Establishing the value of resilience
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Abbreviations and acronyms

General abbreviations are noted below. Project-specific definitions are included in the glossary in appendix B.

CCO	council controlled organisations
EEM	*Economic evaluation manual*
EY	Ernst and Young
GPS	Government Policy Statement on Land Transport 2015 – 2024
GWRC	Greater Wellington Regional Council
LGNZ	Local Government New Zealand
MAO	maximum available outage
MBIE	Ministry of Business, Innovation and Employment
MCDEM	Ministry of Civil Defence and Emergency Management
MoT	Ministry of Transport
Transport Agency	New Zealand Transport Agency
ONRC	One Network Road Classification
RTO	recovery time objective
SRC	Southland Regional Council
USDHS	US Department of Homeland Security

Contents

Executive summary

Research task

Resilience is universally understood to be a 'good' concept. Improving the ability to prevent, or respond to, disruption is objectively desirable. However, the means by which we look to achieve resilience is more subjective and debatable.

- What do we want to be resilient to?
- How do we prioritise investment to improve resilience to disruption?
- How should stakeholders be consulted when making decisions about resilience?

In addition to the subjectivity of resilience is a plurality of terms, definitions and understanding of the various concepts relating to resilience. A lack of consistency in this regard makes it more difficult for decision makers to do what is right for communities of interest.

The New Zealand Transport Agency commissioned research to establish a consistent approach to transport resilience; terminology, levels of service, valuation and responses and also to develop an updatable 'Decision Support Tool' to consistently weigh up different controls to create an acceptable level of resilience in (transport) infrastructure – in a way that achieves desired community outcomes.

To fulfil this research task, Ernst and Young and Tonkin + Taylor asked two fundamental questions.

How can we standardise the discussion of resilience?

The concept of a taxonomy, or a dictionary of terms, that helps to create a common understanding of resilience is important as it means all stakeholders are speaking the same language. This lays the platform for better decisions to be made more consistently.

Our literature review of over 100 documents confirmed the presence of a range of different concepts of resilience – some overlapping, some diametrically opposed and some in complete concert. In addition, we learned that a taxonomy should be simple enough to be communicated to lay people – but should have enough technical rigour to support our Decision Support Tool and this taxonomy should be applicable to a wide range of infrastructure sectors.

To help develop a workable taxonomy we balanced a number of objectives. These included asymmetric definitions of resilience; complexity of terms to provide sufficient rigour vs simplicity of terms to make communication acceptable to a wide stakeholder group and using terms and definitions that are applicable to all infrastructure sectors. To best balance these (often) competing objectives, we developed a taxonomy with three specific tiers:

1. Definition of resilience: The basis for the research and the anchor for the taxonomy.
2. Resilience measures: A short list of 'communicable terms' that enabled us to conveniently aggregate and communicate resilience controls (controls). The measures are: robustness, redundancy, recovery, leadership and governance.
3. Glossary: A comprehensive list of terms and phrases associated with resilience that combined a mix of technical and non-technical terms as well as transport-centric and general terms.

The definition we believe best encapsulates resilience is:

> *Resilience is the ability of systems (including infrastructure, government, business and communities) to proactively resist, absorb, recover from, or adapt to, disruption within a timeframe which is tolerable from a social, economic, cultural and environmental perspective.*

This definition includes the key concepts of:

- Focusing on outcomes of systems. The need to think holistically about the ability of a system to withstand disruption, and a focus on the services that an asset/system provides to communities.
- Confirming notions of 'resist', 'absorb', 'recover', 'adapt' as important components of resilience. The concepts of resist, absorb, recover and adapt appear to be the most appropriate for a definition of resilience as they span the lifecycle from pre-event to post-event.
- Remaining agnostic to disruption source, for example a landslide or a truck roll (and so confirming resilience is not restricted to natural hazards). New Zealand is a seismically and climatically unique country and there is a wealth of knowledge on natural hazards. This body of knowledge has been further progressed on the back of some high-profile events, most notably the Canterbury earthquake sequence. However, we argue that resilience to organisational challenges is equally important.
- Providing for a spectrum of stresses and shocks. Similar to the point above, New Zealand has a long history in reporting on, and attempting to manage, shocks to the transport system (often resulting from natural hazards). However, we believe there is an under-representation in the literature of longer run and accumulative disruptions (stresses). These are harder to account for because of the time horizons at play and the uncertain nature of these events.
- Deliberately focusing on community 'tolerance'. Arguably the most critical finding of the literature review was that resilience should be put in the context of the communities who will feel the disruption. At its core, infrastructure exists to provide services to communities. If these services are disrupted, by any means, then communities miss out. It is these communities that should have a strong(er) say in how resilient they want to be to disruption and also be given the opportunity to say how much they are prepared to pay/forgo/invest in order to achieve an appropriate level of resilience.
- Taking a wide view of value. Value is not just about direct economic costs and benefits. There is a whole range of social, environmental and cultural 'values' that needs to be observed. In addition to the impact on different values, we observed investments in infrastructure to improve resilience can often spark wider (economic or otherwise) benefits that are often not accounted for.

Resilience measures form the next tier of our taxonomy. They categorise resilience controls and collectively add up to the whole. Functionally, these resilience measures help us aggregate controls, communicate resilience to a broader audience and provide some broad guidance to order thinking.

This research report argues that four resilience measures best balance the need for simplicity and technical rigour and include:

- Robustness: The ability of systems to withstand disruption and continue to provide an acceptable level of service.
- Redundancy: Provision of functionally similar outcomes, to an acceptable standard, during lost or degraded levels of service.
- Recovery: The ability to restore an acceptable level of service after disruption.
- Leadership and governance: The ability to develop an organisational mind-set/culture of enthusiasm for responding to challenges (for example through the development of an agile and flexible asset monitoring and management programme).

It is worth noting these four resilience measures can be, and in most instances are, present in different combinations to form a resilient system. For example, robustness implies the system already has the ability to provide an acceptable level of service. Recovery in a robust system would either be redundant or in order to meet 'a desired level of service'.

In support of our definition and our resilience measures is a larger suite of terms – a glossary – which has been established leveraging international leading definitions and legislative definitions where appropriate. This glossary is provided in appendix A.

How do we systematically weigh up different controls?

Following the establishment of a taxonomy which enables stakeholders to 'talk the same language' our attention moved to the development of a tool which would enable decision makers to consistently weigh up controls to improve resilience for communities of interest.

The concept of a 'Decision Support Tool' was collectively agreed upon, with a number of key design principles:

- Practical. We have focused on producing a Decision Support Tool that can be immediately integrated into existing processes, including those at the Transport Agency, if desired. In the first instance, the tool looks best placed to support early stage assessment (strategic case of an indicative business case for example) of controls to improve resilience of local assets.
- Leverages existing work. The Decision Support Tool is built on an explicit acknowledgement that there is a multitude of high-quality work and research being undertaken into resilience – and that this knowledge base will continue to grow over time. What constitutes 'value' will also be context specific. Therefore, an explicit incorporation of the 'state of the art' allows for maturity and progression of inputs (effort) over time.
- Outcomes focused. The Decision Support Tool puts the function of an asset (or assets) within a system at the heart of decision making, and therefore focuses on the consequences of assets not being available to users. In this way, the tool is more concerned about the outcomes of disruption rather than disruption to an asset *per se*.
- Scalable. The Decision Support Tool provides a systematic approach to considering resilience. It is intended to be scalable to a range of sectors[1] as well as being effective when used in both detailed and high-level assessments. In both instances, the usability will be determined (or limited) by the quality of the inputs into the tool; the more comprehensive the informational inputs, the more detailed resilience assessments can be.

The Decision Support Tool has six main stages. The stages and description of the relevant steps are briefly described below.

- Stage one: Understand your asset. Understanding the services that an asset provides consumers is useful to understand the communities of interest (and hence how to go about understanding tolerance to disruption) as well as to obtain a sense of the types of controls (or responses) that can help improve resilience to disruption.

[1] Considerations for this research project are explicitly transport focused, but will have some applicability to other infrastructure types.

- Stage two: Impact assessment. The Decision Support Tool intentionally takes a consequence-based approach rather than one that looks at probability weighted risk and borrows from business continuity theory. It is agnostic to challenge type in the first instance, and simply seeks to build an understanding of the consequences of disruption (across the four wellbeing pillars – economic, social, cultural and environmental). It then seeks to understand a community's tolerance to outage – the length of time and level of service that communities are willing to have taken away from them due to the disruption. Discussions of tolerance also encompass optionality about what 'reduced levels of service' consists of as well as a community's willingness to pay.
- Stage three: Challenges. Fully understanding the challenges facing transport assets and systems means consistently better decisions can be made about investment and resilience. To help inform comprehensive thinking and the removal of inherent biases, we propose the utilisation of a challenge matrix that systemises thinking and exploration by placing challenges within a scalable framework (spanning stresses to shocks and natural to physical/organisational).
- Stage four: Controls. These are the various interventions (both current and future) that exist to mitigate against challenges. Controls can include traditional transport-centric responses (such as construction of retaining walls to prevent rock fall or an internal process to manage regular maintenance of assets), but can also include options that are not traditionally included as part of transport planning (such as communication approaches to enable telecommuting).
- Stage five: Heatmap assessment. The final assessment is presented in a systematic format and allows the user to consistently understand existing levels of resilience to challenges and the wider value different controls can provide. It also enables users to weigh up different resilience controls by determining a high-level 'value of resilience' measure. A hypothetical example of this assessment is provided in stage six:
- Stage six: Summary. This final step is intended to provide a checklist and summary of the outputs of the tool for use in decision making.

Abstract

Resilience is universally understood to be a 'good' concept. Improving the ability to prevent, or respond to, disruption is objectively desirable. However, the means by which we look to achieve resilience is more subjective and debatable.

- What do we want to be resilient to?
- How do we prioritise investment to improve resilience to disruption?
- How should stakeholders be consulted when making decisions about resilience?

In addition to the subjectivity of resilience is a plurality of terms, definitions and understanding of the various concepts relating to resilience. A lack of consistency in this regard makes it more difficult for decision makers to do what is right for communities of interest.

With this in mind, the New Zealand Transport Agency commissioned research to 'establish a consistent approach to transport resilience; terminology, levels of service, valuation and responses'. The scope of the research also included the development an updatable Decision Support Tool to weigh up different controls consistently and to create an acceptable level of resilience in (transport) infrastructure – in a way that achieves desired community outcomes.

1 Introduction

1.1 Project background

Resilience is universally understood to be a 'good' concept. Any number of corporate and government documents refer to the need to be 'resilient'. Improving the ability to prevent, withstand, or respond to, disruption is objectively desirable. However, the means by which we look to achieve this end is more subjective and contentious. For example, there are often differing views as to:

- what we want to be resilient to
- how we prioritise investment to improve resilience to disruption
- which stakeholders should be consulted when making decisions about resilience.

In addition to the subjectivity of resilience is a plurality of terms, definitions and understanding of the various concepts of resilience. A lack of consistency in this regard makes it more difficult for decision makers to do what is right for communities of interest.

By creating a consistent approach to resilience, underpinned by definitions and value appraisal techniques that are agreed by communities of interest, we argue better decisions can be made, more often, for assets that have an important influence on people's lives.

1.2 Purpose

In September 2015, the New Zealand Transport Agency (the Transport Agency) commissioned research to:

> *establish a consistent approach to transport resilience; terminology, levels of service, valuation and responses*

This was subsequently and collaboratively expanded to include:

> *the development an updatable 'Decision Support Tool' to consistently weigh up different controls, to create an acceptable level of resilience in (transport) infrastructure – in a way that achieves desired community outcomes.*

1.3 Methodology

The methodology for this engagement transformed throughout the course of the research in response to the nature of the research findings. However, in general, the project consisted of four main phases:

1. Literature review and scoping
2. Development of an updatable Decision Support Tool
3. Demonstration of the Decision Support Tool through a worked example
4. Documentation, comprising research report preparation and guidance note development.

1.4 Intended audience

The intended audience for this research report is broad. The provision of effective infrastructure is something that benefits all New Zealanders – and therefore any research that furthers the knowledge base, or progresses the dialogue, to improve the resilience of infrastructure to disruptions (over the short, medium and long term) is beneficial to a wide audience.

Specifically, however, we would expect this report to be of most use to those who are:

- tasked with making decisions about investments in the transport network across New Zealand. This explicitly covers the Transport Agency, Ministry of Transport (MoT), Treasury, regional councils and territorial local authorities, but could include others as required
- tasked with making decisions about investments in any infrastructure asset or system
- interested in the research literature of resilience – from any dimension (social, economic, environmental, cultural).

The Decision Support Tool has been explicitly developed to assist decision makers in bullet point 1 above. However, we believe this tool contains a number of principles and elements that would be analogous to any infrastructure system. We would recommend it be customised to suit a particular infrastructure sector should it be deemed appropriate.

1.5 Report structure

This research report has been developed in line with the methodology described in paragraph 1.3.

- Chapter 1 provides an introduction to, and context for, the research report.
- Chapter 2 provides an overview of our literature review and the fundamental research findings. Specifically, this chapter seeks to address the inconsistent terminology that has developed around resilience by creating a user-friendly taxonomy.
- Chapter 3 seeks to address the dual concerns of valuing resilience and understanding how to prioritise future investments and responses by detailing the architecture of the Decision Support Tool.
- Chapter 4 provides a conclusion to our research, discusses some of the inherent limitations in the findings and identifies a range of areas that would benefit from further research.
- Chapter 5 provides the literature reviewed as part of this research

In support of this research are several operational addenda specifically designed to bridge the gap between the theory of the research and the practicality of using the Decision Support Tool on a day-to-day basis.

- Appendix A provides the glossary of terms developed in this research to underpin the concepts of resilience discussed.
- Appendix B provides guidance notes for the use of the Decision Support Tool and a hypothetical worked example to aid new users.
- Appendix C provides the hypothetical worked example in the MS Excel tool (this is located at www.nzta.govt.nz/resources/research/reports/614).

2 Literature review

2.1 Overview

The literature review identified over 100 reports (including government strategy documents) that were deemed to be potentially relevant to this research project. A full list of all documents cited is provided in chapter 5.

We initially narrowed down this substantial body of literature to focus on those contributions that would ultimately help us form a 'taxonomy' based on consistent definitions. We did, however, accumulate and flag knowledge that would help future stages (for example the eventual development of a Decision Support Tool and the development of guidance notes).

Key pieces of literature relevant for the development of a taxonomy included:

- Bruneau et al (2003) *A framework to quantitatively assess and enhance the seismic resilience of communities*.
- Cox et al (2011) *Transportation security and the role of resilience: a foundation for operational metrics*.
- D'Lima and Medda (2015) *A new measure of resilience: an application to the London Underground.*
- Hughes and Healy (2014) *Measuring the resilience of transport infrastructure.*
- Hyder Consulting (UK) Limited (2009) *Network resilience and adaptation – phase 1*.
- Stevenson et al (2015) *Resilience benchmarking and monitoring review*.

2.2 Taxonomy

The concept of a taxonomy, or a dictionary of terms, that helps to create a common understanding of resilience is important as it means all stakeholders are speaking the same language. This lays the platform for better decisions to be made more consistently.

Our literature review confirmed the presence of a range of different concepts of resilience – some overlapping, some diametrically opposed, some in complete concert. This immediate finding supported the rationale for the first limb of the research question '…to establish a consistent approach to transport resilience; terminology…'

In addition, a taxonomy should be simple enough to be communicated to lay people – but should have enough technical rigour to support our Decision Support Tool and should be applicable to a wide range of infrastructure sectors.

Therefore, to help develop a workable taxonomy we tried to balance a number of (often) competing objectives, including:

- asymmetric definitions of a range of components of resilience
- complexity of terms to provide sufficient specificity to be meaningful vs simplicity of terms to make communication to a wide stakeholder group acceptable
- transport-centric terms and definitions that are also applicable for other infrastructure sectors.

