Developing the Business Behaviours Module within MERIT

C. Brown
E. Seville
J. R. Stevenson
S. Giovinazzi
J. Vargo

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Contact organisation for inquiries and correspondence is GNS Science Ltd, 1 Fairway Drive, Avalon, PO Box 30368, Lower Hutt 5040.

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C. Brown, Resilient Organisations, New Zealand www.resorgs.org.nz
E. Seville, Resilient Organisations, New Zealand www.resorgs.org.nz
J. R. Stevenson, Resilient Organisations, New Zealand www.resorgs.org.nz
S. Giovinazzi, Resilient Organisations, New Zealand www.resorgs.org.nz
J. Vargo., Resilient Organisations, New Zealand www.resorgs.org.nz

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ADDENDUM OVERVIEW

To test the business behaviour module for transferability to other disruption events and locations, a series of case study interviews were carried out. The findings of the case studies are detailed in Hatton et al. (2016).

Generally the case study analysis showed:

- Good transferability of the business behaviours module to other urban contexts.
- The importance of sector as a key determinant of impacts.
- The variation in responses to a disruption scenario due to different attitudes and approaches to both preparedness and adaptation.
- Organisations can operate even when services are unavailable and reinforces the importance of the Business Behaviours Module to ensure that these adaptive responses are included in modelled economic outputs.

The case study analysis also showed that the business behaviours module could be improved by some minor amendments. This addendum outlines the specifics of those changes, as they relate to sections within the original report.

SECTION 3.2.2 – STEP1 – EXPERIENCES DISRUPTION DUE TO INFRASTRUCTURE IMPACTS

Impact of relocation and temporary closure

During the case study interviews, some Canterbury organisations indicated that they were not disrupted by short-run network infrastructure disruptions (electricity and phone) following the earthquakes due to the short-term closures or relocations. Therefore their survey responses sometimes indicated a duration of infrastructure disruption but no experienced disruption. The disruption functions could, therefore under-estimate the impact of those infrastructure disruptions.

To check the sensitivity of the original 'infrastructure experienced disruption' functions to these extenuating circumstances, we re-ran the regression analysis. This time, we only included organisations that did not relocate or temporarily (or permanently) close following the 22 February earthquake in the analysis. Approximately 177 organisations remained in the analysis (depending on infrastructure type). The regression analysis results, see Table A, show that the original infrastructure 'experienced disruption' functions (for all sectors combined) are not significantly influenced by these short-term non-infrastructure related impacts. Therefore, the original experienced disruption due to infrastructure impacts functions will be retained. The larger sample size used in the original calculations allows for more robust industry sector-level disruption analysis.

Table A Experienced disruption due to infrastructure outages – function co-efficients.

	Water		Sewage		Electricity		Phone		Data	
	a	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
Original (all)	0	0.2	0	0.3	0.1	0.3	0.2	0.2	0.1	0.3
Those organisations that didn't relocate or temporarily close	0	0.3	0	0.25	0.1	0.3	0.1	0.3	0.1	0.3

Disruption ratings

The case study interview analysis indicated that when organisations reported an infrastructure disruption was 'slightly disruptive', there was very little impact on their organisation. This indicated the need to review the weightings used in the 'experienced disruption' function analysis. The original model was based on a weighting of 0.33 for 'slightly disurptive' (and 0, 0.66 and 1 for not disrupted, moderately disrupted and very disrupted respectively). Selected regression results were re-run with the weighting for 'slightly disrupted' adjusted to be 0.2 or 0.1. The results, Table B, showed the results were relatively insensitive to the assumed weighting of the 'slightly disrupted' response. Given this, and the qualitative nature of the original question – leading to varying interpretations across responses - the original weighting and functions will remain.

Table B Experienced disruption due to infrastructure outages – function co-efficients.

	Water		Sewage		Electricity		Phone		Data	
	a	b	a	b	a	b	a	b	a	b
Original (all)	0	0.2	0	0.3	0.1	0.3	0.2	0.2	0.1	0.3
Change slightly disruptive to = 0.2	0	0.2	0	0.3	0	0.3	0.1	0.2	0.1	0.2
Change slightly disruptive to = 0.1	0	0.2	0	0.25	0	0.3	0.1	0.2	0	0.2

Sector dependency on Infrastructure

The case studies indicated that the operability curves for some industry sectors may under-estimate their capacity to operate. In particular, in response to the water disruption scenario, several sectors (professional, scientific and technical services and transportation and warehouse services) indicated they would not be disrupted at all. A review of the Canterbury survey data, and further analysis by Giovinnazzi et al (in progress), supported that these sectors, and several others, were the least affected by water disruptions. Of the survey respondents 0% of professional, scientific and technical services; transportation and warehouse services; electricity, gas water and waste; financial and insurance services indicated that they could not function if there was a disruption to water services. However, for all these sectors, the majority of organisations indicated dependence on water after 'days' of disruption. Given the water disruption scenario is 5 weeks long, it seems reasonable to expect some disruption in this scenario.

Given that there is little evidence from the Cantebrury data set to change sector dependence on given infrastructure, the 'experienced disruption' funcitons will remain unchanged. However, future calibration and testing of these functions will be carried out when more data is available.

Infrastructure mitigation

In order to test the effectiveness of mitigation, a mitigation lever would be a useful addition to the business behaviour module. MERIT is currently a CGE model built on meshblock data. Correspondingly, ED_{inf} is calculated at meshblock level and assumes no mitigation. To include the impact of mitigation measures, the user could define a percentage of organisations within each sector that has mitigation and that percentage of the sector that has mitigation is randomly, spatially, assigned. If mitigation is in place, then ED_{inf}=0, if not then ED_{inf} is calculated.

Government provision of water

An underlying assumption in the data from the Canterbury earthquakes is that the government provided emergency water supplies, in the form of temporary water tanks that were regularly refilled. The reported 'experienced disruption' and the corresponding model functions, include this implicit assumption. If this model is applied to a scenario where government water is not supplied, the model will need to be adjusted.

Reduced infrastructure service levels

The case study analysis found that organisations are more or less equally disrupted by rolling electricity outages and constant power outages. Therefore, separate disruption functions are not required for these different service levels.

The case studies indicated some sensitivity to different levels of water service and some substitutability between different types of telecommunications services. However, more data is needed to appropriately improve the existing functions to include in the module. This is an area for future refinement.

SECTION 3.2.3 – STEP 2 – EXPERIENCES DISRUPTION DUE TO NON-INFRASTRUCTURE IMPACTS

Disruption ratings

As for the infrastructure disruption ratings, the case studies indicated that non-infrastructure impacts that were 'slightly disruptive' were not necessarily half of a moderate disruption. Therefore, the non-infrastructure disruption functions were tested for their sensitivity to different disruption ratings for 'slightly disruptive'. The regression analysis that created the original functions was repeated with 'slightly' disruptive' changed from 0.33 to 0.2 and 0.1. Equation 2A is a generalised form of equations 2, 3 and 4. In Table C, the coefficients of the original analysis are compared with the new analysis results for Physical, Neighbourhood and Staff type impacts. As for infrastructure disruption, the equation shows little sensitivity to the 'slightly disruptive' weighting. Therefore, the weightings will remain linear as per the original analsyis.

$$\boldsymbol{ED_i = a + bxPGA} \quad \textbf{Equation 2A}$$

Table C Experienced disruption due to non- infrastructure outages – function co-efficients.

	Physical		Neighbourhood		Staff	
	a	**b**	**a**	**b**	**a**	**b**
Original (all)	0	0.9	0	1.1	0.2	0.5
Change slightly disruptive to = 0.2	0	0.9	-0.05	1.1	0.2	0.5
Change slightly disruptive to = 0.1	0	0.9	-0.05	1.1	0.15	0.5

Non-infrastructure disruption for earthquake scenario

Equation 5, 6 and 7 for an earthquake event, require a lower bound: MMI below which the functions are not used (i.e., there is insignificant non-infrastructure disruption). The revised equations are below.

$$\boldsymbol{for\ MMI > 5,\ ED_{premises} = 0.12\ x\ MMI - 0.56} \quad \textit{[if } \boldsymbol{ED_{premises}}\textit{>1, then =1]}$$

$$\boldsymbol{for\ MMI \leq 5,\ ED_{premises} = 0} \qquad \textbf{Equation 5}$$

$$\boldsymbol{for\ MMI > 5,\ ED_{neigh} = 0.13\ x\ MMI - 0.62} \quad \textit{[if } \boldsymbol{ED_{neigh}}\textit{>1, then =1]}$$

$$\boldsymbol{for\ MMI \leq 5,\ ED_{neigh} = 0} \qquad \textbf{Equation 6}$$

$$\boldsymbol{for\ MMI > 5,\ ED_{staff} = 0.07\ x\ MMI - 0.11} \quad \textit{[if } \boldsymbol{ED_{staff}}\textit{>1, then =1]}$$

$$\boldsymbol{for\ MMI \leq 5,\ ED_{staff} = 0} \qquad \textbf{Equation 7}$$

Where $\boldsymbol{MMI}$ *is* Mercalli Macroseismic Intensity

Non-infrastructure disruption for volcanic scenario

Part of the purpose of the case studies was to develop a function to estimate non-infrastructure disruption. The function needs to relate to a measurable feature of the volcanic scenario to allow transferability to other volcanic events. Three key variables were considered to create this function:

- Location relative to volcanic cone and evauation zone
- Increased travel time
- Depth of ashfall

In terms of the location relative to volcanic cone and evacuation zone, there are five categories: permanent exclusion zone; within 3km from volcanic cone, temporary evacuation zone (>3km from volcanic cone), <10km from evacuation zone; and >10km from evacuation zone. 10km was chosen as a cut-off as this approximately represents the upper quartile commuting distance in Auckland (Statistics New Zealand, n.d.).

