TRANSPORT AND RESILIENT CITIES:

A REVIEW OF CURRENT DEVELOPMENTS

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Abstract

As our cities grow and become more and more dependent on infrastructure and technology, and at the same time the risks from hazards are increasing globally, we are becoming more vulnerable to the impacts of shocks and stresses on critical infrastructure. Recent experiences with the Christchurch earthquakes have highlighted the importance of understanding just how resilient our infrastructure, and the organisations managing it, is now and what we can do to improve it.

Christchurch was recently accepted into the Rockefeller Foundation's global 100 Resilient Cities programme, and is developing a Resilience Strategy. This will look not just at infrastructure but at all of the functions of a "resilient city" and how they are connected.

At the same time, a number of other initiatives are underway in the "Resilience" space, and which recognise the importance of Resilience as a key principle in the National Infrastructure Plan. These include the development of a Resilience Framework for NZTA, a project to develop an Economics of Resilient Infrastructure model, and in general an increased interest in embedding "resilience concepts" into asset management planning processes by infrastructure organisations.

This paper provides a topical overview of recent developments and how together they can contribute to the development of a smarter, stronger and safer transport system.

KEY WORDS
Resilience, Cities, Transport, Lifelines, Risk, Hazards, Asset Management, and Economics.

INTRODUCTION

We live in a world in which the known and unknown hazards we face are becoming increasingly frequent, one where the costs of rebuilding from major shock events places massive pressure on governments, infrastructure owners and societies alike. While losses of life have been shown to have decreased from natural disasters, capital losses have exceeded US$2.5T since 2000 (United Nations, 2013). In addition to the often unforeseen shock events, we are also faced with longer term, 'corrosive' stress events, such as coastal erosion due to sea level rise, or pervasive infrastructure degradation. Further still, we face more holistic challenges such as resource depletion and over-exploitation that raises fundamental questions in regard to our approach to sustainable development within societies.

Internationally, there is a growing call for building more 'resilient cities' and for improving the resilience of our critical infrastructure. This is in response to a realisation that the services we take for granted may be robust in the face of predictable hazards, but are actually extremely fragile in the face of unanticipated shocks.
So where do transport and cities fit in? What role does transport play in resilient cities? What would smarter, stronger, safer look like from a transport resilience perspective?

TRANSPORT

We need to look at all modes and forms of transport, both within and connecting cities, when thinking about resilience – it's not just about roads. Rail, aviation, marine, public transport, cycling, and walking should all be part of resilience. If the airport is not available, can we use our port for moving equipment, food and supplies into the city and region? Are road and rail links to the outside world going to be available? Do people have access to essential health and social services when roads are disrupted? **Figure 1** below shows a particularly important location in Wellington, where critical highways and rail links connecting Wellington to the north straddle a known earthquake fault line. Not only does the city face this vulnerability, but other critical infrastructure including the interisland ferry terminal and bulk water supply is co-located. It is vital for the city's resilience that this infrastructure is also resilient.

How could the basic functions and services relating to the movement of people and goods provided by transport be disrupted by shocks and stresses? What consequential or cascading implications could occur? If a bridge carries a 33 or 66kV power cable, what happens to power services if the bridge is damaged? Does the power company have an alternative?

Our assets are managed by people and organisations. Are our organisations, our people, and our processes resilient? To what events? How do we know whether we are equipped to respond effectively? Business as usual is not the same as providing service when a disaster strikes. There are many questions that we should ask of ourselves as transport practitioners.

Figure 1 Confluence of Highways, Rail and Sea Transport Systems with Bulk Water Supply and an Active Earthquake Fault

Interdependence between Transport and Other Lifeline Utilities

In New Zealand, utilities responsible for delivering and maintaining critical infrastructure are defined in the Civil Defence and Emergency Management Act 2002 as 'lifeline utilities'. All lifeline organisations should have a direct interest in understanding and developing resilience to hazards both because of their operational interdependence, and in their desire to function to the fullest possible level of service.

Lifelines work also strengthens relationships and understanding between the various utilities, highlighting interdependencies which can be seen in **Figure 2**. These factors are very important when considering the resilience of a city. The question for transport sector practitioners is whether they understand these relationships, the spatial implications and the needs and expectations between sectors when hazard events occur, and who they need to talk to?

From the mid-1990s, many regions around the country have produced lifelines reports which describe the hazards their regions face and the associated infrastructure vulnerabilities, with most going on to define mitigations such as physical strengthening of assets (e.g. bridges). This was effective in Christchurch's case in reducing the level of damage sustained and enabling partial accessibility throughout the city in the aftermath of the February 2011 earthquake.

Transport agencies must ensure that critical infrastructure is resilient. The operation, maintenance and renewal of assets under predictable conditions is one thing. However, an understanding of the unpredictable hazards that may compromise the continuity of service and implications on communities they serve is essential. Transport agencies should be at the forefront of efforts to improve service resilience and identify the most appropriate use of constrained resources through close relationships with other lifeline utilities.