To best balance these (often) competing objectives, we developed a taxonomy with three specific tiers:

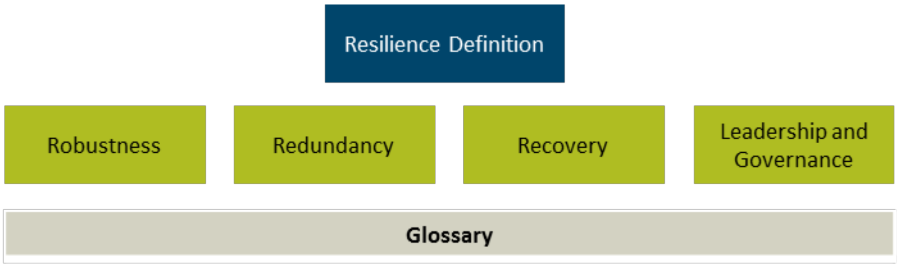
1 Definition of resilience: This is the heart of our research and is the anchor for all elements of the taxonomy. It is intentionally broad enough to cover all infrastructure sectors and has been communicated to a number of government agencies, including the Ministry of Civil Defence and Emergency Management (MCDEM), with the goal of creating an enduring definition that will be widely used by all stakeholders.

2 Resilience measures: A short list of 'communicable terms' enabling us to conveniently aggregate and communicate resilience controls (controls). Resilience measures have been developed to be agnostic to infrastructure type. Resilience measures effectively provide an indication of 'how' you are, or can be, resilient to certain disruptions. The measures are: robustness, redundancy, recovery, leadership and governance.

3 Glossary: A comprehensive list of terms and phrases associated with resilience and combines a mix of technical and non-technical terms as well as transport-centric and general terms.

A stylised version of how to think about the interrelated components of the resilience taxonomy is provided in figure 2.1.

Figure 2.1 Stylised resilience taxonomy



The remainder of this chapter summarises the key themes from our research that have supported the establishment of this taxonomy.

2.2.1 Definition of resilience

A definition of resilience sits at the apex of the taxonomy. It is the objective that all remaining components flow from and to and it forms the focus for all outcomes from the Decision Support Tool described later in this report. The development of a definition of resilience is the anchor for our research – a number of key findings in the literature review have supported the construction of the definition noted below.

The most striking issue we encountered across the literature review was the sheer number of definitions of resilience. By way of an example, researchers working on the Resilience Benchmarking and Monitoring Review Short-term Project as part of the National Science Challenge Programme accumulated 120 distinct definitions of resilience from peer-reviewed academic literature and policy and industry literature.

We observed, and understand, that each definition has been crafted for a very specific purpose, and therein lies part of the problem. 'Resilience' as a concept is something that will mean different things to different people (and can be used to justify different means and ends). Therefore establishing a commonly held definition that is easy to communicate and is uncontentious was a clear part of this research project.

In reviewing the more than 100 definitions of resilience, we found the following to contain the most useful elements:

> *The ability to absorb the effects of a disruptive event, minimize adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving, while mitigating the adverse impacts of future events.* (Stevenson et al (2015)

> *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.* (Hughes and Healy 2014; National Infrastructure Unit 2015)
>
> *Resilience is the ability of assets, networks and systems to anticipate, absorb, adapt to and/or rapidly recover from a disruptive event.* (UK House of Lords 2015)
>
> *Resilience is the ability of systems, infrastructures, government, business and citizenry to resist, absorb, and recover from or adapt to an adverse occurrence that may cause harm, destruction, or loss of national significance.* (USDHS 2009)

Aggregating the key elements of these definitions, as well as building on various observations from the wider body of literature, we arrived at the following definition.

> *Resilience is the ability of systems (including infrastructure, government, business and communities) to proactively resist, absorb, recover from, or adapt to, disruption within a timeframe which is tolerable from a social, economic, cultural and environmental perspective.* Adapted by the research project team from the range of definitions noted above.

MCDEM is currently developing a National Disaster Resilience Strategy which will include a formal definition of resilience and which will ultimately be a guiding light for the sector. Dovetailing these two definitions together will give them the greatest chance of continual use.[2]

This preferred definition of resilience includes a number of important features.

2.2.1.1 Focuses on outcomes of systems

Much of the literature examined focused on the ability of individual assets to withstand disruption, hence resilience is often thought of as an 'asset management' exercise – infrastructure resilience. While the need to consider how best to manage assets to minimise disruption, it is important not to forget that assets often only exist:

- to provide services to a community
- as part of a wider system.

It is the 'system' concept, often encompassing a complex interrelationship between infrastructure, governments, businesses and communities, which is the focus of the definition.

Consider, for example, the Manawatu region's resilience to the landslip in the Manawatu Gorge in 2011. While the Manawatu Gorge was closed for the best part of a year (ie the infrastructure was not robust (enough) to prevent disruption) the region did not strictly lack resilience because this asset failed in isolation. It demonstrated that users of transport infrastructure could still access many (if not all) of the services, albeit with significant delays and inconvenience (adapted from Imran et al 2014).

Users could do this because of the system-wide response including: the response of transport officials to begin clearing debris and repairing the road; the communication and preparation of an alternative connection; the response of the public and businesses to maintain social connectedness to adjoining regions by using alternative routes, and so on.

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[2] We note that many of the concepts we discuss in this paper are consistent with those being considered through MCDEM's work.

This example reinforces the need to think holistically about the ability of a system (and not just the transport system) to withstand disruption – rather than a binary consideration of just one component.

The concept of a spectrum of resilience (where users can still access services albeit at reduced levels) forms a good lead-in to the discussion of 'tolerance' later in this chapter.

Confirmed concepts of 'resist', 'absorb', 'recover', 'adapt' as important components of resilience.

There are numerous ways in which resilience can be gained across a wide spectrum of activity. The concepts of resist, absorb, recover and adapt are, however, the most universally recognised from our literature review and appear to be the most appropriate for a definition of resilience as they span the lifecycle from pre-event to post-event. This is the key concept the definition is trying to convey – that resilience can be gained in a number of different ways over a number of different time-periods.

These concepts align quite closely with the 'resilience principles' discussed in Hughes and Healy (2014), including:

- MCDEM employs the '4 R's' which are reduction, readiness, response and recovery. While these overlap, they are more applicable to the field of emergency management and the cycle before, during and after an event than to a specific resilience assessment.
- Bruneau et al (2003) determined four principles: robustness, redundancy, resourcefulness and rapidity. The US National Infrastructure Advisory Committee has also contemplated including the principle of 'adaptability' in incident response planning (NIAC 2015).

In addition to being prominent in the definition of resilience, these concepts, and others which will be discussed later, have all explicitly helped form the basis of resilience measure definitions (robustness, redundancy, recovery and governance and leadership). While there is a clear linkage between the resilience measures and concepts of resist, absorb, recover and adapt to, they exist to serve different purposes. Where resilience measures are designed to aggregate controls on a like-for-like basis (ie outputs) the concepts covered in the definition above are the 'outcomes' from greater resilience.

Remains agnostic to disruption source and so confirms that resilience is not restricted to natural hazards

New Zealand is a seismically and climatically unique country and there is a wealth of knowledge on natural hazards. This body of knowledge has been further progressed on the back of some high-profile events, most notably the Canterbury earthquake sequence.

However, we argue that resilience to organisational challenges is equally important. This view has been informed by an evolving body of literature, including by resilient organisations and others, on the impacts that breakdowns in the following three areas can have on the ability of systems to perform:

1. Leadership and culture: The potential failure of leadership, staff engagement, decision making, situational awareness, innovation and creativity, and communication within and between relevant firms and organisations.
2. Networks and relationships: The potential failure to break silos, leverage knowledge, partner effectively, utilise internal resources.
3. Change-ready: The potential failure of planning strategies, unity of purpose, proactive attitudes and approaches, stress testing plans, innovation and creativity.

This consideration of natural hazards and organisational challenges being equal implies an agnosticism towards disruption. That is, it is 'disruption' that we care about – and less how it occurs.

Remaining agnostic to disruption can, however, present some problems. For example, consider a partial shut-down of a highway lane owing to rockfall and how it will inevitably create congestion. Why is this congestion different from general congestion, congestion from demographic and land use planning changes or congestion resulting from a truck crash? Should we consider such events in the definition of resilience?

While debatable, we argue that a broad definition of disruption is valid. If a transport system cannot cope with increased pressure resulting from land-use change for example, then it is also less able to cope with disruption from other more exogenous sources of disruption such as flooding. It is this user-centric approach that flows though into the consideration of community tolerance.

Guidance notes supporting the Decision Support Tool explicitly include consideration of natural hazards as well as system-wide or organisational challenges through the ‘challenge matrix’.

Provides for a spectrum of stresses and shocks

Similar to the point above, New Zealand has a long history in reporting on, and attempting to manage, shocks to the transport system (often resulting from natural hazards). However, we believe there is an under-representation in the literature of longer run and accumulative disruptions (stresses). These are harder to account for because of the time horizons at play and the uncertain nature of these events.

We note a number of organisations, including the National Infrastructure Unit, are advocating strongly for a wider recognition of the sources of disruption and ‘shifting beyond a narrow focus on shock events’ (National Infrastructure Unit 2015).

We do not necessarily advocate for a greater focus on shocks or stresses – as both have important impacts on a system – but simply acknowledge (the growing need for) recognition of both pressures.

Additional citations where stresses were explicitly noted include:

- Gordon (2015) *Transport and resilient cities: a review of current developments*.
- Hughes and Healy (2014) *Measuring the resilience of transport infrastructure.*
- NZ Transport Agency (2014) *State highway network resilience national programme business case: delivering state highway resilience*.

Guidance notes supporting the Decision Support Tool explicitly include consideration of shocks and stresses through the challenge matrix.

Deliberately focuses on community ‘tolerance’

Arguably the most critical finding of the literature review was that resilience should be put in the context of the communities who would feel the disruption.

Our scan of the literature suggested community tolerance to outages and disruption is often present in resilience thinking, but is not always at the forefront. This is not to say it does not exist, but rather a much greater focus is needed.

Several useful contributions that have helped shape thinking and helped inform elements of the Decision Support Tool include:

- Bruneau et al (2003) refer to the ‘quality of infrastructure for a community sitting between 100% and 0%’, ie contemplated a scalable assessment of community dependence on assets. Scalable community tolerance to outage, and community tolerance towards restoration times, is something we have explicitly pursued in this research.

- NZ Transport Agency (2014) *State highway network resilience national programme business case: delivering state highway resilience* explicitly refers to 'understanding the vulnerability of communities to disruption.

At its core, infrastructure exists to provide services to communities. If these services are disrupted by any means, then communities miss out. It is these communities that should have a strong(er) say in how resilient they want to be to disruption.

Similarly, it is important 'investors' in infrastructure resilience are also explicitly included within any 'community' discussions. Those parties with the ability to improve resilience outcomes should be explicitly linked to the communities that will benefit from these investments.

Ultimately, by allowing the resilience of the system to be placed in the context of the community's value of the function of the system, we believe better outcomes will be achieved more often.

It is recognised the definition of community is important – as there will be both users and non-users of transport systems that will benefit from resilience improvements in a given asset/network. Moreover, there will not always be (in fact, it can be expected there would not be) a single community voice. Decision makers will ultimately have to exercise a level of judgement in balancing a range of 'sub-community' views (businesses, residents, etc). By eliciting these views explicitly, decision makers do have the best chance of achieving a consensus view.

Takes a wide view of value

Value is not just about direct economic costs and benefits. There is a whole range of social, environmental and cultural 'values' that need to be observed. In some instances these values will be discrete, in some instances they will be complementary and in other instances they will be in conflict.

The NZ Treasury's Living Standards Framework provides a clear central government mandate to consider the wider impacts of public policy across a range of dimensions. Our research focused on the common economic, social, cultural and environmental dimensions – because that is what is present through existing New Zealand legislation (such as the Resource Management Act 1991), although we acknowledge there are considerably more definitions of value.

Being able to assess these values consistently – likely on a monetised/economic basis – is important, and is often the handbrake to further utilisation of these values. We considered the ability to measure resilience on a like-for-like basis to be a highly relevant objective for this research (as considered in the Decision Support Tool and the discussion of consequence, indirect cost and indirect benefits in chapter 3 of this report.

In addition to the impact on different values, we observed investments in infrastructure to improve resilience can often spark wider benefits (economic or otherwise), otherwise known as co-benefits, that are often not accounted for. For example, improving the robustness of the sea wall to combat storm surges could have material benefits for the cycling community by providing a safer and stronger cycling link between two nodes.

This synergy is a two-way relationship, ie investments in other areas can bring resilience improvements. Investments can also result in disbenefits for existing users which should either act as a moderation to consideration of wider benefits or be included as an indirect cost.

We have looked to capture the wider costs and benefits of investments/decisions explicitly in the Decision Support Tool.

2.2.2 Resilience measures

Resilience measures are the periodic table of 'resilience'. They categorise resilience controls and collectively add up to the whole. Functionally, these resilience measures help us aggregate controls, communicate resilience to a broader audience and provide some broad guidance to order thinking.

Crucially for this project, resilience measures also need to act as differentiators for potential investments. For example, *collaboration* as a concept is inherent in every potential investment to improve resilience. Therefore, while it is a vitally important concept in resilience, it does not strictly pass our test for a resilience measure.

Resilience measures (albeit under different guises) are widely cited, with almost every piece of literature we reviewed containing reference to one of the four proposed resilience measures. Of the more than 100 pieces of literature cited, Hughes and Healy (2014) and Hyder Consulting (2009) held the most comprehensive consideration of resilience measures (albeit 'resilience measures' were described as 'principles' in Hughes and Healy 2014). Table 2.1 highlights the 15 resilience measures which were commonly cited in the literature, a brief description of them and our assessment of their appropriateness for this engagements taxonomy. What was not clear, was whether this comprehensiveness is helpful in practice.

In considering the merit of including these 15 concepts in the definitions of resilience measures, we took into account that the taxonomy needed to be communicable to a wide audience and simple enough for non-technical experts to use. Accordingly, we decided to aggregate up these concepts into four simple resilience measures that largely align with the definition of resilience noted above, namely:

- robustness
- redundancy
- recovery
- leadership and culture.

In many instances, the 15 concepts fit within one of these resilience measure definitions, but in some selected cases, we have disregarded them entirely as they were considered to not strictly help us prioritise resilience investments, or were so ubiquitous and important to resilient conversations they were present across all resilience measures.

A brief description of each concept of resilience, and how it has been translated in the taxonomy, is captured in table 2.1. It is worth noting all these concepts have been heavily cited in other literature.

Table 2.1 Resilience measures commonly cited in the literature and their appropriateness

Resilience measure	Relevant literature description	Appropriateness for taxonomy
Robustness	Strength, or the ability of elements, systems and other units of analysis, to withstand a given level of stress or demand without suffering degradation or loss of function (Bruneau et al 2003).	A fundamental response measure.
Redundancy	The extent to which elements, systems, or other infrastructure units exist that are substitutable, ie capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality (Bruneau et al 2003). The transport system contains a number of functionally similar components which can serve	A fundamental response measure.

