Supporting robust decision making on seismic resilience investments: development and trial application of a Decision Support Tool

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Introduction

The 2010-2011 Canterbury earthquake sequence caused significant damage to the central business district of Christchurch and the nearby suburbs, leading to billions of dollars in damage to buildings and infrastructure and significant psycho-social impacts on the community (Potter, Becker, Johnston, & Rossiter, 2015). For several decades prior to this event, New Zealand had experienced a relatively calm seismic period. Where attention was paid to earthquake resilience, this was primarily focused on the Wellington region and on South Island rural areas expected to be heavily impacted by any Alpine Fault rupture. The Canterbury earthquakes were a reminder that questions around how to reduce the impact of seismic events are relevant to much of the country.

This report outlines the development and use of a prototype decision support tool (DST) developed to guide choices about where to invest time, effort, and resources to maximise improvements to seismic resilience. A decision support tool is a helpful device to indicate strengths, trade-offs, and co-benefits of different types of projects in environments where resources are limited and there is significant uncertainty about risk. The DST is intended to be a usable and robust tool that can aid decision making from problem formulation to identifying a range of suitable actions. The prototype DST is user-focused with an emphasis on engagement and participation.

The design of the DST derives from multi-criteria decision analysis (MCDA), deep uncertainty, decision making for long temporal horizons, and multiple futures scenario modelling, each of which are necessary considerations for low-probability/high-impact events such as major earthquakes. More commonly applied decision support methods, such as cost-benefit analysis, tend to be inadequate in these conditions (Bonzanigo & Kalra, 2014). The combination of multi-criteria decision analysis with techniques designed for navigating complex, uncertain, and perhaps relatively distant futures enables a process of holistic decision making beyond financial costs and benefits.

Seismic resilience refers to a system's capacity to reduce the impact of earthquakes through mitigation measures and preparedness (*Reduce*), and increase the capacity of systems to recover quickly from disruptions (*Recover)* and thrive in the aftermath of disruption (*Thrive*) (QuakeCoRE, 2016). There are a number of pathways to enhance a system's ability to reduce, recover, and thrive, and as many alternative pathways that may be more or less effective across multiple criteria. It is up to the decision maker to determine which pathways are optimised to achieve their goals of enhanced resilience.

The DST generates resilience profiles across a portfolio of project pathways. The profiles guide participants through analyses and reflections on the outcomes of their preferences. The DST can be used to generate a deeper understanding of decision makers' preferences and desired outcomes across a set of pathways, and to determine which pathways align with their preferences.

In this report, we explore the conceptual foundations of the decision support tool, explain how it was created, its main components, and the understanding gained from implementing the DST as a prototype in a workshop format. Finally, we look at future uses, variations and further developments required to enhance the DST and enable its use in practice.

Conceptual foundations of the Decision Support Tool

The DST was developed for usage under conditions of deep uncertainty with the aim of bringing resilience thinking into decision making processes. The decision support tool (DST) presented in this paper was developed by drawing on the methods of multi-criteria decision analysis (MCDA[1]) and scenario planning.

Multi-Criteria Decision Analysis

MCDA is often used for complex problems where the trade-offs between outcomes are unclear. As Doumpos and Zopounidis put it, MCDA is a process of decision making for, "ill-structured problems involving conflicting multiple criteria, goals, objectives, and points of view," (2014, p. 12). MCDA has been applied in an incredible variety of contexts from flood and coastal erosion risk management appraisal (Environment Agency, 2010), to strategic analysis in workshop contexts (Montibeller & Franco, 2010), to measuring and prioritizing the resilience of transportation assets and investments (Dojutrek, Labi, & Dietz, 2014). MCDA been applied extensively in environmental sciences where trade-offs are often seen between the social, economic, and environmental impacts of decisions (Huang, Keisler, & Linkov, 2011). Within such diverse and murky environments MCDA, in its variety of forms, provides a transparent and structured approach to decision making (Department for Communities and Local Government, 2009). Seismic resilience is well situated among these complex problems where there are conflicting criteria and deep uncertainty about current conditions and future outcomes.

Despite the variety of approaches and applications of MCDA, at its core the MCDA method aids decision making by breaking down a decision problem into smaller parts. Each part is assessed individually and in relation to the whole as decision makers systematically work through the process (Goodwin & Wright, 2002). Through this process, the decision maker is compelled to thoughtfully consider and articulate their priorities and preferences so that the rationale for each decision can be clearly seen and justified (Goodwin & Wright, 2002; Belton, 1990).

MCDA provides a structure for helping answer the question: given a set of criteria and alternatives, which alternatives are optimal? Key features of MCDA are transparency and understanding. Throughout the MCDA process decision makers explain their preferences, priorities, objectives, and values. This allows them to develop insights about the preferred outcomes for the problem they are facing (Belton & Stewart, 2002). In short, multi-criteria decision analysis is a process aimed at determining the extent to which alternatives fulfil an agreed desired outcome (Kilgour, Chen, & Hipel, 2010).

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[1] Also known as multi-criteria aid (MCA) or multi-criteria decision support, or multi-criteria decision making (MCDM) among other derivatives with essentially the same form and function.

Objectives, Priority Areas, Criteria, and Alternatives

There are contested definitions in the MCDA literature for terms such as alternatives, decisions, choices, priorities, objectives, and outcomes. At times these terms are used interchangeably (Watson & Buede, 1987). However, despite the varied vocabulary used under the umbrella of MCDA, there are consistent elements of the approach.

In this paper, the terms associated with MCDA, including objectives, priorities, criteria, and alternatives, have distinct definitions. The **objectives** are what the users want to achieve (i.e., the goal). In the development of the DST the objective is to enhance the seismic resilience of various systems. The **priorities** are the characteristics or elements of the objective that matter to the decision maker and that can be evaluated as part of the decision process.[2] For example, if the objective was to enhance the seismic resilience of freight transport routes on the South Island, priorities might include the degree to which an intervention improves life-safety, the cost of the intervention, maintenance requirements, and so on. Each priority will have one or more **criteria** for assessment. These can be qualitative, quantitative, or a mix. Quantitative criteria can be assigned a range for easier classification – cost of a given intervention, for example, could be a monetary unit or categorized as high/medium/low.

Generating the criteria is usually the most challenging part of the MCDA process (Bouyssou, 1990; Goodwin & Wright, 2002). MCDA is often used when there are more than one criteria that may conflict with each other. While they may be conflicting, the criteria should be complete – meaning, all important criteria are included with no redundancies. No unnecessary criteria should be included and neither should criteria that measure the same thing. Each criterion should be assessable, albeit by either objective or subjective evaluation (Department for Communities and Local Government, 2009). Decision makers should be able to assess each criterion independently, without knowing the score for another criterion (Goodwin & Wright, 2002; Belton, 1990; Bouyssou, 1990).

