Measuring the resilience of transport infrastructure

Resilient cities are safer, more attractive to investors and new residents, and more able to recover quickly and with less loss of life and assets in the event of crises. UNISDR
Reasons to Focus on Resilience

By 2050 over 70% of the World’s population will live in Cities

Loss of life have decreased from Natural Disasters but….capital losses have exceeded $2.5 T since 2000
Reasons to Focus on Resilience

Direct disaster losses are 50% higher than reported figures

Kobe port before the earthquake in 2005 was 6th busiest port in the world; By 2010 it had fallen to 47th despite massive investment.

Toyota lost $1.2B in product revenue after the 2011 earthquake & tsunami
Reasons to Focus on Resilience

“Economic losses from disasters are out of control and can only be reduced with collaboration with the private sector”

Ban Ki-Moon
Secretary General of the United Nations
Outline of this presentation

1. Project overview and key definitions
2. Risk Vs Resilience
3. Developing a framework to measure resilience
4. Implementation of the framework
5. Next steps
Project overview and some definitions
Introduction to project

- NZTA commissioned research, in response to NIP
- No current, practical frameworks were known to exist for measuring resilience for transport infrastructure
- Need to ensure transport systems operate continually and safely, and deliver a desired levels of service.
- A practical measurement tool was sought which was supported by literature and which could be used to identify and prioritise improvements/investment.
- Able to be applied at various scales and across a range of modes
- Need to be cognisant of NZTA’s parallel work on the ‘Joint Resilience Operating Policy’
The National Infrastructure Plan (Treasury)

- “High performing infrastructure supporting higher living standards”
- Vision: By 2030 New Zealand’s infrastructure is resilient, coordinated and contributes to economic growth and increased quality of life.
- Suite of resilience ‘attributes’
- Engage with infrastructure providers
Related fields

- Disaster Risk Management / CDEM (Reduction, Readiness, Response, Recovery)
- Climate change adaptation
- Sustainability
- Liveability
- Risk management
- Community resilience planning
Why is resilience important?

- ‘Our everyday lives and national infrastructure rely on each other, and operate in a fragile union, vulnerable to even the smallest disturbances in the network’. (Edwards, Resilient Nation).

- Our infrastructure is increasingly complex (system of systems), and subject to a range of possible foreseeable and unforeseeable hazards / failures.

- Natural hazards (and other hazards) appear to be occurring with increasing frequency and intensity

- We EXPECT uninterrupted, increasing level of service, and ‘just-in-time’ delivery.
What is resilience: A few definitions

‘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’ (NIU)

‘The intrinsic capacity of a system, community or society predisposed to a shock or stress to bounce forward and adapt in order to survive by changing its non-essential attributes and rebuilding itself’ (Manyena, 2011)

‘Resilience is the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must’ (Allenby and Fink 2005).
What is resilience: Apparent opposites?

- Efficiency
- Redundancy
- Autonomy
- Collaboration
- Planning
- Adaptability
- Robustness
- Degrade gracefully – Safe to fail
What is resilience: Urban resilience

Source: AECOM - Adapted from Chelleri et al. (2011)
What is resilience – spatial aspects and scale

Drivers for resilience can be at any level (e.g., hazards or failures)

Responses to build resilience can be at any level

Source: AECOM
What is resilience – temporal aspects

SHOCK EVENT

Short term

Prevention/Preparedness/Recovery

Adaptation & Planning

Transformation

NEW SHOCK / STRESS

Long term

Typically:
- Bounce back
- ‘Engineering’ robustness
- Return to status quo
- Lock in dependency?

Flexibility
- Bounce forward

Change paradigm
- New functional regime

Source: AECOM
Resilience and Risk
Resilience of what? To what?

- Of what?
  - Not all infrastructure needs to be ‘resilient’
  - Which infrastructure then?
  - How do we define criticality?

- To what?
  - Which hazards are relevant? Or do we take a ‘hazard-agnostic’ approach?
  - Natural, technological, socio-political hazards
  - Black swans, unknown-unknowns, mean a risk-based approach alone is not sufficient
  - Shock &/or stress events
  - Asset failure and failure modes
Risk vs resilience

- Is Resilience just an outcome of applying good risk management?

<table>
<thead>
<tr>
<th>Risk</th>
<th>Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitigate failure through probability and scenario-based analysis of known hazards.</td>
<td>Minimise the consequences of failure through investigating scenarios with unidentified causes.</td>
</tr>
<tr>
<td>Incrementally modifying existing designs in response to emerging hazards.</td>
<td>Adapting to changing conditions, and potentially allowing controlled failure (‘safe-to-fail’) at a sub-system level to reduce the possibility of broader loss.</td>
</tr>
</tbody>
</table>

Source: Park (2013) and Snowden (2011)
A strategic imperative

“Moving from a system designed for robustness to one that supports resilience represents a significant strategic shift. Whilst systems have commonly been designed to be robust (designed to prevent failure), increasing complexity and the difficulty it poses to fail-proof planning have made a shift to "resilience" strategically imperative.

A resilient system on the other hand accepts that failure is inevitable and focuses instead on early discovery and fast recovery from failure”.

David Snowden
Summary of key focuses for resilience framework

Due to the unpredictability of complex systems, a resilience assessment demands a constant, recursive process, often across multiple organisations.