The majority of building damage is expected in the permanent exclusion zone and within 3km of the volcanic cone. Neighbourhood damage is strongly linked to location (with disruption increasing with proximity to evacuation zone / exclusion zone). Based on case study responses, staff disruption does not appear to be dependent on location at all. All sectors in all locations indicated there would be a high level of disruption to staff.

Based on the questions relating to disruption due to increased travel times for staff, there appears to be some sectoral trends in the level of disruption. However, given the limited number of organisations in the case study analysis, it was difficult to confidently identify trends that would predict this disruption by sector.

The ashfall depth largely corresponds to the above defined locations: for this scenario (due to the wind direction) ashfall greater than 3km from the volcanic cone is expected to be <5mm and would cause only minor disruption. Organisations essentially did not consider these impacts or could not conceptualise the disruption that may be caused due to ashfall clean-up at their premises.

Given the limited, and solely hypothesised data available for this scenario, we propose using a simple disruption function based on location relative to exclusion zone. At this stage the function does not differentiate impacts by sector. The expected disruption values are shown in Table D. Future development of this function could potentially differentiate the disruptions by sector and use ashfall depth also.

Table D Proposed non-infrastructure disruption function values for volcanic scenario (based on location) for MERIT.

Location	Expected disruption to premises	Expected disruption to neighbourhood	Expected disruption to staff
>10km outside evacuation zone	0	0	1
<10km outside evacuation zone	0.2	0.2	1
Inside evacuation zone (greater than 3km from volcanic cone)	0.4	0.8	1
Within 3km of volcanic cone (outside permanent exclusion zone)	0.8	0.9	
Permanent exclusion zone	1	1	1

Section 3.2.4 – Step 3 – Combining disruptions

Modelling of road disruption

Disruption to the roading network was one of the most inconsistently reported infrastructure disruptions following the Canterbury earthquakes. Organisations had varying sensitivity to disruptions from roadworks, traffic delays and detours – some focussing on effects to delivery of service and ***goods*** and other on staff impacts. This helps to explain why the road disruption factored weakly with both the network infrastructure and the node infrastructure type impacts.

The road network is different from other networked services such as electricity, water etc. Within an urban transportation network there are generally alternative routes available or alternative modes of transport that can be used.

Disruptions to roads are rarely on/off events: disruption can mean a wide spectrum of impacts from nuisance, to increased wear on vehicles, to delays and increased travel times. Road disruptions will have a direct impact on business operations and will likely have an impact through increased cost of working or reduced demand due to neighbourhood disruption. Road disruptions will also impact on staff and their ability to access work as well as emotional well-being.

In consultation with economic modelling team, and to reduce the potential for double counting impacts, road disruption will be incorporated in MERIT in two ways: 1) through increased cost of working in the economic module (increased freight transportation costs) and 2) through non-infrastructure disruptions in the business behaviours module (either staff or neighbourhood disruption).

Consequently, the road impacts have been removed from the network impacts function, such that Equation 9 becomes:

$$\boldsymbol{ED_{net\ inf}} = \boldsymbol{max}(\boldsymbol{ED_{inf\ water}}, \boldsymbol{ED_{inf\ sewerage}}, \boldsymbol{ED_{inf\ electricity}}, \boldsymbol{ED_{inf\ phone}}, \boldsymbol{ED_{inf\ data}}, \boldsymbol{ED_{inf\ gas}})$$

Equation 9

SECTION 3.2.5 – STEP 4 – OPERABILITY FUNCTION

The above changes to the disruption functions (specifically, the removal of the roads from the network ifrastructure disruption funciton) had no impact on the operability function.

Return to full operability

The asymptopic nature of the operability curves is useful for showing the shape of the recovery trajectory. However, in reality, organisations will return to full operability after a period. For some events, such as single infrastructure outages, this is approximated as the end of the direct disruption. However, the Canterbury earthquake data indicates that for more widespread disruptions, the organisation's operational disruption extends beyond the end of the direct disruption.

It is likely that the duration of reduced operability is a function of the duration of the disruption and extent of the experienced disruption for the organisation. With the data available, the best approximation is to use the operability curve and to 'force' the function to 1 once it reaches 99% operability[1]. Equation 15 shows the revised operability function with this limit included. Note that, if a sector has maximum disruption (OD=1) then, the maximum disruption duration is 175 days. Further refinement and validation of this model across multiple disaster events is needed.

$$\boldsymbol{for\ t \le e^{\frac{(-0.01+0.63xOD)}{0.12xOD}}}, \quad \boldsymbol{Op(t) = 0.12\ x\ OD\ x\ \ln(t) + (1 - 0.63\ x\ OD)}$$

$$\boldsymbol{for\ t > e^{\frac{(-0.01+0.63xOD)}{0.12xOD}}}, \ \boldsymbol{Op(t) = 1}$$

Equation 15

Where $\boldsymbol{Op(t)}$ *is Operability at anytime, t*

$\boldsymbol{OD}$ *is Overall Disruption and is described in Section 3.2.4*

1 Recall that this operability function is representative of the average organisation in the sector.

Single infrastructure disruptions

For single infrastructure disruption scenarios (such as an electricity or water disruption), case study organisations generally told us they would experience a reasonably constant level of disruption, and then resume full operability as soon as the disruption ends. For community wide disruption scenarios (such as an earthquake or volcanic eruption), however, organisations will experience a much longer recovery trajectory – with reduced operability significantly after the disruption event itself had ended.

Therefore, different operability functions are required to model these single infrastructure outages. Based on the case study interviews, a step function is considered an appropriate model: during the infrastructure disruption, a reduced operability is possible; as soon as the service is restored, full operability is achieved.

The reduced operability during the disruption is calculated by taking the start point of the full operability function, when t=0, as shown in Equation 16.

$$\lim_{t\to 0} Op(t) = \lim_{t\to 0} 0.12\ x\ OD\ x \ln(t) + (1 - 0.63\ x\ OD) = 1 - 0.63OD \qquad \textbf{Equation 16}$$

Therefore, for single infrastructure disruption events, the function for operability can be represented by Equation 17:

$$for\ t < DID,\ Op(t) = 1 - 0.63OD;$$

$$for\ t \geq DID, Op(t) = 1 \qquad \textbf{Equation 17}$$

Where OD = overall disruption (see Section 3.2.4)

And DID = duation of infrastructure disruption: *DID is measured in 1=hours, 2=days, 3=weeks, 4=months.*

While a step function may appear to over-estimate the reduction in operability, compared to a natural log function for a wider disruption, the OD value will be smaller than for larger events, since the OD is essentailly divided by 2 (Equation 11) for a single infrastructure disruption. Organisations are also likely to adapt more readily in the wake of a more disruptive event.

Port disruption scenario

The case studies and Canterbury earthquakes data analysis demonstrate the low levels of anticipated disruptions due to port disruptions. This is potentially due to their ability to use other ports and transportation methods to access supplies and ship goods. It could also reflect the organisation's poor understanding of its own supply chain.

It is recommended that the business behaviours operability function should not be applied to port disruption scenarios (and likely other transportation-only disruptions). Effects of these types of disruption will be modelled in the economic module of MERIT through cost increases of alternative supply routes.

Business closure

The Canterbury earthquake data used to develop the business behaviours module included very few failed businesses. In fact, this is a reflection of low business closure following the earthquakes. However, there will be some events where larger numbers of businesses fail and MERIT should account for failure of these businesses.

The case study results indicate varied rationale for closing, and again, there appeared to be differences between sectors. It is recommended that, initially, a business closure measure is included in MERIT that closes businesses after their turnover has reduced by an average of 50% for 6 months. Further research and sensitivity analysis is needed to test this assumption and to include sector differences.

Recovery variability and model averaging

When interpretting the operability curves, it is important to note that they represent an average recovery trajectory within each sector. The sectors are large and include a wide range of businesses in terms of size, location, ownership structure, property ownership, services or products delivered, customer base, suppliers, etc. As noted earlier in this section, none of these factors specifically were 'predictors' of organsiational recovery; however, they all contribute to significant variability in recovery. Figure 7A demonstrates the variability in recovery by plotting all organisations responses to their 'ability to meet demand' or operability over time. The results show considerable spread in responses – particularly immediately and several months after the earthquakes.