Resilience measure	Relevant literature description	Appropriateness for taxonomy
	the same purpose and hence the system does not fail when one component fails (for example, a number of similar routes are available with spare capacity) (Hyder Consulting 2009).	
Safe to fail	The extent to which innovative design approaches are developed, allowing (where relevant) controlled, planned failure during unpredicted conditions, recognising that the possibility of failure can never be eliminated. This may involve new approaches to design, to complement traditional, incremental risk-based design (Park et al 2011).	This is a part of robustness. The ability of an existing design to resist or absorb a disruption. An asset being safe to fail is also presumably something that is governed through legislation (for example through design standards).
Change readiness	Resilient organisations contemplate change readiness as 'The ability to sense and anticipate hazards, identify problems and failures, and to develop a forewarning of disruption threats and their effects through sourcing a diversity of views, increasing alertness, and understanding social vulnerability. This concept is also considered to involve the ability to adapt (either via redesign or planning) and learn from the success or failure of previous adaptive strategies (Park et al 2011).	An inherent part of all resilience measures – systems, and the services provided to users, will always evolve and so ensuring 'change readiness' is part of redundancy, robustness, recovery and governance and leadership
Networks	The ability to establish relationships, mutual aid arrangements and regulatory partnerships, understand interconnectedness and vulnerabilities across all aspects of supply chains and distribution networks, and; promote open communication and mitigation of internal/external silos (Resilient Organisations 2012).	The need for a wide range of networks to engage with when considering any resilient investments (for example the Transport Agency and local civil defence groups) is an inherent part of any discussion about resilience. Including a bespoke resilience measure on 'networks' will not help us differentiate between the appropriateness of one control over another. This concept is captured within leadership and governance.
Leadership and culture	The ability to develop an organisational mind-set/culture of enthusiasm for challenges, agility, flexibility, adaptive capacity, innovation and taking opportunity (Resilient Organisations 2012).	A fundamental response measure.
Diversity	The transport system contains a number of functionally different components in order to protect the system against various threats (for example, alternative modes of transport are available) (Hyder Consulting 2009).	This is functionally the same as 'redundancy'. We preferred redundancy because it does not imply a need for different or diverse approaches, rather, redundancy provides for functionally similar service options as well as diverse options.
Environmental efficiency	A transport system that is environmentally efficient will be more sustainable, and capacity is less likely to be constrained due to environmental reasons.	A concept that is explicitly captured as part of the Decision Support Tool – we have included

Resilience measure	Relevant literature description	Appropriateness for taxonomy
	(Hyder Consulting 2009).	measures of environmental efficiency in the consequence matrix, indirect costs and benefits – but is not strictly a resilience measure. It is possible to be environmentally efficient and have low levels of resilience.
Autonomy	The components of the transport system can operate independently so the failure of one component does not cause others to fail (for example, can the transport system operate safely in the event of a power cut?) (Hyder Consulting 2009).	Not strictly a resilience measure – greater levels of autonomy can enhance or reduce resilience depending on the circumstance. For example, minimising interdependencies can increase autonomy but may not guarantee resilience.
Strength	The transport system's ability to withstand an incident (for example, how extreme a flood event can the system cope with?) (Hyder Consulting 2009).	'Strength' can be captured as part of robustness.
Collaboration	Information and resources are shared among components and/or stakeholders (for example, contingency plans in the event of an emergency and the ability to communicate with system users) (Hyder Consulting 2009).	The need for collaboration between affected parties (for example the Transport Agency and local civil defence groups) is inherent in any discussion about resilience. Including a resilience measure for 'collaboration' will not help us differentiate between the appropriateness of one control over another.
Mobility	Travellers can reach their chosen destinations at an acceptable level of service (Hyder Consulting 2009).	We argue that mobility is captured as part of robustness, redundancy, recovery and governance and leadership. If users can reach their chosen destination despite disruption, then this mobility could potentially accrue to any resilience measure.
Safety	The transport system does not harm its users or expose them, unduly, to hazards (Hyder Consulting 2009).	Meeting safety standards is a legislative requirement. However, we consider safety provisions are predominantly captured as part of robustness.
Recovery	The transport system has the ability to recover quickly to an acceptable level of service with minimal outside assistance after an incident occurs (Hyder Consulting 2009).	A fundamental response measure.
Adaptability	Can the transport system adapt to change and does it have the capacity to learn from experience (for example, an area-wide traffic management system can adapt to differing traffic conditions) (Hyder Consulting 2009).	Based on the literature review, the view is that adaptability is part, or an outcome, of robustness. A system is robust when it can adapt to change.

Resilience measure	Relevant literature description	Appropriateness for taxonomy
		It can also be considered as part of recovery. A system can recover in a new way to what it originally was.

A summary of this transposition is provided in table 2.2.

Table 2.2 Summary of consolidated resilience measures

Definition	Source	Assessment
Robustness	Hughes and Healy	Considered a resilience measure
Redundancy	Hughes and Healy	Considered a resilience measure
Safe to fail	Hughes and Healy	Included as part of the robustness measure
Change readiness	Hughes and Healy	N/A – part of all resilience measures
Networks	Hughes and Healy	N/A – part of all resilience measures
Leadership and culture	Hughes and Healy	Considered a resilience measure
Redundancy	Hyder Consulting	Considered a resilience measure
Diversity	Hyder Consulting	Included as part of the redundancy measure
Environmental efficiency	Hyder Consulting	Included in the Decision Support Tool – not a resilience measure
Autonomy	Hyder Consulting	Included as part of the robustness measure
Strength	Hyder Consulting	Included as part of the robustness measure
Collaboration	Hyder Consulting	N/A – part of all resilience measures
Mobility	Hyder Consulting	Included as part of the redundancy measure
Safety	Hyder Consulting	Included as part of the robustness measure
Recovery	Hyder Consulting	Considered a resilience measure
Adaptability	Hyder Consulting	Considered as part of the robustness and recovery measures

Further, we have reconsidered the definitions for each of the four resilience measures, and have provided an example to move the concept beyond abstract and towards pragmatic.

In general, we have looked to provide definitions that are simple enough to be communicated to lay people – but should have enough technical rigour to support our Decision Support Tool. In most instances, this has required a simplification of existing definitions.

2.2.2.1 Robustness

'The ability of systems to withstand disruption and continue to provide to an acceptable level of service'

This definition draws heavily on the ideas presented in Bruneau et al (2003) as noted in other literature sources we drew on in considering the definition of robustness. These included:

- Stevenson et al (2015) *Resilience benchmarking and monitoring review.*
- NZ Transport Agency (2014) *State highway network resilience national programme business case: delivering state highway resilience.*
- Reggiani et al (2015) *Transport resilience and vulnerability: the role of connectivity.*
- Bocchini et al (2014) *Resilience and sustainability of civil infrastructure toward a unified approach.*

This definition of robustness primarily attempts to capture the proactive prevention of disruption and in the process effectively captures the ‘resist’ and ‘absorb’ concepts from the resilience definition. In addition, this definition includes important elements of:

- Well-conceived, constructed and managed systems: Explicitly acknowledges that a system-wide response to disruption is typically needed.
- Anticipates failure: Actively considers where the stress points in a system might be and where future points of failure might lie.
- Acceptable level of service: Allows for resilience measures to include the option of returning a partial function of an asset/system within a certain time period based on tolerance of communities of interest.

Robustness typically implies a structural solution or consideration, although this is not always the case. Robust organisational systems can also improve resilience.

Example

Inland ports are becoming an important to step in the aggregation of freight for export, and there is particular reliance on the Timaru/Lyttelton link for the Port of Lyttelton.

Primary outcome(s): Provision of cost-effective bulk transport from freight services via rail from Timaru to Port of Lyttelton

Options to create a robust system:

- Structural: additional drainage and bunding along the line to withstand more intense rainfall events
- Organisational: development and implementation (including audit) of a maintenance regime of a frequency that ensures the line can function in marginal temperatures.

2.2.2.2 Redundancy

‘Provision of functionally similar outcomes, to an acceptable standard, during lost or degraded levels of service’

This definition draws inspiration from both Bruneau et al (2003) and Hyder Consulting (2009) as noted in table 2.1. Other definitions we considered included:

- Cox et al (2011) Transportation security and the role of resilience: a foundation for operational metrics. *Transport Policy 18, no.2: 307–317*.
- Stevenson et al (2015) *Resilience benchmarking and monitoring review*.
- NZ Transport Agency (2014) *State highway network resilience national programme business case: delivering state highway resilience*.
- El Rashidy (2014) *The resilience of road transport networks redundancy, vulnerability and mobility characteristics.*

This definition of redundancy attempts to capture the real-time and post-event management of disruption and in the process effectively fills the void between ‘absorb’ and ‘recover from’ as noted in the resilience definition.

This definition incudes important elements of:

- Function: Decision makers need to be fully aware of the function of the asset in question. What services does a system enable? How important are these services?
- Outcomes: Decision makers should be aware of the outcomes they are trying to provide for – not just focusing on the maintenance of existing assets or provision of new assets.
- Acceptable standards: Understanding the threshold of community acceptability is paramount.

Redundancy options typically evoke structural solutions, such as alternative roads, but we want to stress the importance of considering solutions that serve the same functional purpose, regardless of whether it is structurally the same – for example, IT solutions.

Example

Based on consultation with the local community, it was determined that one bridge predominately provided access to a rural school the community relied upon.

Primary outcome(s): Student participation in class.

Options to create redundancy:

- Development of an additional route (bridge) to the school
- Provision of tablets to students to allow them to work from home
- Arrangement with the local hall to provide alternative accommodation should the bridge fail.

2.2.2.3 Recovery

'The ability to restore an acceptable level of service after disruption'

This definition of recovery draws from Hyder (2009) as noted in table 2.1, but also benefited from consideration of definitions of recovery in:

- Bruneau et al (2003) *A framework to quantitatively assess and enhance the seismic resilience of communities.*
- Cox et al (2011) *Transportation security and the role of resilience: a foundation for operational metrics*.
- D'Lima and Medda (2015) *A new measure of resilience: an application to the London Underground.*
- Pant (2012) *Transportation network resiliency*.

The definition of recovery attempts to capture the real-time and post-event management of disruption and in the process effectively 'recover from' and 'adapt to' as noted in the resilience definition.

This definition of recovery includes important elements of:

- Acceptability: Decision makers need to be fully aware of the acceptability of a loss of service for the asset in question.
- Service: Decision makers should be aware of the service (outcomes) they are trying to provide for – not just focusing on the maintenance or provision of new assets.
- Ability: Restoration of service must be within the bounds of control of decision makers.

Recovery solutions are typically supported by strong processes, robust and wide-ranging networks and good foresight about the likely effects that may be felt.

Example

A landslide occurs on SH3 near Manawatu Gorge entrance.

Primary outcome(s): Restore one lane to full operation within one day – as this will have marginal costs for freight, business and the community. It has been determined that more than one day creates unacceptably high costs and risks for freight delivery and the affected community.

Options to improve recovery:

- Prior consultation with a community about the acceptable levels of outage on the asset
- Prior discussions with contracting companies – who have geographically diverse access to any disruption – to ensure that service can be restored regardless of where a landslide might take place
- Development or update of emergency response plans which can include details such as feasible traffic diversions.

2.2.2.4 Leadership and governance

'The ability to develop an organisational mind-set/culture of enthusiasm for challenges, agility, flexibility, adaptive capacity, innovation and taking opportunity'

This definition of leadership and governance has borrowed significantly from Resilient Organisations (2012). Other supporting definitions are cited in:

- Gillooly (2015) *Ensuring community resilience.*
- Bruneau et al (2003) *A framework to quantitatively assess and enhance the seismic resilience of communities.*
- National Infrastructure Unit (2015) *The thirty year New Zealand infrastructure plan.*
- Hughes and Healy (2014) *Measuring the resilience of transport infrastructure.*

The definition of leadership and governance covers all aspects of the disruption lifecycle as mentioned in the resilience definition – 'resist', 'absorb', 'recover from', 'adapt to'. Specific characteristics include:

- Leadership actively creates and supports the culture.
- Forward looking: The ability to identify, prioritise and address problems (also termed resourcefulness or situational awareness).
- Development of organisational structures that have well-established emergency response plans to manage disruption.
- Responsive: Capacity building to aid recovery and restoration (also termed rapidity).

Example

The Haast/Jackson Bay Road has overtopped more frequently in the last five years than the previous 20-years. The road is the only link between Haast and the small communities to the south.

Primary outcome(s): Provision of a route to transport goods and fuel south of Haast.

Options to support resilience from a governance perspective:

- Structural: Encourage innovation within the engineering community to develop a surface that is less affected by brackish water.

- Network operator: Work collaboratively with subject matter experts to better understand the perceived increased frequency of events in the context of a changing climate to inform a response.
- Community: Formalise current approaches to fuel and goods storage so the community is not disrupted by overtopping events.

2.2.3 Glossary

In addition to both the definition of resilience, and the concept of resilience measures, is a supporting case of more general terms that we have captured in a glossary (see appendix A).

As a general rule, we have looked to leverage international best-practice in defining many of these terms, but have also supplemented this knowledge through discussions with the Steering Group, peer reviewers and other stakeholders.

3 Decision Support Tool

The second major limb of the research was to 'establish a consistent approach to transport resilience valuation and responses'.

In undertaking the preliminary literature review and, in seeking to understand how resilience investments are currently valued and prioritised, we were confronted by a constantly evolving wealth of well-researched, well-reasoned, contributions to the resilience body of literature. This is particularly strong in New Zealand (presumably given New Zealand's exposure to natural hazards and geographic isolation) and includes discussions of valuation and responses.

However, despite this wealth of information, we could not find a tool, or a framework, that could pull all this information together. We therefore saw an opportunity to utilise the knowledge built up through the literature review, and develop something practical that could be used by the network operator and other infrastructure decision makers.

We collaboratively agreed to develop an updatable Decision Support Tool to consistently weigh up different controls and to create an acceptable level of resilience in (transport) infrastructure – in a way that would achieve desired community outcomes.

3.1 Design rationale

3.1.1 Key design principles

Key design principles are noted below:

- Practical: Previous research on resilience was conceptually strong, but did not provide a practical solution. Accordingly, we focused on producing a tool that could be immediately integrated into existing processes.
- Leverages existing work: The Decision Support Tool is built on an explicit acknowledgement there is a multitude of high-quality work and research being undertaken into resilience and this knowledge base will continue to grow over time. Therefore, an explicit incorporation of the 'state of the art' allows for maturity and progression of inputs (effort) over time.
- Outcomes focused: The Decision Support Tool puts the function of an asset (or assets) within a system at the heart of decision making and therefore focuses on the consequences of assets not being available to users. In this way, the tool is more concerned about the outcomes of disruption rather than disruption to an asset *per se*.
- Scalable: The Decision Support Tool provides a systematic approach to considering resilience. Although transport focused, it is intended to be scalable to a range of sectors as well as being effective when used in detailed or high-level assessments. In both instances, the usability will be determined (or limited) by the quality of the inputs; the more comprehensive the informational inputs, the more detailed resilience assessments can be.

The Decision Support Tool is designed to support an objective and systematic consideration of resilience costs and benefits. By encouraging the adoption of relevant thinking on resilience, forcing assumptions to be made explicit and providing for a structured and inclusive process, we trust better decisions about resilience will be made more often.

3.1.2 When to use the Decision Support Tool?

Two fundamental questions about the Decision Support Tool were:

- When would the Decision Support Tool be used?
- Who would use it?

The initial view is the Decision Support Tool is most appropriate when considering decisions at the asset or project level. At this stage, the tool appears best placed to narrow down options to solve a particular resilience issue – that is, it can be used to help shape thinking for the strategic/economic business case rather than being used to make final investment decisions (ie at the detailed business case stage).

This reflects the view that this is currently a Decision Support Tool. In time, as ‘case law’[3] improves, integration of data occurs and best practice builds up, we would see this becoming more useful across the wider business case process, with the goal for it to become a decision *making* tool.

In terms of who would be best placed to use the Decision Support Tool, we see value accruing to a number of different stakeholders:

- Asset owners: Network operator staff (or any asset management professionals) who have responsibility for asset performance could use this tool as a way of better understanding the resilience of assets to key challenges, as well as understanding the impact or benefits that different response measures could have to improve resilience.
- Business case practitioners: Network operator staff (or other agency staff) who have responsibility for the progression of business cases for new capital expenditure could use the Decision Support Tool as a way of considering the best investments to improve resilience outcomes.
- Decision makers: Decision makers could use the Decision Support Tool to consistently consider transport decisions that will maximise resilience outcomes (as well as understand other indirect cost and benefits) across the wide portfolio of options they invariably face.

