Pre-Print Version
Cite as: Brown, C., Seville, E., Vargo, J. Measuring the organizational resilience of critical infrastructure providers: A New Zealand case study, International Journal of Critical Infrastructure Protection (2017) 10.1016/j.ijcip.2017.05.002

Available online at: http://dx.doi.org/10.1016/j.ijcip.2017.05.002

Measuring the organizational resilience of critical infrastructure providers: A New Zealand case study

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Abstract

There is a growing societal dependence on critical infrastructure services. Our dependence is not only on the technology itself but also on the organizations that manage that infrastructure. Initiatives assessing the resilience of infrastructure often concentrate on strengthening the physical infrastructure through robustness and redundancy. Few studies recognize the important role of the critical infrastructure organizations themselves. This study presents a method for assessing the organizational resilience of critical infrastructure organizations. It demonstrates the method using data from a group of critical infrastructure providers in New Zealand. Using the Resilient Organisations Benchmark Resilience Tool, the study finds that the surveyed organizations are strong in effective partnerships but are weak in breaking silos and stress testing plans. In addition, the study found that senior managers have a significantly more positive view of their organization's resilience than other staff members.

Keywords

Organizational resilience; critical infrastructure resilience; benchmarking resilience; measuring resilience; resilience indicators

1 Introduction

Critical infrastructure services, by definition, are crucial to the functioning of our communities. Critical infrastructure services can include a range of services

including water, wastewater, telecommunications, energy, and transportation (road, rail, airport, port). Increasingly our dependence on infrastructure is growing through factors such as increased urbanization and technological advancements [1]. Our infrastructure systems are already significantly interdependent [2] and vulnerable to cascade failures [3].

Infrastructure disruptions can have significant impacts on all aspects of our society: communities lose essential services, businesses face reduced operating ability [4], [5] and there are high economic costs of both the disruption and repair and restoration of services [6], [7]. The impacts of infrastructure disruptions are only going to rise with the increased frequency, severity and complexity of hazards globally.

In an effort to reduce the frequency and extent of infrastructure disruption, there is growing attention on improving the resilience of critical infrastructure, both in New Zealand and around the world. Internationally, resilience initiatives include: Critical Infrastructure Resilience Programme (United Kingdom); Trusted Information Sharing Network (Australia); National Infrastructure Protection Plan (United States).

In New Zealand, there is clear legislative and policy imperatives for critical infrastructure organizations to improve their resilience. Under the New Zealand Civil Defence and Emergency Management (CDEM) Act 2002, each Lifeline Utility[1] has a responsibility to "ensure that it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency". In the early 1990s, New Zealand established regional lifeline groups to enhance preparedness and coordination of Lifeline Utilities[8]. Regional lifelines groups are now active across most regions of New Zealand and at a national level there is a New Zealand Lifelines Committee. In 2011, the New Zealand Government released a National Infrastructure Plan [9]. The plan comprises six guiding principles: one of which is resilience.

To fully develop their resilience, critical infrastructure providers need to build and maintain infrastructure that can withstand hazards, *and* they need to build the capacity of their organizations to cope with crises. The New Zealand National Infrastructure Plan [9] identifies that both physical and system resilience are necessary to ensure that national infrastructure networks are able to deal with significant disruption and changing circumstances. A 'future direction' identified in the Plan to improve infrastructure resilience is: "Organizations and networks of organizations with the ability to identify hazards must share information, assess vulnerabilities, and plan for and respond to emergencies"(p14). In addition, the New Zealand National Infrastructure Unit identified eight attributes

[1] Lifeline Utilities as defined in the CDEM Act are Gas suppliers (bottled and network), Electricity (network and distribution), Water supply, Wastewater (network and disposal), Stormwater (network and disposal), Telecommunications, Road networks, Fuel, Rail network, Airport, Port and Radio NZ and Television NZ.

of resilient infrastructure, one of which was organizational performance (leadership and culture) [10]. The Australian government also identify organizational resilience as one of the four key outcomes of their resilience strategy [11].

Despite the recognized importance of organizational resilience on critical infrastructure resilience, there have been limited studies that assess the organizational resilience of infrastructure providers. This paper presents a method for benchmarking the resilience of critical infrastructure providers. The method is demonstrated using a regional lifeline group in New Zealand in 2014. In particular, the method assesses:

1. The relative resilience strengths and weaknesses of critical infrastructure providers surveyed,
2. The preparedness levels of critical infrastructure organizations,
3. The key risks critical infrastructure organizations face, and
4. The interdependencies of the infrastructure organizations.

This paper presents the results from the case study and discusses the interpretation and transferability of the resilience benchmarking method to other contexts.

2 Background

2.1 Measuring critical infrastructure resilience

Measurement of the resilience of critical infrastructure is an emerging field. The majority of measurement approaches tend to focus on the technical attributes of an infrastructure system – that is the conditions and design of the physical assets and operational systems (for example see Renschler et al. [12] and Vugrin et al. [13]). Few studies look at the socio-technical attributes of critical infrastructure resilience such as organizational resilience.

The capacity of critical infrastructure organizations to prepare for and respond to crises is a vital element of critical infrastructure resilience [9], [11]. With limited resources and foresight to plan for every eventuality, infrastructure services will inevitably fail. And when the systems do fail, the timely and successful restoration of services is dependent on organizations to respond effectively.

A number of authors have conceptually included organizational resilience in frameworks for assessing infrastructure resilience, sometimes as a subset of community resilience [2], [14]–[16]. Bruneau et al. identify organizational resilience as a key dimension of infrastructure (and therefore community) resilience [17].

The authors are aware of only a handful of studies that have attempted to quantify the organizational resilience of critical infrastructure providers. Cimellaro et al. applied Bruneau et al.'s conceptual framework to make a quantitative assessment of the resilience of hospital infrastructure in California

[18]. Francis and Bekera, proposed a resilience measurement framework based on the principles of absorptive, adaptive and restorative capacity that integrates both technical and organizational components. They go on to apply the framework to a fictional electricity network [19]. Hughes & Healy [20] recently developed a prototype resilience assessment tool to measure the resilience of transport infrastructure in New Zealand. The multi-criteria assessment tool incorporated both technical resilience attributes (centred around the principles of robustness, redundancy and safe to fail) and socio-technical attributes (in the form of organizational resilience attributes) [20]. The framework is one of the first known attempts in New Zealand to bridge these two dimensions of resilience.