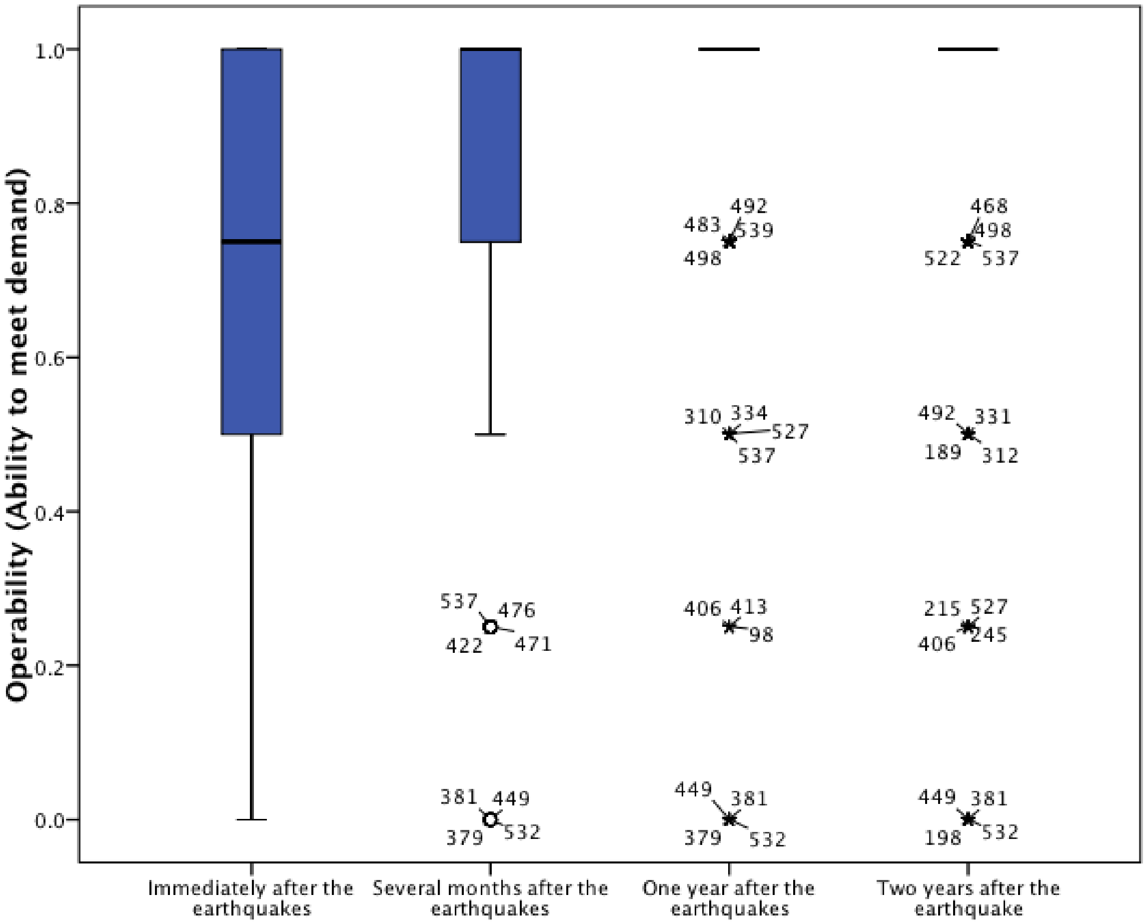

Figure 7A Reported operability following the Canterbury earthquakes (numbers indicate case numbers, retained to demonstrate the number of 'outliers').

Section 3.3 – Supply change effects

Case study organisations indicated a relative ease of finding alternative suppliers with most indicating that they could secure alternative supplies between 1 day and 1 week. However, organisations also had limited visibility and understanding of their supply chain and how supplies might be disrupted by widespread disruption or disruption through key transport nodes or networks.

Because the economic module is based on economy wide availability of commodities, rather than an agent based model that includes individual business to business supply relationships, it is not possible to directly model these supply chain disruptions. It may be possible to model these delays at a sector level, by applying a different operability curve for the proportion of businesses that experience supply chain disruptions. This modification should be considered for future development of MERIT.

Section 3.4 – Productivity changes

The case study results support the case for including productivity increases within MERIT. However, the results from the case studies and the Canterbury earthquakes data do not provide adequate information to model this within MERIT. This will be the subject of further research.

Section 3.5 – Workforce inertia

The case study results confirmed the reluctance of organisations to increase or decrease staff numbers. The case studies indicated that the extent of this inertia is sector dependent. For example, hospitality showed more readiness to change staff levels than professional services firms.

As an initial model for staffing decisions, it is recommended that labour level changes within the economic module of MERIT be based on the previous six months' trading. Ideally the decision would also be based on six month forecast trading as well, however, the added complexity in achieving this is outside the scope of this project but could be included in future versions of MERIT.

Section 3.6 – Government grants

Interviews with case study organisations in Canterbury indicated that the earthquake support subsidy provided to businesses was vital for some organisations' survival and continued operation. The responses indicated that without the subsidy, the average level of operability of organisations may have been notably reduced. As a result, it is recommended that government grants be a lever within MERIT and the lever is 'on' – indicating that the existing operability functions relate to a situation where government grants were available. Further research is needed to determine the counterfactual case where less or no government grants are available.

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EXECUTIVE SUMMARY

This report is an output of the Economics of Resilient Infrastructure (ERI) research project, funded by the New Zealand government to develop a new spatial decision support system for infrastructure disruption in New Zealand. The system, referred to as 'Measuring the Economics of Resilient Infrastructure Tool' (MERIT), will be used to support government and infrastructure provider decision-making by enhancing their understanding of the economic impacts of infrastructure outages.

MERIT consists of a suite of interlinked modules incorporating spatial features of a region and its infrastructure networks, economic activity, business behaviours, interdependencies, and policy options. These modules can be shocked using infrastructure disruption scenarios (e.g., volcanic eruption, significant single infrastructure outage) to understand the economic impacts of such disruptions.

This report describes the proposed method for integrating business behaviour into the larger MERIT model. The business behaviours module for MERIT has been developed using empirical data gathered following the 2010/2011 Canterbury earthquakes. The Canterbury earthquake business behaviours data has provided an effective platform for developing quantitative and qualitative business behaviour models.

The ERI Business Behaviours team has developed a business behaviours causal framework to describe the effect of disruptions on an organisation's operability or their ability to meet demand. The framework links external infrastructure and non-infrastructure impacts to the degree of disruption *experienced* by individual organisations. In turn, the framework shows that an organisation's operability is affected by that experienced disruption; along with other organisational factors that can improve operability levels in the face of disruption, including organisational demographics, pre-event mitigation, post-event adaptation, and resilience.

With this framework as a conceptual guide, linear regression modelling and other complementary statistical methods were used to assess the Canterbury earthquakes dataset. From these analyses we determined the relative strengths of the variable relationships within the framework and subsequently developed an operability function for input into the full MERIT suite. There were four main steps in determining the operability function:

- Development of mathematical relationships describing the experienced disruption as a function of the duration of infrastructure disruption for each infrastructure type (water, sewage, electricity, gas, phone data, road, rail, airport, port, and fuel) at the industry sector level.
- Development of mathematical relationships describing experienced disruption due to non-infrastructure impacts (such as Modified Mercalli Intensity (MMI) for earthquake event).
- Development of an 'overall disruption' level that accounts for multiple disruptions.
- Development of the operability model using overall disruption and other contributing variables.

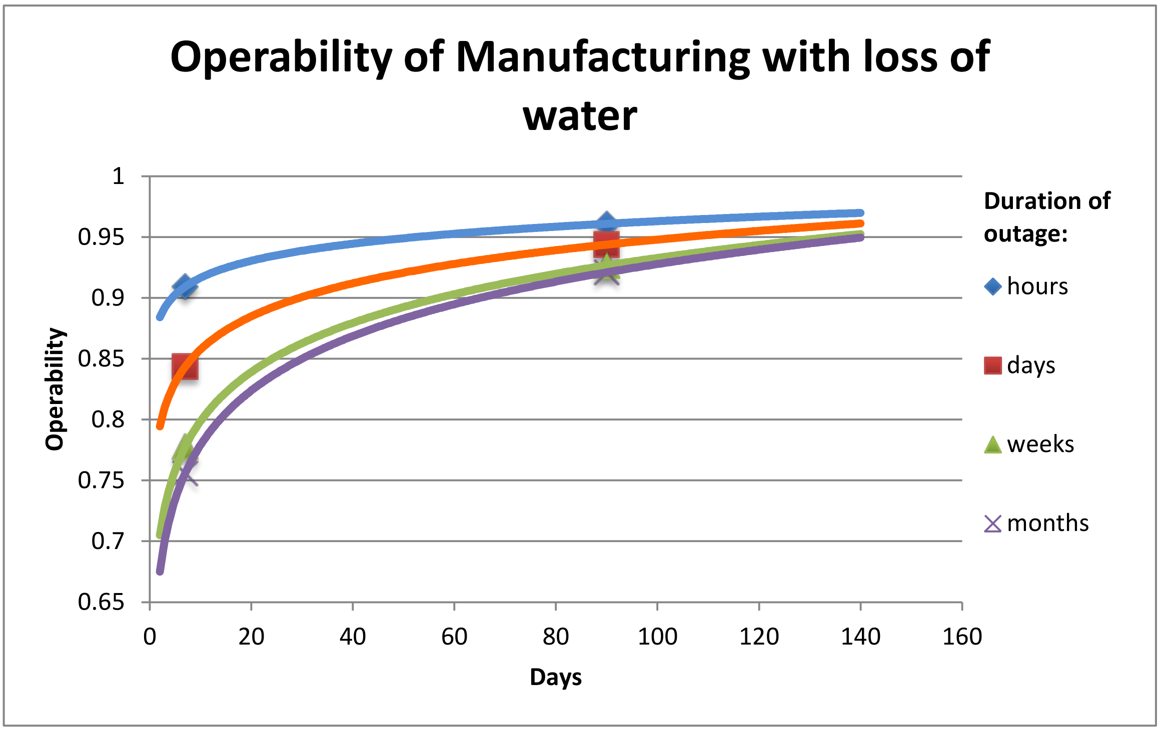
The analysis showed there are two main variables that drive an organisation's post-disaster operability: level of disruption and suppliers' ability to meet demand. Given the interactions between industries within the MERIT economic module, which accounts for some degree of supply chain disruption, the suppliers' ability to meet demand variable was removed for MERIT integration. Subsequently a function for operability as a function of overall disruption was developed:

$$Op(t) = 0.12 \, x \, OD \, x \ln(t) + (1 - 0.63 \, x \, OD)$$

Where $Op(t)$ is Operability at anytime, t

OD *is Overall Disruption (where 0 is not disrupted and 1 is significantly disrupted)*

An example set of operability curves is shown below.



