Strategic Case: Problem	Strategic Case: Benefits of addressing the problem
Poor highway resilience may impede critical services from providing disaster response and recovery support	Better enabled disaster response and recovery
Unreliability of some highways impacts businesses and undermines economic growth	Better support for economic growth
The risky environment of some roads increases the possibility of harm to road users	Reduced risk of harm to road users

The initial activities to fill information gaps and increase preventative maintenance were split into the following three types of activities:

- Resilience Improvements – Priority Corridors
- Resilience Improvements – Spot treatments
- Resilience Management and Preparedness

Methodology included:

- Developing a framework for consistently assessing geologic and hydrologic risks
- Developing an approach to assessment of risk and response on state highway routes, and dependent communities
- Developing a standard for:
  - Assessing Lifelines obligations and responses
  - Assessing and recording alternative routes

- Emergency response plans, including providing emergency access to isolated communities

Maps were created from TREIS data on the number and duration of closures over the past five years. This has been combined into heat maps showing resilience hot spots. The large number of closures recorded in the TREIS data above and the resilience risk data provided by the regions clearly demonstrates the significant economic impact caused by lost hours to business due to closures, and the potential for a number of people to be hurt due to rock fall risk.

Natural Hazard Road Risk Management Part III: Performance Criteria, OPUS, 2006

Overview

This research is the third stage of a programme of research aimed at developing approaches for the strategic management of natural hazard risks to road networks in New Zealand. To facilitate the process, the resilience of each road link in the network can be assessed in terms of appropriate 'resilience states' developed as part of this study, namely:

- Damage state,
- Availability state, and
- Outage state

In Part I, Opus developed strategies for managing natural hazard risks to road networks. This research identified several approaches, firstly for assessing the spatial risk to road networks with the aid of a geographical information system (GIS); secondly, considering risk mitigation; and, finally, prioritising sections of road for management of the risk.

In Part II, Opus presented different levels at which risk management should be addressed and discussed how this may be integrated to achieve a resilient road network. This study recommended that performance criteria and levels of service for different types of roads forming the road networks in New Zealand should be researched.

A methodology was developed to enable the development of robust criteria for setting performance levels for road networks regarding natural hazards risk performance:

- Literature Research
- Reviewing road damage and disruption from past natural hazards
- Consulting road stakeholders
- Identifying issues and assessing factors which affect performance levels
- Workshop on performance expectations
- Developing a framework for setting performance levels
- Pilot application of the framework to a section of the road network

A comprehensive review of literature relating to the management of risks associated with road networks was undertaken to review different methods both nationally and internationally for addressing infrastructure performance criteria, damage states, levels of service, road/bridge classifications and Civil Defence Emergency Management Act requirements. The literature review confirmed that no criteria are available for setting performance levels for road networks, except for performance-based design standards for bridges. Although some have attempted to define the desired levels of performance for a water supply system, little consideration has been given on how to decide on these levels of performance. No information is available to build on from past literature. Guidance for deciding appropriate levels of performance has been developed on the basis of the new research reported here.

In order to produce a questionnaire that encompassed all the principal issues, typical natural hazard scenarios were developed. The purpose of the scenarios was to enable the consultation to be based on some realistic scenarios on which the stakeholders could relate to and provide meaningful comment. The purpose of the workshop was to draw on the collective experience of the participants on important issues for setting performance measures. This pooled experience would provide information for developing a framework for setting performance criteria. The purpose of applying the framework for setting performance levels to the Wellington road network is to demonstrate how the process can be applied in practice to assist practitioners in their road asset and risk management planning.

Appendix C: Hazard and asset data review

· Appendix C Table 1: Overview of the information collected during the data review