2.2 Organizational resilience

Organizational resilience, in particular resilience measurement, is an emerging field. Organizational resilience research integrates a number of more established research and practice areas including risk management, business continuity, disaster management, operations management, engineering and safety, leadership and change management. Essentially, resilience is the ability of an organization to plan for and adapt to crises, in order to both survive and thrive in a world of uncertainty [21].

In 2013, Resilient Organisations developed an organizational resilience benchmark tool. The tool was developed over a number of years based on literature review, in-depth case studies [22] and a prototype survey of 68 organizations (249 individuals) in New Zealand [23]. The resultant tool contains 13 leading indicators of resilience. Leading resilience indicators measure attributes that are thought to contribute to the organization's resilience. They help an organization identify their strengths and weaknesses before a crisis happens [23].

The 13 leading indicators, see Figure 1, are grouped into three attributes for communication purposes – leadership, change readiness and networks. In Lee et al.'s study [23], a factor analysis of the responses identified two key dimensions across these 13 indicators: planning and adaptive capacity.

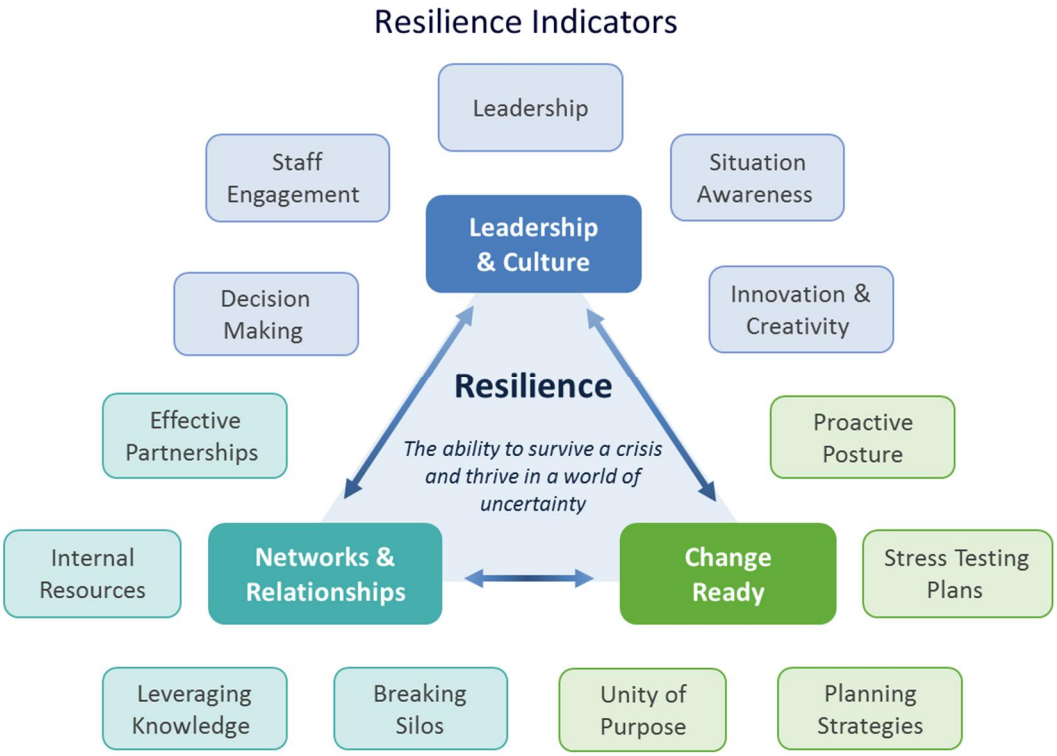

Figure 1 Leading indicators of organizational resilience (www.resorgs.org.nz)

2.3 Critical infrastructure sector in New Zealand

To provide context to the results of this study, it is important to understand the nature of the critical infrastructure sector in New Zealand. Infrastructure providers have a range of ownership models in New Zealand. Local government authorities generally manage water, wastewater and stormwater networks (including supply and distribution). Electricity and gas suppliers and network operators can be either state owned enterprises or privately operated. Generally, electricity supply systems are divided into subsystems of generation, high voltage transmission, local network / distribution and retail supply. As a result, energy supply in a given location can rely on as many as four different organizations. Phone and data providers are private and generally own their own network infrastructure. Fuel providers are privately owned. Road networks are owned and operated by either national (for national roads) or local (for regional roads) government authorities. Port, rail and airport infrastructure is generally owned and operated by state owned enterprises. These ownership structures influence some of the analysis approaches taken in this paper and the transferability of the results to other contexts.

As noted earlier, critical infrastructure provider preparedness is a legislative requirement in New Zealand. As a result, significant efforts have been made to reduce utility vulnerability through the establishment of regional lifeline groups. Critical infrastructure providers within a region join regional lifelines groups on a purely voluntary basis, to work together to collectively improve their preparedness to crises [8]. The lifeline groups provide a forum for networking

and relationship building, information sharing, vulnerability assessment of physical systems and emergency planning and testing. The work of the Canterbury Lifeline Group, as an example, has been attributed to reduced damaged and expedient lifeline recovery following the 2010/2011 Canterbury earthquake sequence, with infrastructure providers showing a good level of coordination, communication, effective mutual aid agreements and contingency measures [24].

Since the 2010/2011 Canterbury earthquake sequence the majority of lifeline utility operators in New Zealand have enhanced efforts in crisis preparedness. While the regulatory environment has largely remained unchanged, the experiences of utility organizations in Canterbury, and the extensive lesson sharing amongst lifeline providers, has contributed to a number of practice and research initiatives focused on improving the resilience of critical infrastructure. The emphasis for most providers is still, however, on improving the resilience of their built infrastructure to natural disasters, particularly earthquake.

This study assesses the organizational resilience of 18 critical infrastructure organizations that are members of the Bay of Plenty regional lifeline group, which is outside of the earthquake affected area[2].

3 Method

3.1 Benchmark Resilience Tool

As discussed earlier, the Benchmark Resilience Tool (BRT) [23] is based around thirteen indicators of resilience. For each indicator, a series of statements are given and respondents are asked to show, on a Likert scale, how much they agree with each statement.