In MCDA, the **alternatives** are the projects or choices that are being decided on, and can be selected either before generating the priorities and criteria or after (Belton , 1990). If the possibilities for alternatives are unclear – either because there are too many to know where to start or the starting point is not well-formed – the decision making process may start with the objectives, priorities, or criteria and these will be used to identify or narrow down the alternatives (Belton, 1990). This is called the top down approach as it starts at the top of the MCDA structure as seen in **Error! Reference source not found.**. In contrast, the bottom-up approach starts with known alternatives from which the criteria and priorities are generated by identifying similar and dissimilar characteristics of the alternatives (Belton, 1990).

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[2] Some publications (see for example, (Department for Communities and Local Government, 2009)), use the terms criteria and sub-criteria. In order to avoid confusion from using the same or similar terms multiple times within the model the level between objectives and the measures of performance are called “priorities”.

Alternatives do not need to be available or considered simultaneously – a complicated decision problem may involve sequential alternatives (Goodwin & Wright, 2002). For examples, certain alternatives may only be available during certain periods, such as a government subsidy to strengthen unreinforced masonry buildings, or may be available sequentially such as when deciding on large infrastructure projects with multiple phases. If an alternative is rejected or allowed to expire it is removed from the decision making model. In this case, the criteria can be set, and when an alternative meets those criteria, or crosses a threshold, it can be accepted or put into a pool of alternatives, while those that do not meet the criteria are rejected. Similarly, if there are too many alternatives they can be shortlisted by multi-staging the MCDA process (Environment Agency, 2010). In the multi-staging process, the criteria are used to set a threshold which must be crossed for an alternative to remain in the mix. This threshold can be derived from the weighting and scoring process or the threshold may be determined by regulatory standards.

Scoring and Weighting

MCDA employs scoring and weighting to help decision makers systematically value each element of the decision. The decision maker assigns a relative value to each alternative which reflects the decision maker's priorities (Belton, 1990). Criteria are weighted to reflect their relative importance in decision making, and are a critical part of deriving learning outcomes from the process (Belton, 1990; Goodwin & Wright, 2002). The scores indicate the relative strength of each alternative for each criterion.

There are two broad types of scoring systems – local and global (Belton, 1990). With a local scale the alternatives are compared to each other in terms of how well they would fulfil each criterion, with 0 being the least likely to fulfil the criterion and 100 the most likely. On a global scale the alternatives are ranked independently on a scale from 0 (worst level of performance) to 100 (best level of performance) (Department for Communities and Local Government, 2009). A global scale can be confounded by a lack of clarity about how to interpret the high and low ends of the scale (Department for Communities and Local Government, 2009) – in other words, the worst or best compared to what? This presents an advantage for a local scale as each end of the scale is assigned to an alternative, thereby setting the basis for comparison. The alternative that best satisfies a given criterion compared to the others is scored 100, the one which least satisfies the criterion is scored 0. All other alternatives are scored relative to the best/worst alternatives. However, if new alternatives are introduced the local scales become less useful as the highest and lowest scores must be reassessed. Alternately, a global scale does not force the assignation of extreme scores when new alternatives are introduced, thereby making it easier to add new alternatives.

Ultimately, the use of a local or global scoring system should have no impact on the outcome as both systems compel the decision makers to score alternatives relative to one another for each criterion (Department for Communities and Local Government, 2009). A local scale was used in the DST because it is the most common form and is the basis for more complex scoring systems such as the various outranking methods and the analytic hierarchy process, which may be relevant to future applications of the DST (Belton & Stewart, 2002).

Deep Uncertainty

Decision makers in seismic resilience planning not only deal with complex and dynamic systems but with long timelines and difficult to predict outcomes. Therefore, deep uncertainty is a fundamental concept that we considered in the development of the DST model. Deep uncertainty occurs when analysts and decision makers do not know or agree on the likelihood and nature of future events, the value of possible outcomes, or even the best method of relating potential actions to outcomes (Lempert, Popper, & Bankes, 2003). Deep uncertainty generally exists for events with long timelines. The challenge of making deep uncertainty accessible to decision makers rather than analysts was addressed with the use of multiple future scenarios. The richness and value of future scenarios comes from the intangibles that are not easily modelled but can be extremely impactful on decisions (Shell International BV, 2008). For example, the effects of climate change on local areas, global economic trends, and population demographics can all create deep uncertainty – even more so on longer timelines. These trends and conditions can be modelled quantitatively but their impacts on decisions made now are drawn out through scenarios which emphasize the hypothetical, yet still supremely relevant and plausible, conditions of the future (Golan, Lorenz, Mendes, Milne, & Obexer, N.D.).

Scenario Planning

As deep uncertainty is a reality that must be grappled with by those interested in seismic resilience, the DST incorporates scenarios as heuristics that allows decision makers to engage with disparate futures. Scenarios themselves are not a strategy or a decision making tool. They provide substance to the decision making process by developing a holistic, plausible, and credible view of future conditions (Martelli, 2014). A basic assumption within scenario planning is that the range of possible futures is actually limited, not infinite (Meinert, 2014). What this means is the future is connected to the past and to our present, therefore the important guiding questions to consider are how did we get to this point, and what are the main drivers relative to our overall objectives (Meinert, 2014). In order to generate a scenario that is meaningful to the decision problem, scenario developers need to identify the driving forces that have impacted the decision context to date and will plausibly do so in the future (Wade, 2012). In this way scenarios have the effect of sharpening focus on the decision making process. They bring together assumptions about future conditions based on our understanding of current conditions and how those conditions evolved. In so doing, scenarios illuminate key aspects of the complexity surrounding the decision problem (Martelli, 2014).

As described in the previous section the aim of futures scenarios is to present plausible and relevant contexts in which decision outcomes will be realised in order to provide focus for the decision maker. By articulating expectations about trends and outcomes, this creates a specific future narrative in which decision makers can evaluate project outcomes and consider how these outcomes may vary if the context shifted. Ultimately, scenarios provide tangible tools that both acknowledge future uncertainty while attempting to mitigate adverse outcomes. Making assumptions about the future explicit, supports decision making transparency, which is an important component of MCDA. Future scenarios development methodologies typically do not contain a detailed or systematic means of assessing outcomes (Montibeller, Gummer, & Tumidei, 2006). Integrating future scenarios

with the MCDA allows decision makers to systematically evaluate outcomes and possible alternatives within a range of explicit future contexts.