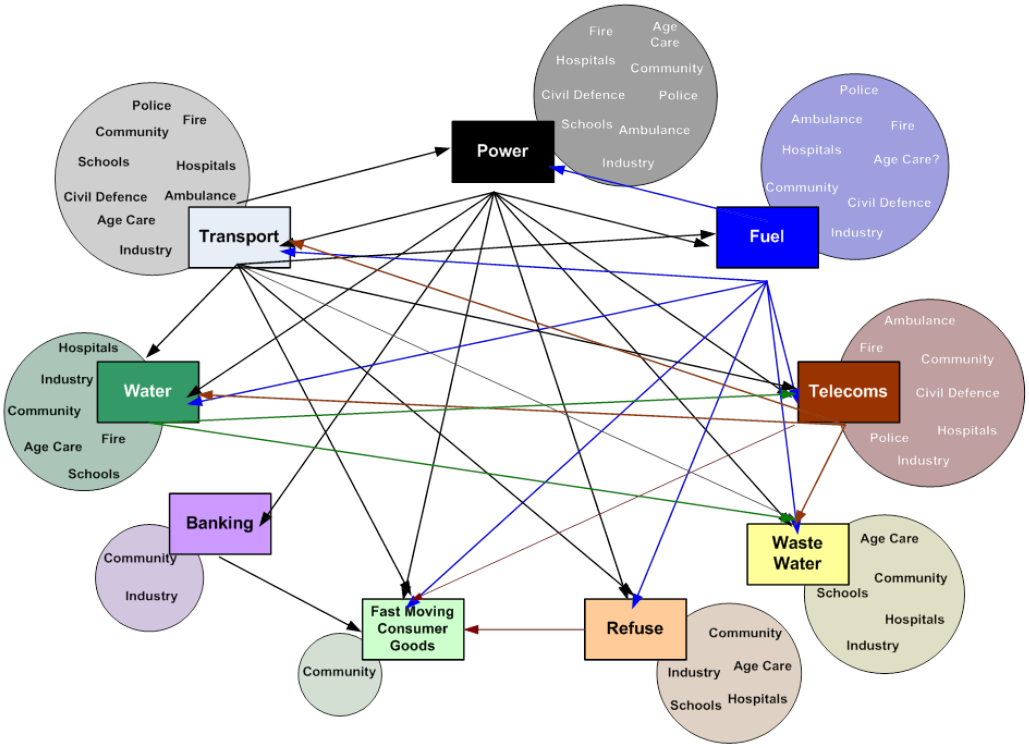

Figure 2 A Systems View of Interdependencies

Around the outside of **Figure 2** can be seen the emergency services and essential community services groups that also depend on the service, and who have defined "priority sites" requiring service continuity or restoration within certain timeframes. Note the inclusion of Banking and Fast Moving Consumer Goods as "lifeline utilities" in the context of interdependencies.

Complex interdependency in modern infrastructure networks means we need to look further afield than the principal sector (e.g. roading network) to other interdependent sectors to identify potential failure modes and hazards. Power and fuel are amongst the most critical utilities, as all other sectors depend on them. In times of critical shortage, arrangements for the supply of fuel to transport users need to be carefully managed to make sure those that need it most can obtain it. All utilities need a basic level of service from transport to ensure they can access critical sites for the operation of their own services.

Interdependencies can lead to a wide range of potential failure modes and the emergence of previously unidentified hazards which can cause failure. Hollnagel (2011) categorises the range of failure modes as simple-linear (or cascade) failure, complex-linear failure (caused through hidden interdependencies or latent conditions), or complex-nonlinear failure resulting from concurrence of unexpected events. It is vital that a detailed consideration and understanding of interdependencies and potential failure modes is included in any assessment of resilience.

Ongoing effort in making infrastructure networks robust is a vital asset management task. In the case of Orion, Christchurch's electricity lines company, its "management approach featuring systematic and sustained investment in seismic mitigation was central to rapid and effective electricity restoration" following the Christchurch earthquakes (Kestrel Group, 2011).

Fuel is critical to all forms of transportation, and cities depend on petroleum supply and storage arrangements for transport continuity. Most bulk storage facilities are co-located with sea ports, and may be vulnerable to events such as tsunami, storm surge and fire events. Many have been built on engineered reclaimed land such as the bulk storage facility in Lyttelton, Christchurch shown in **Figure 3**. This facility, a critical site, was operational following the Christchurch earthquakes and enabled the city's fuel needs to be met. Special arrangements were made for tankers to transport fuel through the Lyttelton road tunnel due to the closure of Evans Pass which would normally be used.

Figure 3 Petroleum Bulk Storage Facility at the Port of Lyttelton

RESILIENCE

The concept of resilience has evolved from an early ecosystem focus (Holling, 1973) to a focus on socio-ecological systems and disaster risk reduction (Gunderson, 2000; Walker et al., 2004), through to a more recent focus on resilience of infrastructure and the built environment (UNISDR, 2014; Hughes and Healy, 2014). Resilience can be defined as the ability to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and grow over time (National Infrastructure Unit (NIU), 2011).