A series of additional points for integrating business behaviours into MERIT have also been proposed. These include:

- A delay or other adjustment for changes to supply chain
- Adjustments for post-disaster productivity gains
- A delay in movement of labour within the economy
- The effect of Government grants
- Relocation triggers and effects

We highlight a number of results supporting each point, present causal networks demonstrating the relationships, and suggest methods for integrating these business behaviour components into the MERIT model.

A delay or other adjustment for changes to supply chain

- The Canterbury dataset indicates that when organisations are forced to change their suppliers, there is a negative impact on their operability.
- *To account for this we suggest incorporating a delay into the MERIT model whenever industries substitute commodities.*

Adjustments for post-disaster productivity gains

- The Canterbury dataset shows that organisational productivity levels were still surpassing pre-earthquake levels two and a half years after the earthquakes. Longer-term productivity gains were particularly evident in industry sectors that experienced significant increases in demand.
- *To account for disruption induced productivity increases, we propose including a scenario specific factor in the model that adjusts the productivity formula for each sector within MERIT.*

A delay in movement of labour within the economy

- A key dimension in understanding organisational recovery from disruption is understanding how organisations manage their workforce. There is a cost associated with bringing on new staff (recruiting, training etc.) and this must be balanced against needs to reduce payroll expenditure. In addition, organisations need to be confident that the demand change will endure before they decide to hire or fire staff.
  - *MERIT can incorporate adjustments to account for labour constraints. Options for including this are:*
    - ➢ *a limit on the 'labour' variable within the model: either as a cap on labour markets or a delay in securing additional labour*
    - ➢ *an increase in productivity of existing workforce, reflecting that organisations will make more intensive use of their existing staff.*
  - The appropriate approach will need to be determined in collaboration with the economic modelling team.

The effect of Government grants

- The effect of government grants (such as the Christchurch Earthquake Support Subsidy) on business behaviours is a potential lever that could be incorporated within the MERIT model.
  - *The effect of the Earthquake Support Subsidy was unclear in our dataset. It appears that it helped some businesses to survive but the extent to which this occurred is unclear. Future case studies conducted by the ERI business behaviours team are an opportunity to understand this further.*

Relocation triggers and effects

- Data from the Canterbury earthquakes show that organisations do not choose to relocate lightly in the face of disruptions and take time to do so once decided. There was a median lag time of approximately three months between the February 2011 earthquake event and organisations' actual relocation. If organisations relocate, there are likely effects on an organisation's ability to operate and, consequently, their economic performance.
  - *If relocation is included in the MERIT model, both a delay in relocation decisions and a reduction in 'operability' during the relocation period should be considered. However, the current ERI survey data does not provide enough evidence to quantify these effects. The relocation model will be further developed, using the case studies for data collection.*

The next step for developing the business behaviours module is the completion of a series of case studies. The case studies will help verify and adjust the business behaviour module and, where possible, add further quantification of some of the relationships. In addition, the business behaviours team will continue to work with the disruption scenario and economic modelling team to align and merge our findings into the MERIT model.

KEYWORDS

Business behaviour, spatial decision support system, operability, infrastructure disruption, economic impacts, MERIT, model, resilience.

1.0 INTRODUCTION

The Economics of Resilient Infrastructure (ERI) research project is funded by the New Zealand government to develop a new spatial decision support system for infrastructure disruption in New Zealand. The system, referred to as 'Measuring the Economics of Resilient Infrastructure Tool' (MERIT), will be used to support government and infrastructure provider decision-making by enhancing their understanding of the economic impacts of infrastructure outages.

MERIT consists of a suite of interlinked modules incorporating spatial features of a region and its infrastructure networks, economic activity, business behaviours, interdependencies, and policy options (Figure 1). These modules can be shocked using scenarios (e.g., volcanic eruption, significant single infrastructure outage) to understand the economic impacts of such disruptions.

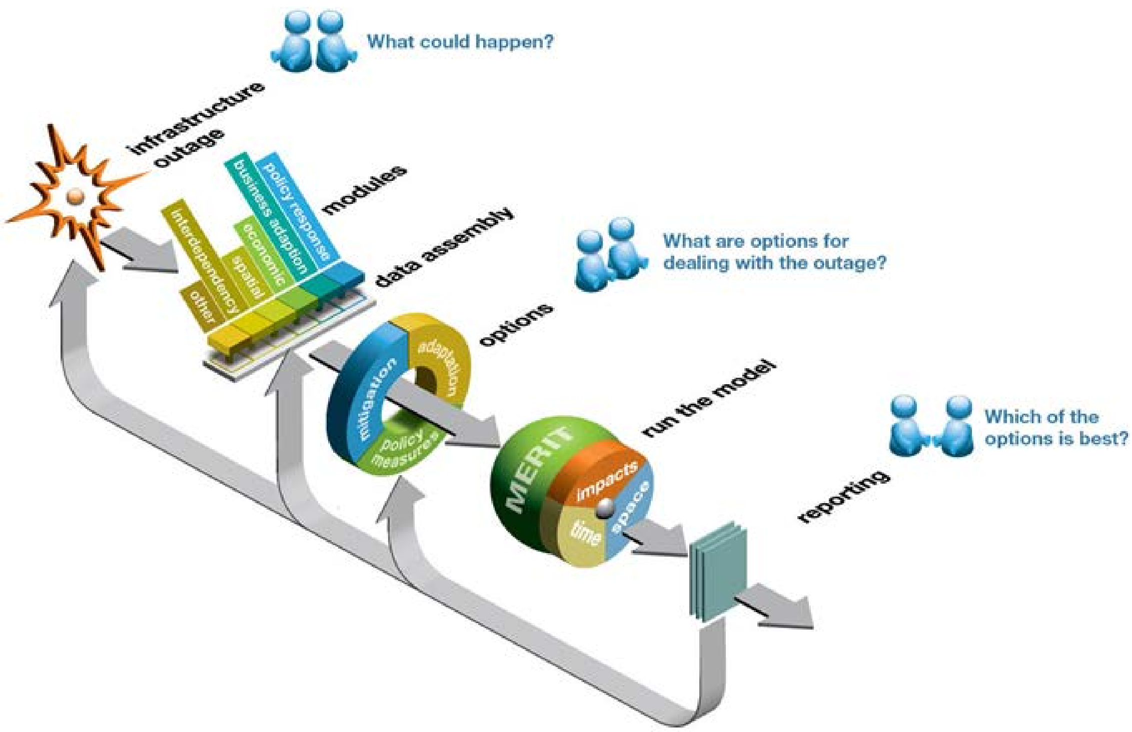


Figure 1 The relationships between the various components of MERIT (NHRP, 2014).

A business behaviours module is being developed as a component within the MERIT model. This module incorporates the responses and behaviours of businesses and other organisations to contribute to more dynamic and accurate assessments of the economic impacts of disruptive events. Within an economy, businesses, government agencies, and community service providers are the actors-on-the-ground that experience the direct and indirect impacts of infrastructure failures. They are the actors whose responses, decisions, and adaptive behaviours collectively shape the path of economic recovery and patterns of growth and decline. Therefore, understanding and modelling the responses of public and private organisations to major disruptions provides an essential component in understanding how local and regional economies fare in the aftermath of these events.

This report describes the proposed method for integrating business behaviour into the larger MERIT model. The business behaviours model for MERIT has been developed using empirical data gathered following the 2010/2011 Canterbury earthquakes. This represents an improvement over models with inputs based on the assessments and estimates of organisations that have not been affected by disasters. Previous studies show that organisations often significantly under-estimate their capacity to function during and following a disruption. For example Chang et al. (2002) found that organisations that had never experienced infrastructure disruptions usually under-estimated their capacity to cope with them, compared with organisations that had experienced some kind of disruption. Data from the Canterbury business behaviours survey, conducted two and a half years after the earthquakes, has been analysed to determine the true level and form of impact experienced by organisations facing various degrees of disruption.