While traditional decision analysis accounts for uncertainty by attaching probabilities to each stem of a decision tree (Montibeller, Gummer, & Tumidei, 2006), for decision making with deep uncertainty resulting from either long timelines, complex events, or both, assigning probabilities to specific outcomes is not suitable (Maier, et al., 2016). In situations where decisions need to be made in the face of deep uncertainty, future scenarios can help with decision making by sensitizing decision makers to uncertainty related to the decision problem, while still enabling them to explore plausible outcomes based on current trends and emerging issues (Stewart, 2005). In this way, MCDA and future scenarios are complimentary – they offer a means of systematic and transparent decision making while taking into consideration complex and even competing future outcomes.

By combining future scenarios with multi-criteria decision analysis, we can add multiple layers of input to the decision making process. The aim of these additional 'layers' is to challenge decision makers to explicitly convey and evaluate their assumptions about seismic resilience and future outcomes. The first layer is a basic MCDA process that leads to a single decision. Additional layers are then added by introducing multiple future scenarios and allowing for multiple decisions and trade-offs to be evaluated in parallel with the initial 'best' outcome. Although not especially common, this combination of scenario evaluation and MCDA has been utilised in a variety of contexts from infrastructure prioritization (Karvetski, Lambert, & Linkov, 2009) to managing food security (Ram, Montibeller, & Morton, 2011) and transport planning (Zegras, Sussman, & Conklin, 2004). Ultimately, practical considerations may dictate how a MDCA and future scenario process is applied. There is a risk that such an approach could become time consuming and tiring, resulting in inconsistencies and user fatigue (Salminen & Lahdelma, 2001; Montibeller, Gummer, & Tumidei, 2006). Therefore, developers need to be cognisant of the number of evaluation steps and scenario layers they build into the system.

Developing a Decision Support Tool for seismic resilience

Overview

The aim of this section is to describe the components of the Decision Support Tool and how they relate. As seen in Figure 1, the DST combines three elements: preferred alternatives (i.e., different pathways to achieving your goals), future scenarios that may influence the outcomes of each alternative, and the multi-criteria assessment component. The scenarios give context to the decision making environment, while the MCDA component gives structure and transparency leading to a decision based on agreed criteria taking into consideration current conditions and plausible future outcomes.

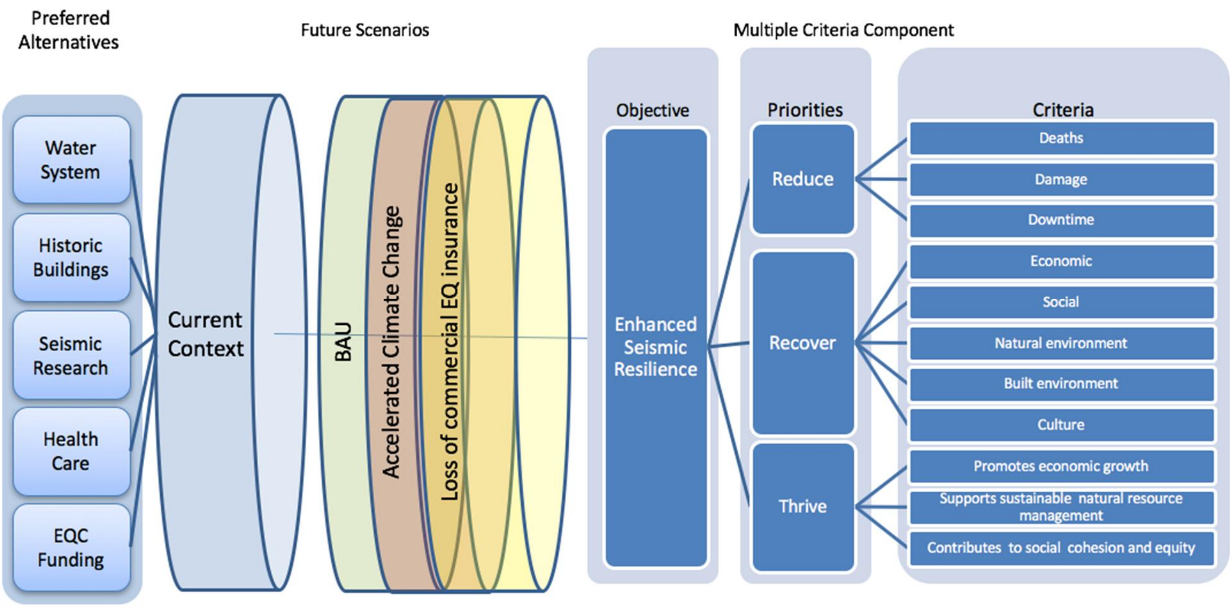

Figure 1: The components and process of the Seismic Resilience Decision Making Tool.

Preferred alternatives

Unlike standard MCDA, the DST allows users to select more than one alternative to create a portfolio of projects that incorporate concerns specifically related to "seismic resilience". As the overall aim is to help bring seismic thinking into decision making, the act of creating a portfolio allows users to see the trade-offs being made by selecting a group of projects.

A technique used when trialling the DST was to have users establish alternatives before using the DST. This way, the selection of alternatives is not influenced by scores, weights, or future scenarios. The selected alternatives can be compared to the outcome of the DST process as an indicator of how the process influenced decisions. This additional step can add great insight into how the process of

considering future scenarios and discussing preferences and priorities can lead to different outcomes.

To test the DST in a workshop format the developers generated five projects, which could reasonably be expected to fulfil the objective of enhancing seismic resilience for a generic system at a national-scale. In practice, alternative projects would be determined by the decision makers but, given the time constraints, this step was completed by the facilitators before the workshop. The alternatives evaluated in the workshop were intended to illustrate the trade-offs between different priority areas. The briefs for the five alternatives are as follows:

Water Systems: This is a funding programme aimed at increasing the seismic resilience of fresh water and sewage systems. Up to $50 million is available as a 50% cost-sharing scheme for local authorities.

Historic Buildings: This programme aims to bring historic buildings in commercial areas (CBDs) up to at least 66% of the Building Code. Up to $50 million is available in a 50% cost sharing scheme for building owners.

Seismic Research: This programme would see $50 million earmarked for QuakeCoRE over the next 10 years.

Health Care: The aim of this project is to improve basic health measures in low socio-economic areas facing high-seismic risk. $50 million over 10 years.

EQC: This project is aimed at building the capacity of EQC to process insurance claims and to build a large reserve of funds. $10 million would go toward capacity development for recovery management (within government) and $40 million into a reserve fund earning 4% interest per year.