Asset Data		
Category	Asset	Commentary
Roads	The Transport Agency Roads	GIS spatial data and ONRC data has been obtained for state highways, which provides a useful proxy for criticality. The Transport Agency have also provided "Natural Hazard Resilience Prioritisation" road asset information which provides varying risk ratings to highlight the level of risk for SH segments (in relation to natural hazards) across the network. Further information on the "Natural Hazard Resilience Prioritisation" data can be found below this table.
	Local Roads	Publicly available LINZ data will be sourced for local roads. Local roads will only be incorporated into the assessment where they provide access to a critical interdependency, or where they provide a detour or evacuation route (if known).
	Bridges	The Transport Agency "Natural Hazard Resilience Prioritisation" data also provided information on road bridges, which have been assessed for both seismic and storm risk and given risk ratings from low, medium, high or significant.
	Operation centres	No data provided.
	EV Charging stations	EV charging stations have been obtained from the Transport Agency's EVROAM.
Rail	Rail	KiwiRail data was downloaded from their online data portal[14] and provides geospatial information on both their electrified and non-electrified network.
	Bridges	Rail bridge locations were also downloaded from their online data portal.
	Critical functional elements	KiwiRail information included key locations within their network and with a priority rank of either: · High – Passenger stopping points and yards · Medium – Other network operational areas · Low – Attributes in the data that only indicate the name of a place in which the assets are located
Airports	Airports	Airport locations were manually digitised into GIS and categorised by the size of the airport (local/regional/international). Note, while we have obtained information around airport locations and flights, air

[14] KiwiRail Data Portal

		travel falls out of scope of this study. The airport location data will be used to inform ground transportation linkages, and interdependencies within the wider transport network.
	Oceanic Control Centre	No data.
Utilities	Telecommunications	Considered not relevant at a national level.
	Water	Considered not relevant at a national level.
	Fuel	Data obtained from National Lifelines Vulnerability Assessment 2017.
	Gas	Transmission points/lines sourced from First Gas.
	Electricity	Transmission lines downloaded from Transpower Open Data Portal[15]. Key generation points across the country were manually digitised into GIS.
Ports	Ports	Major Port locations were manually digitised into GIS and categorised by the number of containers that are processed per year.
Hazard Data		
Category	Hazard	Commentary
Geophysical	Landslide	National Road network assessment has been carried out and provided by the University of Auckland
	Liquefaction	National Road network assessment has been carried out and provided by the University of Auckland
	Seismic	The national seismic hazard model provides a high-level indication of high seismic hazard risk areas across the country.
Low Probability	Tsunami	Tsunami has been identified as a low probability hazard. However, it is worth noting that there needs to be cooperation between emergency management and network planning to ensure that evacuation routes are of high criticality and there is appropriate infrastructure to ensure evacuation can occur efficiently.
	Volcanic	Significant impacts on the transport network have been identified as a low probability hazard. Volcanic ashfall can result in significant disruption to the land transport network and alternative routes should be planned. Lahars have been identified as the volcanic hazard, which has the greatest possibility to cause significant damage to the transport network both around Ruapehu/Tongariro and Mt Taranaki.[16]
Hydrometeorological	Coastal Erosion	A national coastal erosion assessment is underway and currently consists of a 50 m, 100 m and 150 m buffer from the National Coastline boundary to account for coastal erosion rates.

[15] Transpower Open Data Portal
[16] The Tangiwai disaster in 1953 is a clear example of this, which had significant damage to infrastructure, and loss of life.

	Coastal Inundation	NIWA have carried out a National 'Coastal Flooding Exposure under Future Sea-level Rise' Assessment as part of the Deep South National Science Challenge. The report includes coastal inundation hazard maps for the entire New Zealand Coastline.
	Fluvial/River Flooding	NIWA has provided the flood polygons collated as part of the Deep South National Science Challenge 'New Zealand Fluvial and Pluvial Flood Exposure' report.
Technological	Crash information	The Road Safety metric layer form the Mega Maps national dataset and has been provided by the Transport Agency via Abley Ltd. This includes crash information and DSi (Death and serious injury) equivalents are derived from the Transport Agency Crash Analysis System data. This information has been analysed to give risk information for both Collective and Personal along a given length of road.
	Outage Data (TREIS)	Traffic Road Event Information System (TREIS) data has been provided by the Transport Agency. This information has been separated into both planned (e.g. planned road improvements and maintenance) and unplanned (e.g. road closure due to landslip, flooding, crashes etc.) outages. This has allowed us to hot spot the data geospatially and identify areas where outages occur most across different hazard types.
Climate	Extreme Temp	Projections for changes in extreme temperature have been sourced from NIWA[17] and MfE[18] national projections
	Wind	Projections for changes in wind have been sourced from NIWA[17] and MfE[18] national projections

[17] NIWA Mean Temperature and Wind Projections
[18] 2016, MfE, Climate Change Projections for New Zealand

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