Section 2 of this report provides an overview of the Canterbury earthquake sequence and the business behaviours survey used in this research. Section 3 presents the proposed business behaviour module and how it integrates with the MERIT model. The report concludes in Section 4 with a discussion on the further development and verification of the business behaviours module.

2.0 THE CANTERBURY EARTHQUAKES

In 2010 and 2011, the Canterbury region of New Zealand was affected by a series of damaging earthquakes. The two largest earthquake events on September 4th, 2010 (M7.1) and February 22nd, 2011 (M6.3) were followed by thousands of aftershocks, some of which caused additional damage or exacerbated existing damage.

The earthquakes resulted in extensive building damage from shaking and caused thousands of tonnes of silt to surface as soils liquefied (shown in Figure 2). Liquefaction caused extensive damage to land, buildings, and buried infrastructure (CCC, 2011). Together, these earthquakes were the most expensive and socially disruptive disasters that New Zealand has ever experienced (Stevenson, 2014).

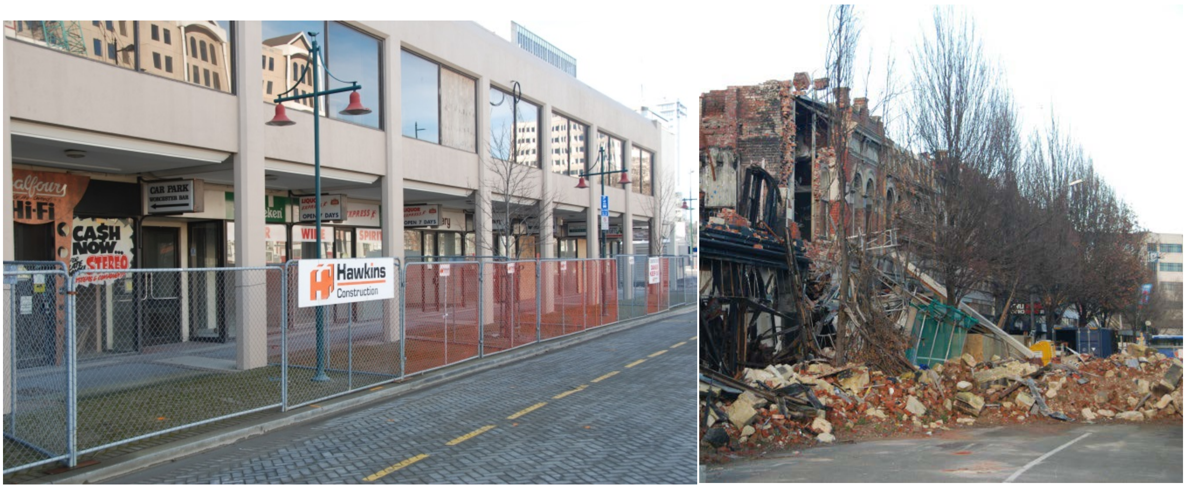


Figure 2 (Left) Businesses unable to access their premises in Christchurch CBD; (Right) Damage to unreinforced masonry facade in an historic street in Christchurch: the street remains inaccessible four years after the earthquakes. (Photo Credit: Dr Graham Tobin).

The unique challenges presented to organisations by the Canterbury earthquakes offered a varied landscape in which to examine organisations facing disruption scenarios. Organisations across the region experienced a range of different disruption profiles. Some organisations suffered total capital loss, while others faced a single short-term infrastructure outage. To capture business experiences, a business behaviours survey was conducted by ERI researchers. Between July and December 2013 ERI researchers sampled approximately 2,170 organisations across Greater Christchurch – which includes the Christchurch City, Waimakariri District, and Selwyn District Council areas (see Figure 3). In total, 541 organisations responded to the survey (a response rate of about 25%). Organisations included in our sample belonged to at least one of 17 industry sectors and covered a range of business sizes, ages, organisational ownership structures, and locations. The survey captured information on more than 200 different variables including organisation demographics, impact measures, pre-event mitigation measures, post-event business changes and adaptation, and financial information: providing over 100,000 data points for analysis. This series of events and rich data set has allowed us to investigate and better understand how organisations with a range of attributes are affected by and respond to different kinds of disruptions.

Further details on the Canterbury earthquakes, the business behaviours survey and the preliminary findings from the survey are available in an earlier ERI report (Seville et al., 2014)

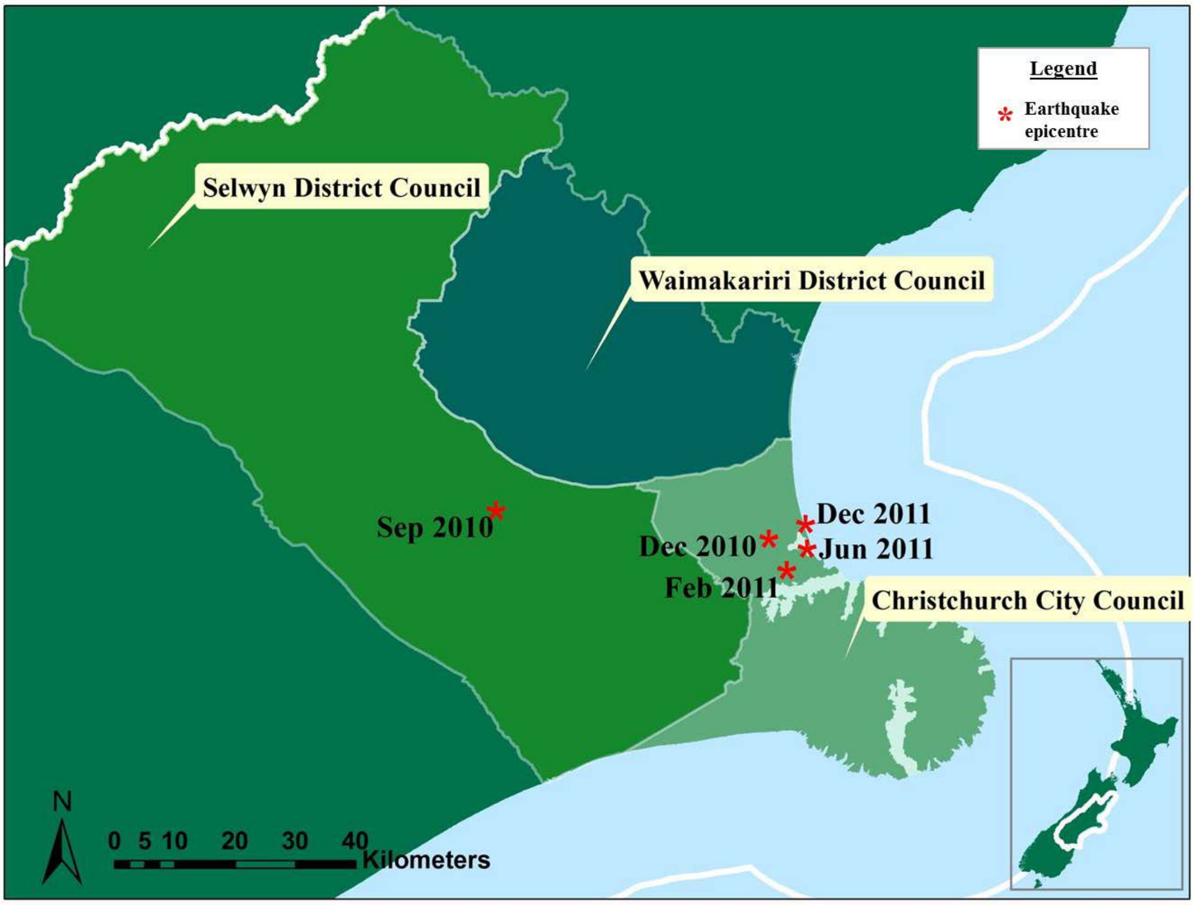


Figure 3 The district council areas within Canterbury most affected by the 2010/2011 earthquakes.

3.0 MERIT MODEL INTEGRATION

Supported by data gathered following the Canterbury earthquakes, ERI researchers have derived a multi-faceted business behaviour module for integration into the MERIT model. In this section we provide a brief overview of the MERIT model and its functions. We then describe the key features of the business behaviour module. Based on analysis of the Canterbury earthquake data, six integration points between the business behaviours module and the full MERIT model have been identified:

1. Operability function
2. Supply change effects
3. Productivity changes
4. Workforce inertia
5. Government grants
6. Relocation effects

This section explains each of these integration points in detail to guide the integration of the business behaviours module into the MERIT model.

3.1 MERIT OVERVIEW

As discussed in Section 1.0, MERIT consists of a number of different modules. The primary links for the business behaviours module within MERIT are with the infrastructure outage scenarios module and the economic module.

The infrastructure outage module provides infrastructure disruption data for five different scenarios: a water supply outage in Auckland, an electricity outage in Auckland, a Lyttelton Port disruption, an Alpine Fault earthquake and an Auckland volcanic field event. The infrastructure disruption data is projected onto maps showing land-use, industry locations, and economic production activities.

The economic module within MERIT is based on the principles of Computable General Equilibrium (CGE) models. In basic terms, the economic module creates a complex web of economic system components. It links multiple types of industries and commodities, and models the relationships between these using a systems dynamics framework. Unlike traditional CGE models, it does not rely on optimisation to equilibrate supply and demand and therefore is arguably more effective at modelling the effects of economic shocks and allows for more convenient interface with other system models.