Future scenarios

As Alesch, Arendt, and Petak (2010) put it in their extensive study of seismic decision making in policy and law in California, the long-term success of public policy depends on the entire context in which the decision making takes place. This includes consideration of contextual changes over the lifetime of the policy (Alesch, Arendt, & Petak, 2010).

Within the DST, future scenarios are case specific. They are generated for each application of the DST relative to the decision making environment. The nature of the scenarios depends on the decision problem and can be generated by the analysts and presented to decision makers. They can also be developed jointly or even by the decision makers themselves through a facilitated process.. In the workshop test of the DST, however, the decision making contexts were prescribed by the DST developers.

The decision making context included an overall scenario and three potential future scenarios. The overall scenario presents a context that was intended to be familiar and credible to the participants, but distinct from projects in which workshop participants may be engaged. In this overall scenario, participant groups were told that they were part of a new unit within the Ministry for Business,

Innovation, and Employment. Their mandate was to increase the seismic resilience of New Zealand. To this end they were allocated a budget of $150 million to support three projects with $50 million for each. A given project could not receive more than $50 million and no other funding would be available.

The basic conditions for the future scenarios were derived from scenario planning literature – they had to be plausible and relevant to the decision problem. The three scenarios were business as usual (BAU), accelerated climate change, and the loss of earthquake insurance from commercial providers. The scenarios as provided in the workshop are in Appendix A.

Business as Usual: This scenario described a period similar to the late 20th century in New Zealand in which the population has experienced some moderate earthquakes, a few severe storms, and consistent demographic trends. Groups who were assigned the BAU scenario were asked to think about how they would address seismic risk if conditions were expected to carry on in this vein.

Accelerated climate change: In this scenario, decision makers needed to consider a context in which there is a heightened degree of competition for resources from other, non-seismic, hazard types. With limited resources the participants were challenged to think about how such a future would influence their investment decisions.

Loss of commercial earthquake insurance: In this scenario decision makers needed to consider a world where commercial earthquake insurance, which is still relatively available in New Zealand, is no longer available or affordable. In this scenario people’s risk ownership is fundamentally different from current conditions.

Multi-criteria component

The multi-criteria component of the DST includes the overall desired objective the decision maker hopes to achieve, the orienting priorities that underpin that objective, and the detailed criteria that allow decision makers to rank the relative merits of the alternatives being evaluated (Figure 1). In the first DST prototype, the authors established *a priori* the objective, priorities, criteria, and alternatives. It is possible to do this as a collaborative process with decision makers, which is an area for further testing and refinement as the model develops.

The objective of projects evaluated using the DST is to enhance seismic resilience. The priorities were also aligned with stated QuakeCoRE vision to reduce the impacts of seismic events and increase recovery capabilities for thriving communities.

There are three priorities in the current iteration of the DST: Reduce, Recover, Thrive. **Reduce** refers to actions taken to lessen the impacts of a disaster, including building strengthening, physical infrastructure improvement, and actions that reduce social vulnerabilities. Drawing on earthquake engineering standards (Mander & Huang, 2012) , the criteria for the ‘Reduce’ priority area were death, damage, and downtime (Table 1).

Table 1: Criteria for the Reduce Priority.

Criteria	Condition for meeting criteria
Reduces deaths (Deaths)	A substantial reduction in deaths could be reasonably anticipated.
Reduces damage (Damage)	A substantial reduction in damage to the built or natural environments.
Reduces downtime (Downtime)	A substantial reduction in anticipated financial losses and business interruptions.

Recover refers to the priority area in the period after the immediate crisis has settled, and activities focus on rebuilding and renewal (Table 2). The criteria were adopted from the Ministry of Civil Defence and Emergency Management's (MCDEM) recovery framework, which covers five capitals: Built, Economic, Social, Cultural, and Natural (MCDEM, 2005). In the MCDEM Recovery Framework capability is defined as capacity plus delivery (MCDEM, 2005). Capability requires planning and the wherewithal to implement and adapt plans through cooperation and coordination.

Table 2: Criteria for the Recovery Priority.

Criteria	Condition for meeting criteria
Supports capabilities for economic recovery (Economic)	Promotes, assists, or enables the return of business and the economy functionality.
Supports capabilities for social recovery (Social)	Promotes, assists, or enables individuals to continue functioning in the wider community by establishing a safe environment and the provision of health, welfare, and education.
Supports recovery of the natural environment (Natural)	Promotes, assists, or enables the regeneration of the natural environment in areas affected by the earthquake and minimizes impact of recovery activities (such as waste management and the demand for resources from the rebuild).
Supports recovery in the built environment (Built)	Promotes, assists, or enables recovery of the built environment including buildings, housing, transport, and infrastructure.
Supports cultural recovery (Cultural)	Assists in restoring cultural identity including heritage, history, sports and recreation, traditions and the arts of the impacted areas.

The priority area **Thrive** captures the ability of communities to prosper in an inclusive and sustainable world. Thrive refers to the state of communities during non-disaster periods. The criteria for Thrive were generated from the Treasury's Higher Living Standards Framework (LSF) which was

designed to generate holistic thinking about the impacts of policy decisions (The Treasury, 2014). The LSF was designed to be adapted to different contexts, and can be applied holistically or allow users to focus on certain components (Au & Karacaoglu, 2015). As such, the five primary dimensions of the LSF were adapted down to three for the DST: Prosperity, Sustainability, Inclusiveness.

Table 3: Criteria for the Thrive Priority.

Criteria	Condition for meeting criteria
Promotes economic growth (Prosperity)	Supports macroeconomic stability and meaningful employment.
Supports natural resource management for current and future generations (Sustainability)	Supports sound management of environmental resources and kaitiakitanga responsibilities under the Treaty of Waitangi.
Contributes to social cohesion and equity (Inclusiveness)	Provides opportunities for economic and social participation across all sectors of society.

System for Scoring and Weighting

The DST prototype uses a local scoring system, wherein the alternatives are compared to each other in terms of how well they would fulfil each criterion. The alternative that is determined to fulfil a given criterion most completely is scored 10, and the alternative that will do the worst job of fulfilling a criterion is scored 0. More than one project can receive a given score (including 0 or 10) if they would result in an identical outcome (Figure 2).

Score Alternatives against criteria						
	Criteria	Water System	Historic Buildings	Seismic Research	Health Care	EQC Fund
1.1	Reduce deaths	10	8	0	8	5
1.2	Reduce damage	2	10	0	1	2
1.3	Reduce downtime	10	6	0	5	5

Figure 2:- Example scoring matrix for the Reduce priority area.

Output

The output used to make decisions comes from the performance matrix which shows the results of the scoring and weighting process. This is accompanied by auto-generated charts that help decision makers visualise components of the decision process.