The term **adaptive capacity** is often used in explaining resilience. Many definitions exist (e.g. IPCC, 2001; Burton et al., 2002; Adger et al., 2003); broadly speaking it may be described as the

ability of a System to modify or change its characteristics or behaviour so as to cope better with existing or anticipated external stresses. Brooks (2003) differentiates between adaptation (the actual adjustment in system or behaviour that enhance its ability to cope), and adaptive capacity (the potential to adapt to future hazards). The latter implies the capacity to adapt to known hazards that may occur in the future, and requires planning and concerted implementation of these plans.
Infrastructure (or **technical**) **resilience** is considered to include the following key principles Hughes and Healy, 2014):

- **Robustness** – strength or the ability of elements to withstand a given level of stress or demand without functional degradation
- **Redundancy** – the extent to which elements, systems, or other infrastructure units exist that are substitutable
- **Safe to fail** - the extent to which innovative design approaches are developed, allowing controlled, planned failure during unpredicted conditions, where the possibility of failure can never be eliminated

Organisational resilience addresses the findings of the Commonwealth of Australia (2011) and Resilient Organisations (2012) and Lee et al., (2013), identifying three core behavioural principles:

- **Leadership and culture** – leadership, staff engagement, decision making, situational awareness, Innovation and creativity
- **Networks** – breaking silos, leveraging knowledge, effective partnerships, internal resources
- **Change ready** – planning strategies, unity of purpose, proactive posture, stress testing plans, innovation and creativity

A holistic approach to 'urban' resilience should cover all aspects relating to the urban environment, as summarised in **Figure 4** below. Recent studies relating to 'resilience' measurement / assessment have led to improvements in the understanding of which factors enhance resilience in societies and within the built environment infrastructure.

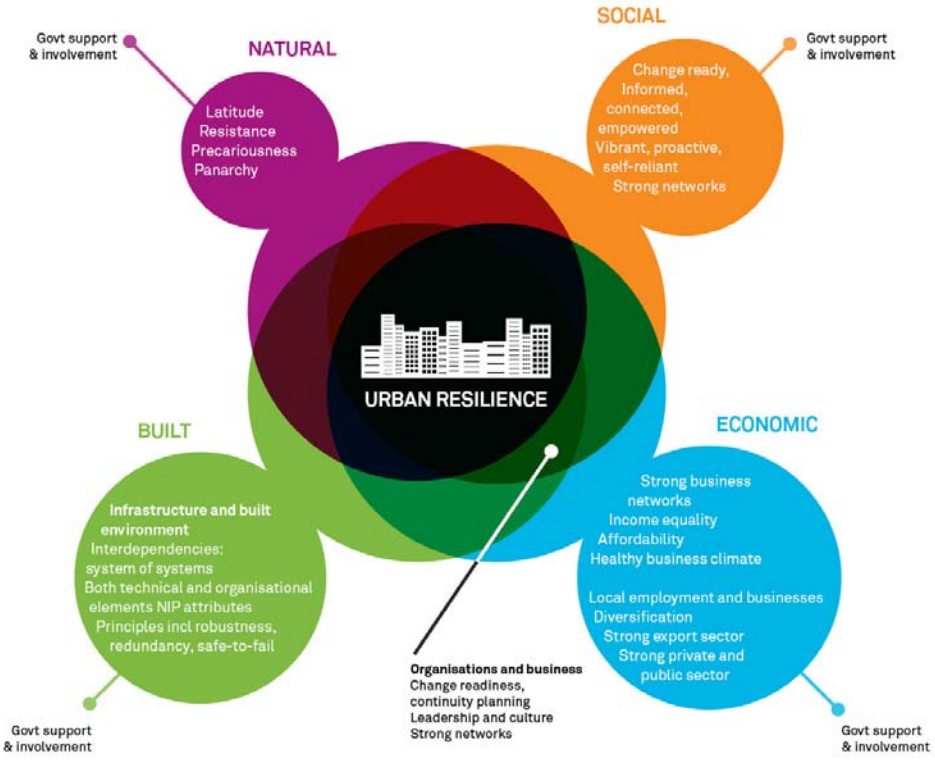

Figure 4 Urban resilience schematic (adapted from Chelleri and Olazabal, 2012)

Importance of resilient infrastructure

Worldwide, infrastructure is recognised as a critical element for healthy economies and stable communities. It enables commerce, movement of people, goods and information, and facilitates society's daily activities.

Croope (2010) states 'Critical infrastructure not only responds to the needs of society for the smooth daily continuation of activities, but also provides the basis on which society exists and relies'.
Godshalk (2002) lists two reasons behind the importance of resilience.

1. Because the vulnerability of technological, natural and social systems cannot be predicted, the ability to accommodate change without catastrophic failure in times of disaster is critical.
2. People and property fare better in resilient cities when struck by disasters. Fewer buildings collapse, fewer power outages occur, fewer businesses are put at risk, and fewer deaths and injuries occur.