- A resilience assessment requires recognition of incompleteness: inherent uncertainty and incompleteness in our knowledge

- New approaches to design: embrace uncertainty and failure via anticipation and adaptation

- A traditional risk-based approach is not sufficient to understand, plan and prioritise resilience improvements.
How can we categorise resilience within a framework?
Resilience framework

- Consists of Dimensions, Principles and specific Measures which can map to the NIP attributes if required.
### How did we categorise resilience of infrastructure?

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical / Asset</td>
<td>The ability of the physical system(s) to perform to an acceptable/desired level when subject to a hazard event.</td>
</tr>
<tr>
<td>Organisational</td>
<td>The capacity of an organisation to make decisions and take actions to plan, manage and respond to a hazard event.</td>
</tr>
</tbody>
</table>
How did we categorise resilience of infrastructure?

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Principle</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical / Asset</td>
<td>Robustness, Redundancy, Safe-to-fail</td>
<td>Measures</td>
</tr>
<tr>
<td>Organisational*</td>
<td>Change readiness, Networks, Leadership &amp; Culture</td>
<td>Measures</td>
</tr>
</tbody>
</table>

*Refer work by Resorgs
<table>
<thead>
<tr>
<th>Category</th>
<th>Measure</th>
<th>Measurement</th>
<th>Measurement Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Processes exist to maintain critical infrastructure and ensure integrity and operability - as per documented standards, policies &amp; asset management plans (e.g. - roads maintained, flood banks maintained, stormwater systems are not blocked). Should prioritise critical assets as identified.</td>
<td>4 – Audited annual inspection process for critical assets and corrective maintenance completed when required. 3 – Non-audited annual inspection process for critical assets and corrective maintenance completed when required. 2 – Ad hoc inspections or corrective maintenance completed, but with delays/backlog. 1 – No inspections or corrective maintenance not completed.</td>
<td></td>
</tr>
<tr>
<td>Renewal</td>
<td>Evidence that planning for asset renewal and upgrades to improve resilience into system networks exist and are implemented.</td>
<td>4 – Renewal and upgrade plans exist for critical assets, are linked to resilience, and are reviewed, updated and implemented. 3 – Renewal and upgrade plans exist for critical assets and are linked to resilience, however no evidence that they are followed 2 – Plan is not linked to resilience, and an adhoc approach is undertaken 1 – No plan exists and no proactive renewal or upgrades of assets.</td>
<td></td>
</tr>
<tr>
<td>Structural</td>
<td>Percentage of assets that are at or below current codes</td>
<td>4 – 80%+ are at or above current codes 3 – 50-80% are at or above current codes 2 - 20-50% are at or above current codes 1 - nearly all are below current codes</td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>Assessment of general condition of critical assets across region.</td>
<td>4 – 80%+ are considered good condition 3 – 50-80% are considered good condition 2 - 20-50% are considered good condition 1 - nearly all poor condition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of assets that are in zones/areas known to have exposure to hazards</td>
<td>4 – &lt;20% have some exposure to known hazards 3 – 20-50% are highly exposed, or &gt;50% are moderately exposed 2 - 50-80% are highly exposed 1 - 80%+ are highly exposed to a hazard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of critical assets with additional capacity over and above normal demand capacity</td>
<td>4 – 80%+ of critical assets have &gt;50% spare capacity available 3 – 50-80% of critical assets have &gt;50% spare capacity 2 - 20-50% of critical assets have &gt;50% spare capacity 1 - 0-20% have spare capacity</td>
<td></td>
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</table>

Individual Score: 3  
Category average: 4  
Weighting (%): 33.33  
Weighted Score: 94.4
Approach to measurement

1. Determine **context** of the assessment: ‘All-hazards’ or ‘specific hazards’ (including shock or stress event, rare events etc)

2. Determine **Scale**: Asset / network / regional context

3. Undertake the assessment and using the questions relative to the context above, select scores for each.

4. Apply weightings to categories as required.

This will generate resilience scores for categories, principles and dimensions and a Total Score.
Implementation
Implementation

- Which infrastructure should be assessed for resilience?
- What level of resilience is appropriate for a given asset/network?

**Focus on criticality (using NZTA framework)**
*All Hazards or Specific Hazard approach*
Measuring resilience – ‘all-hazards’

Criticality assessment → Resilience assessment → Improvements / intervention

Measuring resilience – ‘specific-hazard’

Criticality assessment → Risk assessment → Resilience assessment → Improvements / intervention
## Implementation

<table>
<thead>
<tr>
<th>Criticality Score</th>
<th>Risk Score*</th>
<th>Desired level of Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly critical</td>
<td>4 (Extreme)</td>
<td>Very High (4)</td>
</tr>
<tr>
<td>Medium</td>
<td>3 (High)</td>
<td>High (3)</td>
</tr>
<tr>
<td>Low</td>
<td>2 (Moderate)</td>
<td>Moderate (2)</td>
</tr>
<tr>
<td>Not critical</td>
<td>1 (Low)</td>
<td>Low (1)</td>
</tr>
</tbody>
</table>

*If using a 'hazard-specific' approach*
Next Steps
Next steps

- Research report recently published on NZTA website
- Looking for opportunities to trial (move from theory to implementation!)
- Apply / modify to other infrastructure types
- Further questions remain:
  • How do we design for resilience?
  • How much do we spend on resilience?
  • How well do we understand criticality of interdependent infrastructures? Link to lifelines work.
  • Understanding relationship between resilience and sustainability (and liveability?)
Thank you

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