It is important to note that the scores are indicative rather than definitive. They should support decision making rather than compel the selection of the highest or lowest scoring projects. To this end, the selection of more than one project for a portfolio affords decision makers the opportunity

to think further about the attributes they want to include and make trade-offs or compensate between attributes of each project.

The DST follows a linear additive model for the scoring and weighting system (Figure 3). Weighting the priorities and criteria is done through a three-step process (Department for Communities and Local Government, 2009; Belton, 1990; Goodwin & Wright, 2002). It is the most commonly used MCDA method and suitable for the DST as the criteria were not preferentially dependent nor was uncertainty built into the model (Triantaphyllou, 2000; Department for Communities and Local Government, 2009; Belton & Stewart, 2002). In other contexts, the DST could use a different scoring system from among the numerous MCDA variations depending on the resources and time available.

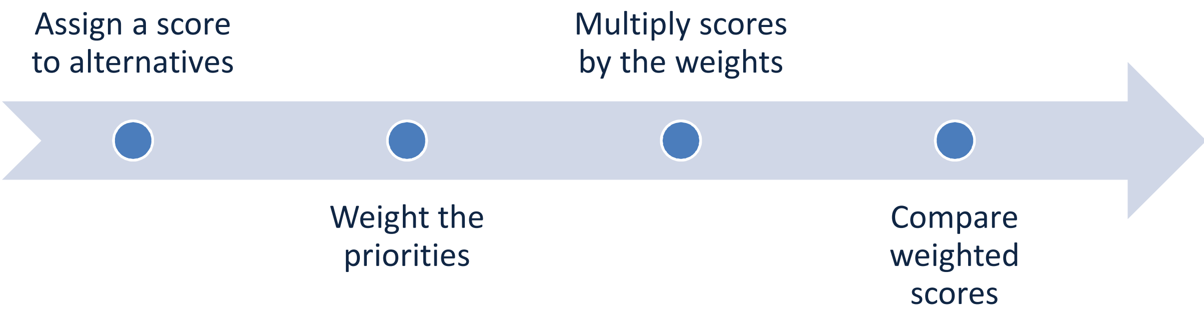

Figure 3: Scoring and weighting process.

In the first step the alternatives are scored. In Figure 4, scores given by workshop participants for each alternative can be seen for three criteria. If two or more alternatives would fulfil a given criterion equally, for example by reducing deaths by the same number, then they would receive the same score. After assigning a high and low score (10 and 0) the remaining alternatives are scored relative to those extremes as in the example.

Score Alternatives against criteria						
	Criteria	Water System	Historic Buildings	Seismic Research	Health Care	EQC Fund
1.1	Reduce deaths	10	8	0	8	5
1.2	Reduce damage	2	10	0	1	2
1.3	Reduce downtime	10	6	0	5	5

Figure 4: Relative scoring example.

Second, decision makers determine weights for each priority area that represents the relative importance of each priority within the model. For example, in the DST a decision maker may

determine that Reduce = 30, Recover = 20, and Thrive = 50. In this case 'Thrive' is 2.5 times more important than Recover. In the DST the priority weights must add up to 100.[3]

Third, the criterion within each priority area is allocated points totalling 100 (see Figure 5). In the DST Excel sheet the points allocated to a priority area are divided by 100 then multiplied by the Weight for that Priority Area (30/100*40 = 12) such that the "Actual Weight" adds up to the Weight for that Priority Area (Figure 5).

Apply weighting to criteria							
Priorities	Weight		Criteria	Point Allocation	Remaining Points Out of 100	Actual Weight	Less than or Equal To:
1. Reduce	30	1.1	Reduce deaths	50	0	15	100
		1.2	Reduce damage	30		9	
		1.3	Reduce downtime	20		6	
						30	

Figure 5: Actual weight per criterion.

As the numbers are added to the "Point Allocation" column the adjacent column would update to show the remaining points (
Figure 6).

Apply weighting to criteria					
Priorities	Weight		Criteria	Point Allocation	Remaining Points Out of 100
1. Reduce	30	1.1	Reduce deaths	50	0
		1.2	Reduce damage	30	
		1.3	Reduce downtime	20	
2. Recover	20	2.1	Improves economic recovery	30	20
		2.2	Improves social recovery	30	
		2.3	Improves recovery of the natural environment	20	
		2.4	Improves recovery in the built environment	0	
		2.5	Improves cultural recovery	0	
3. Thrive	50	3.1	Promotes economic growth	0	100
		3.2	Supports natural resource management for current and future generations	0	
		3.3	Contributes to social cohesion and equity	0	

Figure 6: Weighted criteria points allocation.

[3] For the DST, an Excel sheet was programmed with conditional formatting so the figure at the bottom of the Weight column would show the cumulative total with the cell turning green when the total reached 100, otherwise it would be red.

The total weighted scores are displayed with a colour-coded matrix (
Figure 7) – red showing lowest scores, shades of blue for middle scores, and shades of green for the highest scores. Scores can only be compared across in this matrix because of the weighting system.

	Total Weighted Score for Each Priority Area				
	Water System	Historic Buildings	Seismic Research	Health Care	EQC Fund
Reduce	249	210	12	150	135
Recover	146	110	156	132	76
Thrive	265	100	355	500	195
Total	**660**	**420**	**523**	**782**	**406**

Figure 7: Colour coded output scores.

The performance matrix shows total scores for the alternatives at the bottom (Figure 7). The performance matrix where the weight assigned to a criterion is multiplied by the score for that criterion relative to each project.

The scores cannot be compared vertically in
Figure 7 or Figure 8 (i.e., decision makers cannot compare across the priority areas using the performance matrix). To facilitate comparisons of the alternatives between the priority areas the total score for each priority area was divided by the total possible score for each priority area and converted to a percentage. The chart shown in Figure 9 demonstrates how the DST uses visualisation tools to facilitate in-depth comparisons of the various elements of the decision.