There are a limited number of economic models specifically designed for and applied to infrastructure outage and disaster situations. Some models assume business as usual behaviours but there is a danger that this will not represent adequately behaviours during these ‘unusual’ circumstances. For example, mitigation and adaptation initiatives, such as using back-up generators or water supplies, having emergency plans, alternate suppliers, alternative working arrangements etc. The business behaviour module of MERIT is designed to moderate the economic module to ensure it appropriately reflects post-disruption business behaviour.

3.2 OPERABILITY FUNCTION

3.2.1 Overview

The main MERIT integration point for the business behaviours module is the operability function. Here, operability is defined as the proportion of demand for products and services that the organisation is able to meet at a given point in time. This function essentially links the infrastructure disruption scenario module to the economic module.

CGE models are commonly used to study the impacts of some type of a 'shock' on an economic system, particularly where there is a desire to obtain information on the distribution of effects (e.g., across economic sectors, locations and/or income groups). These models typically consider only changes in the 'equilibrium position' of the economic system under consideration where, among other conditions, supply equals demand. However, following an infrastructure disruption, the supply-demand relationship will be affected because organisations and industry sectors cannot operate fully. For example, if there is an electricity network failure many manufacturers will not be able to operate their machinery at full capacity. As a result, the manufacturer may be temporarily unable to supply their customers at pre-disruption levels. Therefore, when modelling infrastructure disruption, it is necessary to adjust this traditional supply–demand relationship to account for the degree to which organisations are able to meet demand for their products and services. The ERI Business Behaviours team has developed a business behaviours causal framework to model this disruption to the supply–demand relationship (see Figure 4). The central variable to this framework is an organisation's 'Operability'. Note that the business behaviours framework can be applied at either an organisational level or aggregated to represent the operability of industry sectors.

The 'operability' approach taken here is similar to an established approach in economic literature. Inoperability input-output modelling (IIM) has been developed and used by a number of authors (Jonkeren & Giannopoulos, 2014; Ali & Santos, 2012; Santos & Haimes, 2004; Haimes & Jiang, 2001) to assess the ripple effect of sector disruptions in highly dependent economic systems. In these studies, inoperability is defined as "the fraction of change in output of a sector over its normal expected output" (Ali & Santos, 2012). As the name suggests, operability is the inverse of inoperability. Although the inoperability/ operability definitions differ slightly (our definition includes the relating the output to demand as opposed to normal output) the concept and application of the approaches are similar.

In the framework, operability is first linked to supply and demand relationships. This includes not only the supply of products by the organisation but also the supply of goods to the organisation. The framework then includes the effect of disruptions (such as loss of infrastructure services, physical disruptions, neighbourhood and staff impacts) that negatively affect an organisation's operability. Last, the framework includes organisational factors that can improve operability levels in the face of disruption, including organisational demographics, pre-event mitigation, post-event adaptation, and resilience.

Figure 4 also shows how the operability framework integrates with other modules within MERIT. The 'overall impact' will be determined using inputs from the Disruption Scenarios module (see following sections). The operability function will be an input into the economic module.

With this framework as a conceptual guide, linear regression modelling and other complementary statistical methods were used to assess the Canterbury earthquakes dataset. From these analyses we determined the relative strengths of the variable relationships within the framework and subsequently developed an operability function for input into the full MERIT suite.

To determine the operability function there are four main steps:

Step 1: Experienced disruption due to infrastructure impacts

Step 2: Experienced disruption due to non-infrastructure impacts

Step 3: Combining disruptions

Step 4: Operability function

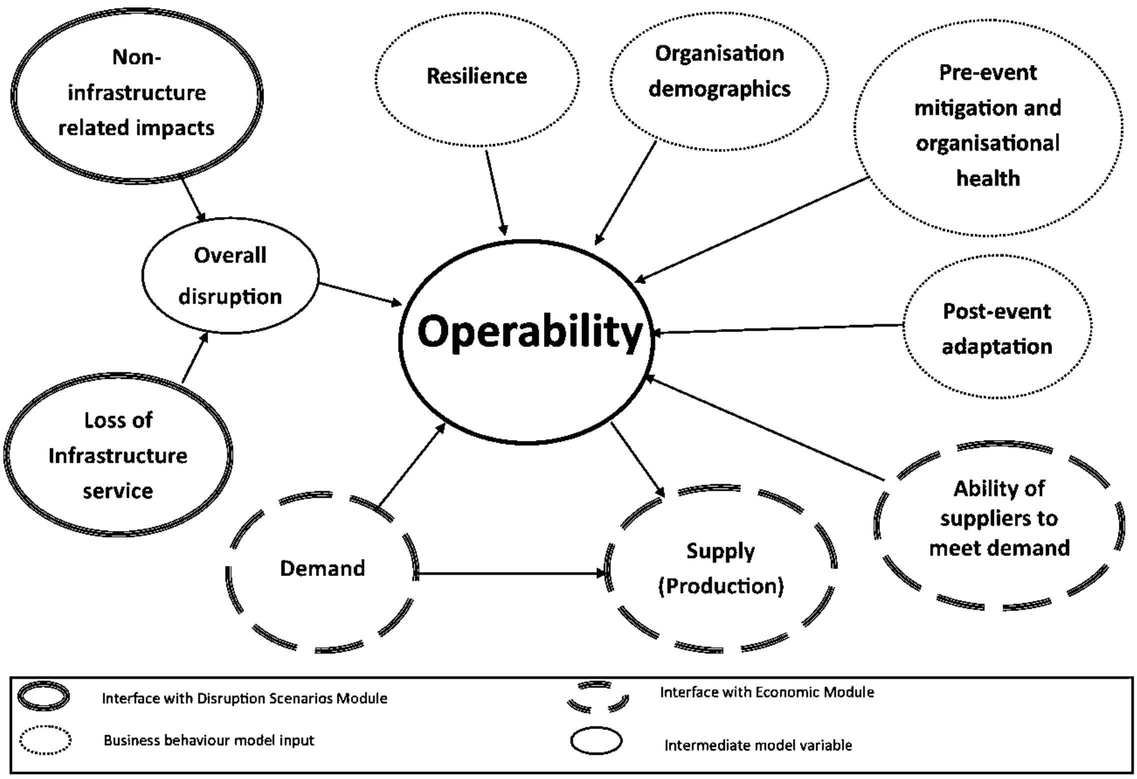


Figure 4 Business behaviours causal framework.

3.2.2 Step 1 – Experienced Disruption due to infrastructure impacts

The first step in developing the operability function is to translate infrastructure disruption data into ‘experienced disruption’ from the perspective of the organisation. This allows the infrastructure disruption information from the Disruption Scenarios module to interface with the business behaviours module. The experienced disruption takes into account both the duration of the disruption and the dependency of the organisation on the infrastructure.

Analysis of the survey data showed that there were significant differences between the level of experienced disruption, ED_{inf}, (for a given duration of infrastructure disruption, DID) for different sectors. For example, both the Health Care and Social Services sector and the

Retail sector, on average, experienced about 2 weeks of disruption to water services. The Health Care sector reported a level of experienced disruption of ED_{inf} =0.61 (where ED_{inf} =0 is not disrupted and ED_{inf} =1 is very disrupted) compared to retail which reported a much lower experienced disruption (0.42).

As a result, mathematical relationships describing the experienced disruption (ED_{inf}) as a function of the duration of infrastructure disruption (DID) were developed for each infrastructure type (water, sewage, electricity, gas, phone data, road, rail, airport, port, and fuel) at the industry sector level. The relationships were developed using a linear regression analysis. The majority of the analyses showed a statistically significant relationship between duration of outage and level of experienced disruption ($p<0.005$). The analyses also returned relatively high R^2 values showing strong positive relationships (see Appendix 2, ERI Results Bulletins 2015-K02-01 for details). The general form of these relationships is shown in Equation 1. The value of the coefficients, a and b, are dependent on the infrastructure type disrupted and the sector affected. The coefficients and the experienced disruption for different durations of infrastructure disruption are included in Appendix 1.

$$\boldsymbol{ED_{inf} = a + b\ x\ DID} \qquad [\boldsymbol{If\ ED_{inf} > 1, then = 1}] \qquad \textbf{Equation 1}$$

Where $\boldsymbol{ED_{inf}}$ *= Experienced disruption due to infrastructure disruption (ranging from 0 (not disrupted) to 1 (very disrupted).*

$\boldsymbol{DID}$ *= duration of infrastructure disruption, and DID is measured in 1=hours, 2=days, 3=weeks, 4=months.*

Figure 5 shows a plot of the relationship for three example sectors experiencing water service disruption. The graph shows that the Health Care and Social Assistance sector has a much higher dependence on water than both Retail and Wholesale sectors. The level of experienced disruption by the Health Care sector is higher when compared to the one experienced by the Retail and Wholesale sectors for the same duration of service outages.

