Resilience of transportation systems

P. Brabhaharan & Doug Mason

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High impact – low frequency
Lower impact - higher frequency
Resilience

- Ability to recover quickly and resume original service after damage

Diagram showing the concept of resilience:
- Normal level of service
- Reduced level of service (Vulnerability)
- Event causing loss of service
- Recovery time to return to normal service

Source: After Brabhaharan, 2006
Resilience metrics

**Availability State**

<table>
<thead>
<tr>
<th>Level</th>
<th>State</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Full</td>
<td>Full access except condition may require care.</td>
</tr>
<tr>
<td>2</td>
<td>Poor</td>
<td>Available for slow access, but with difficulty by normal vehicles due to partial lane blockage, erosion or deformation.</td>
</tr>
<tr>
<td>3</td>
<td>Single lane</td>
<td>Single lane access only with difficulty due to poor condition of remaining road.</td>
</tr>
<tr>
<td>4</td>
<td>Difficult</td>
<td>Road accessible single lane by only 4x4 off road vehicles.</td>
</tr>
<tr>
<td>5</td>
<td>Closed</td>
<td>Road closed and unavailable for use.</td>
</tr>
</tbody>
</table>

**Outage State**

<table>
<thead>
<tr>
<th>Level</th>
<th>State</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open</td>
<td>No closure, except for maintenance</td>
</tr>
<tr>
<td>2</td>
<td>Minor</td>
<td>Condition persists for up to 1 day</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Condition persists for 1 day to 3 days</td>
</tr>
<tr>
<td>4</td>
<td>Short term</td>
<td>Condition persists for 3 days to 2 weeks</td>
</tr>
<tr>
<td>5</td>
<td>Medium term</td>
<td>Condition persists for 2 weeks to 2 months</td>
</tr>
<tr>
<td>6</td>
<td>Long term</td>
<td>Condition persists for 2 months to 6 months</td>
</tr>
<tr>
<td>7</td>
<td>Very long term</td>
<td>Condition persists for greater than 6 months</td>
</tr>
</tbody>
</table>
## Resilience metrics

<table>
<thead>
<tr>
<th>Availability State</th>
<th>Disruption</th>
<th>Outage State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Poor</td>
<td>None</td>
<td>Limited</td>
</tr>
<tr>
<td>Single Lane</td>
<td>None</td>
<td>Limited</td>
</tr>
<tr>
<td>Difficult</td>
<td>None</td>
<td>Limited</td>
</tr>
<tr>
<td>Closed</td>
<td>None</td>
<td>Limited</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disruption</th>
<th>&lt; 1 day</th>
<th>1-3 days</th>
<th>3 days - 2 weeks</th>
<th>2 weeks - 2 months</th>
<th>2-6 months</th>
<th>&gt;6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability State</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Poor</td>
<td>None</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Single Lane</td>
<td>None</td>
<td>Limited</td>
<td>Limited</td>
<td>Moderate</td>
<td>High</td>
<td>Severe</td>
</tr>
<tr>
<td>Difficult</td>
<td>None</td>
<td>Limited</td>
<td>Limited</td>
<td>Moderate</td>
<td>High</td>
<td>Severe</td>
</tr>
<tr>
<td>Closed</td>
<td>None</td>
<td>Limited</td>
<td>Moderate</td>
<td>High</td>
<td>Severe</td>
<td>Extreme</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

- **Availability State**: Open, Full, Poor, Single Lane, Difficult, Closed
- **Disruption**: Full, Poor, Single Lane, Difficult, Closed
- **Outage State**: None, Limited, Moderate, High, Severe, Extreme, Catastrophic
National state highway assessment
Objectives

- Assess the resilience of the whole state highway network.
- Assess at a broad brush high level, efficiently and quickly.
- Assess resilience to large natural hazard events.
  - Large earthquake
  - Large storm / flooding
  - Tsunami
  - Volcanic eruption
- Use a consistent basis applied across the country.
Methodology

• Develop resilience metrics
• Gather national data
• Identify hazard impacts of relevance
• Characterise road corridors
• Capture into GIS & prepare resilience maps
• Assessment of key resilience issues
Road characterisation

1. Characterise road corridor into categories
   • Terrain
   • Geology
   • Hydrology
   • Hazards
   • Road environment