Performance Matrix				Unweighted Rating					Weighted Score				
Priorities		Criteria	Weight	Water System	Historic Buildings	Seismic Research	Health Care	EQC Fund	Water System	Historic Buildings	Seismic Research	Health Care	EQC Fund
1. Reduce	1.1	Reduce deaths	15	10	8	0	8	5	150	120	0	120	75
	1.2	Reduce damage	9	5	10	0	0	0	45	90	0	0	0
	1.3	Reduce downtime	6	9	0	2	5	10	54	0	12	30	60
		Total Priority Score		*24*	*18*	*2*	*13*	*15*	*249*	*210*	*12*	*150*	*135*
		Highest Possible Score	*300*										
2. Recover	2.1	Improves economic recovery	6	8	8	10	7	6	48	48	60	42	36
	2.2	Improves social recovery	4	8	10	2	3	0	32	40	8	12	0
	2.3	Improves recovery of the natural environment	4	4	5	8	10	0	16	20	32	40	0
	2.4	Improves recovery in the built environment	4	10	0	9	8	6	40	0	36	32	24
	2.5	Improves cultural recovery	2	5	1	10	3	8	10	2	20	6	16
		Total Priority Score		*35*	*24*	*39*	*31*	*20*	*146*	*110*	*156*	*132*	*76*
		Highest Possible Score	*200*										
3. Thrive	3.1	Promotes economic growth	15	2	0	5	10	3	30	0	75	150	45
	3.2	Supports natural resource management for current and future generations	15	5	0	8	10	2	75	0	120	150	30
	3.3	Contributes to social cohesion and equity	20	8	5	8	10	6	160	100	160	200	120
		Total Priority Score		*15*	*5*	*21*	*30*	*11*	*265*	*100*	*355*	*500*	*195*
		Highest Possible Score	*500*										
							Total Score		660	420	523	782	406

Figure 8: Performance Matrix.

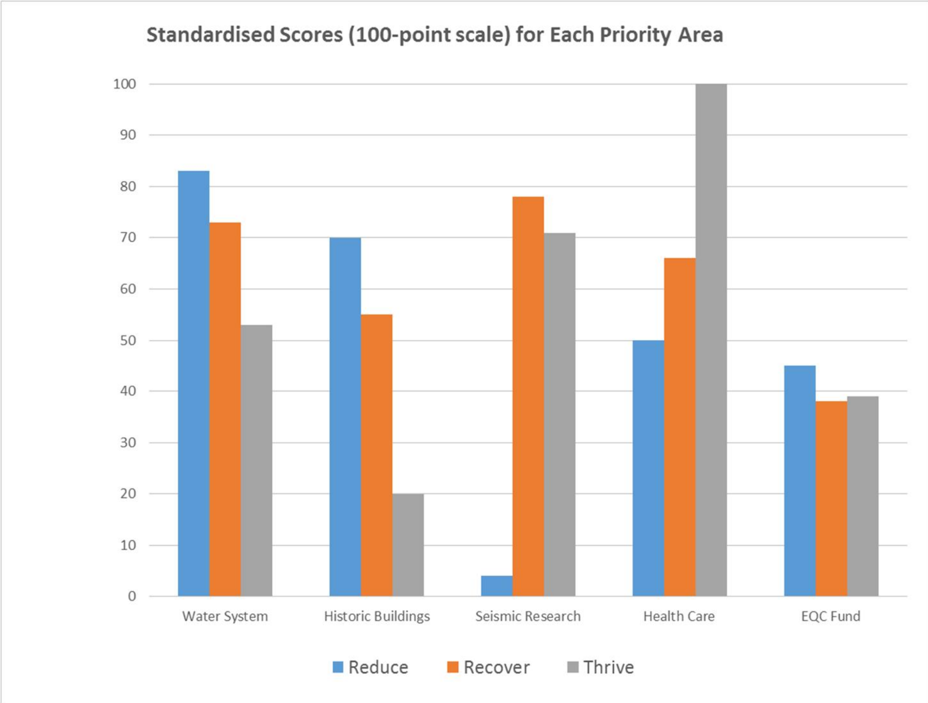

Figure 9: Standardized Scores.

It is important to keep in mind when comparing across the priorities that although the scores are standardized they are generated based on different criteria. Therefore, these standardized scores were useful as a guideline for roughly how projects did in one Priority Area compared to another.

Testing and refining the Decision Support Tool

The tool was first trialled as a prototype in a workshop at the QuakeCoRE Annual Meeting in August 2016. The aim was to get feedback on the process in general and evaluate how the participants engaged with the weighting and scoring system and the future scenarios. The workshop participants were primarily academics and practitioners who were knowledgeable about risk and resilience, but not necessarily familiar with the multi-criteria process itself. This demographic allowed us to focus on the DST without also having to explain fundamental concepts such as the meaning of risk, resilience, vulnerability, or hazard as most participants would be familiar with those concepts. At the workshop, approximately 25 participants were divided into four groups with an appointed group leader.

The workshop lasted three hours. As the workshop participants were not actually making a decision, the context and content were presented to them as part of the overall scenario.

The Workshop Process

The workshop followed a 7-step process:

Individually participants,

1. Choose their top-3 alternatives out of five;

In groups participants,

2. Familiarize themselves with the context and their future scenarios;
3. Score projects for their relative effectiveness at fulfilling each criterion;
4. Weight priorities;
5. Review top-scoring projects against initial instincts and current preferences – reflect on the differences;
6. Decide on top-three projects for the group's portfolio;
7. Share results and feedback.

Alternative selection (step 1) establishes a baseline estimate of the participant's decision making priorities without the influence of a group, and before examining their preferences for each priority area. The projects were explained to the participants as a group with a PowerPoint presentation and with handouts for each person. Participants were given three plastic chips each worth "$50 million", which they could allocate to one of five projects by dropping their chips into a labelled cup in the centre of each group's table. The cups were collected and the chips counted first for each group and then combined to show the entire workshop's initial preference.

In step 2, all groups were given the same overall context then groups were randomly assigned a future scenario. Participants were given several minutes to read and reflect on their future scenario,

and facilitators clarified points as needed. Participants were instructed to refer to their scenario during the decision making process.

Project scoring (step 3) was first explained by the facilitator. The participants were instructed to reach consensus on the score for each project with the assigned group leader able to make an executive decision to settle disputes and manage time.

Then participants were instructed to weight the three priority areas (Reduce, Recover, Thrive) (step 4). As with the scoring component consensus had to be reached and the group leader had permission to make a final decision to keep the process moving.

Participants reviewed the outputs of the DST in step 5. This process allowed the facilitators to present the results using several formats (e.g., a performance matrix, a summary table, histograms, and a spider chart) and to evaluate which was interpreted most clearly by participants. Using the outputs as a guide, participants discussed and reached consensus on their top three projects (i.e., they chose their portfolio – step 6). In their final decisions, participants considered both the final scores and the input that went into generating the scores. In the final decisions, much greater weight was given to projects that offered "co-benefits" with other hazards and enhanced thriving in the community.

The process ended with a group discussion and assessment of the DST workshop (step 7). The discussion was initially framed around the way the DST process had shifted the portfolio mix decided at the start of the workshop. We can see an absolute drop in support for strengthening historic buildings and a substantial drop in support for earthquake insurance and equality among water, health, and research (Figure 10).