Societies have an increasing reliance on transportation networks for their daily activities. The ability of the transport system to function during adverse conditions and quickly recover to acceptable levels of service after an event is fundamental to the wellbeing of people within society.

RESILIENT CITIES

There are many resilience related projects and initiatives either recently completed or underway, some of which are described further in this paper:

- Rockefeller 100 Resilient Cities with Christchurch City Council
- NZTA Research Report 546, Measuring the Resilience of Transport Infrastructure
- Resilience in the context of the National Infrastructure Plan, National Infrastructure Unit
- Resilient Organisations, including the Bay of Plenty Lifelines Benchmark Resilience project
- Economics of Resilient Infrastructure research project

Rockefeller 100 Resilient Cities (100 RC)
The New York based Rockefeller Foundation recently established a global 100 Resilient Cities project, recognising an increasing urbanisation trend with more than 75% of the world's population expected to live in cities by 2050, coupled with the need for cities to be resilient to future shocks and stresses.

The project involves Rockefeller working with 100 selected cities – their local government, communities and stakeholders – to better understand resilience and to develop and implement resilience strategies. Christchurch was selected earlier this year as one of the first 33 cities from 372 applications to be part of the global program, along with Melbourne. Rockefeller funds a Chief Resilience Officer and provides a platform of services, information and tools to support strategy development and implementation. It includes membership in the 100RC Network, which enables knowledge sharing and peer-to-peer collaboration during and following the strategy development process.

Identifying the particular chronic stresses and acute shocks that could affect a city are an important first step, not only the "knowns" but also the possible "unknowns" and those that could be triggered by other events or trends.

- **Chronic stresses** include a wide range of potential issues, such as: lack of affordable housing, pervasive/high unemployment, poverty/inequity, homelessness, aging infrastructure, water or air pollution, drought and water shortage, rising sea levels and coastal erosion, crime and violence, societal instability, depressed macroeconomic conditions, etc.
- **Acute shocks** include earthquakes, flooding, fire, hazardous materials accidents, tornado, terrorism, disease outbreak, riot/civil unrest, infrastructure/building failure, etc.

A resilience strategy helps cities prepare for, adapt to, and quickly rebound from these shocks and stresses, and a successful strategy has three key outcomes:

1. To catalyse resilience across private, public and civic stakeholders at local, city, state, national, international levels
2. To inform the market, identifying the city's needs, helping to create a market signal on resilience priorities through a partnership principled approach
3. To establish a resilience practice, enabling knowledge and best practice sharing between 100RC cities and expansion/scaling of effort beyond 100RC cities to other cities

Figure 5 describes generic qualities associated with urban resilience. From a transport perspective, we need to look at each one of these and consider how well we measure up. While terms such as "robust" and "diverse" can easily be associated with transport assets, all of these qualities are really about the behaviours of people and organisations.

Figure 6 highlights the essential functions of a resilient city, and how well we achieve each of them depends or is influenced by the qualities in the diagram above. The 100RCs approach works through a process of jointly identifying strengths and weaknesses across this broad spectrum. From a transport perspective, Protect, Maintain and Enhance Assets is important, but so too are others such as Safeguard Human Life and Health and Foster Economic Prosperity.

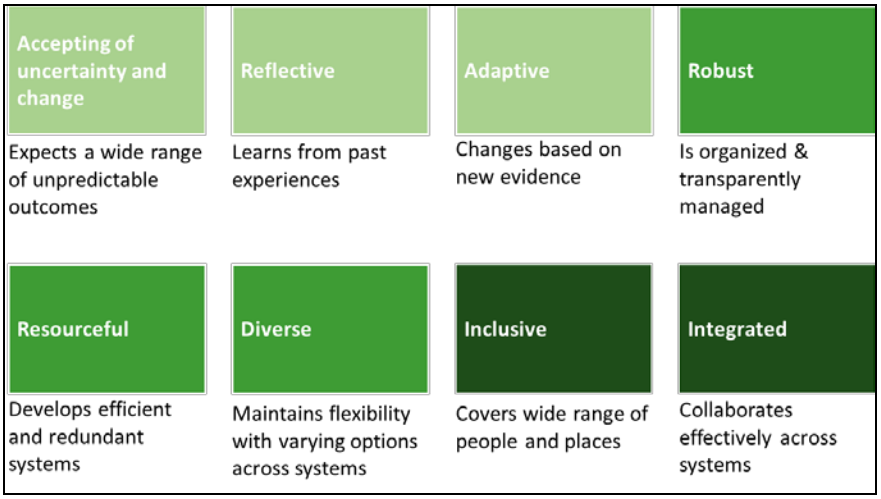

Figure 5 Qualities Associated with Urban Resilience (Rockefeller Foundation)

Figure 6 Essential Functions of Resilient Cities (Rockefeller Foundation)

With an understanding of shocks and stresses and the strengths and weaknesses in the fabric of our city and the organisations which serve it, we can begin to map out actions to help us become more resilient. A particular strength of the 100 RCs approach is that it enables a holistic perspective to be developed, which enables interdependencies that may not have been considered before to be identified.

