Wellington region land transport resilience business case

P. Brabhaharan
WSP, Wellington.

M. Siazon
Waka Kotahi. New Zealand Transport Agency, Wellington.

ABSTRACT

Wellington region's transport network has poor resilience to natural and anthropogenic hazards, given the rugged terrain, high seismicity and wet climate. This exposes the capital to potentially be cut off from the rest of New Zealand for several months, and the individual cities making up the region to be isolated from each other.

A pioneering programme business case was developed by WSP Opus for the New Zealand Transport Agency, Kiwi Rail and the local authorities that make up the region. The business case considered all resilience risks, developed a methodology and assessed the criticality of the risks, and on that basis prioritised the resilience risks facing the region. This prioritisation also considered the risks to other lifelines utilities such as power, water and telecommunications that shared these transport corridors.

Considering these resilience risks holistically, interventions were developed and grouped into programmes to improve resilience for immediate post-event response as well as recovery, in a range of high frequency low impact and low frequency high impact earthquake, storm and tsunami events. Programmes of interventions were compared and prioritised, and on this basis short, medium- and long-term programmes were developed and formed the basis of the business case.

This novel business case will provide a pathway for investment to enhance the resilience of the region's transport network. In addition, this provides a pathway for development of resilience business cases for transport networks in other regions as well as for other lifeline utilities throughout New Zealand and beyond.

1 INTRODUCTION

A combination of high seismicity, rugged terrain, coastal environment and weather conditions make Wellington's transport system highly vulnerable to natural hazards, and in particular earthquakes, storms and tsunami events. Over the past 30 years, Wellington has led the way with understanding the resilience of its lifeline infrastructure, starting with the lifelines study (Centre for Advanced Engineering, 1991) and subsequent studies focusing on resilience of its transport system (Brabhaharan, 2004, Brabhaharan and Mason, 2012, Mason and Brabhaharan, 2013).

A systematic characterisation of the earthquake resilience of Wellington city's road network was first completed with the aid of a geospatial platform (Brabhaharan, 2002) and was enhanced over the following years in parallel with research into road network resilience (Brabhaharan et al, 2001, 2002, and 2006). This enabled Wellington City Council to implement a long-term programme of strengthening its road infrastructure which continues over the past 20 years (Arumugam and Brabhaharan, 2018). This was followed by a similar assessment and mapping of the resilience of the cities of Upper Hutt, Hutt City, Porirua and the state highway system over the next decade. Appreciating that the state highway and local authority network operate as a combined network to provide access, an integrated resilience study updated and brought the earthquake resilience of the road network together in a joint study for the state highways, and the local authority networks in Wellington city, Hutt city, Upper Hutt city, Porirua city and Kapiti Coast District (Brabhaharan and Mason, 2012).

This was followed by the development of a strategic business case for resilience by the NZ Transport Agency (2016) and the commissioning of a programme business case for transport resilience by the NZ Transport Agency and Greater Wellington Regional Council.

2 PROGRAMME BUSINESS CASE FOR TRANSPORT RESILIENCE

The need for a business case to understand and develop resilience enhancement measures for the region's entire land transport network led the NZ Transport Agency and Greater Wellington Regional Council to commission a study in 3 stages. The first two stages carried out by Opus (now WSP) involved extending the resilience assessments to include a region-wide assessment of the resilience of the network to storm events, as previous resilience studies had assessed storm impacts for only the Hutt City and parts of the state highway network. Recognising the impact of building damage on transport access as observed in Christchurch city after the 2010-11 Canterbury earthquake sequence and in Wellington city after the 2016 Kaikōura earthquake, the Wellington city road network was also assessed and mapped for post-earthquake accessibility due to earthquake events. The study also included developing a methodology for assessing the "importance" of the entire regional road network, based on a methodology developed by Brabhaharan (2004). A new methodology was also developed and applied to assess the criticality of the resilience issues and prioritise them for resilience enhancement interventions.

The third stage involved the development of resilience interventions and a programme business case for resilience for the NZ Transport Agency by Opus, supported by Aurecon on the updating of the strategic case and providing peer review on business case aspects. This work was completed in 2018.

3 RESILIENCE OF THE TRANSPORT ROUTES

3.1 Earthquake resilience

Earthquake resilience assessment of Wellington's transport routes (Brabhaharan and Mason, 2012) indicated that the transport system has a significant vulnerability to a large earthquake in the region, see Figure 1. The resilience has been assessed and mapped using the resilience metrics derived from the resilience triangle, see

Figure 2, where the availability state represents the level of service after the event, and the outage state represents the duration of reduced availability of access or complete lack of access. The outage state map while not shown here, shows a similar pattern where post-earthquake closures are for periods in excess of six months.