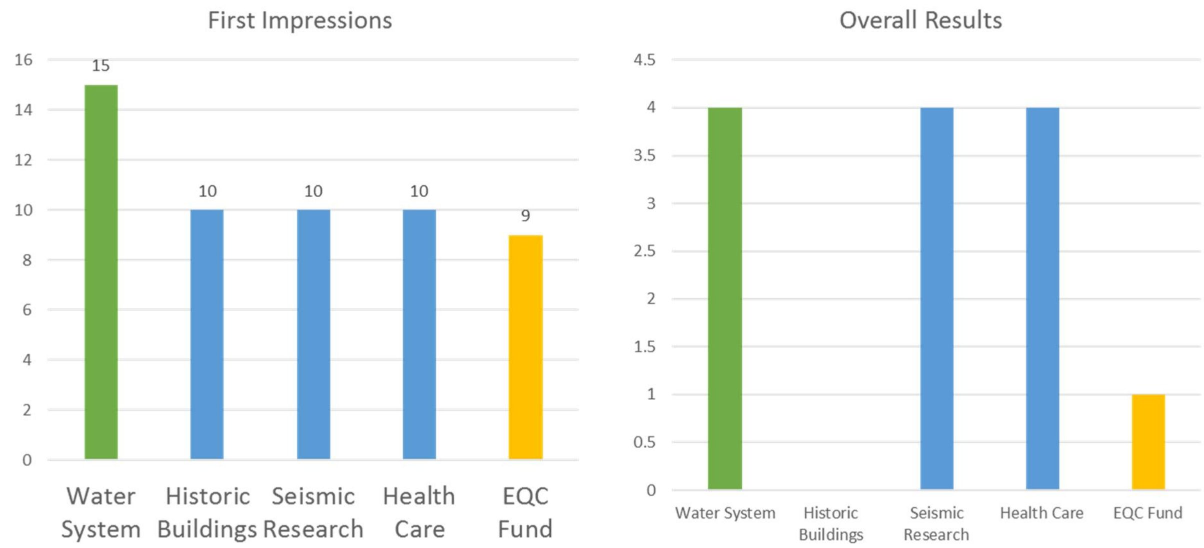

Figure 10: First impressions vs Overall results.

Reflections on workshop participants' evaluations of the DST

Feedback from participants is considered an important part of the ongoing DST development and is essential for refining the methods used to test the DST. *Participants wanted more details about the alternatives and more time to review them.* In future uses it may be beneficial to use a familiar example, such as the Cathedral in Christchurch, where the participants can generate a strong impression for the practical issues and implications based on their own experiences.

Participants wanted more time to reflect on the scenarios in the beginning before the groups were assembled. Future use of the DST could employ more detailed scenarios or, if enough time is available, scenarios could be developed by the participants themselves as in scenario planning exercises (Wade, 2012). Additionally, scenarios can be co-created by the facilitator and participants (Bradfield, Wright, Burt, Cairns, & Van Der Heijden, 2005). For example, the raw data from the climate change scenarios could have been provided by the facilitator, and the participants would then discuss and generate a relevant future scenario (Amer, Daim, & Jetter, 2013).

Participants wanted greater clarity about the decision making context. Future scenarios and selected alternatives will unfold differently in different places. The way facilitators develop and present scenarios also needs to be conscious of the knowledge and interests of the participants. For example, if the DST were used with a community group or even local council officials it could be expected that they are highly knowledgeable about the local context but would need more time and instructions on the priorities and criteria.

The assumptions behind the criteria need to be made explicit and alternative and additional criteria may need to be selected. Participants identified mutual dependencies between criteria; for example, a thriving community might be better positioned to recover from other non-seismic hazards and future disasters. Additionally, a participant noted that criteria for the priority area "Reduce" is based on earthquake engineering principles. This may be limiting and difficult to measure for non-structural interventions. Additionally, participants noted that dividing recovery capabilities across the five capitals created redundancy.

Incorporate more explanation about the relative scoring system. Many participants noted that the scoring and weighting systems provided an excellent basis for concrete discussions about seismic resilience. For some, however, it was counterintuitive for a score of 0 to be meaningful.

Explore ways to better visualise the decision-making process. The way users can engage visually with the material throughout the decision-making process can be enhanced, although the workshop setting presents limitations. The use of a portfolio of several projects is designed to allow participants to understand the trade-offs between different decisions. However, while the outcomes for each criterion were displayed in the decision matrix, only the outcomes for priorities were displayed in the charts and graphs. This was a practical choice for running the DST in a workshop environment, as each user did not have access to a large computer display to view the many charts and graphs that would be necessary for conducting a criteria-level comparison of trade-offs.

If using the DST with participants who are co-creating the criteria and priorities with the facilitators, it would be beneficial to allow participants to visualise more details on the trade-offs their decisions make at the criteria level. Such a process would need to account for the logistical demands of such detailed visualisation in a group setting.

The DST has value as an engagement tool. Participants at the workshop expressed positive feedback about being part of the decision making process under the DST. They felt it gave them a chance to reflect and give voice on a decision that could quite reasonably be a part of their life. Additionally, the use of future scenarios challenged them to think broadly about how their decision making for seismic resilience might intersect with and be impacted by other hazard types and social outcomes. This reflects an emerging area of usage for MCDA and scenarios as a tool for stakeholder engagement within a decision making process. There is an emerging field of literature on their use for community engagement and capacity building as part of a decision making process involving deep uncertainty (Sheppard, et al., 2011; Shaw, et al., 2009). In this space, the scenarios are not just a part of project decision making but also learning via structured public engagement with the decision making process. The prototype developed for the workshop would be suited for use with community groups to get feedback on what they feel is important (for example, on the priorities and criteria), the sort of projects they would be willing to support in their community, and how they perceive the risks they face.

Neither MCDA nor future scenarios guarantee a pathway to the “right” decision. Rather, they provide a systematic, robust, engaging, and transparent process for helping to choose between decision outcomes (Majumder, 2015). The decision to use a technique can be determined by the time available, the resources and data available, the types of decisions being made, the skill of the analysts facilitating the process, and legal requirements of the organisations involved (Department for Communities and Local Government, 2009). Future developments of the DST, in particular for real world problems, would necessarily be guided by these conditions.

Conclusions

The prototype DST for seismic resilience combines future scenarios with MCDA to aid decision making on a very long timeline. This is a unique combination that brings together strategic and practical decision making tools. The components such as the future scenarios, priorities, criteria, and outputs can be adapted to meet the needs of different users and contexts.