There are several existing resources for Transport Agency staff (such as the One Network Road Classification ((ONRC)), Better Business Case clinics and the Risk Management Framework) and we would see the Decision Support Tool complementing rather than duplicating (or being in conflict with) these processes. This view is reinforced by the fact the Decision Support Tool actively looks to leverage the best available information. Precisely how these information sources can be used is canvassed in the guidance notes (in appendix B) and in the Decision Support Tool itself.

One particular area where the Decision Support Tool could be useful in a Transport Agency context is in supporting the Investment Assessment Framework. The framework uses three factors (strategic fit, effectiveness, and benefit and cost appraisal) to determine how well proposed new activities meet the government’s investment strategy, as demarcated in the Government Policy Statement on Land Transport 2015–2024 (GPS).

The current GPS includes a specific objective around resilience (‘a land transport system that is resilient’) and so the Decision Support Tool could help network operator staff, and other decision makers, further their understanding of, and populate a score for, ‘effectiveness’ for individual projects with a specific resilience

[3] ‘Case law’ in this sense refers to users building up a library of examples of when they have used the tool. Learnings from the utilisation of the tool may inform future utilisation of the tool.

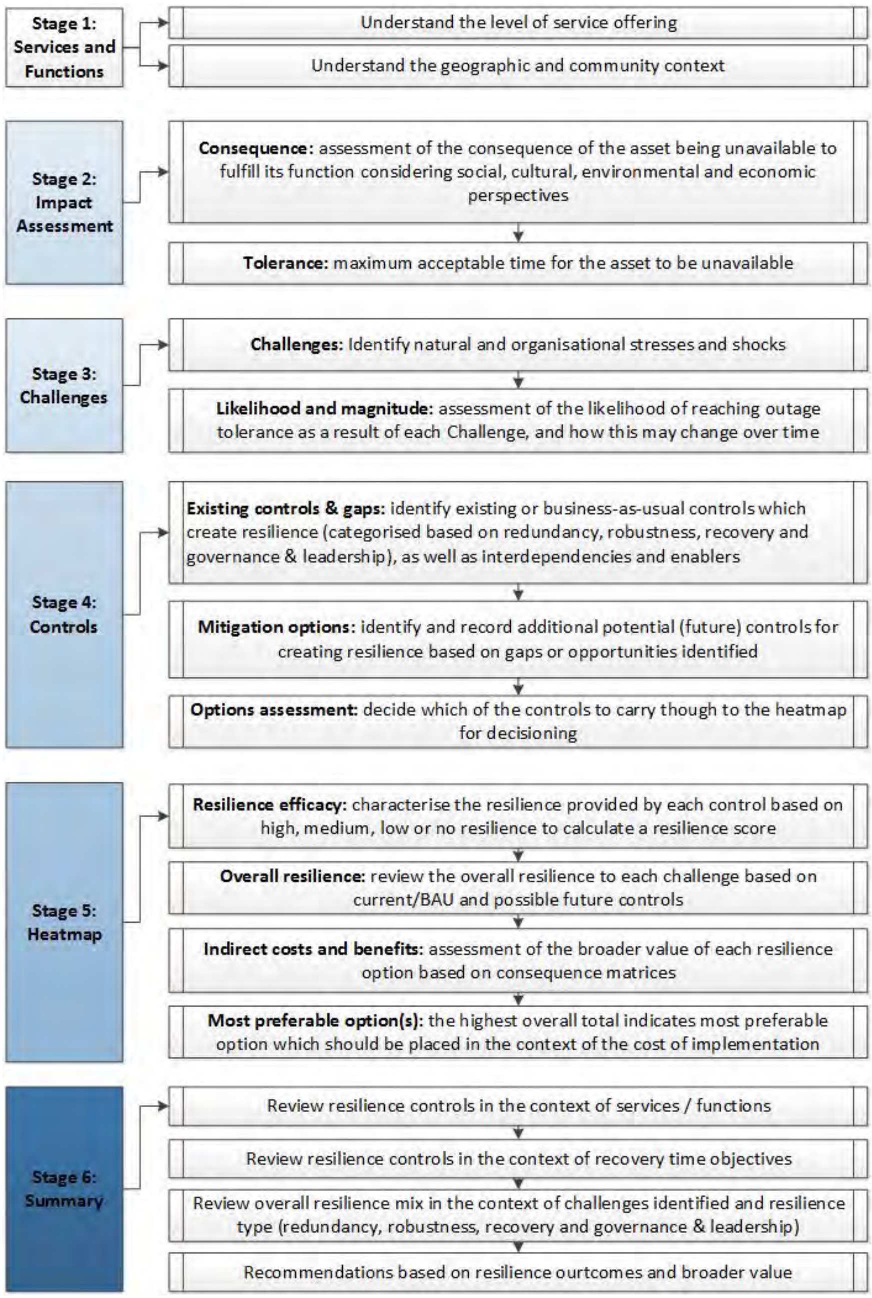
lens. The tool is less relevant for benefit–cost appraisal, owing to its lack of detailed measurement techniques, and strategic fit is almost by definition something best determined by decision makers.

3.2 Structure of the Decision Support Tool

The structure of the Decision Support Tool has been informed by a literature review, professional judgements and feedback from the Steering Group and peer reviewers. In this sense, and distinct from the previous chapter, the remainder of this chapter largely focuses on the key elements of the Decision Support Tool, rather than providing a linear evidential basis for each component.

For presentational purposes, we have grouped the discrete elements of the Decision Support Tool and also discussed their constituent parts. A high-level overview of the tool is provided in figure 3.1.

Figure 3.1 Decision Support Tool



3.2.1 Services and function

Understanding the core function of an asset/system is a critical, and often overlooked, step in decision making. Understanding the services that an asset provides consumers is useful to both understand communities of interest (and hence how to go about understanding tolerance to disruption) as well as to obtain a sense of the types of controls (or responses) that may help improve resilience to disruption. Specifically, a full understanding of the core function of an asset (rather than thinking about the asset *per se*) can help asset owners and decision makers think laterally about alternatives).

The Decision Support Tool acknowledges the function of an asset is always context-specific. Accordingly, it takes a systematic approach to the collection of inputs by asking users a range of questions designed to elicit information that will help determine an asset's function.

Fundamental questions centre on understanding:

- interdependencies
- physical and spatial properties
- approaches to maintenance.

3.2.1.1 Understand interdependencies

'There is a need to increase the sophistication of how we think about resilience, shifting beyond a narrow focus on shock events or infrastructure failure and thinking more about interdependencies…' (National Infrastructure Unit 2015).

The importance of interdependencies cannot be overstated. In an increasingly interconnected world, the function of good infrastructure is more and more reliant on a multitude of different networks. Moreover, the increasing number of activities that come with a growing population mean the importance of good infrastructure provision is increasing.

In a transport context, it is important that users are aware of the transport-centric interdependencies (where a particular asset fits within a wider transport system) and infrastructure-centric interdependencies (which other infrastructure sectors rely on transport assets and *vice versa*). This may help asset owners and decision makers understand (or support existing understanding of) the importance or significance of an asset to a community.

This understanding will supplement more traditional considerations (such as the economic, social, cultural and environmental outcomes provided for, and the role of an asset in an emergency) and will help colour users' considerations of the 'services' an asset provides.

The Decision Support Tool provides pre-populated potential answers for the following (with free text for the user to describe in more detail):

- facilitating personal connections
- access to essential services
- access to leisure activities
- emergency access or other emergency function
- freight movement
- access to other social services
- connector of people to labour markets

- facilitator of tourism
- access to sites of cultural significance
- emergency access or other emergency function.

In reality, transportation assets will provide for a multiple of these different services and it is important to document this at the outset.

3.2.1.2 Understand the physical and spatial properties

Understanding the physical and spatial properties of an asset is in the domain of traditional asset management and we understand that initiates such as the ONRC are looking to systemise this knowledge.

The Decision Support Tool looks to leverage this existing information as much as is possible and in general looks to understand:

- current physical properties of the asset/system (number of lanes/tracks, materials used, maximum load, traffic capacities, technical standards etc)
- geological and geographical properties that surround the asset/system.

Understanding geographic and spatial context is particularly important when considering the challenges that an asset might face.

3.2.1.3 Understanding approaches to maintenance

By being explicit about previous approaches to maintenance (both in terms of expenditure as well as the types of maintenance undertaken) users can understand whether there are patterns of disruption. For example road assets may be maintained under a 'run to fail' approach which results in a large volume of unpredicted major asset maintenance tasks. The pattern present with this approach is that no proactive maintenance tasks are undertaken, which accelerates the deterioration of the road and leads to large unplanned expenditure. Understanding approaches to maintenance also provides an indication about the types of challenges that an asset may face, and some of the controls which may, or may not, have worked in the past.

Appendix B includes guidance notes for the Decision Support Tool. These notes provide more direction about how to gather the necessary information to understand the function of an asset.

3.2.2 Impact assessment

The Decision Support Tool includes two broad components to understanding the impact of disruption:

- understanding the consequences of outage
- understanding community tolerance towards disruption (and measures of resilience).

3.2.2.1 Consequences of outage

The Decision Support Tool intentionally takes a consequence-based approach rather than one that looks at probability weighted risk. It is agnostic to challenge type in the first instance, and the tool simply seeks to build an understanding of the consequences of disruption to communities of interest.

Consequences of disruption are not just an economic consideration. Building on the work of the Treasury Living Standards Framework, and many similar frameworks (particularly wellbeing frameworks as championed by earlier editions of the Local Government Act 2002, the current version of the Resource Management Act 1991 and concepts such as the quadruple bottom line), the Decision Support Tool includes four concepts of value through which the consequence of outage can be measured across four pillars (economic, social, cultural and environmental).

The Decision Support Tool includes a ‘consequence matrix’ worksheet which provides guidance to users about the scale and magnitude of consequences across all four pillars.

While the Decision Support Tool encourages a fairly high-level assessment of consequence across the four pillars (ie users must score on a 1–5 scale) the evidence required to support this score may be considerably more detailed depending on the asset and the nature of the investment. Ultimately the level of analysis should be commensurate with the scale of the investment.

This research project has not sought to catalogue and standardise all the different approaches to determining the consequence of disruption. However, it has provided some guidance about how to collate and synthesise this information (in the guidance notes) and has identified several approaches that could assist users and decision makers to make this assessment. For example, one way users can look to understand the aggregate consequence of disruption is to break down each pillar into categories. The identification of these categories can come from a wide range of sources including existing Transport Agency documentation as well as consultation with communities of interest.

To illustrate this concept, we note the Transport Agency’s *Economic evaluation manual* (EEM) includes a comprehensive list of economic benefits expected to accrue from transport investments as broken down in the left-hand column of table 3.1. Users of the Decision Support Tool could therefore consider utilising these benefits as a starter for the kinds of economic consequences that can accrue if a transport asset is disrupted, and can form the basis of a conversation with communities of interest about the levels of disruption they would face.

Table 3.1 *Economic evaluation manual* benefits

Benefit type	Road	Transport demand management	Transport services	Walking and cycling	Education promotion and marketing	Parking and land use	Private sector financing and road tolling
Travel time cost savings	✓	✓	✓	✓	✓		
Vehicle operating cost savings	✓	✓	✓	✓	✓		
Crash cost savings	✓	✓		✓	✓	✓	
Seal extension benefits	✓						
Driver frustration reduction benefits	✓						
Risk reduction benefits	✓	✓	✓		✓		✓
Vehicle emission reduction benefits	✓					✓	
Other external benefits	✓	✓	✓	✓	✓	✓	✓
Mode change benefits		✓	✓	✓	✓		
Walking and cycling health benefits		✓		✓			
Walking and cycling cost savings		✓		✓	✓		
Transport service user benefits			✓			✓	
Parking user cost savings		✓			✓	✓	
Journey time reliability benefits	✓	✓	✓	✓			
Wider economic benefits	✓		✓				
National strategic factors	✓	✓	✓		✓		

It is conceivable some of these benefits may:

- directly translate to a resilience assessment (for example travel time reliability), or
- require an inverse type assessment (‘travel time savings’ becomes ‘travel disruption time avoided’)

Some of these benefits however, may not be relevant at all (eg seal extension benefits) and so users can exercise judgement about what is most applicable.

As ‘journey time reliability’ is a category that appears to have some level of direct transferability, particularly *ex-ante*, we have focused some attention on the applicability of the measurement techniques delineated in the EEM.

Trip time reliability is measured by the unpredictable variations in journey times, which are experienced for a journey undertaken at broadly the same time every day. The impact is related to the day-to-day variations in traffic congestion. In instances where travel time is disrupted, reliability levels decrease. Therefore, any controls that improve resilience to disruption will have flow-on benefits to travel time reliability, across all resilience measures.

Adapting the EEM, we note journey time reliability includes three broad considerations which are closely aligned with the systematic consideration of resilience proposed in this research and in the Decision Support Tool.

Users could look to leverage the methodology included in the EEM to determine an *ex-ante* journey time reliability measure to help determine the impact a control may have (and hence help determine the level of effectiveness of the control). These considerations, and the supporting elements of the Decision Support Tool where such information may be derived, are outlined in table 3.2.

Table 3.2 EEM travel time reliability comparison

EEM – components of travel time reliability	Decision Support Tool translatability
Travel time value ($/h)	Understand your asset and its function (ie what services it provides and what freight/economic activity it enables). This can be used to form a proxy for a specific travel time value.
Reduction in the network variability (in min)/60	Challenges and impact assessment – understand what the impact of outage or disruption would have on a community of interest.
Traffic volume for time period (veh/h)	Understand your asset and its function (ie what services it provides and what freight/economic activity it enables).

Another element of assessment of travel time reliability identified through our research was the idea of ‘a buffer index’ whereby there is explicit recognition of the buffers that consumers build into their travel patterns to account for travel time variability US Department of Transport (2015). Moreover, we understand that freight companies also have to include a ‘buffer’ into their scheduling. Many of the UK hauliers now work on ‘just in time’ deliveries due to restrictions on access times. A key benefit of improved reliability (partly through better resilience) is the ability to reduce this buffer and save on vehicle fleet numbers and overall operating costs.

Seeking to understand whether this buffer is growing or shrinking, through active engagement with communities of interest, could help understand whether resilience benefits are in fact accruing.

Other important dimensions to the ‘consequence matrix’ include:

- Consequences for essential and non-essential services: In the case of social value, we have also incorporated the concept of essential and non-essential services, with non-essential being access to retail shops and essential services being health and wellbeing services.
- Permanent and temporary consequences: All four concepts of value include an escalating scale that incorporates concepts of permanent and temporary loss of value (for example, economic value encourages users to develop an understanding of the expected levels of permanent loss of economic activity from an asset being unavailable as well as temporary disruption to economic activity).
- Local, regional and national level consequences: All four concepts of value include an escalating spatial scale where, in general, national level effects are considered to be more detrimental than local level effects (for example, cultural value includes a temporary loss of access to sites of cultural value as well as concepts of permanent loss of access to, or sites inherently of, significant national cultural value).

In reality, the determination of whether the consequence is *very low* or *very high* (and everything in between) is subjective and will be a judgement call that is best made in conjunction with relevant stakeholders, in particular the communities of interest. Although some of these judgements may not always be able to be reconciled by all stakeholders, by making assumptions clear and using the most up-to-date information to inform judgements, decision makers give themselves the best chance of success.