Both state highways 1 and 2 and local alternative routes are likely to be closed for many months, and the population centres and cities in the region are also likely to be cut off for months. The network is also vulnerable to close in storm events, although for shorter periods. This highlights the importance of the resilience business case so that there is a coherent and co-ordinated strategy to enhance the resilience of access over time.

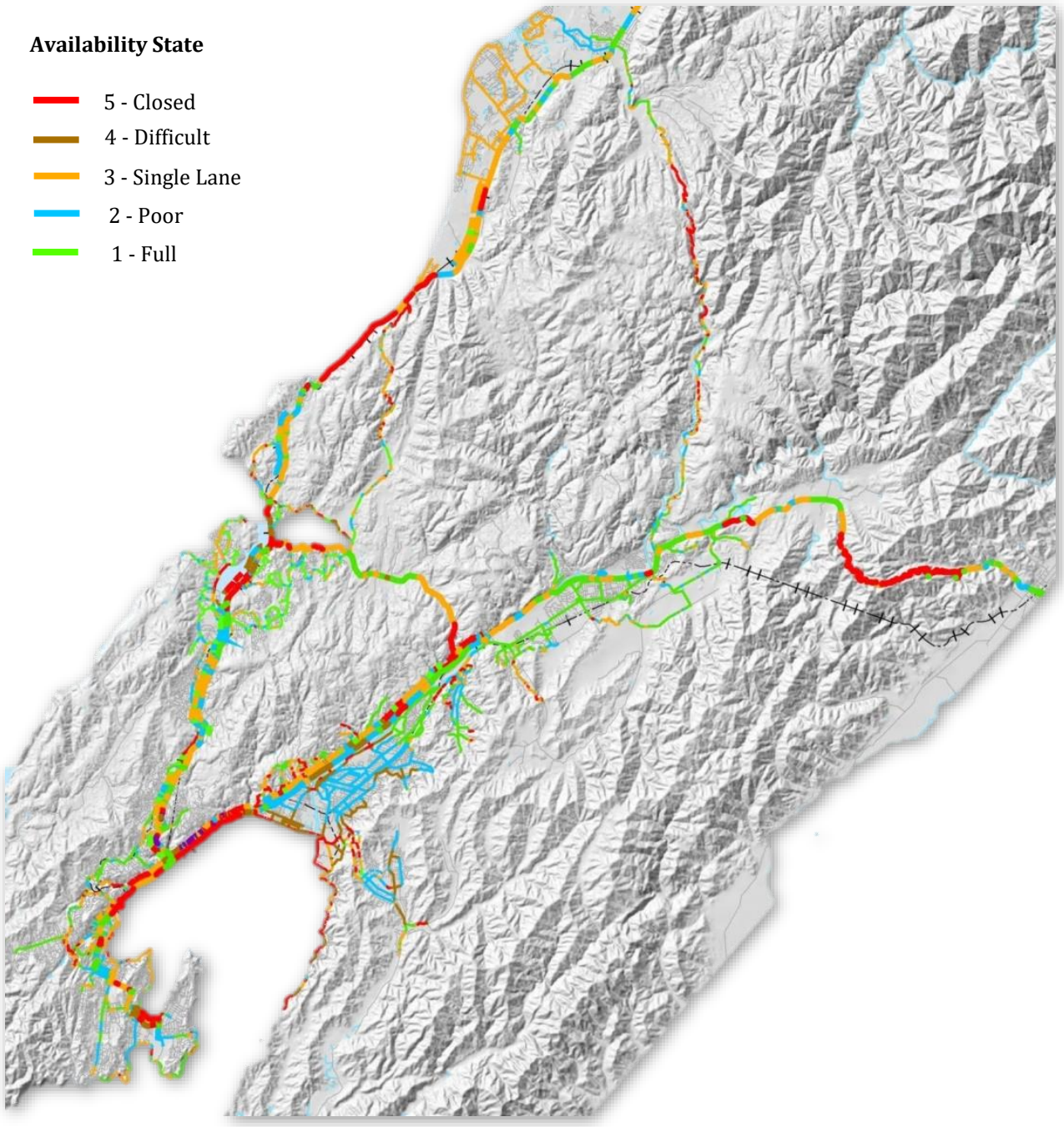

Figure 1: Resilience of Wellington road transport network in a local large earthquake event