Overall the workshop trial for the prototype revealed areas for improvement and identified new areas to implement such a process. Feedback from the participants was very positive about the use of future scenarios together with MCDA and future variations are likely to further develop this pairing. Recommendations for future use based on the first trial run include:

- **Utilize specific cases with unique local context –** Workshop participants felt a specific locale would help them understand the implications of the scenarios and decision making. For example, a city with a historic buildings precinct constructed with unreinforced masonry would be vulnerable to a major seismic event and is easy to imagine the local context.
- **Give sufficient time for each component –** Decision making takes time, even in workshops when the stakes are zero. This applies especially with consensus-based decision making – from the discussions emerged valuable reflections by the participants about their own assumptions, biases, and preferences. Ample time should be given to demonstrating the scoring section with examples.
- **Leverage the difference between principles and practice –** the orthodoxy within MCDA literature is for the priorities and criteria to be mutually exclusive. In practice this was very difficult to achieve and some overlap had to be accepted. The group discussions about the priorities and criteria however were very valuable aspects of the decision making process as they compelled each participant to articulate how they understand each component. This revealed some striking differences in interpretation which would not have been possible if the components were taken at face value.
- **Refine the components –** to focus the DST towards seismic resilience it would be helpful to develop a clearer meaning of the concept and what it entails in practice. Using the DST with a group of stakeholders engaged with seismic resilience in practice would be a good means of developing robustness in the DST.

This DST can be part of a dynamic engagement process, particularly when combined with future scenarios. Recent application of MCDA and future scenarios for situations with deep uncertainty demonstrate that stakeholder engagement and public participation are areas with strong potential for further use. Those impacted by a decision could readily reveal their preferences and priorities by going through the MCDA process – the outputs from a stakeholder workshop would be informative and fed into the formal decision making process. Additionally, by integrating criteria covering multiple capitals, decision makers must explicitly state whether or not certain aspects will be prioritized or minimized thereby making it clear to all other stakeholder groups what the decision makers are focusing on, or neglecting.

As the DST evolves, it would be useful for the developers to further explore the concept and attributes of seismic resilience itself to understand its dimensions and implications. For example,

one attribute is the propensity toward physical interventions for developing seismic resilience. During the trial run we saw a shift from preferences for physical to social interventions only after the participants had multiple alternatives with very different attributes put before them and the opportunity to consider and articulate their preferences.

In its current form the DST makes use of several unique features to make deep uncertainty comprehendible to decision makers rather than analysts – namely, the use of multiple future scenario and making trade-offs by selecting multiple alternatives simultaneously. This process could arguably be used for other types of decision making scenarios under deep uncertainty. To further develop the tool it would be useful to have greater clarity on the choices available for seismic resilience in practice to better demonstrate alternatives, implications, and costs involved. Additionally, with greater insights on the nature of seismic resilience the priorities and criteria could be refined – this would put constraints on part of the MCDA process but the trade-off would be made with greater clarity of the concept and a more specific and streamlined decision support tool.

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Appendices

Appendix A – Future scenarios

The following are the future scenarios as presented at the workshop. Each scenario explored outcomes over a 20-35-year period.

A World of Business as Usual

In this scenario the world will continue much as it is now.

The Treasury predicts stable increases in GDP and population growth. The country will try to balance an aging population with a steady intake of young immigrants. There will be the usual economic downturns and upswings. Suburbs in the major cities will continue to grow as bedroom communities become small cities within themselves.

Transport systems will develop to not only accommodate the population but also technological developments in self-driving cars and communication systems. In the post-Global Financial Crisis world governments will be much more cautious of booms and take pride in slightly more conservative fiscal management.

Old trade relationships will give way to closer regional ties and the economy will adapt to suit the new markets. Natural resources, agriculture, and tourism will continue to be important parts of the New Zealand economy while IT and financial services will contribute more and more to GDP.

In terms of natural hazards this period will be not unlike the post-war years in New Zealand – some major weather-related disasters and a few moderate earthquakes but always with the potential for "the big one".

With this future in mind how would you prioritize the main components of the decision making framework – Reduce, Recover, Thrive? In this future what sort of projects would contribute the most to seismic resilience?

A World Without Commercial Earthquake Insurance

The decades between now and 2035 will be a wild ride for the global insurance industry.

The Great Los Angeles earthquake of 2018 will be the first of the shocks to hit the industry, followed in quick succession by large earthquakes in Vancouver and Santiago the following year. The industry will then have to contend with a series of large typhoons in Asia. For a while it will appear the industry will pull through, until the 2022 Yokohama quake south of Tokyo, which will not only cause great physical damage and loss of life, but also send turmoil right through the world financial markets.

Over the next few years there will be a number of high profile collapses of large global reinsurers, as well as scores of local insurers. For New Zealand, this will lead to a rise in the cost of insurance, and earthquake insurance in particular, will become prohibitively high. We will face a situation where 70% of commercial property owners may become uninsured for earthquakes. Homeowners will remain insured through EQC, but there will be serious concerns about EQC's ability to pay in the event of an earthquake with difficulties securing adequate reinsurance and managing payouts. Some market analysts predict that by 2050 the earthquake insurance market will have disappeared in New Zealand.

Imagine this future and consider the decisions you will have to make. How would such a scenario impact the ratio you decided for Reduce-Recover-Thrive? What sort of projects would you select?

A World of Unchecked Climate Change

By the year 2035 inaction within the global community will result in the actualisation of the more extreme predicted impacts of climate change.

For all the hope and promises that emerged from the 2015 Paris Climate Change Accord, little will actually take place. By 2035 we will see the effects of that inaction with rising sea levels, more frequent and more severe storms, and extended droughts.
The snowline will rise by 100-200 meters and glaciers will continue their rapid retreat. Flood protection and sewage systems will regularly experience failure due to the demands of storms and flooding and dams and bridges will need to be reassessed in light of increased water flows.

While warmer winters and higher CO2 concentrations will have some positive impacts on farming, once profitable crops such as kiwi fruit will no longer be grown in Northland and many areas of the Waikato. Invasive plant species will prove to be more adaptable to these new conditions with many native flora heading towards extinction.

From 2035 to 2050, communities near the Southern Alps will be advised to brace themselves for increased flooding, erosion, and landslides; the low-lying areas of the east coast will experience increasingly severe water security issues; the Bay of Plenty region will struggle to manage the impact rising sea levels will have on roads and natural areas of commercial and cultural significance.

With this future scenario in mind it is time to make some decisions.
To what extent does a future with heightened risk from weather-related hazards impact your decisions about seismic resilience? Some issues to think about as you create your portfolio - the extent to which your projects will be sustained over the long run given competing demands for managing weather-related hazards and the co-benefits you might be able to generate with different project portfolios.