3.2.2.2 Community tolerance

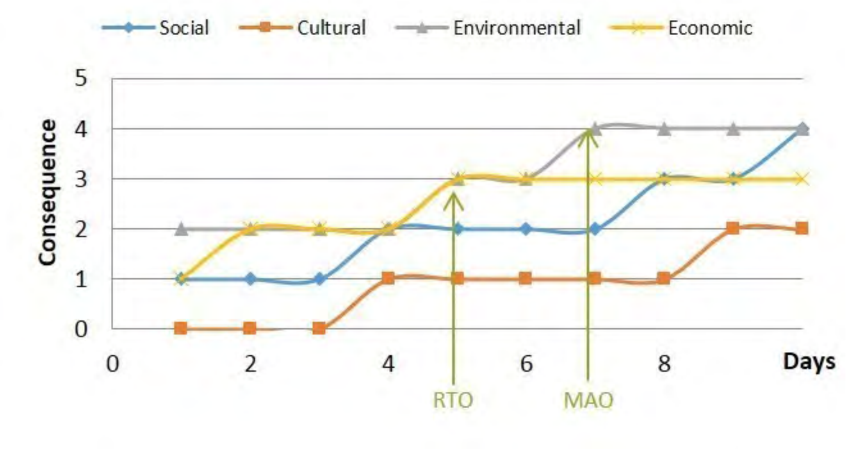
The second part of the impact assessment is the determination of a community's tolerance to outage – the length of time and level of function that communities are willing to have the function taken away from them due to the disruption. Discussions of tolerance also encompass a community's willingness to pay.

Different challenges will (of course) have different effects on the nature and duration of outage, which will in turn have different effects on concepts of value (social, cultural, economic and environmental). Like the consequence assessment, there is also an element of subjectivity inherent in this discussion.

An important feature, and one which is borrowed from business continuity theory, is the idea of a sliding scale of tolerance; specifically maximum acceptable outage (MAO) and recovery time objective (RTO). RTO is the maximum amount of time a community can withstand losing the services an asset provides, and can be thought of as the restoration of service time objective (noting that service may not have to be restored to 100% to meet the RTO). MAO is the time beyond which it is unacceptable to stakeholders for the services an asset provides to be unavailable, and can be considered the point beyond which it is extremely difficult to recover from, or beyond which there is significant threat to life, community and/or the economy.

What the impact assessment phase helps to do is make assumptions transparent from each of the four pillars represented in figure 3.2. In this sense, it can be considered both a specific input into the Decision Support Tool, as well as an important communication mechanism for engagement with affected communities (and presentation to decision makers).

Figure 3.2 Stylised assessment of community tolerance to outage



Decision makers and communities will also have options about what 'reduced levels of service' may look like for any disruption event. For example, does a 50% reduction in service consist of one lane open on a two-lane highway or is it both lanes open for 12 hours a day?

The Decision Support Tool guidance notes (appendix B) provide more direction about how to gather the necessary information to make informed impact assessments.

3.2.3 Challenges

Fully understanding the challenges facing transport assets and systems means consistently better decisions can be made about investment and resilience. If you do not know what challenges your asset faces, you cannot determine what you need to be resilient to.

We propose the utilisation of a challenge matrix to help inform comprehensive thinking and the removal of inherent biases on the challenges that an asset/system may face. The concept of a challenge matrix effectively systemises thinking and exploration by placing challenges within a scalable framework (spanning stresses to shocks and natural to systemic/organisational). We also propose to incorporate concepts of likelihood and short, medium and long timeframes into this phase.

3.2.3.1 Challenge identification

The challenge matrix is a four-quadrant system that enables stakeholders to identify and categorise the possible challenges to an asset in a visual manner. The challenge matrix enables challenges to be segmented into categories based on whether a challenge is 'human-made' (organisational/systemic) or created by the forces of nature (natural). Challenges can then be divided even further based on their exposure time; those with short exposure times are categorised as shocks whereas those with a longer exposure times are considered stresses.

We have identified these specified categories may not be sufficient for all scenarios as some challenges may sit in between multiple categories. Each axis can therefore be thought of as a continuum – stress through to shock and natural through to organisational/systematic challenges.

A conceptual example of the challenge matrix is provided in figure 3.3.

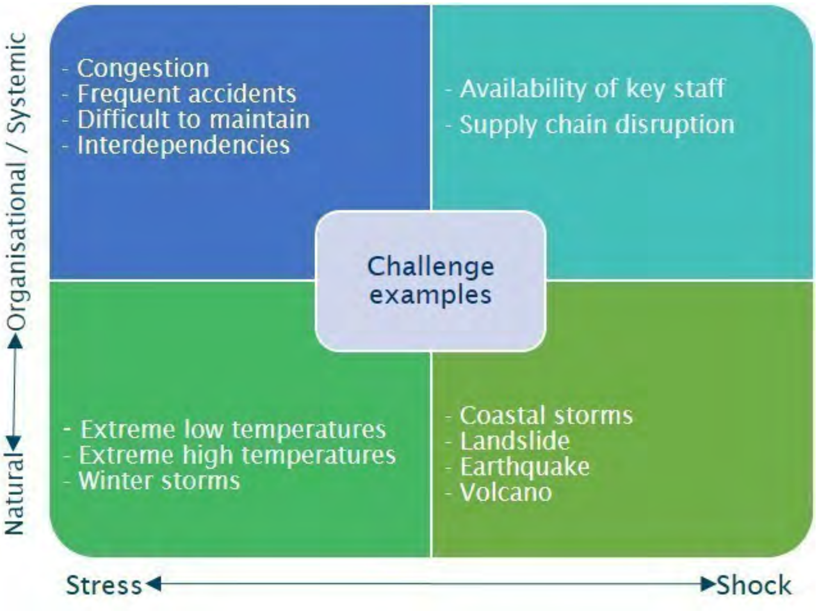


Figure 3.3 Challenge matrix example

Using the challenge matrix will build an initial understanding of the 'universe of challenges' that could affect the function provided by an asset/system. The major benefit of the matrix is that it puts a systemic framework around thinking to enable all types of challenges to be considered.

The challenge matrix can also be used as a communication tool with affected communities and the beginning point for identifying and categorising what other challenges they think they could be exposed to.

Another important consideration for challenges is the link between cause and effect. For example, while a volcano is something that would widely be considered a cause of risk/threat/challenge, the actual effect of a volcano is lava flow, ash clouds, landslide and so on.

While we appreciate it is important to distinguish cause and effect, and we agree effects are what matter most for an asset, we do not think that ignoring obvious threats (or causes) helps to be comprehensive about challenges to an asset. It also does not help us catalogue challenges – as in some high-profile instances (such as volcanoes and earthquakes) there is a significant literature and science dedicated to understanding likelihood and risk of these causes. Leveraging this wealth of information is an important component of the Decision Support Tool.

3.2.3.2 Likelihood

Likelihood is considered to be the probability of an event occurring, and so forms an integral part to understanding the extent to which time and resources should be spent on controls. As a general rule of thumb the more likely a challenge is expected to happen the more of a priority it is, hence more time and resources should be devoted to mitigating or dealing to that challenge.

The problem is that likelihood of a certain challenge presenting and enforcing itself on the asset is a commonly debated topic and a subjective issue. It is not this research report's intention to develop a fully comprehensive list of likelihoods for the infinite number of challenges or assets. Rather, the Decision Support Tool accepts there is a wealth of knowledge available on a wide array of challenges, and hence looks to include links to databases, certified websites and academic information that can provide more in-depth guidance for qualifying likelihood.

We expect (should this tool be used by network operator staff) these links will be continually and periodically updated to enable knowledge transfer over time.

We have, however, provided a simplified way of considering likelihood in the Decision Support Tool. We have provided an assessment of whether a challenge is likely to present itself in the short, medium or long term. This likelihood assessment is not of the event occurring *per se*, but rather, the event occurring to a magnitude that is consistent with the level of consequence identified in the impact assessment (step 2). An assessment of these likelihood ratings is provided in figure 3.4. These assessments should not be read literally as periodically expecting disruption in the timeframes discussed, ie just because an event is deemed to be a medium likelihood does not strictly mean it will occur every 3–10 years.

Figure 3.4 Challenge likelihood

	Rare	Low	Medium	High	Very High
Challenge Likelihood	Challenge may occur in exceptional circumstances	Challenge may occur in the next 10-30 years	Challenge may occur in the next 3-10 years	Challenge may occur in the next 1-3 years	Challenge can be expected in the next 12 months
	<1%	1-9%	10-19%	20-50%	>50%

The combination of challenge, consequence and likelihood therefore forms an automated assessment of the priority. An example of how challenges are prioritised is provided in figure 3.5. Challenges characterised as urgent, high and moderate are automatically carried through to the next steps where resilience controls are considered, so users focus their effort on the challenges that are most important.

Figure 3.5 Challenge priority

	Low	Moderate	High	Urgent
Challenge Priority	Challenge is not a priority for control measures	Challenge requires monitoring and potentially control	Challenge requires evaluation and control measure(s)	Challenge requires control measure(s)

The Decision Support Tool guidance notes (appendix B) provide more direction about how to gather the necessary information to make judgements about challenges.

3.2.4 Resilience controls

Resilience controls (controls) are the various interventions that exist to mitigate against challenges. Controls can include traditional transport-centric responses (such as construction of retaining walls to prevent rock fall, response plans including route diversion for disruption events, internal process to manage regular maintenance of assets) but can also include options that are not traditionally included as part of transport planning (such as communication approaches to enable telecommuting).

This broad focus on controls is entirely in keeping with current policy and protocol, as demarcated in the EEM, where users are encouraged to think about transport-centric solutions as well as non-transport ones.

> *Alternatives considered can include non-transport solutions or determining if the problem is tangible or significant enough to progress for consideration.* (EEM, chapter 2-4)

The Decision Support Tool makes a clear distinction between those controls that are existing (including for a legislative/insurance requirement, or emergency response plans to maintain business continuity) from those controls that are potential – and in effect form the basis for the prioritisation of future investment responses. This distinction is displayed in the tool with those 'above the line' (current or required) from those 'below the line' (future). In this sense, existing controls are identified collectively and must be made explicit. Future controls can then be isolated and assessed in a way that enables prioritisation.

There are an infinite number of potential controls and an equally inordinate number of scenarios that can be devised. The Decision Support Tool does not try to narrow down lateral thinking about specific controls, although it does provide some guidance about the spheres within which controls can exist. In particular, the tool systematically prompts thinking across a matrix of dimensions: resilience measures (robustness, redundancy, recovery, leadership and governance) as well as channels of controls (civil engineering, IT, processes, people).

This systematic linkage creates a system where users and decision makers can see if they are only considering controls linked to 'robustness' for example, and hence prompt thinking about whether there are other controls that provide resilience in different ways. The linkage also provides enough latitude (through free text) to tailor controls to specific situations.

When determining appropriate controls it is also vital the 'owners' of those controls are brought into the process. For example, telecommuting solutions are not under the direct purview of Transport Agency officials and so those responsible for such solutions (private sector providers, Ministry of Business, Innovation and Employment ((MBIE)) etc) must be brought into the decision-making process to ensure the control is characterised appropriately, is able to be implemented and that all the indirect costs/benefits and financial cost assessments are fact based. Involving wider stakeholders early also gives the control the best chance of success (should it be determined a preferred option).

The Decision Support Tool guidance notes (appendix B), provide more direction about how to gather the necessary information to make these assessments.

3.2.5 Assessment

The final assessment is effectively the culmination of the previous stages of work. By preparing the assessment in a systematic format, this phase allows the user to consistently:

- understand existing levels of resilience to challenges
- understand the wider value that different controls can provide
- weigh up different resilience controls by determining a 'value of resilience' for each measure.

3.2.5.1 Understanding existing resilience to challenges

An indication of existing resilience to challenges can be demonstrated by the calculation of the 'resilience score' as demonstrated in figure 3.6. This example is taken from the hypothetical worked example provided in appendix C (this is located at www.nzta.govt.nz/resources/research/reports/614).

This hypothetical example shows the asset in question is currently exposed to a number of challenges (flooding, winter storms, congestion, earthquakes, landslide and interdependencies). Of these, the asset is least resilient to two challenges as indicated by their low score (earthquakes, and landslide). The susceptibility of the asset to these challenges will change over time (ie it is dynamic) and so re-running these assessments periodically may help ensure our understanding of resilience is current.

Figure 3.6 Resilience score – current situation (example)

	9-Jan-17				Challenge	Challenge	Challenge	Challenge	Challenge	Challenge
		Control	Primary Characteristic	Secondary Characteristic	Flooding	Winter storms: snow, ice, hail	Congestion	Earthquake: liquefaction, tsunami, landslide, sinkholes	Landslide	Interdependencies with other assets (operation or maintenance)
☑	Current	Stop banks	Robustness through Civil Engineering		H	L	H	L	L	M
☑	Current	Recovery contracts	Recovery through Processes		M	L	L	L	L	L
☑	Current	Capacity improvements	Robustness through Civil Engineering		L	H	L	L	L	M
☑	Current	Recovery contracts	Recovery through Processes		L	L	L	M	M	L
☐	Future	Communication around working from home	Governance through Information Technology	Recovery through People	H	L	H	L	L	L
☐	Future	Land use change	Governance through People	Robustness through Processes	L	M	L	L	L	L
☐	Future	Cross Valley Link	Redundancy through Civil Engineering		M	H	L	M	L	M
☐	Future	Barge Landing	Redundancy through Civil Engineering		M	L	L	M	M	M
				Existing Resilience Score	7	6	6	5	5	6

Cumulative resilience to each challenge based on resilience measurers selected

By way of demonstration, if we consider the potential for 'communication around working from home' to be employed as a control, figure 3.6 shows the impact of flooding and congestion can be better mitigated. However, the ability of this control to mitigate the challenges the asset is most exposed to (earthquake and landslide) is largely unaffected.

By selecting and deselecting controls, it is possible to weigh up the effects of different controls on different challenges. By enabling a check box approach, it is also possible to layer up multiple controls (should this be desired).

An additional benefit of this approach is that users and decision makers can assess which challenges they are most exposed to, and can accordingly look to prioritise those controls that look to provide the best resilience against the challenges.

Figure 3.7 Resilience score – working from home (example)

	9-Jan-17				Challenge	Challenge	Challenge	Challenge	Challenge	Challenge
		Control	Primary Characteristic	Secondary Characteristic	Flooding	Winter storms: snow, ice, hail	Congestion	Earthquake: liquefaction, tsunami, landslide, sinkholes	Landslide	Interdependencies with other assets (operation or maintenance)
☑	Current	Stop banks	Robustness through Civil Engineering		H	L	H	L	L	M
☑	Current	Recovery contracts	Recovery through Processes		M	L	L	L	L	L
☑	Current	Capacity improvements	Robustness through Civil Engineering		L	H	L	L	L	M
☑	Current	Recovery contracts	Recovery through Processes		L	L	L	M	M	L
☑	Future	Communication around working from home	Governance through Information Technology	Recovery through People	H	L	H	L	L	L
☐	Future	Land use change	Governance through People	Robustness through Processes	L	M	L	L	L	L
☐	Future	Cross Valley Link	Redundancy through Civil Engineering		M	H	L	M	L	M
☐	Future	Barge Landing	Redundancy through Civil Engineering		M	L	L	M	M	M
				Existing Resilience Score	10	7	9	6	6	7

Resilience to folding improved based on additional control

3.2.5.2 Understanding the wider value that different investments/controls provide

Consistently understanding the wider value of resilience is also an important feature of this tool. As noted in section 2.2.1 our assessment of value is not just about direct economic costs and benefits. There is a whole range of social, environmental and cultural 'values' that need to be observed.

In addition to the different direct value created (ie the direct resilience to challenges), we observed investments in infrastructure to improve resilience can often spark wider (economic or otherwise) benefits that are often not accounted for – for example consider the value cyclists could receive should the sea wall along Tamaki Drive be widened. This benefit is not the sole intent of the investment, but is an ancillary or wider social benefit that is obtained. The assessment phase of the Decision Support Tool requires users to explicitly note these expected indirect costs and benefits.

The Decision Support Tool includes indirect economic, social, cultural and environmental values, which are all weighted equally, as are costs and benefits. This is in keeping with the intention of frameworks such as the Living Standards Framework, and also the basis for the four wellbeing models noted in section 3.2.2. Should weightings look to be developed for each of these values (eg a community prioritises cultural values over economic values) then these figures can feasibly be adjusted within the Decision Support Tool.