Since the Benchmark Resilience Tool was validated in 2013, some minor improvements to the tool have been made. These include:

- Changing the Likert scale from a 5-point scale to an 8-point scale (ranging from strongly disagree to strongly agree).
- Changing the indicator name from 'external resources' to 'effective partnerships'.
- Making some minor wording changes and adding some additional questions for some indicators.

The effect of these changes on the reliability of the BRT is checked in the results section.

In addition to the resilience indicator questions, the BRT includes a range of other demographic and preparedness questions, ranging from respondent gender and age, to organization use of emergency plans, staff turnover and

[2] Note that the infrastructure providers in this study were from a region not affected by the Canterbury earthquakes. Some surveyed are part of nation-wide organizations, so may have been directly involved in the Canterbury earthquake response and recovery.

financial performance. Another important feature of the BRT is that it is designed to be both answered by senior managers and staff across an organization, so that an organization-wide view of resilience can be obtained. The surveys answered by managers and staff members are identical, except that senior managers are required to provide some organization specific demographic information.

A copy of the survey questions relevant to this project is included in the Appendix.

3.2 Survey deployment

This research was conducted in conjunction with the Bay of Plenty Regional Lifelines Group in New Zealand. All organizations that participated in the survey participants were members of the Bay of Plenty Lifelines Group. A senior manager from each organization (or organization department, if applicable) was approached via email and asked to complete a senior manager survey. Once the senior manager had completed the survey, an email was automatically sent to them with a web-link to the staff survey. The senior manager was asked to send this weblink to all, or a random selection of, staff members. Once a specified number of staff (as defined by the manager) had completed the survey, the survey was closed. A resilience report was then generated for each organization, summarizing the organization's resilience strengths and weaknesses, as well as a suggested action plan for improving that organization's resilience.

The survey was launched in June 2014. The Bay of Plenty Lifelines group sent weekly reminders to participants to encourage them to complete the survey.

3.3 Participation

32 organizations were invited to participate in the survey. Of these, 18 organizations participated giving a response rate of 56%. Of those 18, six organizations were Territorial Authority organizations (e.g. city or district councils) that own and operate transport and water services for their local territory. Three of the councils divided themselves up into departments and ran the survey separately for each department so that they could separate the different utility services (transport and water services) from other council functions. In total, 30 senior manager surveys were completed and 189 staff surveys.

To preserve confidentiality of results for individual organizations but to enable inter-organization comparisons, responses were grouped into four utility groups for data analysis and results processing:

- Electricity, telecommunications, gas and fuel – generation and retail;
- Electricity, telecommunications and gas – networks;
- Road (including Council transport departments), rail and port; and

- Water, wastewater and stormwater (also includes some Council support functions such as Human Resources, Finance etc)[3].

The above groups were selected based on the type of lifeline and service they provided and in a way that ensured three or more organizations were in each category. The division was made both by the utility service type and by the nature of the service delivered.

Survey participation is summarized in Table 1.

Table 1 Bay of Plenty Lifelines Group Benchmark Resilience Survey, participation rates

	Number of senior manager surveys	**Total number survey responses**
Total number of individual organizations	18	189
Total number of senior manager surveys*	30	
Survey response by utility type		
Electricity, telecommunications, gas and fuel – generation and retail	5	49
Electricity, telecommunications, and gas - networks	4	7
Road, rail, port	4	32
Water, wastewater and stormwater (including other Council departments)	17	101
* The total number of senior manager surveys is greater than the number of organizations because several councils divided into different departments for the survey, reflecting the fact that councils in New Zealand provide multiple infrastructure services, including roading, water, wastewater and stormwater infrastructure services.		

Note that for the remainder of the paper, when referring to 'organization' scores, this refers to the 30 different entities, which could be a whole organization or a department within a council.

4 Results

4.1 Benchmark Resilience Tool validation

Due to the changes made to the original Benchmark Resilience Tool, it is necessary to test the reliability of the revised tool before presenting the analysis results. The overall reliability of the full BRT scale was high: achieving a Cronbach's alpha of 0.959. This is notably greater than 0.7 noted by Hinkin as an absolute minimum for scale development [25].

All the indicator internal scales achieved Cronbach's alpha of >0.8, see Table 2. As part of ongoing verification of the tool, the effect of individual items on the

[3] Other council functions were grouped with water, wastewater and stormwater department responses because there were insufficient responses from water, wastewater and stormwater departments to report their results in isolation.

scale reliability was also checked. There were only three indicator questions that, if removed, would improve the Cronbach's alpha. These were:

- Breaking silos: "Staff are encouraged to move between different departments or try different roles to gain experience". Removing this item would increases alpha to 0.856.
- Internal resources: "When a problem occurs, it is easier to get approval for additional resources to get the job done". Removing this item would increase alpha to 0.893.
- Unity of purpose: "Our organization consistently demonstrates commitment to its values". Removing this item would change alpha to 0.922

The potential increases in scale reliability by removing these items are minor. Therefore, all scale items were retained for the analysis in this paper.

Compared to Lee et al.'s study [23], the reliability of the 'Planning' indicator scale has significantly improved. In Lee et al.'s original study, the item had a Cronbach alpha below 0.7. In this study, the results are much stronger, returning a high Cronbach alpha of 0.949. Originally this indicator only had two statements. The additional statements now included for this indicator have clearly improved the reliability of the results.

Table 2 Indicator scale internal reliability results

Indicator	Cronbach's alpha
Leadership	0.884
Staff engagement	0.874
Situation Awareness	0.916
Decision making	0.829
Innovation and Creativity	0.846
Effective partnerships	0.909
Leveraging knowledge	0.904
Breaking silos	0.829
Internal resources	0.891
Unity of purpose	0.921
Proactive posture	0.954
Planning strategies	0.949
Stress testing plans	0.874

A Kaiser-Meyer-Olkin (KMO) co-efficient of 0.957 for the data indicated that the data were suitable for factor analysis. A principal factor analysis, with varimax rotation, was then carried out. Unlike the Lee model [23], which found two underlying factors (planning and adaptive capacity), just a single factor emerged. This result does not necessarily preclude the presence of the two factors. The previous factor analysis was based on data from a range of different organization types. The emergence of a single factor could be a characteristic of critical infrastructure organizations. The presence and underlying causes of various resilience factors is the subject of further research.