Having recently endured an unprecedented scale of natural disaster events, Christchurch is now in the early stages of the 100 RCs process, having appointed a Chief Resilience Officer and commenced the initial phase of developing the Resilience Strategy.

NZTA State Highways Resilience Project

NZTA research report 546 (Hughes and Healy, 2014) describes an approach to measuring the resilience of state highways, and the principles are equally applicable to other road networks and indeed other forms of infrastructure. The results offer the transport practitioner a framework from which to develop their own resilience thinking. As a key driver for NZTA, this has led to a specific focus on resilience and how it could be defined, measured and improved across the transport system.

The measurement framework covers **both technical and organisational dimensions of resilience** and breaks these down into specific principles and measures which can be utilised to qualitatively assess resilience.

A resilience assessment requires an awareness that the hazard itself may be unpredictable (Park et al., 2013) and the organisation needs to think beyond typical disaster scenarios (Brunsdon and Dalziell 2005). The Christchurch earthquakes of 2011 were a classic example, violent movement of an unknown fault lying directly underneath the city. A risk management approach alone is not sufficient and needs to be complemented by a resilience approach to events that fall outside the realms of predictability and where failure may be inevitable.

A resilience approach should consider “critical assets”, those assets where the consequences are too great for failure of the asset to be acceptable – such as a lengthy total loss of service on a

motorway corridor or key access corridor. In carrying out assessments and developing management plans, desired levels of resilience are defined on a four point scale in **Table 1** and linked to different levels of asset criticality:

Criticality score	Desired level of resilience
Highly critical	Very high (4)
Medium	High (3)
Low	Moderate (2)
Not critical	Low (1)

Table 1: Levels of Asset Criticality and Desired Resilience

Either an all-hazards approach or a hazard-specific approach may be used as summarised in **Figure 7**. In both cases a criticality assessment is conducted first. An all-hazards approach involves a high-level assessment looking at resilience in response to all hazards irrespective of the level of risk exposure. It asks the question what happens if this asset or system fails? For what reason?

A hazard-specific assessment includes the consideration of relative risk, and is more appropriate when determining risk-based priorities for a particular asset or part of the network. For example, should limited funding be expended first on seismic strengthening of a bridge or flood protection measures?

In both cases, the tool developed allows an analyst to systematically assess the current level of resilience using a series of detailed measures in the technical and organisational categories.

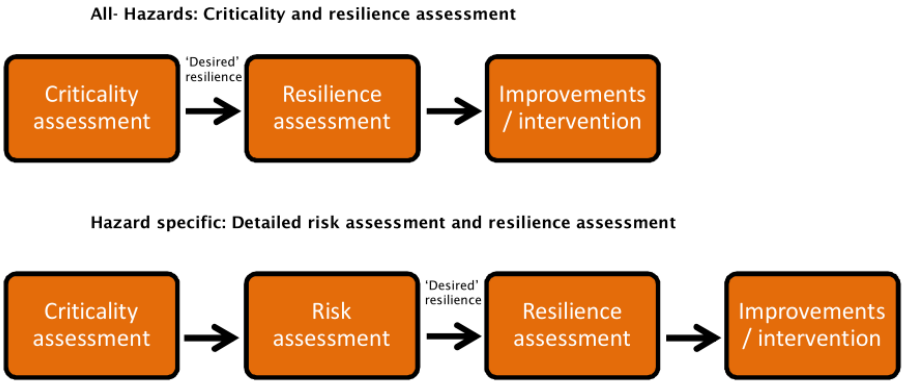

Figure 7 Two Approaches to Assessing Resilience

National Infrastructure Plan

The 2011 NIP (NIU, 2011) covers the transport, telecommunications, energy, water and social infrastructure sectors, and sets out a vision that 'by 2030, New Zealand's infrastructure is resilient and coordinated and contributes to economic growth and increased quality of life'.

The 2011 NIP established six guiding principles as a platform for infrastructure development: investment analysis, resilience, funding mechanisms, accountability and performance, regulation and coordination. The 2011 NIP acknowledged that significant work was required to develop indicators for these assessment areas, both within and across sectors.

Since then, the nine priority themes and issues have been defined in the matrix presented in **Figure 8**, with Resilience being located in the "geographic middle" of the diagram.

The NIP is currently being re-written for 2015, and is intended to be significantly more evidence based than the directional 2011 version. Resilience assessment is a key part of the process, with inputs required from the various infrastructure sectors.

Figure 8 Key Themes (NIU)

Resilient Organisations

Resilient Organisations (ResOrgs) is a public-good research programme based in New Zealand, and has been researching what makes organisations resilient to crises since 2004. It is a collaboration between top New Zealand research universities, particularly the University of Canterbury and the University of Auckland and is funded by the Natural Hazards Research Platform supported by a diverse group of industry partners and advisors. The group produces practical frameworks and guides to help organisations develop and implement resilience strategies suitable to their environment, providing a valuable resource for those looking for approaches to becoming smarter and stronger.