2. Assess type & extent of potential hazard impacts for road categories, and typical duration of repair

3. Apply metrics of availability & outage to hazard impacts

4. Assign to road categories
Resilience maps – earthquake
Resilience maps – storm

Disruption State
- None
- Limited
- Moderate
- High
- Severe
- Extreme
- Catastrophic
Resilience maps – tsunami

Disruption State
- None
- Limited
- Moderate
- High
- Severe
- Extreme
- Catastrophic
Resilience maps – volcanic
Why Resilience?
Transport is critical for Response and Recovery
Interdependencies

Transport access is critical for
- Access
- Food and medicine
- Fuel
- Hospital
- Airport
- Port

Recovery of
- Water
- Electricity
- Telecommunications
Government Policy Statement

National Resilience Objectives

1. Capacity to withstand disruption
2. Capacity to absorb disturbance
3. Act effectively in a crisis
4. Adapt to changing conditions including climate change
5. Grow over time change

Result: Metropolitan and high growth urban areas are better connected and accessible
Regional network assessments
Western Bay of Plenty – storm & earthquake

Resilience and gaps identified through regional study of local and state highway routes
Taranaki - storm

- Resilience studies helped identify improvements at Awakino and Mt Messenger sections
Wellington Land Transport Resilience

Presents Business Case developed, but yet to be confirmed by NZ Transport Agency
Trip Generation

Daily Employment Trips (Road / Rail)

<table>
<thead>
<tr>
<th>Location</th>
<th>Trips Generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>WELLINGTON</td>
<td>27,000</td>
</tr>
<tr>
<td>PORIRUA</td>
<td>4,000</td>
</tr>
<tr>
<td>LOWER HUTT</td>
<td>17,000</td>
</tr>
<tr>
<td>UPPER HUTT</td>
<td>15,000</td>
</tr>
<tr>
<td>KAPITI COAST</td>
<td>8,000</td>
</tr>
<tr>
<td>WAIRARAPA</td>
<td>2,200</td>
</tr>
</tbody>
</table>

LEGEND

- Employment travel
- Hospital
- Fuel depot
- Airport
- Port
Wellington’s Economic context

$16B
Potential GDP impact of a major event occurring on the Wellington Fault

Location of:
- Central Government
- Half of employed population
- International airport
- International port

SEVERE impact on NZ’s economy and admin
Learnings from Christchurch and Kaikoura Earthquakes

Christchurch
- Earthquakes in 2010 & 2011
- Major road closures (45% of roads damaged)
  - Passenger + freight rail disruption
- Extensive road network redundancy, response and recovery largely unaffected

*Wellington has very little transport redundancy*

Kaikoura
- 2016 Earthquake
- Rail closures, disruption to rail passenger + freight, for over 1 year . . . and disruption continuing
- Community isolation
- Loss of resilience, illustrated the effect of lack of redundancy on small centre

*Resilience impacts are not just from an earthquake, but ongoing for many years from storms*
Kaikōura earthquake

- $360M impact to National GDP
- 18 months to rebuild
- $2bn rebuild cost (SH1 and rail along coast)
- Closure of SH1 for over a year
Land Transport Resilience Business Case

Assess resilience

Importance of links

Criticality for intervention

Prioritised resilience risks
Resilience of Land Transport

Availability

- 5 - Closed
- 4 - Difficult
- 3 - Single Lane
- 2 - Poor
- 1 - Full
Resilience of Land Transport

Outage

- 5 - Long Term (> 3 months)
- 4 - Severe (2 weeks to 3 months)
- 3 - Moderate (3 days to 2 weeks)
- 2 - Minor (up to 3 days)
- 1 - Open (no closure)
Importance and Criticality of Links