In the following sections we use the Bay of Plenty case study findings to illustrate the ways the BRT results can be interpreted and used to provide insight into the patterns of resilience characteristics across participant organizations.

4.2 Overall resilience strengths and weaknesses

The average resilience scores for all organizations surveyed in this study, by indicator, are shown in Table 3. To help understand the significance of any differences between resilience indicator scores, a one-sample t-test[4] was carried out. The results showed that *effective partnerships* was statistically higher scoring than the other indicators. This means that effective partnerships is an area of common strength across the participant organizations. The weakest indicator, on average, was *stress testing plans*. However, this result was not statistically significant (indicating there was a significant spread in the responses). *Breaking silos* was, however, statistically significantly below the average score, indicating that this is an area of common weakness across the organizations.

The responses were also analyzed to determine whether staff viewed their organizational resilience differently to their senior managers. On average, senior managers scored their organization's resilience 11% higher than other staff members (76% and 65% respectively). This difference was statistically significant ($F(1,187)=11.476$, $p=0.001$).

Table 3 Indicator scale relative indicator strengths across all organizations

Indicator	Average score	t-test
Leadership	74.1%	t(29)=0.569, p=0.574
Staff engagement	75.2%	t(29)=1.200, p=0.240
Situation Awareness	74.5%	t(29)=0.794, p=0.433
Decision making	76.7%	t(29)=1.830, p=0.078
Innovation and Creativity	69.1%	t(29)=-1.701, p=0.100
Effective partnerships	77.6%	t(29)=2.303, p=0.029
Leveraging knowledge	75.4%	t(29)=1.125, p=0.270
Breaking silos	68.0%	t(29)=-2.148, p=0.040
Internal resources	70.4%	t(29)=-1.021, p=0.316
Unity of purpose	72.9%	t(29)=-0.053, p=0.958
Proactive posture	74.7%	t(29)=0.922, p=0.364
Planning strategies	76.0%	t(29)=1.325, p=0.196
Stress testing plans	66.7%	t(29)=-1.971, p=0.058
Total Resilience Score	*73%*	
To interpret a t-test score: if an indicator is statistically significantly different from the mean, then $p<0.05$. The 't' score indicates whether the indicator is higher than average (positive t value) or lower than average (negative t value).		

4.3 Relative performance based on utility type

[4] A Shapiro-Wilk test determined that the organization level indicator data was normally distributed and suitable for a one sample t test.

We also analyzed the data to see if there were any significant differences between the resilience of the four different utility types (Table 4): first for overall resilience and second by indicator.

To help us understand if the differences in overall resilience scores across the infrastructure types are statitistically significant we used the Kruskal-Wallis test. A non-parametric test was used because of the small number of organizations in three of the four infrastructure type groups. The Kruskal-Wallis test result showed no significant difference between the utility types' responses ($\chi^2(3)=5.354$, $p=0.148$).

In interpreting these results, it is important to note that the number of responses per organization was much lower in the electricity, telecommunications and gas network providers. This means that the scores have a higher proportion of senior manager responses than other utility groups. This may have had an inflationary effect on the scores: as noted in the previous section – senior managers scored their organizations on average 11% higher than staff.

Therefore, to test the effect of different staff response rates, the analysis was repeated but included only senior manager responses . Resilience scores increased for all utility groups, see **Error! Reference source not found.**. The Kruskal Wallis analysis shows that there is still no significant difference between resilience scores for each utility group ($\chi^2(3)=5.609$, $p=0.132$).

Next, differences between indicator scores were analyzed. The results show that electricity, telecommunications, and gas network providers scored higher than the other utility group types for all but one indicator (**Error! Reference source not found.**).

Again, given the small sample sizes in some of the utility groups, non-parametric tests have been selected. A Kruskal Wallis was carried out and the results showed significant differences in one indicator: *effective partnerships* ($\chi^2(3)=9.029$, $p=0.029$). *Proactive posture* was slightly outside the 0.05 significance level ($\chi^2(3)=9.029$, $p=0.058$). For *effective partnerships* a Mann Whitney test[5] showed that electricity, telecommunications and gas network organizations scored better than electricity, telecommunications, gas & fuel generation and retail organizations ($U=0$, $p=0.014$). For *proactive posture*, a Mann Whitney U test confirmed that the electricity, telecommunications and gas network providers scored higher than both water, wastewater and stormwater (Councils) ($U=7.5$, $p=0.018$) and electricity, telecommunications, gas & fuel supply and retail providers ($U=1$, $p=0.027$).

Table 4 Mean resilience indicator score by utility type

[5] A Mann Whitney test was used to confirm statistically significant differences between two of the utility types (the Kruskal Wallis determines whether there is a difference between any of the 4 utility type groups)

	Electricity, telecommunications, gas & fuel - generation and retail	Electricity, telecommunications and gas - networks	Road, rail, port	Water, wastewater and stormwater (and other council functions)
Number of organizations	5	4	4	17
Indicator	*Mean %*			
Leadership	76.2%	83.4%	77.4%	70.6%
Staff Engagement	74.2%	84.8%	78.2%	72.5%
Situation Awareness	70.9%	84.4%	75.2%	73.1%
Decision Making	77.1%	88.9%	76.1%	73.9%
Innovation and Creativity	65.8%	81.4%	75.4%	65.7%
Effective Partnerships	65.9%	87.9%*	77.9%	78.5%
Leveraging Knowledge	74.5%	88.1%	77.7%	72.1%
Breaking Silos	66.9%	82.0%	68.6%	64.8%
Internal Resources	65.5%	82.9%	74.1%	68.1%
Unity of Purpose	72.3%	87.3%	72.2%	69.8%
Proactive Posture	73.8%	86.1%*	77.8%	71.5%
Planning Strategies	68.4%	90.4%	77.2%	74.6%
Stress Testing Plans	64.0%	64.3%	71.7%	66.8%
TOTAL Resilience score	70.4%	83.9%	75.3%	70.7%
TOTAL Resilience scores (only senior manager responses)	79.7%	85.6%	78.2%	72.5%
The scale used in this table is 100% = strongly agree, 0% = strongly disagree. * denotes where a utility group scored statistically significantly higher ($p<0.05$) than other utility groups.				