This resource includes a unique set of tools for resilience assessment, capability building, and benchmarking, including the Resilience Benchmark Tool (http://brt.resorgs.org.nz/). This tool uses a series of indicators shown in **Figure 9**, based on three key attributes, Leadership & Culture, Networks, and Change Ready, for measuring organisational resilience. Respondents are asked to indicate how much they agree, or disagree, with a number of statements on a Likert scale (an eight point graduated scale ranging from strongly disagree to strongly agree). An important feature of the Benchmark Resilience Tool is that it is designed to be both answered by senior managers and staff across an organisation, so that an organisation-wide view of resilience can be obtained.

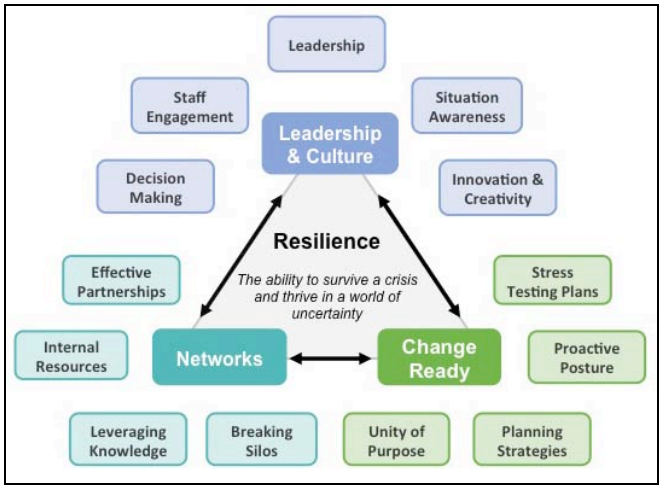

Figure 9 Resilience Indicators (Resilient Organisations)

A benchmarking study recently completed in the Bay of Plenty used this tool and reported on results from 18 organisations who took part (Brown, Seville and Vargo, 2014). The results are illustrated in **Figure 10** highlighting a number of strengths and weaknesses, such as:

- Relatively higher levels of organisational resilience in the power and energy network distributors – but lower scores for generation and retail
- A range of scores across the measurement attributes with particular weaknesses for Stress Testing Plans, Internal Resources, Breaking Silos

The use of such a tool can provide valuable insights not only for the organisations themselves, but also in better understanding the "whole of city or region" resilience. From such a perspective, a number of improvements and actions can be developed to help make the city stronger, safer and importantly, smarter. Such initiatives may include:

- City or region-wide crisis scenario exercises
- Breaking down silos between and within organisations
- Staff engagement with emergency preparedness
- Processes for combined rapid impact assessment and information sharing
- Target critical dependencies where there is insufficient planning

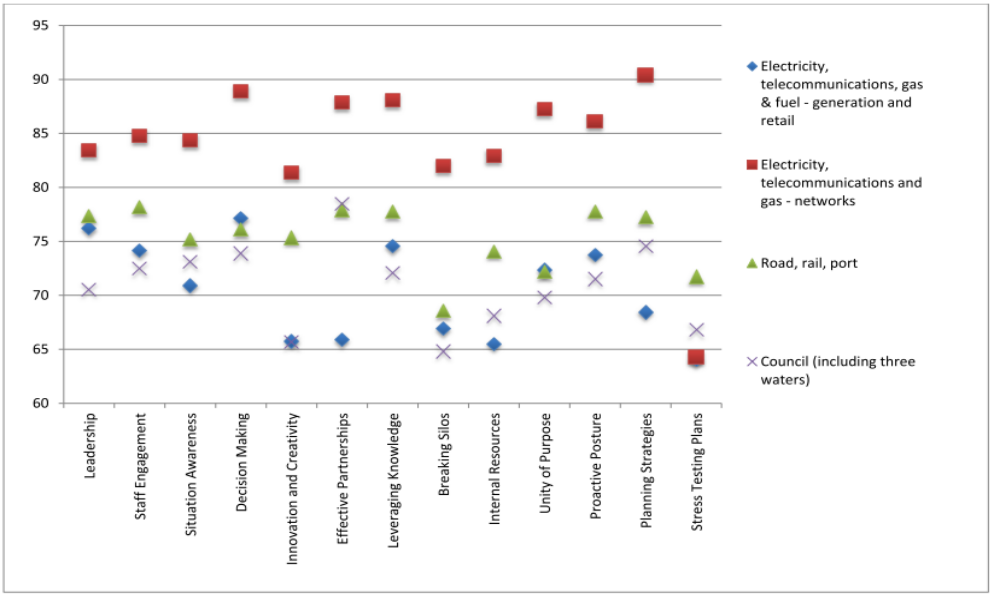

Figure 10 Benchmarking Results for Bay of Plenty

MERIT – Economics of Resilient Infrastructure

The Economics of Resilient Infrastructure project being delivered under the Natural Hazards Platform is developing a tool called MERIT (Modelling the Economics of Resilient Infrastructure). The key output will be a high resolution assessment across space and through time of the economic consequences of infrastructure failure, business response and recovery options. The project which runs until September 2016 will develop a new tool to:

- Quantify the economic implications of vulnerabilities to infrastructure failure from both natural hazards and infrastructure-only events
- Explore alternative post disaster recovery strategies

It is focussing on two key areas in New Zealand:

- Auckland, recognising its importance for national economic development (nationally-significant investment decisions, some existing infrastructure vulnerabilities)
- Christchurch, where earthquake recovery decisions are being made (benefits are expected for the rest of New Zealand following other large hazard events)

It will model two infrastructure disruption case studies for the Canterbury region – the first being a disruption of access to Lyttelton Port, and the second being an Alpine Fault Scenario. With much of the groundwork already done to develop the MERIT model, there are several possibilities for how regions such as Canterbury could leverage this work, including:

- Using MERIT to analyse additional infrastructure disruption scenarios, with lifeline utilities being involved in selecting and characterising the scenarios to be modelled.
- The MERIT tool being applied to evaluate the benefit/cost of infrastructure investment decisions (although the model is currently being designed to evaluate the impacts of disruption, some modifications would be needed to be useful in a benefit/cost type analysis).
- Using the MERIT model to help pre-thinking different recovery measures that might be used, for example, to boost recovery following an Alpine Fault earthquake.

Other Perspectives

Resilience is also topical internationally. In Australia two items worthy of note are briefly described below.

Victoria to Mandate Resilience Audits of Key Infrastructure

In August 2014 Victorian Police Minister Kim Wells tabled the Emergency Management Amendment (Critical Infrastructure Resilience) Bill (http://www.parliament.vic.gov.au/static/www.legislation.vic.gov.au-bills-archive.html) for its second reading, stating that "as critical infrastructure becomes more interdependent, demand for services increase and climate variability affects the frequency and severity of emergencies, the challenge of ensuring continuity of supply in the face of natural disasters becomes all the more important". Owners and operators of critical infrastructure deemed "vital" will be required to complete a "resilience improvement cycle", including "development of a statement of assurance, risk management planning and documentation, an annual exercise and an audit". They will have to provide a statement of assurance to the relevant minister at the end of each annual cycle to continually build resilience.

This bill establishes a standardised assessment methodology to help owners and operators determine criticality in terms of commercial operations and delivering the state's essential services. There are four levels: local, major, significant or vital.

Inaccessible Disaster Data Hindering Smart Response

A recent report (July 2014) from the Australian Business Roundtable for Disaster Resilience & Safer Communities, Building an Open Platform for Natural Disaster Resilience Decisions (http://australianbusinessroundtable.com.au/white-paper/research-report) said that while a large number of organisations contribute to natural disaster research, crucial data can be difficult and costly to access, incomplete, duplicated or not suitable for its different users. The report makes three recommendations:

- To develop a national open platform that centralises key data so all Australians have access to information that's critical to protecting homes and property. This would include data such as information on flood elevation, the location of assets, the resilience of building materials and long-term weather patterns.
- Remove restrictive barriers on accessing data and research by standardising research and addressing concerns such as unnecessary restrictive licensing.
- To establish a framework for prioritising investment in resilience.

APPLYING RESILIENCE AND RISK IN DECISION MAKING

Recent natural and technological catastrophes have highlighted:

- A failure to predict extreme events
- An inability to understand the complex systems involved and the potential range of failure possibilities.

Park et al., (2013) emphasise our ignorance: *'not the assumption that future events are expected, but that they will always be unexpected'*. This is further elaborated through the concept of 'black swan' events (Taleb, 2008), which are characterized by three factors.

- They lie outside the realm of regular expectations, because nothing in the past can convincingly point to their possibility
- They carry an extreme impact
- In spite of their outlier status, human nature causes people to concoct explanations for the occurrence after the fact, making it explainable and predictable.

Typically, a risk analysis approach is used to identify risks and then develop management/mitigation approaches. However, as many hazards and failure modes are unknown, or inadequately understood, risk analysis becomes inadequate, and arguably impossible (Park et al., 2013). In short, risk analysis requires the hazards to be identifiable, and therefore, to prepare for the unexpected, an alternative (and complementary) approach is required to consider these unpredictable events. This is why a focus on resilience, instead of solely risk is emphasised by many. Some key differences in a traditional 'risk-based' approach versus a 'resilience' approach are as follows (Park et al., 2013 and Snowdon, 2011):

- A risk-based approach looks to mitigate failure through probability and scenario-based analysis of known hazards. A resilience approach looks to minimise the consequences of failure through investigating scenarios with unidentified causes.
- A risk-based approach would involve incrementally modifying existing designs in response to emerging hazards, whereas a resilience approach would involve adapting to changing conditions, and potentially allowing controlled failure ('safe-to-fail' design) at a sub-system level to reduce the possibility of broader loss of function within the larger system.

'Risk' and 'resilience' approaches are considered complementary and applicable in different circumstances. They are not considered mutually exclusive, and their use will depend on the context of the assessment being undertaken and the understanding of the relevant hazards. A simplified decision tree as in **Figure 11** could help to identify when a resilience assessment or risk assessment would be most appropriate. This is ultimately determined by the level of certainty relating to the likelihood / consequence of the hazard, and the complexity of the system (eg infrastructure system) being assessed.