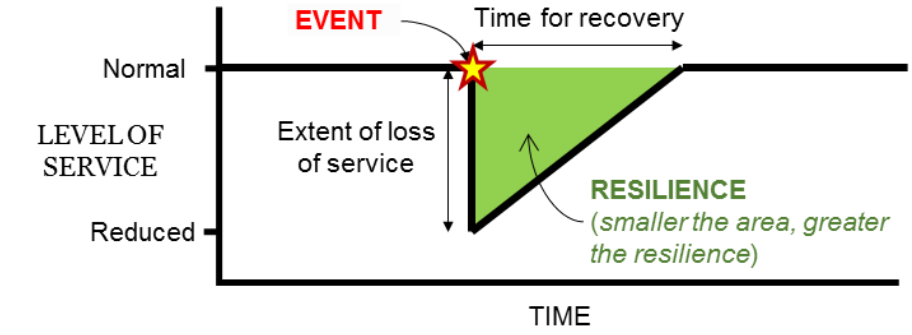

Figure 2: Concept of resilience for transportation routes

3.2 Resilience of inner-city transport routes due to earthquake building damage

The availability of access along inner-city transport routes due to potential earthquake damage from buildings along the routes were assessed based on the type and height of the buildings and the likely impact on accessibility considering potential building collapse, damage and safety hazards for road users. The likely availability state of the inner-city transport routes is shown on Figure 3. This shows that the roads in flat areas that are themselves unlikely to be damaged by an earthquake sufficiently to cause closure, could still be closed due to earthquake damage to adjacent buildings.

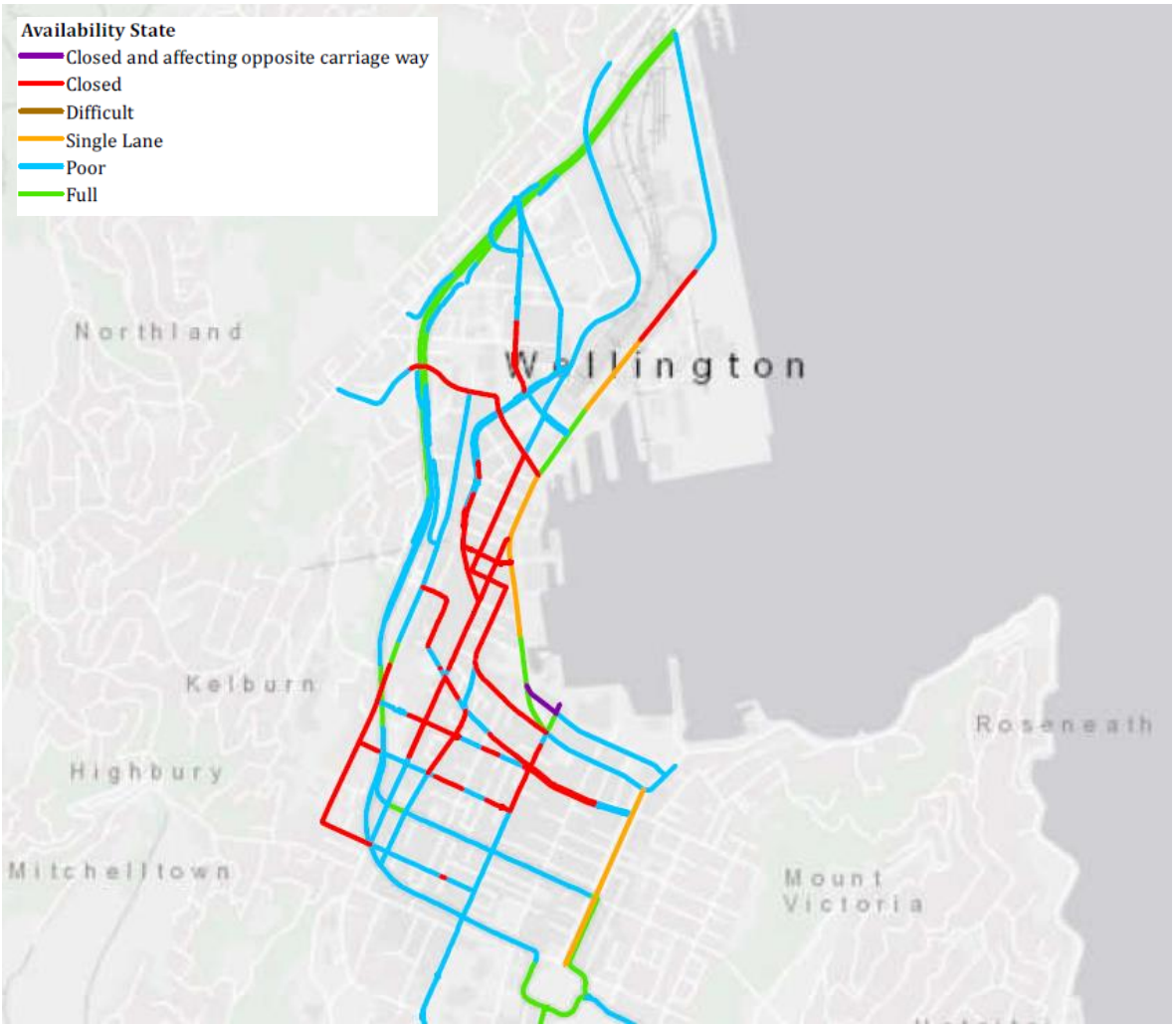

Figure 3: Resilience of Wellington inner-city transport routes from potential building damage