4.4 Preparedness measures

Having emergency, crisis and business continuity[6] plans are an important component of crisis preparedness. The majority of respondent organizations, as expected for lifeline utility organizations, have developed emergency and continuity plans and have staff overseeing these functions, see

Table 5. A lower proportion have crisis plans. The majority of respondent organizations also have risk managers.

The results presented are the responses from senior managers only, because, in almost every organization where both the senior manager and staff responded,

[6] Note that organizations plan for disruptions in a variety of ways and use varying terms to describe their plans. The plan types included here are intended to allow respondents to select the most appropriate plans type(s) for their organization.

there was an inconsistent response to these questions. This indicates that staff understanding of these roles and plans do not concur with senior managers. In fact, 5% of staff indicated that they didn't know what crisis roles the organization had and 13% didn't know what types of plans they had.

Table 5 Organization roles and plans (as indicated by senior managers)

	Yes, Our organization has this Role	Yes, Our organization has this Plan
Risk management	83%	N/A
Crisis management	60%	40%
Emergency management	100%	87%
Business continuity	63%	73%
None of these	0%	3%
Don't know	0%	7%

Generally respondents indicated that the plans they had were of sufficient quality (Table 6), however senior managers again reported a higher confidence in the quality of their plans than other staff. An ANOVA test indicated that the difference between staff and senior manager views in this case was not statistically significant ($F(1,161)=2.162$, $p=0.143$).

Table 6 Sufficiency of crisis / emergency plans

Are plans of sufficient standard to be useful in an emergency?	Senior managers	Staff
Yes	82%	60%
Don't know	14%	22%
No	4%	6%

As can be seen in Table 7, the frequency of testing plans is quite varied between organizations, and there are a notable number of organizations that hardly test plans at all. In contrast to the varied understanding of roles and plans, the understanding of plan testing is much more consistent between managers and staff. This likely indicates that staff members are being included in exercises to test plans.

Table 7 Frequency of plan testing

Type of plan		Frequency of plan testing			
		Hardly ever	Every second year	Annually	Twice a year
Business Continuity	**Senior manager**	36%	14%	36%	14%
	Staff	36%	16%	28%	20%
Emergency Management	**Senior manager**	17%	9%	39%	35%
	Staff	19%	10%	40%	31%
Crisis Management	**Senior manager**	23%	0%	54%	23%
	Staff	28%	9%	38%	25%
Other	**Senior manager**	16%	17%	50%	17%

	Staff	29%	13%	46%	12%

4.5 Key risks

All respondents were asked to identify the top five risks that could lead to a crisis for their organization. The top risks identified by respondents, in order of frequency, were:

1. Loss of critical services
2. Reputation damage
3. Earthquake
4. Severe weather
5. Regulatory changes
6. Flooding

Other threats that were of concern in the utility subgroups were a major accident, staffing issues and financial crises. These results are summarized in Table 8. It is interesting to note that electricity, telecommunications, and gas network providers have the most consistent views (across all respondents) of what the top risks are (over 70% of staff chose each of the top four risks). This shows a consistent understanding of key risks across these organizations and the utility group. The results may again be skewed by the high percentage of senior managers that completed the survey within this group.

Six percent of respondents identified 'other' risks. These included: market volatility, travel mode changes, loss of accreditation, failure of internal services, market over supply, depopulation (loss of income through rates), local government reform, and health and safety incidents.

Organizations were also asked about recent crisis experiences. The major challenges faced during these crises included repairing infrastructure damage, managing customer and community expectations, managing staff resources (some noted that business as usual services suffered as staff were diverted to emergency operations, others noted that crisis events at holidays periods caused challenges due to staff being on leave), and a lack of understanding of the severity of the event.

Table 8 Major risks that could lead to crises in respondent organizations

Hazard / Risk	Total	Electricity, telecomminucations, gas and fuel – generation and retail	Electricity, telecommunications and gas – networks	Roads, Rail, Port	Water, wastewater and stormwater (and other Council functions)
Loss of critical services	50%	45%	71%	38%	55%
Reputation damage	44%	55%	14%	75%	32%
Earthquake	43%	22%	71%	44%	51%

Severe weather	42%	29%	71%	50%	44%
Regulatory changes	37%	35%	86%	25%	39%
Flooding	37%	4%	14%	34%	55%
Major accident	29%	69%	29%	38%	7%
Staffing issues	27%	22%	0%	22%	33%
Financial Crisis	25%	29%	29%	38%	19%
Tsunami	24%	4%	29%	28%	32%
Pandemic	18%	22%	0%	6%	21%
Volcanic activity	18%	10%	29%	16%	22%
Information security breach	18%	29%	0%	16%	14%
Landslides	13%	4%	14%	25%	13%
Technology change	11%	10%	0%	13%	12%
Contamination	11%	18%	0%	0%	11%
Fire	9%	14%	0%	0%	9%
Drought	8%	14%	0%	0%	8%
Litigation	6%	4%	0%	9%	7%
Other	6%	6%	29%	3%	6%
Failure of key supplier	6%	10%	14%	9%	2%
Loss of key customer	5%	12%	0%	6%	1%
Climate change	4%	4%	0%	3%	4%
Fraud	3%	0%	0%	3%	5%
Terrorism	2%	4%	0%	0%	1%

The top risks (scoring over 30%) for each group are highlighted in dark grey.

Risks selected by over 60% of respondents are highlighted in light grey.

4.6 Interdependencies

Respondents were also asked about how long they could continue operating without normal supply of a given utility. Overall, as shown in Table 9, there is very high dependency (i.e. they could not function without these services) on data networks (30%), electricity (30%) and phone networks (24%). There is a high dependency (could for function for only hours and days) on water supply, sewage, road networks and fuel. It should be noted when interpreting these results that several studies have found that organizations tend to under-estimate their capacity to function following disruptions and/or without critical services [6], [26], so the relative dependence should be the focus as opposed to the noted duration.