Wellington Land Transport Resilience Programme Business Case covers local roads and state highways.
<table>
<thead>
<tr>
<th>Network Segment</th>
<th>Nature of Vulnerability</th>
<th>Current Resilience</th>
<th>Effect of interventions</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellington North / Hutt City</td>
<td>NZTA considering limited resilience improvements to prop the span vulnerable to fault rupture, the overbridge is likely to be still closed by liquefaction, lateral spreading and fault displacements.</td>
<td>None</td>
<td>NZTA considering limited resilience improvements which has as yet undefined.</td>
<td>Wellington North</td>
</tr>
<tr>
<td>Wellington North</td>
<td>None</td>
<td>Limited resilience improvements being considered.</td>
<td>NZTA considering limited resilience improvements which has as yet undefined.</td>
<td>Wellington North</td>
</tr>
<tr>
<td>Kapiti</td>
<td>NZTA considering limited resilience improvements which has as yet undefined.</td>
<td>None</td>
<td>NZTA considering limited resilience improvements which has as yet undefined.</td>
<td>Kapiti</td>
</tr>
<tr>
<td>Hutt City</td>
<td>None</td>
<td>None</td>
<td>NZTA considering limited resilience improvements which has as yet undefined.</td>
<td>Hutt City</td>
</tr>
<tr>
<td>Upper Hutt - Rimutakas</td>
<td>None</td>
<td>None</td>
<td>NZTA considering limited resilience improvements which has as yet undefined.</td>
<td>Upper Hutt - Rimutakas</td>
</tr>
<tr>
<td>Parys</td>
<td>None</td>
<td>None</td>
<td>NZTA considering limited resilience improvements which has as yet undefined.</td>
<td>Parys</td>
</tr>
<tr>
<td>Wellington East</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Wellington East</td>
</tr>
<tr>
<td>Wellington East</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Wellington East</td>
</tr>
</tbody>
</table>
## Impacts on Society

### L / H / P

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSPORT ROUTES</td>
<td>Potentially large economic disruption</td>
</tr>
<tr>
<td>INTER-REGIONAL JOURNEYS</td>
<td>OPEN but disrupted</td>
</tr>
<tr>
<td>ECONOMY</td>
<td>Potentially large losses, unnecessary</td>
</tr>
<tr>
<td>CENTRAL GOVT</td>
<td>Minimal / no disruption</td>
</tr>
<tr>
<td>SOCIAL WELLBEING</td>
<td>Temporary loss of access to jobs, schools, emergency services, supplies</td>
</tr>
<tr>
<td></td>
<td>Variable cost to society</td>
</tr>
</tbody>
</table>

### H / I / L / P

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAJOR disruption / closures</td>
<td>Potentially large economic disruption</td>
</tr>
<tr>
<td>CLOSED</td>
<td>OPEN but disrupted</td>
</tr>
<tr>
<td>MAJOR losses, completely stopped</td>
<td>Potentially large losses, unnecessary</td>
</tr>
<tr>
<td>MAJOR disruption; contingency plan required</td>
<td>Minimal / no disruption</td>
</tr>
<tr>
<td>Potential for isolation, harm, lack of access to basic needs. Longer term disruption of access</td>
<td>Temporary loss of access to jobs, schools, emergency services, supplies</td>
</tr>
<tr>
<td>Differential impacts – lower socio-economic classes are less resilient</td>
<td>Variable cost to society</td>
</tr>
</tbody>
</table>
Land Transport Resilience Business Case
Resilience interventions

Resilience interventions consider

- minimising the loss of access and
- enabling quick recovery
- Alternate routes
- Response
- Recovery
- Range of HILP, LIHP and routine events
**Resilience enhancement**

### Resilience Investment Objectives

<table>
<thead>
<tr>
<th></th>
<th>Improve response &amp; recover, reduce closure times</th>
<th>Reduce population isolation, restore access</th>
<th>Economic and social functionality (LIHP &amp; HILP)</th>
</tr>
</thead>
</table>

### NON-INFRASTRUCTURE

- Median barrier gates

### ENHANCE INFRASTRUCTURE

- Reducing vulnerability of existing strategic routes
- Robustness/availability of existing alternative routes

### NEW INFRASTRUCTURE

- New alternative routes
- Alternative access options

**EXAMPLES**

- **Wadestown route strengthening, Ngauranga I/C strengthening**
- **Haywards – Eastern Hutt Link, Petone to Grenada Link Road.**
Improvement of Critical Journeys

**Obj 2  External Access**
- Manakau ↔ Tawa (Wellington District) via SH 1
- Mt Bruce ↔ Masterton (Wairarapa) via SH2
- Masterton ↔ Upper Hutt (Hutt Valley) via SH 2
- Kapiti ↔ Hutt Valley (via SH58)