4 PRIORITISATION OF THE RESILIENCE ISSUES

4.1 Approach

Given the wide range of resilience issues facing the Wellington region, it is important that these are prioritised for action. The resilience issues facing Wellington's transport network were prioritised through a methodology developed as part of this study.

The resilience state metrics of *availability* and *outage* were combined into a single metric *disruption state*, for each hazard, for use in the prioritisation process. The relative importance of the transport routes was characterised. This enabled the criticality of the resilience issues to be assessed as a combination of the importance of the transport link and the disruption state.

This process is described in the following sections.

4.2 Importance of transport routes

The relative importance of transport routes was assessed considering a range of issues:

- Availability of alternatives routes
- Traffic volumes
- Access for lifelines facilities
- Emergency response routes
- Use for public transportation
- Commercial use

The importance of the transportation routes is shown on Figure 4.

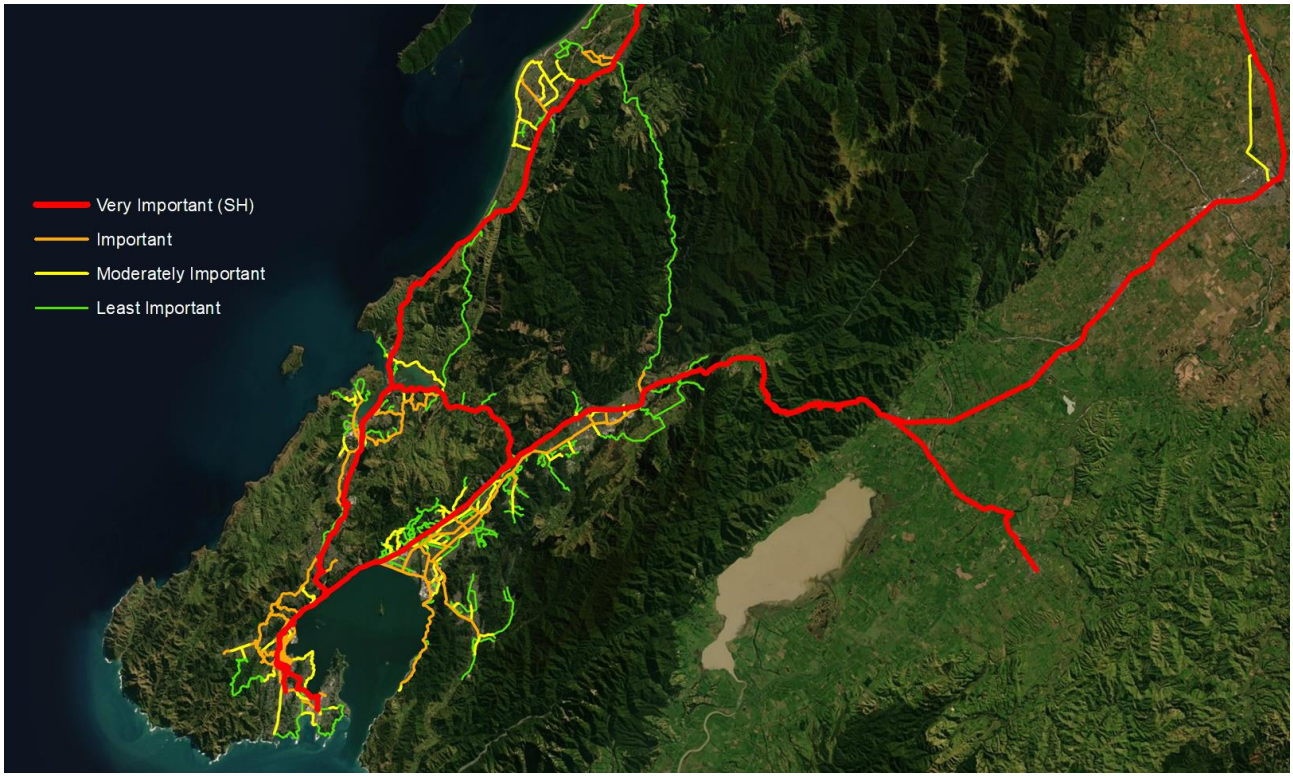

Figure 4: Importance of Greater Wellington's transport routes

The relative importance of the transport routes was used to assess the criticality for intervention.