Table 9 Predicted ability to continue operation with different lifelines disruption (based on responses from all staff)

Lifeline Service that has been disrupted	Duration organization can operate without lifeline service				
	Could not function	Hours	Days	Weeks	Months
Water supply	9%	29%	40%	14%	8%
Sewage	10%	34%	35%	11%	10%
Electricity	30%	26%	28%	11%	5%
Gas	5%	6%	13%	20%	56%
Phone networks	24%	32%	29%	9%	6%
Data networks	30%	28%	30%	7%	5%
Road networks	17%	19%	36%	19%	9%
Rail	1%	2%	10%	12%	75%
Airport	3%	2%	9%	15%	71%
Port	5%	1%	11%	15%	68%
Fuel	14%	15%	53%	11%	7%

Comparing interdependency among the utility groups demonstrates that the provision of different critical services depends on other critical services. The responses were scored from zero (could continue functioning for months without this service) to four (could not function without this service). The responses from individuals in each utility group were then averaged and ranked from least dependent to most dependent. The results are summarized in Table 10. The results show that there are noticeable differences in how the various utility types are impacted by lifeline disruptions. Electricity, telecommunications, gas and fuel generation and retail; water, wastewater and stormwater; and road, rail and port are all most dependent on electricity, data, and phones. Whereas the electricity, telecommunications, and gas network providers are most disrupted by road, fuel, and data networks outages.

Table 10 **Rank of lifeline dependency for each utility group (based on all survey responses)**

	Rank of lifelines dependency by utility group*			
	Electricity, telecommunications, gas and fuel - generation and retail	**Electricity, telecommunications, and gas - networks**	**Road, rail, port**	**Water, wastewater and stormwater (and other Council functions)**
Water supply	6	5	7	5
Sewage	7	7	4	4
Electricity	1	6	1	3
Gas	8	11	8	8
Phone networks	3	4	3	2
Data networks	2	2	2	1
Road networks	4	1	5	7
Rail	11	10	11	11
Airport	10	8	9	10
Port	9	8	10	9
Fuel	5	2	5	6
* 1 is most dependent, 11 is least dependent.				

The highest dependencies (rank 1-3) are highlighted in dark grey, moderate dependencies (rank 4-6) are highlighted in light grey, lowest dependencies (rank 7-11) are in white.

Respondents were also asked how well prepared they were to manage disruption of other lifeline services. Overall, organizations ranked their preparedness for lifeline disruption fairly evenly across all the critical infrastructure types – average 62% (where 100% is strongly agree or very well prepared). Electricity, telecommunications and gas network providers reported they were on average more prepared for critical infrastructure disruption (77%) than any other utility group (again noting the low level of staff that completed these surveys).

Table 11 shows preparedness for disruption to each critical infrastructure service, ranked for each utility group. Comparing these rankings to the rankings in Table 10 – critical infrastructure dependency - concern should be raised when there is a high level of dependency on a infrastructure service (1, 2 or 3) and low level of preparedness (9, 10, 11). Key observations from this data include:

- Electricity, data, and phone networks are likely to cause significant disruption to all utility operators. Table 11 shows that road, rail, and port operators and councils have a low level of preparedness despite a high dependence on these services.
- Electricity, telecommunications, and gas network providers indicated a high dependency on road networks, yet a low level of preparedness for road network disruption.

Table 11 Rank of critical infrastructure disruption preparedness for each utility group (based on all survey responses)

		Rank of lifelines disruption preparedness by utility group**			
	Average preparedness*	**Electricity, telecommunications, gas and fuel - generation and retail**	**Electricity, telecommunications, and gas - networks**	**Road, rail, port**	**Water, wastewater and stormwater (and other Council functions)**
Water supply	62%	9	11	7	1
Sewage	58%	11	9	11	3
Electricity	65%	1	6	8	4
Gas	64%	4	1	6	6
Phone networks	59%	5	2	10	9
Data networks	61%	2	2	9	10
Road networks	62%	8	9	1	8
Rail	61%	7	4	5	7
Airport	62%	6	4	3	5
Port	62%	9	7	2	2
Fuel	60%	3	8	4	11
Average preparedness	**62%**	**62%**	**77%**	**53%**	**61%**

* The scale used in this table is 100% strongly agree, 0% strongly disagree.
** 1 is most prepared, 11 is least prepared.

Highest preparedness (rank 1-3) is highlighted in dark grey, moderate preparedness (rank 4-6) is highlighted in light grey, lowest preparedness (rank 7-11) is in white.

5 Discussion

5.1 Interpretation of case study results

The emergence of the strongest resilience indicator - effective partnerships – is a signal of the strength of the New Zealand critical infrastructure coordination efforts. The effective partnership indicator measures the level of planning, resource sharing, relationship building and general understanding of how an organization is connected to other organizations. All survey respondents are members of an active lifeline coordination group that meet regularly to discuss their crisis preparedness and work together to improve their readiness. It is possible that this has positively benefited participant organizations and contributed to higher scores in this indicator. The New Zealand lifeline group initiative has been acknowledged as a significant contributor to reduced critical infrastructure impacts following the 2010/2011 Canterbury earthquakes [24].

The two weakest resilience indicators, breaking silos and stress testing plans, indicate areas that need to be focused on for the respondent organizations. Despite strong effective partnerships, the organizations show some siloed behaviors. This suggests that while good networks between organizations exist, they are not utilized well during day-to-day operations. Departmental and organizational boundaries are presenting a barrier to sharing of skills and ideas: something that is essential during a crisis where innovation and resource sharing is vital for tackling emergent issues [27]. To reduce siloed behaviors, the respondent organizations need to work together more regularly to improve the quality of relationships and create pathways for readily sharing knowledge and skills between departments and organizations.

A weakness in stress testing plans indicates that currently the organizations don't actively practice their emergency, crisis or business continuity plans. Responses to the question on plan testing frequency indicated a significant spread across the organizations surveyed: with a notable number of organizations practicing plans twice a year and a similar proportion practicing hardly ever. To improve this aspect of their resilience, there is a need for more deliberate testing of plans and practicing agile and adaptive responses in the face of a range of expected and unexpected crises. Practicing plans will help to familiarize staff with their roles in a crisis, make staff more confident going into a crisis and will also help to identify areas where the plans are insufficient or could be improved.

One of the major findings of this study is the large and consistent disparity between senior manager and staff responses. For all questions, senior managers showed, on average, a higher agreement with statements than staff. The results

show a disconnect between senior manager and staff understanding, or awareness, of emergency/crisis plans and procedures. The effectiveness of an organization's response during a crisis may be compromised as a result.