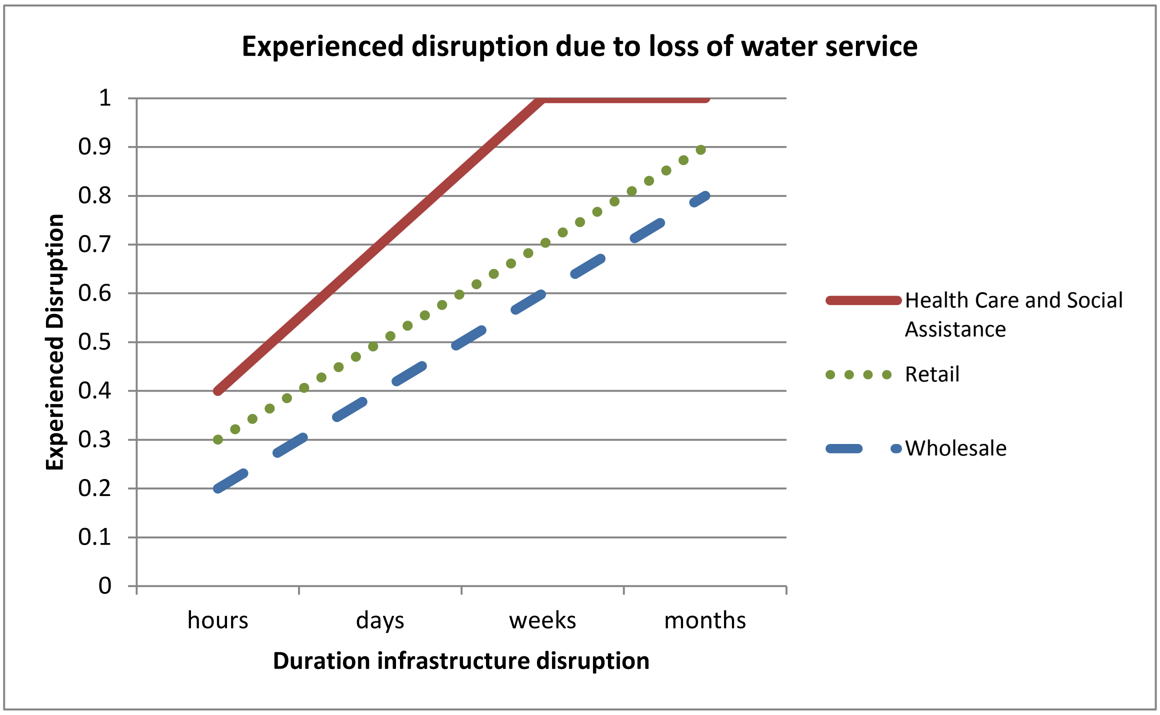


Figure 5 Experienced disruption as a function of duration of infrastructure disruption.

The effect of mitigation measures (back-up/alternatives to water, sewerage, electricity, communications and backup/alternatives to Information Technology (IT)) on experienced disruption was also investigated. The majority of organisations that had back-ups for 'water, sewerage, electricity and communications' and 'IT' rated the back-up as very or moderately important. However, when the 'use of mitigation measures' was added as a factor to the regression analysis, it was not found to be a statistically significant determinant of experienced disruption. It is possible that this is because the infrastructure impacts following the Canterbury earthquakes were significantly greater than the capacity of mitigation measures employed by most organisations. The nature and use of mitigation measures will be further investigated during the case study stage of this research.

The experienced disruption (ED_{inf}) functions will be further developed so that they can model partial levels of infrastructure service. The disruption scenarios module includes stepped levels of service, for example, water supply disruption includes: no water, limited water, boil water notice and full water supply; road network disruption is measured by change in travel time. The functions above are based on an organisation's own interpretation of the 'duration of disruption'. A disruption for one organisation could be a total loss of service, while for another it could be any level of reduced service. The effect of partial levels of infrastructure service will be investigated further through case studies.

The analysis used in the development of the experienced disruption due to infrastructure function, including sector dependency analysis, is in Appendix 2, ERI Results Bulletins 2015-K01-1 and 2015-K02-01.

3.2.3 Step 2 – Experienced Disruption due to Non-infrastructure impacts

The second step in modelling 'operability' is to develop a function to represent non-infrastructure impacts. Non-infrastructure impacts include damage to premises (e.g., building, inventory, equipment damage), damage to neighbourhood (e.g., damage to adjacent buildings, damage to pavements, access difficulties), and effects on staff (e.g., emotional well-being, availability, health and safety issues). Non-infrastructure impacts are likely to occur following community-wide hazard events. In the ERI project this includes the Alpine Fault and Auckland Volcanic Field disruption scenarios.

For MERIT, the degree of non-infrastructure disruption for these different community-wide scenarios needs to be estimated and inputted into the model. We suggest estimating non-infrastructure generated disruption as a function of the hazard magnitude or as the hazard's impact on the built-environment. For an earthquake, for example, a quantitative measure for the hazard could be the peak ground acceleration (PGA), while a qualitative measure for the earthquake-induced impact on the built environment could be the Modified Mercalli Intensity (MMI). For the volcanic scenario, a quantitative measure for the induced impact on the built environment could be amount of ashfall, while a possible measure for the exposure to the hazard could be the proximity to the volcano.

Using the Christchurch data, functions for estimating the relationship between physical disruption levels and the degree of non-infrastructure disruption for an earthquake scenario were developed. In the business behaviours survey, organisations indicated the level of disruption for a number of different impact including items such as building damage, contents damage, staff well-being, neighbourhood disruption, access restrictions. The items were scored on a four-point Likert scale ranging from 'not disrupted' (0) to 'very disrupted' (1). The Canterbury data indicated that non-infrastructure disruption could be grouped into three categories: damage to premises, neighbourhood damage, and staff impact. Using linear

regression analysis the level of disruption in these categories can be approximated based on peak ground acceleration (PGA), using the following equations. All three regression analyses show there is a statistically significant ($p<0.005$) relationship between PGA and non-infrastructure disruption. Equation 2, Equation 3 and Equation 4 have adjusted R^2 values of 0.149, 0.135 and 0.048 respectively. The R^2 values are low because of the variability of impact across organisations. It may be possible to improve R^2 values by grouping the organisations in like groups – e.g., by sector, by size, by location, by customer location.[1]

$$\boldsymbol{ED_{premises} = 0.9\ x\ PGA} \qquad [\boldsymbol{if\ ED_{premises} > 1, then = 1}]$$ **Equation 2**

$$\boldsymbol{ED_{neigh} = 1.1\ x\ PGA} \qquad [\boldsymbol{if\ ED_{neigh} > 1, then = 1}]$$ **Equation 3**

$$\boldsymbol{ED_{staff} = 0.2 + 0.5\ x\ PGA} \qquad [\boldsymbol{if\ ED_{staff} > 1, then = 1}]$$ **Equation 4**

Where $\boldsymbol{ED_{premises}}$ *is Experienced disruption due to damage to premises*

$\boldsymbol{ED_{neigh}}$ *is Experienced disruption due to neighbourhood damage*

$\boldsymbol{ED_{staff}}$ *is Experienced disruption due to staff impact*

$\boldsymbol{PGA}$ *is peak ground acceleration in g*

Equations for assessing the experienced disruption to premises ($ED_{premises}$), neighbourhoods (ED_{neigh}), and staff (ED_{staff}), as a function of MMI (Mercalli Macroseismic Intensity), were derived from Equations 2, 3 and 4. The development of the experienced disruption as a function of MMI relationships are provided in Appendix 2 ERI Results Bulletin 2015-K03-01.

$$\boldsymbol{ED_{premises} = 0.12\ x\ MMI - 0.56} \qquad [\mathit{if}\ \boldsymbol{ED_{premises}} > 1, \mathit{then} = 1]$$ **Equation 5**

$$\boldsymbol{ED_{neigh} = 0.13\ x\ MMI - 0.62} \qquad [\mathit{if}\ \boldsymbol{ED_{neigh}} > 1, \mathit{then} = 1]$$ **Equation 6**

$$\boldsymbol{ED_{staff} = 0.07\ x\ MMI - 0.11} \qquad [\mathit{if}\ \boldsymbol{ED_{staff}} > 1, \mathit{then} = 1]$$ **Equation 7**

Where $\boldsymbol{MMI}$ *is* Mercalli Macroseismic Intensity

For the volcanic scenario, a different set of functions will be developed. These functions are still to be determined in consultation with the disruption scenarios team and through case study investigations (refer to Section 4.0).

For infrastructure-only disruption events, the non-infrastructure experienced disruption functions will be set to zero.

The analysis used in the development of this function is in Appendix 2, ERI Results Bulletin 2015-K03-01.

[1] This analysis only accounts for PGA. It does not adjust for other external influencing factors such as the impact of the central city cordon in Canterbury or the impact of liquefaction, or the different seismic performance of the premises. This will be subject to further analyses.

3.2.4 Step 3 – Combining disruptions

Following community-wide disaster events, such as the Canterbury earthquakes, organisations face a number of different types of disruptions. As discussed in previous sections – these can be due to infrastructure or non-infrastructure impacts. The next step is to understand the effects of the aggregate of the different disruptions. For example, is there one type of disruption that has a higher impact on operability than another? Or are disruptions additive?

A series of analyses were carried out to determine how to combine the types of disruptions. First a principal component factor analysis was carried out to see which types of disruptions were similar. The disruptions formed three groups: non-infrastructure, network infrastructure, and node infrastructure impacts.