4.3 Combined resilience metric – the disruption state

The resilience metrics of *availability state* and *outage state* were combined into a single metric known as *disruption state* using the approach developed as part of our previous research (Brabhaharan et al, 2001). A description of the resilience metrics of *availability state* and *outage state*, and the combination into a single metric of *disruption state* is shown in Figure 5.

Availability State \ Outage State	Open	< 1 day	1-3 days	3 days - 2 weeks	2 weeks - 2 months	2-6 months	>6 months
Full	None	None	None	None	None	None	None
Poor	None	Limited	Limited	Limited	Moderate	High	High
Single Lane	None	Limited	Limited	Moderate	High	Severe	Extreme
Difficult	None	Limited	Limited	Moderate	High	Severe	Extreme
Closed	None	Limited	Moderate	High	Severe	Extreme	Catastrophic

Figure 5: Resilience states – derivation of disruption state from availability and outage states

4.4 Criticality of transport routes for resilience intervention

The criticality of the resilience of the transport routes for society was assessed as a combination of the importance of the route to society and the degree of severity of potential disruption as represented by the disruption state, as shown in Figure 6. Transport routes that are very important for the functionality of society which also have resilience issues that are extreme to catastrophic as represented by the disruption state will have the greatest criticality for prioritised consideration.

Disruption State \ Importance Level of Transport Link	Least Important	Moderately Important	Important	Very Important
None	Very low	Very low	Very low	Low
Limited	Very low	Low	Low	Moderate
Moderate	Very low	Low	Moderate	High
High	Low	Moderate	High	Very high
Severe	Low	High	Very High	Extreme
Extreme	Moderate	High	Extreme	Extreme

Figure 6: Criticality from importance and disruption state

The criticality represented an important metric in providing a prioritisation of the resilience issues facing the Wellington region's transport network.

Criticality was developed for earthquake, tsunami and storm risks and these were combined taking the most critical of these risks.

In addition, allowance was made in the criticality where the transport corridors are also shared by other modes (eg rail) and other utilities (eg. main electricity or water supply mains), to cater for the increased risk to society associated with damage to these corridors.

4.5 Geospatial mapping

The importance was derived geospatially using its component maps. Similarly, the disruption state was geospatially derived from the availability and outage states developed previously. This allowed the criticality to be derived efficiently using a geospatial combination of importance and disruption state. The criticality was derived at transport link level.

4.6 Prioritised resilience risks

The criticality of the resilience risks for the key routes connecting the region are shown in Figure 7. Similar maps showing the resilience risks were developed at district or sub-district level. The extreme resilience risks of highest priority turned out to be the Petone to Ngauranga link and the Ngauranga interchange area. The prioritised resilience risk maps provided a very useful basis for the development of resilience enhancement initiatives and programmes for action.