While weightings of value are currently held constant, *measures* of high, medium or low value (costs or benefits) are all 'value-specific'. Specific criteria have been established for social, economic, cultural and environmental value.

A framework to guide this assessment is provided in the Decision Support Tool and in appendix B. A framework approach, rather than absolute measures or monetary limits, has been developed because these assessments of 'high' 'medium' or 'low' will be subjective. Deference to bespoke studies, existing evidence, as well as input from communities of interest should help guide this assessment.

Much like the consequence matrix, important elements of the framework include:

- *One off benefits vs sustained benefits*: All four pillars include an escalating scale taking into account temporary vs sustained benefits/costs. In the example of the construction of new infrastructure, there can be indirect benefits to a region that accrue from construction (ie the employment and expenditure benefits from the investment).[4] There can also be benefits that will be long standing, such as the benefits to the cycling community from an improved sea-wall in the Tamaki Drive example. Sustained benefits are presumed to be more desirable than one-off ones, with the inverse true for costs. An important caveat is size and magnitude considerations.
- *Local, regional and national level costs/benefits*: All four concepts of value include an escalating spatial scale – where, in general, national level benefits are considered to be more desirable than local level effects (for example, local heritage protection scores 'lower' than a net increase in national habitat) with the inverse being true for costs.

There are a range of approaches to determining the scoring of these indirect costs and benefits, many of which will flow from discussions with communities of interest. However, we note the social return on investment model provides a good starting point for assessing these values consistently.

[4] It is debatable whether construction costs should be included. The normal argument is that from a national economy perspective the benefit is simply transferred from one region to another and so any benefits are displaced. However, for some regions, civil projects may result in meaningful temporary economic activity.

The Decision Support Tool guidance notes (appendix B) provide more direction about how to gather the necessary information to make these assessments.

An example of how this assessment of value is expressed is provided in figure 3.8. In this example, the wider social benefits of the 'Cross Valley Link' control are considered to be substantial as the Petone community gains a heightened level of pedestrian friendly access to the Petone waterfront. These wider benefits must be weighed up against the potentially substantial wider disruptive social costs for other parts of Lower Hutt associated with the new transport link needed for the Cross Valley Link.

	13-Jan-17			Indirect Costs of Control				Indirect Benefits of Control					
		Control	Primary Characteristic	Environment	Social	Cultural	Economic	Environment	Social	Cultural	Economic	Total	Cost of control
☑	Current	Stop banks	Robustness through Civil Engineering	M	L	L	L	M	M	L	M	27	20m
☑	Current	Recovery contracts	Recovery through Processes	L	L	L	L	L	L	L	L	23	$1m
☑	Current	Capacity improvements	Robustness through Civil Engineering	M	M	M	M	L	L	L	M	22	$20-90m
☑	Current	Recovery contracts	Recovery through Processes	L	L	L	L	L	L	L	L	24	$3m
☑	Future	Communication around working from home	Governance through Information Technology	L	L	L	L	L	M	L	M	28	$1m
☐	Future	Land use change	Governance through People	M	M	M	M	L	L	L	L	0	$1m
☑	Future	Cross Valley Link	Redundancy through Civil Engineering	M	H	M	L	L	H	M	M	27	$70m
☐	Future	Barge Landing	Redundancy through Civil Engineering	H	L	M	L	L	L	L	M	0	$100m

Higher overall score indicates a higher preference

Figure 3.8 Wider value of resilience (example)

The conclusion of this assessment is that controls will have been:

- scored in terms of their effectiveness in creating resilience to challenges
- coupled with an assessment of the indirect costs and benefits which accrue when each control is realised.

The combination of scoring against challenges as well as the assessment of indirect costs and benefits derives a 'total resilience value'. This value is presented numerically to aid with prioritisation. The higher the number, the greater value the control provides.

3.2.5.3 Weighing up different resilience controls – determining a 'value for resilience' measure

Once the total resilience value is determined, it can be divided by the indicative financial cost of the control, to develop an indicative 'resilience for money' measure.

The determination of financial costs can be gained from:

- estimates from designers of controls
- considering comparative historical controls.

Provided different controls can be broadly costed on a consistent basis, it is then possible to weigh different controls against each other (as well as potential controls on different transport systems) to understand which provide users and decision makers with the best value for money.

There are potentially some issues around 'gaming' that need to be considered, as proponents of different controls may over inflate the value of each control. We consider this risk is no different from existing business case processes, in that the quality of the supporting information ultimately determines the validity of the conclusions. The value of the Decision Support Tool is that it makes all assumptions clear and transparent, and provides a systematic frame through which to consider all alternatives.

The value of adopting an updatable and systematic approach to measuring and weighing up value is that over time these subjective judgements should hopefully become more objective as 'case law' builds up through the experience of using the tool on a more regular basis.

3.2.6 Summary

The following is a summary of all analysis and assessment done in prior stages of the Decision Support Tool.

The first step in the process is designed to provide users with a check and balance of some of the key components of the tool, namely:

- Do the controls identified enable the core function(s) of the asset to resist, absorb, recover from, or adapt to, disruption?
- Do the controls allow services to be provided within acceptable timeframes?
- Do the controls respond to the challenges facing an asset?

If the answer to these questions is 'yes' then the remainder of this step is used to present all the relevant information in a digestible form – specifically with the intention of aiding decision making and communication options and decisions by the wider public.

Scenario testing can feasibly take place, although at this stage of the Decision Support Tool development, this must be done manually by saving each result and comparing each individual output, due to the limitations of MS Excel.

If the answer to any of these questions is 'no' then it pays to revisit the suite of controls and reconsider alternatives.

3.2.6.1 Understanding the balance of resilience measures

Another feature of the Decision Support Tool summary is the development of a spider diagram which visually depicts the balance of controls being explored in the context of resilience measures. This helps to ensure the user is not considering controls that adhere to one resilience measure too strongly (for instance, all controls might be categorised as improving robustness).

Figure 3.9 Spider diagram (example)

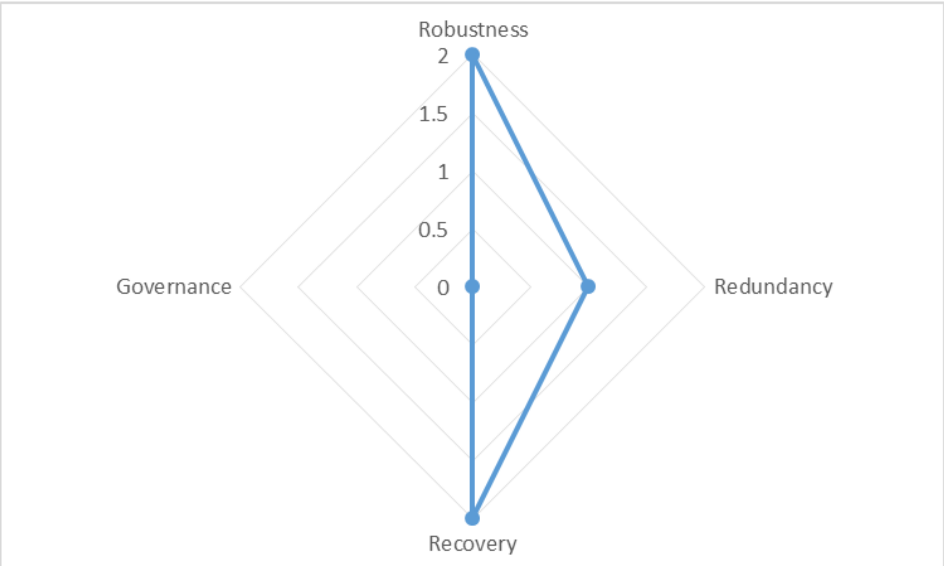


Figure 3.9 demonstrates that of the controls being pursued in this hypothetical example, the user has not considered any leadership and governance alternatives. This might be appropriate for the asset in question, but the procedure acts as a check and balance in the name of transparency.

3.2.6.2 Comparing different packages of controls

At a high level, scenario testing *between investments in different assets* (ie is it best to invest in a robustness measure on asset A vs a redundancy measure on asset B?) can feasibly be done, although at this stage of the Decision Support Tool development, it must be done manually, by completing the full process for each asset (ie separately completing the tool for each asset) and comparing the individual results.

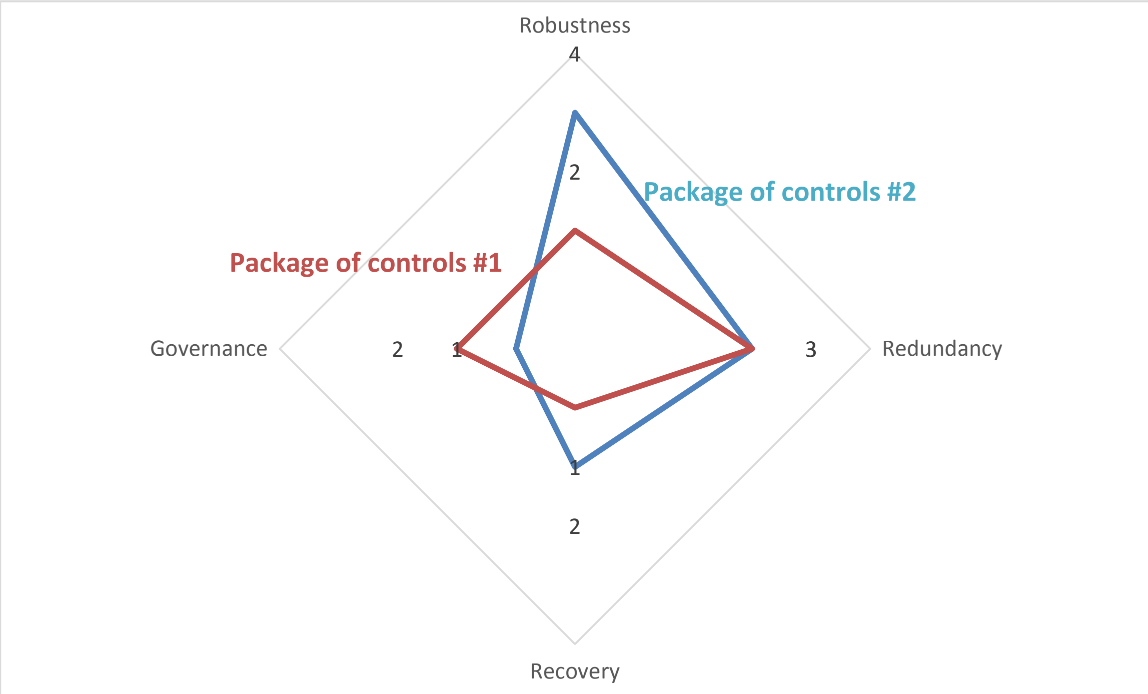
Scenario testing of different packages of controls *within the same asset* is feasible, although it will need to be done manually by checking the relevant boxes for each package of options (as shown in figure 3.10) within a single completion of the Decision Support Tool. Individual results will then need to be manually mapped. An example of this has been presented in the spider diagram as shown in figure 3.11.

If this 'proof of concept' phase progresses towards a full trial, additional functionality (such as an ability to easily compare options, as well as conversion away from MS Excel) is expected to be built into the Decision Support Tool.

Figure 3.10 Check boxes (example)

	6-Dec-16		
		Control	Primary Characteristic
☑	Current	Stop banks	Robustness through Civil Engineering
☑	Current	Recovery contracts	Recovery through Processes
☑	Current	Capacity improvements	Robustness through Civil Engineering
☑	Current	Recovery contracts	Recovery through Processes
☑	Future	Communication around working from home	Governance through Information Technology
☐	Future	Land use change	Governance through People
☑	Future	Cross Valley Link	Redundancy through Civil Engineering
☐	Future	Barge Landing	Redundancy through Civil Engineering

Figure 3.11 Spider diagram (comparison example)



4 Future research areas

The fundamental conclusion of this research is the presentation of a consistent approach to transport resilience; terminology, levels of service, valuation and responses. The scope of the research was expanded to include the development of an updatable Decision Support Tool to consistently weigh up different controls, and to create an acceptable level of resilience in (transport) infrastructure – in a way that achieves desired community outcomes.

Both of these outputs have drawn heavily from the existing body of literature, coupled with our professional judgement, and have been determined collaboratively with a wide group of stakeholders.

However, in developing the Decision Support Tool, we encountered some areas where we believe there were limitations to our analysis, and further research and effort would be warranted. These areas are highlighted in table 4.1.

Table 4.1 Limitations of research and future research areas

Limitations of research	Future research areas
A critical finding of our research is the need to put communities (including the investment community) at the heart of decision making – particularly about tolerance to outage and willingness to pay for resilience improvements. Eliciting this information out of communities, who may not have time to engage in the topic or the necessary technical knowledge, imposes some immediate barriers which have not been detailed in this research.	**Design best practice around community engagement.** Future research could focus on techniques to overcome consultation barriers and enable better information to flow through to decision makers. This research could take the form of a synthesis of effective consultation approaches from the transport sector domestically and in overseas jurisdictions. Consideration also needs to be given to the ability to gain input from communities while managing expectations.
Our research focused on the development of a consistent *approach* to determining transport resilience. It did not, however, explicitly develop *methodologies* to put a monetisable (or otherwise) metric around the *ex-ante* 'value' of resilience.	**Better measurement of direct and indirect costs and benefits:** The development of agreed methodologies to calculate all the elements of direct costs and benefits, as well as the indirect cost and benefit matrices is important. This can be useful for both *ex-ante* investment decision making and *ex-post* assessment. While these concepts of value will be subjective, the integration of established methodologies will help achieve consensus more often. We would recommend the development of a handbook, or a supplement to the EEM, which catalogues a range of these different valuation approaches. For example, consider the benefits that resilience can provide in terms of travel time reliability. Redefining or reconsidering the existing method to calculate travel time reliability may enable resilience improvements to be better reflected. One such theory looks to develop a 'buffer index', whereby there is explicit recognition of the buffers that consumers build into their travel patterns to account for travel time variability. Understanding whether this buffer is growing or shrinking could help understand whether resilience benefits are in fact accruing.[5]

[5] John Spiers, pers comm (2016) 'This is a fundamental area that has to be improved across all aspects of transport appraisal not just resilience. It is very difficult to compare non-quantitative values in the overall appraisal (such as the

Limitations of research	Future research areas
This research report has developed a Decision Support Tool – a framework which we believe will be useful for users and decision makers. However, there is a critical step out of scope from our research that links the theory of the tool and an ability to translate this into practice and socialise it appropriately with users. For example, it is unclear whether the Decision Support Tool will be useful when considering the merits of different detailed design options for road investment. It is also unclear whether the tool will work in concert with other more traditional risk-based tools that currently are employed by the Transport Agency.	**Implementation of tool and development of business rules** [6] It is believed that there are two main Transport Agency-centric activities that could be sequentially undertaken: 1 Further operational testing of the Decision Support Tool within a range of different areas of the network operator (for example those staff responsible for early stage business case assessments, and those staff who are responsible for business as usual asset management decisions) and under a range of different scenarios (for example comparing 'resilience investments' across regions and comparing detailed design parameters). This will help prove that the tool is robust both theoretically and operationally. 2 If this assessment phase is deemed successful, then the completion of a range of operationally focused pieces of work will inevitably give the tool a greater chance of success. These include: a Training: Roll-out of a training programme accompanied by the development of Transport Agency (or other transport centric user group) business rules. This ensures that good practice gets embedded into business decision making. b Support for communication of outputs to decision makers: We believe that the ability to communicate the outcomes of the Decision Support Tool (to communities and decision makers) is an essential part of the programme of work that can make this a success. c Ongoing tool support and development: As this tool continues to evolve we believe there will be a need to continue to: i improve internal capability ii catalogue 'case law' and update tool accordingly iii integrate data.

distributional impacts in the UK WebTAG guidance) with the quantifiable savings (such as time or vehicle operating costs). The overall 'value for money' then becomes a more subjective assessment which can be heavily influenced by political expediency. Until this is done, the establishment of the "case law" as you explain below will be fundamental to the successful use of the tool.'