Moreover, this disconnect between staff and senior managers can be detrimental from a resilience perspective as it can indicate a lack of communication and involvement of staff in planning and decision-making. Organizations need to work hard to actively engage staff in crisis preparedness and resilience initiatives. Staff will offer necessary operational perspectives on crisis plans and will feel more engaged and necessary in a crisis response if they are part of the planning process.

The key risks identified by respondents are notable in the prominence of non-natural hazards. Many crisis plans focus on management of physical hazards such as weather events, earthquakes, vandalism etc.; however, two of the top five risks identified were non-physical risks: reputation damage and regulatory change. This is in line with top threats reported across other industries [28]. This is a reminder to critical infrastructure providers that their crisis planning should include a wide range of crises. One method of planning for a wide range of risks is to use a consequence based plan where plans focus on consequences (such as loss of customers, damage to a given asset, loss of key supplier, building damage etc) instead of events. This allows a potentially more efficient planning process as consequences are shared across multiple events. It may also help to prepare for unforeseen events that share consequences with other known events.

This study highlighted some key interdependencies between infrastructure types that have not been well planned for. In particular, road, rail, and port operators and water, wastewater and stormwater (and other Council functions) have a low level of preparedness for the loss of electricity, data and phone network services. Electricity, telecommunications and gas network providers have a low level of preparedness for road network disruption. Infrastructure providers need to get together and consider their dependence both from a top down approach (looking at end user / service delivery to critical customers and the services required to meet those customer needs) as well as a bottom-up approach (looking at the physical systems and how the functioning and repair of the system depend on other infrastructure services).

The lifeline group in this study has recently developed a GIS software platform to help utility providers identify 'pinchpoints' (where multiple services are located in the same geographic location) and 'hot spots' (where infrastructure is affected by multiple hazards). This spatial software provides an opportunity for participant organizations to work through scenarios with other infrastructure providers to understand the extent and nature of dependence; and to work together to collectively improve the recovery times of all utility services following a disruption. Recognizing and managing key interdependencies is an essential element of crisis preparedness and resilience.

The results presented in this case study should be interpreted in light of several limitations. First, the inclusion of 'other council functions' in the water and wastewater utility category means that this category is representing a broad range of functions and does not solely reflect the capacity of water and wastewater utility providers. Unfortunately, due to the low number of responses from water and wastewater utility providers (that is, those specific departments within local councils) it was not possible to represent them in isolation in the aggregated reporting, whilst still maintaining confidentiality for individual organizations' results.

Second, the low number of staff responses within the electricity, telecommunications and gas networks utility group may have impacted their results. Compared to other respondent groups, this utility group had proportionally more senior managers represented and given the difference between senior and staff score discussed above, this may have inflated their overall scores.

While findings of this study may provide insights into the resilience of critical infrastructure organizations in other contexts, the primary objective of this paper is to present an example of an organizational resilience benchmarking study of critical infrastructure organizations. To confidently generalize the findings as characteristic of critical infrastructure providers elsewhere would require a larger scale study.

5.2 Transferability of benchmarking approach

This resilience benchmarking study enabled participating organizations to: identify their relative resilience strengths and weaknesses; determine their relative preparedness levels; understand the key risks they collectively face, and to; understand the interdependencies between their organizations. In doing so, the study provided participant organizations with:

1) a baseline measure of resilience,
2) indicative areas for potential improvement,
3) organizational and sector strengths that can be leveraged to help improve the resilience of the group,
4) a measure against which improvements can be measured, and
5) a common language for organizations to use.

The benchmarking process is primarily a relative measure. It allows individual organizations, or groups of related organizations (such as those in this study), to assess and manage their resilience over time. Results of different benchmarking studies can also be compared. However, careful interpretation of comparison is needed as there may be contextual or sectoral factors that underpin the resilience benchmarking results.

For example, a resilience benchmarking exercise was carried out with water utilities in Australia (using the same benchmarking tool). In the Australian study, effective partnerships was one of the lowest scoring indicators [29]. In

this study, it was one of the highest. This relative difference indicates that there may be contextual differences between New Zealand and Australia that is influencing the effectiveness of how utility organizations work together. One contributor to this could be the different structure of lifeline coordination in the two countries. In Australia, lifeline coordination is typically by sector, whereas New Zealand's approach is regional and has been acknowledged internationally as an innovative and progressive approach to critical infrastructure coordination [30].

The above example is illustrative and more investigation is required to fully understand the differences between the relative strength of effective partnerships between the two study groups. However, the example demonstrates how patterns in the relative resilience scores can be used to generate insights between study groups.

Interpreting the resilience measure as a 'relative' measure is also helpful in combatting the potential limitations related to self-report surveys. Self-report surveys, particularly where individuals are required to respond based on a perception, can be influenced by a number of factors such as consistency motif (the desire to answer questions consistently), social desirability, temporal influences and biases [31]. The limitations of self-report method are also less impactful in the resilience benchmark survey as the tool is primarily used as a measure in time and is not being used to demonstrate causality or correlations within groups [31], [32].

Currently the authors recommend using the resilience benchmark approach primarily as a relative measure rather than as an absolute measure, particularly when comparing organizations operating in different contexts: a relative measure that can show progress over time and can indicate differences between resilience strengths in organizations. The authors are currently working on developing a 'value case' for resilience. That is, collating evidence on how organizations have responded to crises and relating this to the benchmark scale to provide a business case for investing in resilience. The complexity of organizations and sectors, and the uncertain and variable nature of the external operating environment (market changes, legislation, crises etc), make the case challenging to establish. But this work is in progress.

6 Conclusions

Society is becoming increasingly reliant on complex and interdependent technologies. Critical infrastructure is one of those technologies that we rely on daily to provide our basic needs and to support our economic endeavours. The majority of effort in improving the resilience of critical infrastructure systems is currently on improving the capacity of the physical systems to withstand hazards. However, with finite resources and understanding of the extent of hazards we face, infrastructure service disruption is inevitable. Consequently,

there is increasing awareness, internationally, on the importance of developing the organizational resilience of critical infrastructure providers.

This paper has provided an example assessment of the organizational resilience of a group of critical infrastructure organizations. The method identified the strengths and weakness of the participant organizations, their level of planning, key risks and key interdependencies. The assessment provides areas for organizations to focus their efforts on.

Being able to identify and measure resilience strengths and weaknesses before an event will help our critical infrastructure organizations to better prepare themselves for crises: and this is turn will help to create more resilient infrastructure systems and communities.