**Obj 1  Internal Access**
- Porirua / Tawa ↔ Wellington CBD
- Airport ↔ Wellington CBD
- Petone (Hutt Valley) ↔ Wellington
- Seaview / Hutt East ↔ Hutt West /SH2
- Upper Hutt ↔ Lower Hutt
- Masterton (Wairarapa) ↔ Wellington CBD
- Karori ↔ Northern Suburbs ↔ Johnsonville
- Lower Hutt ↔ Wainuiomata / Moores Valley
- Western Hill Linkage: Grenada ↔ Haywards
- Porirua East ↔ Porirua West / Titahi Bay
- Porirua ↔ Pukersa Bay
- Featherston ↔ Martinborough
CONNECTING THE REGION
INTERVENTIONS

- Petone to Grenada enhancement
- Grenada to Keison Western Hills link
- Rimutaka one way road tunnel
- Western Hills link
- Pukerua Bay to Paekakariki One way rail tunnel
- Petone to Grenada enhancement
- Rimutaka Hill slope strengthening
- Peka Peka to Otaki enhancement
- Waterfall to Poplar Expressway improvements
- Transmission Gully enhancement
- Peka Peka to Otaki enhancement
- Rimutaka rail tunnel approach strengthening
- SH58 Haywards Hill realignment
- SH58 extension to Eastern Hutt
- Rimutaka one way road tunnel
- Ngauranga to Petone resilience enhancement
- Ngauranga Interchange strengthening
- Ngauranga to Petone resilience enhancement
WELLINGTON CBD TO JOHNSONVILLE
INTERVENTIONS

Key vulnerabilities that require attention

- Hutt Road slopes / walls / overbridges
- Ngaio Gorge Road walls and slopes
- Wadestown to Johnsonville route walls and bridges
- Ngauranga Overbridge and slopes
- Thorndon Overbridge and seawalls
- Port Access Road from North
- Ngauranga to Petone landslides, coastal
- Johnsonville bypass landslides
- Ngauranga Interchange
- Southern Rail Overbridge
- Ngauranga to Thorndon Seawalls

Ngauranga Interchange
Port Access Road from North
Hutt Road slopes / walls / overbridges
Ngaio Gorge Road walls and slopes
Wadestown to Johnsonville route walls and bridges
Ngauranga Overbridge and slopes
Thorndon Overbridge and seawalls
Port Access Road from North
Ngauranga to Petone landslides, coastal
Johnsonville bypass landslides
Ngauranga Interchange
Southern Rail Overbridge
Ngauranga to Thorndon Seawalls

WSP Opus
Nguaranga to Thornden
Seawalls
Johnsonville bypass
landslides

Ngauranga Overbridge and
slopes

Wadestown to Johnsonville
route walls and bridges

Hutt Road slopes / walls / overbridges

Ngaio Gorge Road walls and slopes

Wadestown to Johnsonville
route walls and bridges

Ngauranga Overbridge and
slopes

Thorndon Overbridge and seawalls

Port Access Road from North

Ngauranga to Petone landslides, coastal
Johnsonville bypass landslides
Ngauranga Interchange
Southern Rail Overbridge
Ngauranga to Thorndon Seawalls

Key vulnerabilities that require attention
WELLINGTON CBD TO AIRPORT INTERVENTIONS

- Sea walls Waterloo to Jervois Quay strengthening
- Urban motorway retaining wall assessment and strengthening
- Slope strengthening for Mt Victoria tunnel approaches
- Wellington St / Crawford Road strengthening
- Cobham Drive strengthening
Recommended Management Case

Recommendations to infuse resilience into existing projects

Stand-alone strengthening works – pre-implementation study

Local road strengthening

New transport links – detailed business case

Recommendations to address resilience as part of planned projects

Consider as part of Corridor improvements

Integrated with Urban and land use planning
Improving resilience

Strengthening of key structures to enhance resilience of key routes
Summary

- Resilience metrics and consistent assessment helped address complex issues.
- Spatial GIS helped consider across geographies and society.
- Multi-hazards and spectrum of hazard levels need consideration – addressed through LIHP and HILP events.
- Integrated approach with local road and rail essential to address transport resilience issues.
- Impact on customers – society – is important, and addressed by considering:
  - Response
  - Recovery
  - Socio-economic functionality
  - Social resilience
- Business case approach adopted and this has never been used for resilience projects – required some innovative thinking.
- Affordability and risk appetite is a challenging issue – introduces personal views.