[6] We are also conscious that the Decision Support Tool has been developed in Excel. Should this testing stage determine that the tool has wider value, then it is advocated that a more user friendly platform for the tool be explored.

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Appendix A: Glossary

This glossary defines the specific meaning of certain words and phrases used in the public domain with regards to risk and resilience. In order to create a common understanding of risk and resilience, these terms should be used purposefully to mean the definitions provided. Where a different meaning is intended, a different word should be selected in order to begin to harmonise the lexicon of risk and resilience.

This glossary focuses on terms used in the transport sector; however, each specific term has been genericised to cover all infrastructure types, where appropriate.

Where there is a New Zealand government defined definition, we have provided this verbatim, otherwise sources of the definitions have been included for reference.

Assets (at risk): In the context of this study, assets refer to physical transport assets (eg road, rail), but there is explicit recognition that these assets have implications for populations, systems, communities, the rest of the built environment, the natural domain, economic activities and services, trust and reputation; and other things we value which are under threat from challenges in a given area (UNISDR).

Challenge: A potentially damaging physical event, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental damage (modified).

All challenges are covered by this term, eg malicious, technological and natural. Hazards can be single, sequential or combined in their origin and effects. Each challenge is characterised by its timing, location, intensity and probability. (Provided by the Ministry for the Environment.)

Civil engineering solutions: Tangible control measures that are constructed using physical components.

Communities of interest/affected communities: Communities that are impacted by, or depend on, specific (transport) infrastructure assets/systems.

Consequence: An outcome of an event (that may result from a hazard) affecting objectives (ISO 31000). It may be expressed quantitatively (eg monetary value), by category (eg high, medium, low) or descriptively.

Consequences are influenced by the exposure and vulnerability of elements at risk (eg human like and property) to the hazard, and by the hazard characteristics.

Cultural value: Cultural value is generally determined through an assessment specific to a location and stakeholder groups. Cultural value may be attributed to physical natural and built environment landmarks, and may be tangible or intangible. Cultural value extends from what is valued today to sites or artefacts which are part of New Zealand’s history.

Disruption: A disturbance or problem which partially or permanently interrupts (a transport assets) service provision.[7]

Economic value: A measure of the current levels of consumer or producer surplus. Often presented in monetary terms – or in terms of monetary proxies such as exchange value or productivity.

Environmental: Ecosystems and their constituent parts, including people and communities, and all natural and physical resources.

[7] Adapted from the Oxford English dictionary

Exposure: People, property, systems, or other assets present in hazard zones or exposed to hazards that are thereby subject to potential losses.

Frequency: A measure of likelihood expressed as the number or rate of occurrences, usually for a given time period (American Global Standards 2000).

Information technology- based solutions: Control measures which result from the better management of information flows and transfers within a system.

Likelihood: The chance of something happening. This can be expressed as probability either quantitatively as a ratio (eg 1 in 10), percentage (eg 10%) or value between 0 and 1 (eg 0.1) or qualitatively using defined and agreed terms such as unlikely, almost certain or possible (modified).

Mitigation: The lessening or limitation of the adverse impacts of challenges.

People- based solutions: Control measures that are a result of better managing or using human resources within the community, supply chain or organisation.

Process- based solutions: Control measures that are based on changes to existing processes, or the implementation of new processes, to provide resilience.

Resilience: The ability of systems (including infrastructure, government, business and communities) to proactively resist, absorb, recover from or adapt to disruption within a timeframe which is tolerable from a social, economic, cultural and environmental perspective.

Resilience controls: Responses that improve the ability to absorb, resist, recover or adapt to disruption to (transport) infrastructure assets.

Risk: The effects of uncertainty on objectives.

- An effect is a deviation from the expected (positive and/or negative).
- Risk is often characterised by reference to potential events and consequences, or a combination of these.
- Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.

Modern thinking on risk, as set out in ISO 31000, provides a particularly helpful approach to dealing with actual and potential threats and opportunities. One of the key paradigm shifts in ISO 31000 is a change in how risk is conceptualised. The definition of 'risk' is no longer 'chance or probability of loss', but 'the effect of uncertainty on objectives' ... thus causing the word 'risk' to refer to positive possibilities as well as negative ones. Risk therefore needs to be considered in the context of objectives (ie the function or provision of service within a system).

Shocks: Sudden, sharp events that threaten a system, such as earthquakes, floods and terrorist attacks.

Social: The social pillar encompasses social cohesion and access to social net networks, as well as to services, including critical services (including health and wellbeing services (doctor, hospital) and lifeline service); essential services (including educational facilities, financial institutions and insurance providers; non-essential services (including retail (excluding lifeline utilities) and places of worship) and recreational facilities.

Stresses: Longer-term challenges that weaken the fabric of a system (modified) (Rockefeller Foundation).

System: The 'system' includes both the (transport) network and the communities that depend on the (transport) network.

Tolerance: Community of interest acceptance to an asset being unavailable, or available at reduced capacity, for a defined period of time.

Uncertainty: The state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequences or likelihood.

Vulnerability: The characteristics and circumstances of elements of risk (eg human life, asset or property) that make them susceptible to, or protected from, the damaging effects of a hazard (LGNZ 2014).

Appendix B: Decision Support Tool guidance notes

There are three components to the guidance notes:

1 The rationale for the utilisation of the tool

2 The operational instructions to use the tool

3 How to gain the necessary information to populate the tool.

Bullets 1 and 2 directly above are covered through this research report and are embedded in the Decision Support Tool respectively. This guidance note therefore explicitly covers the steps that are needed, and the potential sources of information, to populate the Decision Support Tool.

At an operational level, these notes should be read in conjunction with the Decision Support Tool at a minimum, and ideally (but not strictly) the rest of this research report.

A hypothetical worked example, provided as appendix C in MS Excel (this provides further guidance for users about the practical utilisation of this Decision Support Tool and is located at www.nzta.govt.nz/resources/research/reports/614).

This worked example is purely hypothetical, and while it uses some actual data, it should not be considered an accurate reflection of the authors' or the Transport Agency's view of the asset in question. Rather, actual data has been used to show how the tool *could* be applied to the asset in question.

B1 Stage one: Understand the function of your asset

Understanding an asset/system is not a simple undertaking. There are a range of steps and practices that you can explore to build up a suitable picture. The Decision Support Tool aims to systemise a lot of these considerations by encouraging you to answer prepopulated questions. A full worked example is provided in appendix C (located at www.nzta.govt.nz/resources/research/reports/614).

The best way for you to answer these questions will always be case specific, and depend on the knowledge held, and the urgency of the response required, although the following suggestions may assist.

B1.1 Tasks

The first task should always be to define the asset in question, and provide a map (or technical drawing) to show readers visually what is under consideration. Then, the following steps should be pursued.

B1.1.1 Understanding interdependencies

The second task is to define the purpose of the asset and is something that may not be immediately obvious. Interrogating regional land transport plans, any strategic business cases for investment in the asset, as well as investigating telemetry may give an initial indication of the time of traffic flows (indicating commuter importance), nature of traffic (heavy vehicles imply more freight importance), district plan overlays (to understand what amenities are nearby).

This desktop scanning exercise can then be supplemented by engaging the community. This is often a difficult task and requires well thought out processes, as there may be many stakeholders with a wide variety of opinions. Nevertheless, engaging the community can take place through the use of:

1 Focus groups: Good for speaking to multiple people at once, and (potentially) reaching consensus; however, some voices may dominate the conversation skewing results. This method has a reasonable level of scalability while remaining granular enough to get good responses.

2 Face-to-face interviews: Good for in-depth information, and it is more likely stakeholders will discuss personal or negative information both of which can be valuable; however, this can be time intensive and is not a scalable option.

3 Official surveys and questionnaires: Good for reaching a large number of people and is not overly resource intense, in-depth information can be harder to extract from this source. Must be wary of non-response bias removing certain subgroups that are unwilling to take part or do not have an understanding of what is being asked. Questions need to be framed in a manner that is easily understood and avoids leading the respondent to an intended answer.

4 Telephone interviews: These are helpful when trying to reach difficult to access stakeholders, but are less likely to produce socially desirable outcomes and are less resource efficient than surveys/ questionnaires, but more scalable than face-to-face interviews. This form of community engagement can also be deemed by stakeholders as being intrusive and lead to non-true negative responses.

5 Public meetings: Excellent way to communicate with a very large group of people in a face-to-face manner; however, it can become a place where only dominant personalities speak about the issues and those with more introverted personalities may not speak up.

6 Elected representatives: Elected representatives, and the offices that support them, have a responsibility to represent their communities of interest and should have a handle of the major issues their communities face (as well as tolerance to outage).

This is not an exhaustive list and it should be added to as the Decision Support Tool is used and tested with a variety of projects and stakeholders.

When conducting community engagement sessions a representative sample of the community must be selected otherwise a level of bias will be present in the results and they will not be representative of the community's population. It must also be noted when creating questions for any community engagement it must be well understood what is trying to be achieved and questions/ discussion topics must be clearly articulated to all parties.

Overall community engagements must be well publicised, well facilitated, open and fair, subject to evaluation, cost effective, flexible and produce accurate feedback results.

The third task is to define the interdependencies of the asset. There are a range of good sources of information that are available to better understand genuine independencies.

At a transport level, investigating the following is a good start:

- asset management plans
- regional land transport plans
- Transport Agency risk management documentation.

At a wider infrastructure level, investigating the following is preferable:

- HazardScape: identifies threats, and then generally discusses ways to manage through the four R's (reduction, readiness, response, recovery).
- asset management plans for ancillary infrastructure (to the extent it is available)

- annual plans for council controlled organisations (CCO).

The fourth task is to define the importance of the route in an emergency. Local MCDEM plans are a good starting point for this. Secondary sources of information can be found above.

The fifth task is to define the current physical properties of the asset, the geographic context, and issues to do with maintenance. These sub tasks should be a core part of asset management. Accordingly, the following sources can be investigated to understand these elements:

- asset management plans
- ONRC
- engineers' technical design reports, design specifications, design drawings
- business cases for investment
- technical standards
- contractors as-built information with accompanying notes
- regional council, territorial local authority and CCO plans.

B2 Stage two: Impact assessment

Impact assessments are a complementary part of stage one. When engaging with your communities of interest about the level of service they expect from their assets, it is important you determine their tolerance to outage and their willingness to pay to improve resilience.

The Decision Support Tool encourages this knowledge to be developed by focusing attention on the maximum acceptable outage (MAO) and minimum business continuity objective (MBCO) and for each function of the asset:

- MAO: Time it would take for adverse impacts which might arise as a result of not providing a service or performing activity, to become unacceptable.
- MBCO: Minimum level of service or function needed for the function of the asset to be restored during or after a disruption
- Recovery time objective (RTO): Period of time following an incident within which the service or activity must be resumed or resources must be recovered to at least MBCO. The RTO must be less than the time it would take for the adverse impacts that would arise as a result of not providing a service of performing and activity to become unacceptable.

Testing different levels of service provision with communities of interest will help users to prepare emergency response plans in an informed fashion.

The following stakeholder engagement techniques can again be used, but this time to determine the economic, social, cultural and environmental consequences from removing an asset's function for various time intervals:

- focus groups
- face-to-face interviews
- official surveys and questionnaires
- telephone interviews

- public meetings.

This is not an exhaustive list and it should be added to as the Decision Support Tool is used and tested with a variety of projects and stakeholders.

B2.1 Tasks

The functions of the asset will automatically be carried through from stage one.

The first task is to plot the tolerance levels to outage across each capital. Ultimately you will have to input scores based on a five-point scale ranging from ‘very low’ to ‘very high’. These scores relate to communities of interest tolerance levels, and guidance for scoring is located in the ‘Consequences criteria’ tab.

Inputs for these assessments will likely be a combination of the inputs from the community consultation noted in stage one and above, as well as some professional judgements. There are free text boxes beside this scale to house any specific comments/evidence. Therefore, any decisions you make about impact assessments should be documented so independent parties can understand the logic of each score.

The second task is to translate these tolerance levels into specific MAO, MBCO and RTO levels.

When a consequence gets to ‘medium’ severity, across *any* of the four wellbeing pillars, this is where the RTO is generally set. When a consequence gets to ‘high’ across *any* wellbeing pillar, this is where MAO is generally set. RTO and MAO are the targeted recovery times that Controls are expected to support maintaining or achieving.

Once the timeframes for MAO and RTO are established it is also important for users to gain an understanding of the translation of these times to business operations. This is captured in the MBCO column.

If a community expects a road to be returned to full operation within three days, what does the transition plan look like? Is it 30% on day one, 60% on day two and then 100% on day three? Also, what do these percentages actually consist of? For example, is ‘50%’ a one lane open on a two-lane highway or is it both lanes open for 12 hours a day? These percentages do not have to be limited to only representing capacity they could also represent the quality of assets. For example a road of 30% after a landslide may be partially open but may also have significant level of soil debris left on the road, making it more difficult to drive over (but still within safe levels of coverage).

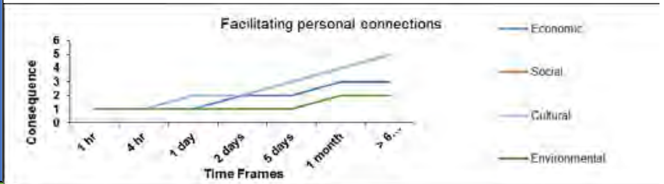
The third task is done automatically and effectively plots a chart that shows how severe the consequences of disruption is across all four wellbeing pillars over time. These charts are designed to make it easier for you to communicate with decision makers and communities of interest, and so can be used in reports as well as communication material.

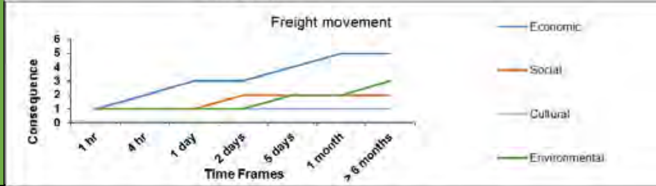
The development of visual aides to support communication can also help decision makers to really test whether communities of interest have a high or low tolerance to disruption.

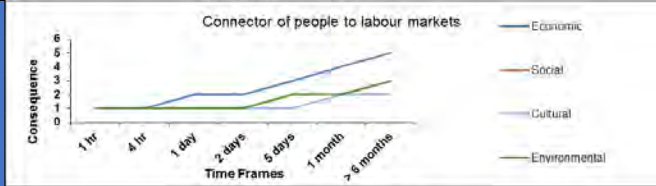
Tolerance is a dynamic concept and can be amended depending on the information available and the persuasiveness of arguments. For example, these aides can be used to lower or raise a community’s tolerance towards disruption, particularly if accompanied with an example that shows how disruption has occurred before and while services were disrupted, they were not curtailed. A worked example of an impact assessment is provided for four asset functions in figure B.1.