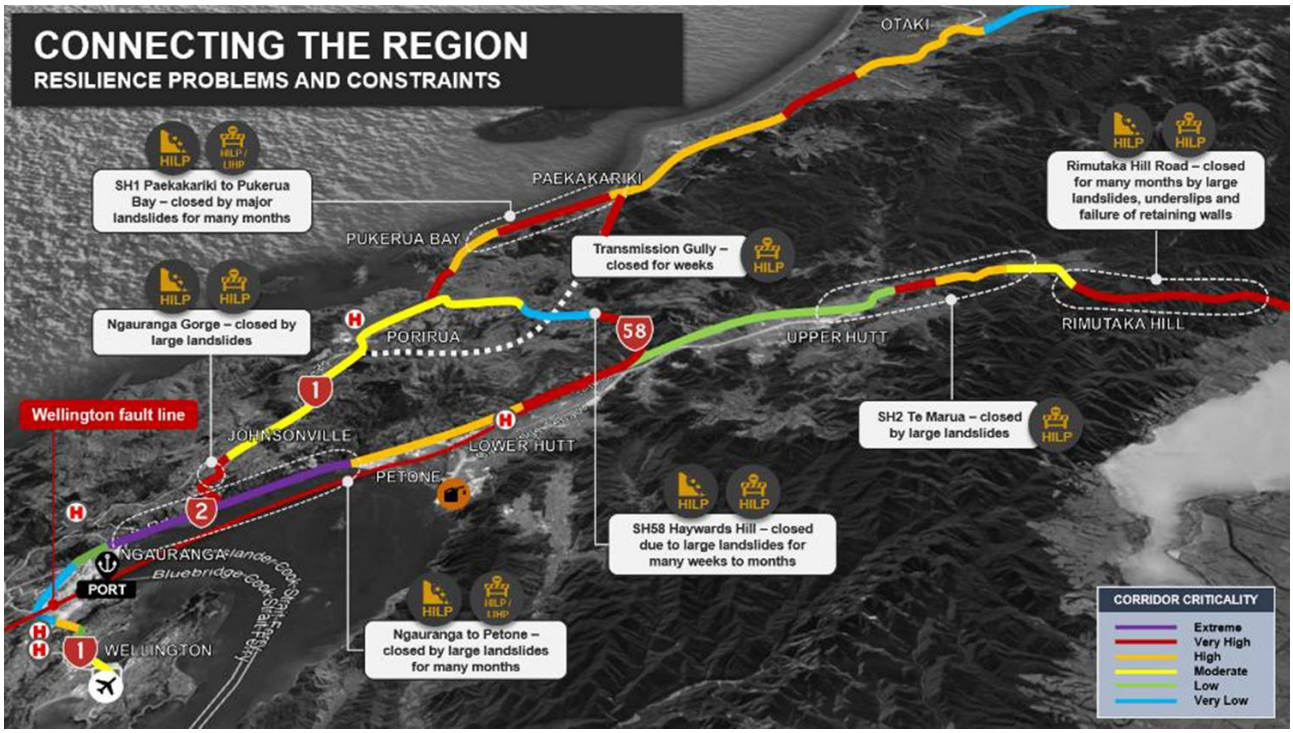

Figure 7: Criticality of resilience risks in the Wellington transport network

5 CONSIDERATIONS FOR DEVELOPING RESILIENCE INITIATIVES

5.1 Hazard event levels

Societal resilience needs in different level of hazard events differ. In more frequent and low impact events such as modest storm events, society will be almost fully functional, and the need would be to provide near full capacity access to facilitate socio-economic functionality. The need in these low impact high probability (LIHP) events will be for resilience initiatives that provide near full capacity access.

In contrast in infrequent large hazard events such as the 2010-2011 Canterbury earthquake sequence or the 2016 Kaikōura earthquake, the socio-economy will almost grind to a halt while society recovers, and the

imminent need will be for access that enables emergency response and recovery to functionality. In this case full capacity functionality is not required in that scenario, but limited access for recovery is necessary. Therefore, the resilience initiatives would need to focus on providing access for emergency response in the immediate aftermath in such high impact low probability (HILP) events.

5.2 Response and recovery stages

Particularly in the aftermath of large events, different levels of access will be required to provide at least limited access for response in the first instance, and subsequently improved capacity of access for recovery of society. The ability to provide even very limited access immediately after the event, and progressive improved access for recovery is important.

5.3 Critical journeys

In a network with multiple routes, strengthening to address each of the individual risks may not provide the best functional or economical solution. Some resilience risk may require multiple interventions to cater for the access needs after LIHP events and HILP events, as well as for timely access for response and with adequate capacity for recovery. Similarly, one resilience enhancement initiative may provide a solution for multiple resilience risks. And the resilience interventions may be on transport links different to the one at risk, as the particular resilience risk may be difficult, impractical or too costly to resolve. Therefore, a network level consideration of the resilience risks becomes appropriate.

To address the network level access requirements, critical journeys for socio-economic functionality were identified, and included:

- External journeys that provide access into and out of the region
- Internal journeys within the region.

Access to provide for these journeys were considered in the development of resilience initiatives and assessment of the effectiveness of programmes.

5.4 Improving resilience through robustness and quicker recovery

The resilience initiatives aim to enhance resilience by addressing the two dimensions of resilience, ie reducing reduction in availability of access by improving robustness, and by reducing outage by enabling quicker recovery. This is illustrated diagrammatically in Figure 8.

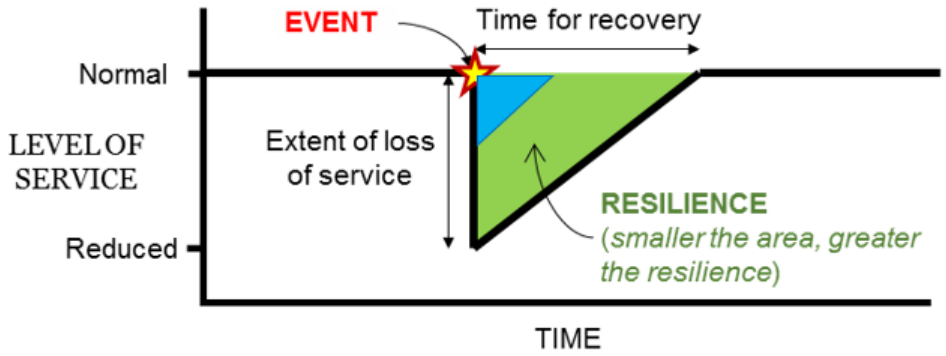

Figure 8: Enhancing resilience

5.5 Multi-dimensional consideration

Consideration of the multiple dimensions of availability and outage, the resilience needs in LIHP and HILP events, and the need to consider functionality, response and recovery, is challenging, but essential for a spatially distributed and interconnected network. Therefore, a holistic consideration and development resilient enhancement measures became essential. Considering the spatially interconnected network, critical journeys (rather than individual routes) that are necessary for the functionality of society were chosen and used as a benchmark for considering resilience enhancement and to measure the improvements achieved by various programmes of measures.