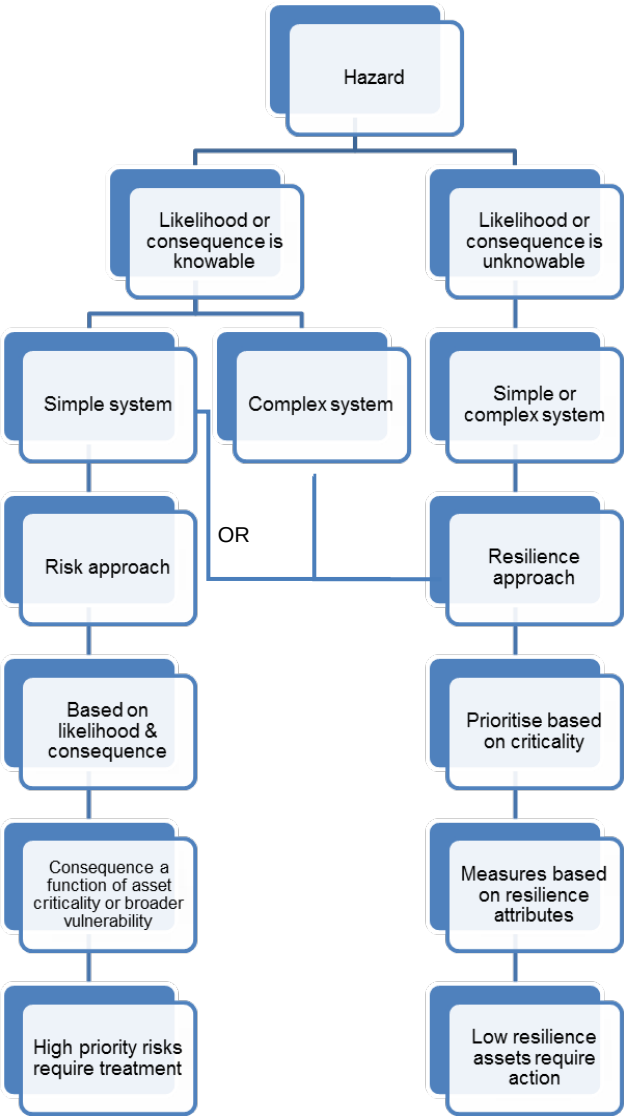

Figure 11 Suggested Approach to Risk and Resilience for Infrastructure / Systems

CONCLUSIONS

Transport systems play a vital part in ensuring our cities and communities will be able to function and respond effectively and to recover and thrive in the face of major shocks and stresses. Some of these shocks and stresses we are familiar with, however the possibility of unknown "black swans" must also be taken into account.

A resilience framework can help any transport organisation providing services, whether by land, air, sea, by vehicle, train, bus, cycle or on foot. Critical customers include hospitals, emergency services, and other utilities, and there are interdependence relationships between all "lifeline utilities" which are vital and must be effective for a city to be truly resilient.

Resilience is about "Smarter Stronger Safer" and it is relevant to the physical network that enables these services to be provided and the organisations and people that are part of the supply chain:

- **Smarter** transport means having the right information and making the right decisions about transport AND understanding how transport contributes to the wider notion of a resilient city and related interdependencies
- **Stronger** transport means networks and assets which are robust and have diversity AND organisations which can withstand and respond continuing to function in adversity

- **Safer** transport means protecting road system users and customers AND ensuring transport systems make a positive long term contribution to long term health and safety outcomes for society

A number of initiatives have been described in this paper. It is important to decide how the tools and processes described can be applied in better understanding the resilience of transport systems and how it can be enhanced. Different approaches are summarised in the **Table 2** below.

Theme	Comment
Organisational Resilience and Capability Assessments	Benchmarking assessments similar to the Bay of Plenty example. There is also a MCDEM capability assessment tool being trialled in Auckland that could be used for operational capability purposes.
Infrastructure Network Resilience Scorecard	This would utilise a quantitative tool similar to that developed for NZTA's state highways assets. Customisation would be required for different types of asset networks, but the principles are the same. Such a tool would be evidence based.
Infrastructure Network Resilience Framework	Similar to the Scorecard approach above, based around a common set of principles along with a series of indicators for evaluating each and a qualitative, discussion and joint understanding based approach utilised. Has the advantage of creating inter-agency relationships.
Leveraging the MERIT tool for evaluating Infrastructure Resilience Investment	Using the MERIT tool to carry out different quantitative analyses including cost/benefit assessment of investment options.
Modelling of Infrastructure Network Performance and Resilience	These are more intense, analytical processes which require good data and can be resource hungry.
Risk assessment	Standard risk or vulnerability assessments are appropriate in making asset specific decision, but less suited to the low probability extreme events for which a greater level of resilience is desired.

Table 2: Approaches to Understand the Resilience of Transport Systems

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