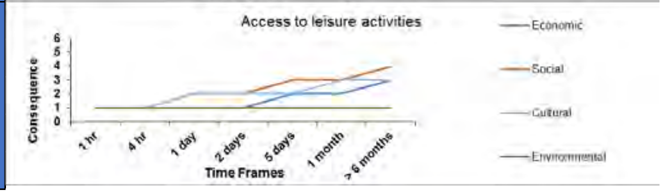
Figure B.1 Impact assessment – worked example

Service / Function	#	Consequence of service disruption over time									RTO	MBCO (if different than BAU)	MAO
											# of days		# of days
Facilitating personal connections	1		1 hr	4 hr	1 day	2 days	5 days	1 mth	>6 mths	Comments		20% service level is expected to be	
		Economic	vl	vl	vl	l	l	m	m	It is expected that the service industry would		40% service level within 5 days	
		Social	vl	vl	l	l	m	h	vh	Assumed that the region can cope with a few days	5.00	80% within 20 days	30.0
		Cultural	vl	vl	l	l	m	h	vh	Assumed that the region can cope with a few days		Diversions around waione st bridge	
		Environmental	vl	vl	vl	vl	vl	l	l	Minimal impact expected			
Freight movement	2		1 hr	4 hr	1 day	2 days	5 days	1 mth	>6 mths	Comments		30% service level is expected to be	
		Economic	vl	l	m	m	h	vh	vh	Given the importance of oil to the Wellington		50% service level within 3 days	
		Social	vl	vl	vl	l	l	l	l	It is assumed there would only be marginal	1.00	100% within 20 days	5.0
		Cultural	vl	vl	vl	vl	vl	vl	vl	There are not considered to be any cultural		Diversions around waione st bridge	
		Environmental	vl	vl	vl	vl	l	l	m	The GHG emission impacts from defered			
Connector of people to labour markets	3		1 hr	4 hr	1 day	2 days	5 days	1 mth	>6 mths	Comments		20% service level is expected to be	
		Economic	vl	vl	l	l	m	h	vh	The 2013 storms in Wellington supported a		40% service level within 5 days	
		Social	vl	vl	vl	vl	l	l	m	The social impacts of a disruption of people to	5.00	80% within 20 days	30.0
		Cultural	vl	vl	vl	vl	vl	l	l	It is assumed that thee would be minimal		Diversions around waione st bridge	
		Environmental	vl	vl	vl	vl	l	l	m	It is assumed that there would be a reasonably			
Access to leisure activities	4		1 hr	4 hr	1 day	2 days	5 days	1 mth	>6 mths	Comments		20% service level is expected to be	
		Economic	vl	vl	vl	vl	l	l	m	The economic impact would predominantly be		40% service level within 5 days	
		Social	vl	vl	l	l	m	m	h	The inability to access leisure activities (such	5.00	80% within 20 days	180.0
		Cultural	vl	vl	l	l	l	m	m	It is expected that there would be fairly minor		Diversions around waione st bridge	
		Environmental	vl	vl	vl	vl	vl	vl	vl	It is expected that there is no environmental		BAU	









B3 Stage three: Challenges

The Decision Support Tool establishes an expectation that you will think broadly about the challenges that might face a particular asset or system. This forms the basis of the development of a challenge matrix.

B3.1 Tasks:

The first task is to consider the universe of challenges. You are not strictly expected to develop and publish a challenge matrix, although if doing so will enable a more holistic consideration of challenges, then this should be pursued.

There are a range of potential inputs that might go into the population of a conceptual challenge matrix (or at least the consideration of a universe of challenges) including:

- Outcomes from stage one: Understanding your asset:
  - consideration of historic disruptions to the asset/system
  - consideration of the geographic and geological context.
- Internal workshops (at the Transport Agency or with any relevant user group) to brainstorm potential challenges and populate a draft challenge matrix.
- Stakeholder workshops with communities of interest – stakeholders will enhance the ability to identify and categorise challenges correctly, and may bring locally-held knowledge of challenges that are not immediately obvious to asset owners.

We would also expect the considerable body of hazard and risk literature to be leveraged in identifying these challenges. A sample of this body of work could include:

- The Transport Agency Risk Management Framework – identifying the principles and operational approach to risk
- The Transport Agency Research programme – for example, measuring the resilience of transport infrastructure
- HazardScape: Identifies threats, and then generally discusses ways to manage through the four R's (reduction, readiness, response, recovery)
- ResOrgs: How to create resilient individuals, organisations and communities
- NIWA: Improving our understanding of climatic impacts
- GeoNet (EQC and GNS Science): Improving our understanding of geological risks
- Geotechnical database: Based on the data required for land assessments as a result of the Canterbury earthquake sequence, now being extended to provide national coverage of land conditions
- MERIT: A dynamic general equilibrium model that calculates the resulting economic impacts due to the loss of lifeline services
- National Science Challenge – Resilience to Nature's Challenges: An inclusive, up-to-date, resource of theoretical and practical resilience frameworks and reviews of current resilience literature and relevant datasets
- Natural Hazards Research Platform: A multi-party research platform funded by MBIE dedicated to increasing New Zealand's resilience to natural hazards.

Over time through continual use of the challenge matrix it is expected that many of the identified challenges and categorisations can be reused as the challenges will remain the same. Therefore it is intended that the Transport Agency look to develop a comprehensive list of 'challenges' which can then be used as a starting point for specific asset/system considerations.

A selection of potential challenges is provided in table B.1. These can be used as a starting point for thinking about challenges in the Decision Support Tool.

Table B.1 Example of challenges

Natural shocks	Natural stresses	Systemic stresses	Systemic shocks
Earthquake: liquefaction, tsunami, landslide, sinkholes	Extreme low temperatures	Congestion	Disruption of supply chain (materials)
Volcano: ash fall, lava flows, lahar	Extreme high temperatures	Difficult to maintain (location or technology)	Disruption of supply chain (people)
Bush/scrub fire	Winter storms: snow, ice, hail	Frequent crashes (alignment/driver behaviour/usage)	Terrorism
Coastal storms: inundation, overtopping		Interdependencies with other assets (operation or maintenance)	Regulatory change
Erosion		Less than optimal maintenance (capability or capacity)	
Flooding			
High winds			
Landslide			
Liquefaction			
Rockfall			
Sinkholes			
Tsunami			

The second task is to document the universe of challenges in the tool. This is done in two ways:

1 **You are invited to enter all relevant challenges into the 'challenges' cell**. Simultaneously, users are expected to categorise these challenges as being: a natural shock, natural stress, systemic stress or a systemic shock. The logic behind this categorisation is to prompt thinking about whether you are exploring one 'category' of challenge over the others.

2 **You are then invited to estimate the likelihood of that challenge occurring over a range of time periods**: Today, 50 years, 100 years. This is intended to ensure that decision makers understand the degree to which challenges may be mitigated or intensified by future changes including demographic shifts and climate change.

All data and supporting information for these assessments is expected to be highlighted in the interests of transparency. Measures of likelihood include:

Figure B.2 Challenge likelihood

Challenge Likelihood	Rare	Low	Medium	High	Very High
	Challenge may occur in exceptional circumstances	Challenge may occur in the next 10-30 years	Challenge may occur in the next 3-10 years	Challenge may occur in the next 1-3 years	Challenge can be expected in the next 12 months
	<1%	1-9%	10-19%	20-50%	>50%

This assessment will automatically determine a 'priority rating' which helps you understand the order in which Challenges should be mitigated against. These ratings are noted below.

Figure B.3 Challenge priority

	Low	Moderate	High	Urgent
Challenge Priority	Challenge is not a priority for control measures	Challenge requires monitoring and potentially control	Challenge requires evaluation and control measure(s)	Challenge requires control measure(s)

It is important to remember that the likelihood assessment is not of the event occurring *per se*, but rather, the event occurring to a magnitude that is consistent with the level of consequence identified in stage 2 of the Decision Support Tool.

1 **The third task is to populate a cell titled 'disruption scenarios'**. This cell is designed to capture the effect(s) of a challenge in the instance that these effects are different from the description of the challenge. For example, consider the effects of an earthquake potentially being: landslides, tsunamis or rockfall – rather than just 'earthquake'.

2 **The fourth task is to document the information sources that have been relied upon to form estimations of the likelihood of an event occurring**. These data sources will be case specific and will evolve over time as knowledge of challenges improves. An indicative selection of these information sources is provided in table B.2.

Table B.2 Indicative data sources for various challenges

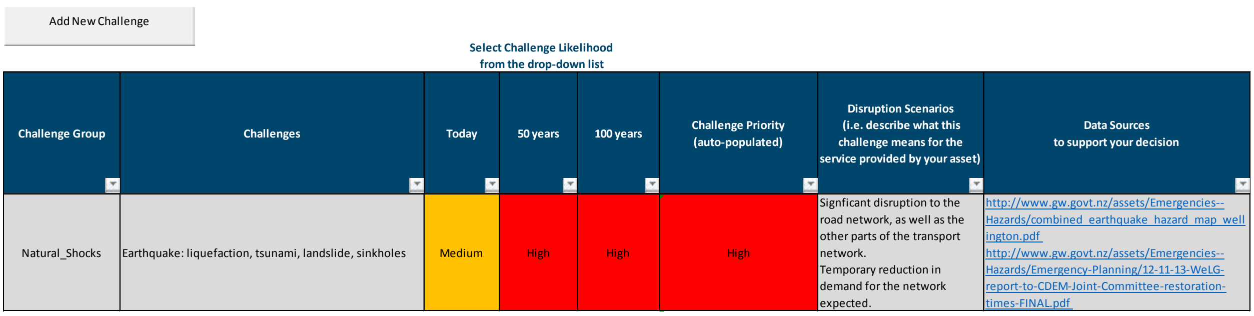
Challenge	Indicative data sources
Flooding (rainfall)	www.mfe.govt.nz/more/natural-hazard-management/flood-risk-management/managing-flood-risk www.mfe.govt.nz/node/5153
Inundation/ overtopping (sea)	www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios www.niwa.co.nz/services/online-services/tide-forecaster www.niwa.co.nz/natural-hazards/hazards/coastal-storm-inundation www.mfe.govt.nz/node/18468 www.mfe.govt.nz/more/natural-hazard-management/flood-risk-management www.mfe.govt.nz/node/5153
Undermining (erosion)	www.mfe.govt.nz/publications/climate-change/factsheet-5-coastal-erosion www.mfe.govt.nz/more/environmental-reporting/land/soil-erosion-risk-indicator
Rockfall	http://info.geonet.org.nz/display/slide www.avalanche.net.nz/
Landslide	http://info.geonet.org.nz/display/slide www.avalanche.net.nz/
Sinkholes	www.landcareresearch.co.nz/publications/factsheets/rare-ecosystems/subterranean-or-semi-subterranean/sinkholes
Extreme low temperatures	www.niwa.co.nz/
Snow/ice/hail	www.niwa.co.nz/
High winds	www.niwa.co.nz/ www.niwa.co.nz/publications/wa/vol10-no1-march-2002/how-often-is-new-zealand-hit-

Challenge	Indicative data sources
	by-tropical-cyclones
Extreme high temperatures	www.nrfa.org.nz/Pages/default.aspx
Interdependencies with other assets	Network operator asset register and maintenance forecasts Local council water authority (eg Auckland: watercare). Gas authority (eg Vector)
Congestion	Transport Agency, Ministry of Transport and local council organisations (eg Auckland Transport) maps, annual reports and forecasts
Frequent crashes	Transport Agency, Ministry of Transport and local council organisations (eg Auckland Transport) maps, annual reports and forecasts www.transport.govt.nz/research/roadcrashstatistics/
Bush/scrub fire	www.nrfa.org.nz/Pages/default.aspx
Volcano	http://info.geonet.org.nz/display/volc/Volcano
Earthquake	http://info.geonet.org.nz/display/quake/Earthquake
Tsunami	www.civildefence.govt.nz/cdem-sector/cdem-research-/mcdem-research-projects-and-resources/review-of-tsunami-hazard-in-new-zealand/ http://info.geonet.org.nz/display/tsunami
Poor maintenance (capability or capacity)	Network operator asset register and maintenance forecasts
Disruption of supply chain (people)	www.business.govt.nz/worksafe www.business.govt.nz/worksafe/research/research-reports/health-and-safety-attitudes-and-behaviours-survey

Important note: These challenges should be considered in detail before moving onto future sheets. Once these are locked in and controls are populated in the next worksheet, a user cannot go back and make amendments without having to recomplete all challenge control entries.

A worked example of this stage in its totality is shown in figure B.4.

Figure B.4 Challenges – worked example


Add New Challenge

Select Challenge Likelihood from the drop-down list

Challenge Group	Challenges	Today	50 years	100 years	Challenge Priority (auto-populated)	Disruption Scenarios (i.e. describe what this challenge means for the service provided by your asset)	Data Sources to support your decision
Natural_Shocks	Earthquake: liquefaction, tsunami, landslide, sinkholes	Medium	High	High	High	Signficant disruption to the road network, as well as the other parts of the transport network. Temporary reduction in demand for the network expected.	http://www.gw.govt.nz/assets/Emergencies--Hazards/combined_earthquake_hazard_map_wellington.pdf http://www.gw.govt.nz/assets/Emergencies--Hazards/Emergency-Planning/12-11-13-WeLG-report-to-CDEM-Joint-Committee-restoration-times-FINAL.pdf

B4 Stage four: Controls

There are a wide range of different controls that can be produced for each and every challenge. The guidelines in this note and in the Decision Support Tool are designed to structure your thinking to ensure that a range of quality controls are produced – albeit to a commensurate scale to the size of the problem (it is not advisable to assess 1,000 controls for a rare disruption event that will have limited impact on communities of interest).

A wide variety of resources can be leveraged to identify/design controls including previous work from:

- Stage 1: Understanding interdependencies and understanding the asset
- Stages 1 and 2: Outputs from stakeholder engagement workshops as to what the community thinks are acceptable controls
- Stage 3: Hazard and risk literature which also proposes suggested controls to the challenges.

New resources that can also be used to produce/ design controls are:

- internal brainstorming workshops
- past experience from previous projects and similar assets
- discussions with communities of interest and other agencies
- desktop research with comparable challenges in comparable jurisdictions.

B4.1 Tasks

The first task is to click on the 'Setup challenge controls' button. Challenges identified as urgent, high and medium from the previous section will be auto populated in this worksheet.

The second task will be to name and categorise preferred controls. This consists of a number of steps as noted below. Crucially, categorisation aids users and decision makers to assess whether assets are 'too resilient' in certain categories. For example, are we over-investing in engineering solutions? This categorisation helps to correct for inherent biases in our own judgement. Formal definitions of these categories are provided in the glossary:

1 Primary generic control: includes a combination of:

   a resilience measure: robustness, redundancy, recovery, leadership and governance

   b type: civil engineering, information technology, processes, people

   c secondary generic control: an opportunity to include an additional combination of resilience measures and types (if relevant)

   d control name – is what carries through into the heatmap – shorthand for the detailed option

   e detailed control –a full description of the control or a link to where this may be found

   f interdependencies and enablers – controls will not always be 'owned' by the network operator; it is important to collaborate with all parties who will have responsibilities for delivering on controls to ensure that all costs and benefits are understood and apportioned correctly

   g current/future state – this assessment allows users to understand whether a control is new (and hence should be considered as part of a prioritisation exercise) or current (and hence forms a view of the existing level of resilience to a challenge).

The third task is to understand the indicative financial cost for each control. This will flow through into the Assessment Phase and the determination of 'resilience for money' assessments. Indicative financial costs can be determined from those options above - internal brainstorming workshops; past experience from previous projects and similar assets; discussions with communities of interest and other agencies; and desktop research with comparable challenges in comparable jurisdictions.

The fourth step in this segment is to decide whether or not the control should pass through to the Heatmap for decision making. This is a critical step that requires subjective discussion between all informed users of this tool. To guide you through this step it is important to reconsider the spread and quality of suggested controls (are we assessing too many engineering solutions? Do we have too much redundancy? Multiple controls can be passed through for the same challenge but it is important to keep a spread of challenge controls in the next step.

A worked example is provided in table B.3.

Table B.3 Example of control and the various categorisations

Challenges: Coastal storms: inundations and overtopping

Primary generic control	Secondary generic control	Control name (for heatmap)	Detailed control	Current/future	Carried through to heatmap?
Redundancy through civil engineering	Redundancy through process.	Alternate road	Alternate route directly adjacent to Tamaki Drive	Future	N
Redundancy through information technology	N/A	Remote working	Communication campaign to business encouraging them to work with staff over 'working from home' options' in the case of disruption, avoiding the need to travel to the office	Current	Y

Appendix C: Decision Support Tool

This is an Excel file located at www.nzta.govt.nz/resources/research/reports/614.