6 RESILIENCE ENHANCEMENT PROGRAMME

6.1 Types of resilience initiatives

An outline resilience enhancement programme was developed and included the following types of initiatives:

- Planning for emergency response
- Planning for communications to inform society
- Low cost maintenance initiatives
- Strengthening of critical assets and routes, including alternative routes
- New links to provide inter-connectivity to more resilient routes
- Initiatives to infuse resilience into transport initiatives
- Governance framework for overseeing implementation of long-term programme.

A broad spectrum of initiatives was necessary to effectively deal with the widespread transport resilience issues in the Wellington region over a period of time.

6.2 Short, medium- and long-term programmes

Transport resilience enhancement programmes were developed and compared to assess their effectiveness in providing access for these multiple dimensions. It was recognised that the critical resilience issues cannot be resolved in a short period. Therefore short, medium- and long-term programme of resilience enhancement initiatives were developed for consideration.

6.3 Consultation with stakeholders

The resilience initiatives need to be actioned by multiple agencies across the Transport Agency, local authorities and KiwiRail. Also, the initiatives need to cater for the emergency response needs of society. Therefore, the resilience programme business case was developed from the beginning in consultation with the stakeholders and obtaining their buy-in to the programme was achieved.

6.4 Key resilience initiatives

Some of the key resilience initiatives to enhance resilience of access in connecting the region externally and between the cities in the region are illustrated in Figure 9.

There were many other resilience enhancement initiatives developed for each sub-region, and an example of those developed for the Hutt Valley is shown in Figure 10. All the resilience initiatives developed are not presented in this paper.