7 Acknowledgements

We are gratefully acknowledge the Bay of Plenty Lifelines Group for funding this study. We would also like to acknowledge all the participants for giving their time to complete the survey.

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9 Appendix

Resilience indicator questions *To what extent do you agree or disagree with the following statements for your organization* (Response options 0=strongly disagree to 1 = strongly agree and Don't know)
Leadership
There would be good leadership from within our organization if we were struck by a crisis.
In a crisis, staff accept that management may need to make some decisions with little consultation
Our managers monitor staff workloads and reduce them when they become excessive
Our management think and act strategically to ensure that we are always ahead of the curve
Management in our organization lead by example
Our organization regularly re-evaluates what it is we are trying to achieve

Staff engagement
People in our organization feel responsible for the organization's effectiveness
People in our organization are committed to working on a problem until it is resolved.
Our organization's culture is to be very supportive of staff
Our organization has high staff morale
Staff know what they need to do to respond to a crisis
Situation awareness
We proactively monitor our industry to have an early warning of emerging issues.
We learn lessons from the past and make sure those lessons are carried through to the future
Staff interact often enough to know what's going on in our organization
Our managers actively listen for problems
We are mindful of how the success of one area of our organization depends on the success of another
Staff feel able to raise problems with senior management
Decision making
Should problems occur, staff have direct access to someone with authority to make decisions
We can make tough decisions quickly
In our organization, the most qualified people make decisions, regardless of seniority
Innovation and creativity
Staff are actively encouraged to challenge and develop themselves through their work
We are known for our ability to use knowledge in novel ways
Staff are rewarded for "thinking outside of the box"
Effective partnerships
In a crisis, we have agreements with other organizations to access resources from them
We have planned for what support we could provide to the community in a crisis
We build relationships with others we might have to work with in a crisis
We understand how we are connected to other organizations and actively manage those links
We understand how Government actions would affect our ability to respond in a crisis
Leveraging knowledge
Staff have the information and knowledge they need to respond to unexpected problems
If something out of the ordinary happens, staff know who has the expertise to respond
Critical information is available by different means and from different locations
If key people were unavailable, there are always others who could fill their role
We readily obtain expert assistance when there's a problem
Breaking silos
Staff are encouraged to move between different departments or try different roles to gain experience
There is a sense of teamwork and camaraderie in our organization
There are few barriers stopping us from working well with other organizations
We work with others regardless of departmental or organizational boundaries, to get the job done
Internal resources
We have sufficient internal resources to operate successfully during business as usual
Our organization maintains sufficient resources to absorb unexpected change
When a problem occurs, it is easier to get approval for additional resources to get the job done
Unity of purpose
We have clearly defined priorities for what is important during and after a crisis
Our priorities for recovery would be sufficient to provide direction for staff in a crisis
We understand the minimum level of resources our organization needs to operate
We are mindful of how a crisis in our organization would impact others

Our organization consistently demonstrates commitment to its values
Proactive posture
We have a focus on being able to respond to the unexpected
We are able to collaborate with others in our industry to manage unexpected challenges
We are able to shift rapidly from business-as-usual to respond to crises
Whenever our organization suffers a close call, we use it for self-evaluation rather than confirmation of our success
We are regarded as an active participant in industry and sector groups
Our organization readily responds to changes in our business environment
In a crisis we seek opportunities for our organization
We tend to be optimistic and find positives from most situations
Planning strategies
Our organization plans for the medium- and long-term
We plan our strategy carefully before taking action
Given how others depend on us, the way we plan for the unexpected is appropriate.
We are mindful of how a crisis could affect us
We actively plan with our suppliers how to manage disruptions
We actively plan with our customers how to manage disruptions
We actively plan how to support our staff during times of crisis
We have a good understanding of how an event impacting the community may impact our ability to respond
Stress testing plans
Our organization is committed to practicing and testing its emergency plans to ensure they are effective
Staff can take time from their day to day roles to practice how to respond in a crisis

Planning and Preparedness	
Question	**Response options**
Our organization currently has people who perform the following roles *(tick all that apply)*	Risk management, Crisis management, Emergency management, Business continuity, None of these, Don't Know
Our organization has the following Plans *(tick all that apply)*	Business Continuity Plan, Emergency Plan, Crisis Plan, None of these, Don't Know, Other type of Plan (please describe)
Are your organization's plans of a sufficient standard to be useful in an emergency? (Please tick one)	Yes Don't know No (Please say why)
How regularly does your organization rehearse and test its plans? Business Continuity Emergency plan Crisis plan Other type of plan	N/A Twice a year Annually Every 2nd year Hardly ever Don't know

Key risks
Think of the overall highest risks that could lead to crisis for your organization, please tick the top 5 in the list below: Financial crisis, Major accident or fire, Pandemic (e.g. influenza, bio-security), Loss of critical services (e.g. electricity, water, gas, telecommunications), Reputation damage, Fraud, Regulatory changes, Failure of a key supplier, Loss of a key customer, Staffing issues, Information security breach, Technological change, Contamination, Litigation, Climate Change, Terrorism, Flooding, Bushfire, Drought (water shortage), Severe weather (e.g. storm, tornado), Tsunami, Volcanic activity, Landslides, Earthquake, Other (please specify).

Crisis experience	
Question	**Response options**
Has your organization experienced a crisis or emergency in the last 5 years?	Yes No Don't know
On the scale shown please rate, how severe your organization's most recent crisis was for your organization.	We dealt with it as part of business-as-usual, It challenged us but was not overly disruptive, It definitely challenged us and was moderately disruptive, It definitely challenged us and was very disruptive, It could have shut us down permanently, Don't know
Please briefly describe what the crisis was, how long it lasted for and what the impact was on your organization.	Open text

Interdependencies	
Question	**Response options**
How long could your organization continue functioning if normal supply to the following infrastructure services were disrupted? Water supply Sewage Electricity Gas Phone networks (cell and landline) Data networks Road network Rail Airport Port Fuel	Could not function Hours Days Weeks Months
Our organization has done sufficient planning for how disruption to the following infrastructure might affect us: Water supply Sewage Electricity Gas Phone networks (cell and landline) Data networks Road network Rail Airport Port Fuel	8-point Likert scale ranging from Strongly disagree to Strongly agree Don't Know