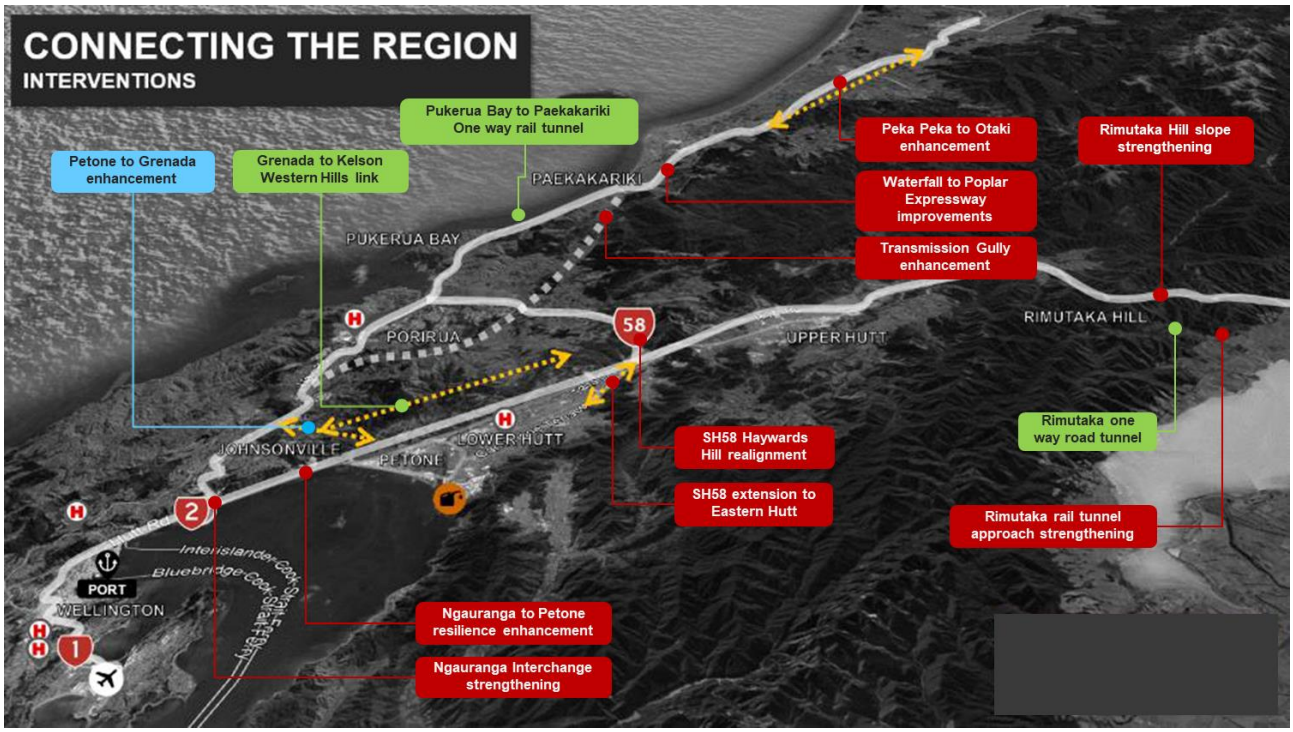

Figure 9: Some resilience interventions to connect the region

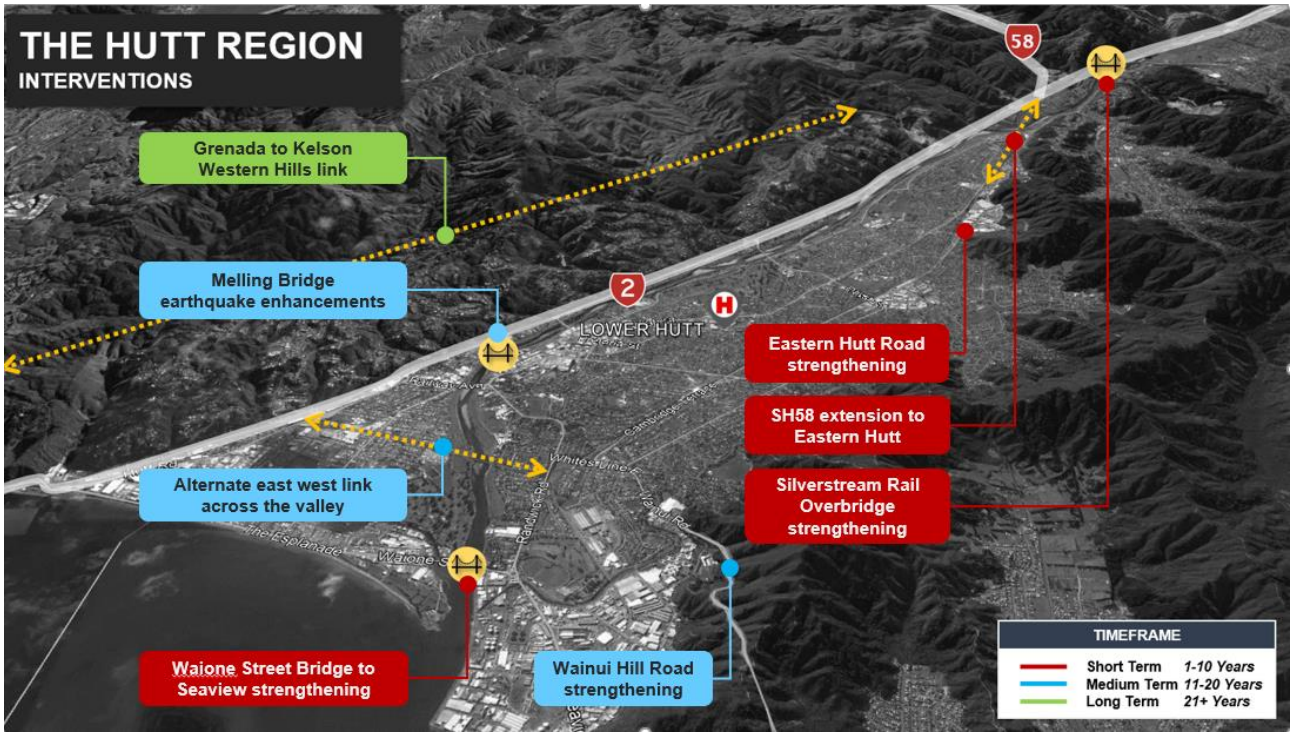

Figure 10: Some resilience interventions developed for the Hutt Valley sub-region

7 CONCLUSIONS

Wellington region has significant resilience risks in a range of natural hazards including earthquakes, tsunami and storms. A systematic approach enabled these risks to be assessed and mapped across all land transport networks, regardless of the managing authority. Characterising the importance of routes and their resilience risks in a range of hazard events enabled the criticality of the resilience issues to be assessed and therefore enabled the development of a prioritised list of resilience risks based on criticality.

This foundation enabled the complex multi-dimensional resilience issues to be considered across different levels of hazards, for different response and recovery needs and addressing the resilience for access rather than for individual links. Such an approach was fundamental to develop a long-term programme of resilience enhancements that have the buy-in of stakeholders.

8 ACKNOWLEDGEMENTS

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