The division of infrastructure type impacts into network (*water, sewerage, electricity, phone, data, road, gas)* and node (*rail*[2]*, port, airport, and fuel)* infrastructure is noteworthy. The authors suggest several reasons for these statistically generated groupings. First, network type infrastructure have multiple delivery paths and geographically extensive systems. Therefore, partial or location level service may be possible. The node type infrastructures are generally services with one or a few (critical) service locations that must be operational for the service to be available. Second, the node infrastructure are all transport related. Generally transport services are substitutable and where one transport service is disrupted, another could be used in it's place (with associated time and cost implications). Third, in Christchurch, compared to the network infrastructure, which was damaged significantly by liquefaction, there were very low levels of damage to the node type infrastructure. The emergence of these two infrastructure groups has interesting implications for economic modelling in general and will be the subject of future research.

To represent the disruptions for each organisation, the maximum experienced disruption within the group was taken. For example:

$$\boldsymbol{ED_{non-inf} = max(ED_{premises}, ED_{neigh}, ED_{staff})}$$ **Equation 8**

$$\boldsymbol{ED_{net\ inf} = max(ED_{inf\ water}, ED_{inf\ sewerage}, ED_{inf\ electricity}, ED_{inf\ phone}, ED_{inf\ data}, ED_{inf\ road}, ED_{inf\ gas})}$$

Equation 9

$$\boldsymbol{ED_{node\ inf} = max(ED_{inf\ rail}, ED_{inf\ port}, ED_{inf\ airport}, ED_{inf\ fuel})}$$ **Equation 10**

Where $\boldsymbol{ED_{non-inf}}$ *is Experienced disruption due to Non-infrastructure impacts*

$\boldsymbol{ED_{net\ inf}}$ *is Experienced disruption due to Network infrastructure disruption (water, sewerage, electricity, phone, data, road, gas)*

$\boldsymbol{ED_{node\ inf}}$ *is Experienced disruption due to Node infrastructure disruption due to (rail*[2]*, port, airport, and fuel)*

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[2] Note that rail is considered a 'node' type infrastructure because a) it statistically grouped with the other infrastructure types and b) it is either working or it is not working. In New Zealand there are no or limited alternate routes for rail traffic. Generally the entire route needs to be operational for train travel to be possible.

Second, a series of analyses was carried out to determine how these three different types of disruptions were best combined to determine the Overall Disruption (OD). Both regression and correlation analyses indicated that the best approach for modelling the effect of disruption on operability was to average the two highest scoring disruptions (one from each of the three disruption categories: non-infrastructure, network infrastructure and node infrastructure disruptions). This is represented mathematically below:

$$\boldsymbol{OD} = \boldsymbol{max}\left(\left(\frac{ED_{non-inf}+ED_{net\ inf}}{2}\right), \left(\frac{ED_{node\ inf}+ED_{net\ inf}}{2}\right), \left(\frac{ED_{non-inf}+ED_{node\ inf}}{2}\right)\right) \quad \textbf{Equation 11}$$

Where $\boldsymbol{OD}$ is overall disruption and is measured between 0 (not disrupted) and 1 (very disrupted)

$\boldsymbol{ED_{non-inf}}$ *is Experienced disruption due to Non-infrastructure impacts*

$\boldsymbol{ED_{net\ inf}}$ *is Experienced disruption due to Network infrastructure disruption (water, sewerage, electricity, phone, data, road, gas)*

$\boldsymbol{ED_{node\ inf}}$ *is Experienced disruption due to Node infrastructure disruption due to (rail[2], port, airport, and fuel)*

Note, if there is only one type of impact (e.g., water outage scenario), then the other ED values will equal zero.

The analysis used in the development of this function is in Appendix 2, ERI Results Bulletin 2015-K04-01.

3.2.5 Step 4 – Operability function

The last step in this process is to generate a function that predicts operability. To determine this function, a step-wise linear regression was carried out with organisational 'operability' as the dependent variable. The independent variables included the level of impact, the change in demand and supply to an organisation, the organisation's level of resilience, the types of pre-event mitigation and post-event adaptation measures employed, and other demographic factors that might influence an organisation's ability to recover. The model used for the regression is shown in Figure 4.

The operability variable used in this analysis was taken from the survey question **"**To what extent was your organisation able to meet demand for your products and services a) immediately after the earthquakes, b) several months after the earthquakes, c) a year on from the earthquakes, d) two years on from the earthquake". The answers are based on a five point scale ranging from 1 (completely able to meet demand (80–100% of demand)) and 0 (completely unable to meet demand (0–20%)).

Initially the regression analysis was carried out for all four time periods[3]; however, the number of organisations that could not meet demand quickly reduced. By one and two years after the earthquakes, only a small number of outlier organisations were unable to fully meet

[3] The analysis was also initially attempted at the industry sector level; however, there was such large variation in the organisational impact and recovery within sectors that the results were unreliable. In addition, for some sectors the number of cases were too low. Other clustering of the data, such as by size or location or customer delivery method, could be tried to raise the reliability.

demand. As a result, two functions for operability were determined: one for immediately after the earthquakes (assume one week) and one for several months after the earthquakes (assume three months).

The independent variables analysed included[4]:

- Overall disruption
- Resilience – planned
- Resilience – adaptive
- Feasibility of relocation
- Level of mitigation
- Post-event adaptation
- Change in demand
- Suppliers' ability to meet demand
- Ownership – individual proprietorship
- Number of employees
- Number of locations outside Canterbury
- Need to relocate following earthquakes
- Use of the Earthquake wage subsidy

The step-wise regression analysis showed that only two independent variables were significant predictors of ability to meet demand. These were 'overall disruption' and 'suppliers' ability to meet demand'.

For the purposes of integrating the model, 'suppliers' ability to meet demand' was removed from the model because of the interactions within the economic module of MERIT. The economic module links industries to each other (through commodities) already accounting for supply chain disruptions. It is important not to double count the impact of changing suppliers. However, our analysis suggests there may need to be some further adjustments to the economic model to account for disruptions caused by changing suppliers, see Section 3.3 for more detail.

After 'suppliers' ability to meet demand' was removed from the linear regression, the operability functions at one week (7 days) and three months (90 days) were determined (see Equation 12 and Equation 13 respectively). For both time periods, the relationship between operability and disruption were statistically significant ($p<0.005$) and the R^2 values for the equations were 0.117 and 0.029 respectively. As for the non-infrastructure relationships, these R^2 values are low due to the large variability across organisations.

$$\boldsymbol{Op_7 = 1 - 0.4xOD}$$ **Equation 12**

$$\boldsymbol{Op_{90} = 1 - 0.1xOD}$$ **Equation 13**

Where $\boldsymbol{Op_7}$ *is operability at 1 week (7 days)*

$\boldsymbol{Op_{90}}$ *is operability at 3 months (90 days)*

$\boldsymbol{OD}$ *is Overall Disruption and is described in Section 3.2.4.*

[4] For a full description of the variables and survey questions corresponding to each variable see Appendix 2, ERI Results Bulletin 2015-K05-01.

To merge with the economic module, a function that shows how operability changes over time was needed. The 'ability to meet demand' data shows that operability increases in the pattern of a logarithmic curve, with an asymptote of 1. Therefore, the operability at one week and three months will be used to set the operability curve over time. The generalised logarithmic operability curve for any time (t) following the disruption is:

$$\boldsymbol{Op}(\boldsymbol{t}) = \frac{(\boldsymbol{Op_7}-\boldsymbol{Op_{90}})}{-2.55}\ln(\boldsymbol{t}) + \left(\boldsymbol{Op_7} + \frac{(\boldsymbol{Op_7}-\boldsymbol{Op_{90}})}{1.31}\right) \quad \textbf{Equation 14}$$

Or, substituting Equation 14 and Equation 15, this can be expressed in terms of overall disruption (OD):

$$\boldsymbol{Op}(\boldsymbol{t}) = \mathbf{0.12}\ \boldsymbol{x}\ \boldsymbol{OD}\ \boldsymbol{x} \ln(\boldsymbol{t}) + (\mathbf{1} - \mathbf{0.63}\ \boldsymbol{x}\ \boldsymbol{OD}) \quad \textbf{Equation 15}$$

Where $\boldsymbol{Op}(\boldsymbol{t})$ is Operability at anytime, t

$\boldsymbol{OD}$ *is Overall Disruption and is described in Section 3.2.4.*

Figure 6 and **Figure 7** below are example operability curves using the operability function derived above. **Figure 6** shows how manufacturing organisations are affected by differing durations of water disruption. The plot shows that all organisations regain operability over time, however, the longer the water outage organisations experienced the worse the long-term effect it had on the organisations' operability. This affect, however, attenuates beyond a multi-week outage. There is very little increased disruption between weeks and months of water disruption. This may indicate that after several weeks organisations will utilise alternative sources of water or relocate outside of the affected area. It should be noted that the operability curve for the short duration outage (hours) appears to be overly pessimistic. The curve shows that organisations, on average, would still be recovering over hundred days after the outage. We suspect there may be a threshold effect, where the operablity curves are not suitable for short duration outage events. This is to be further investigated through case study investigations (see Section 4).

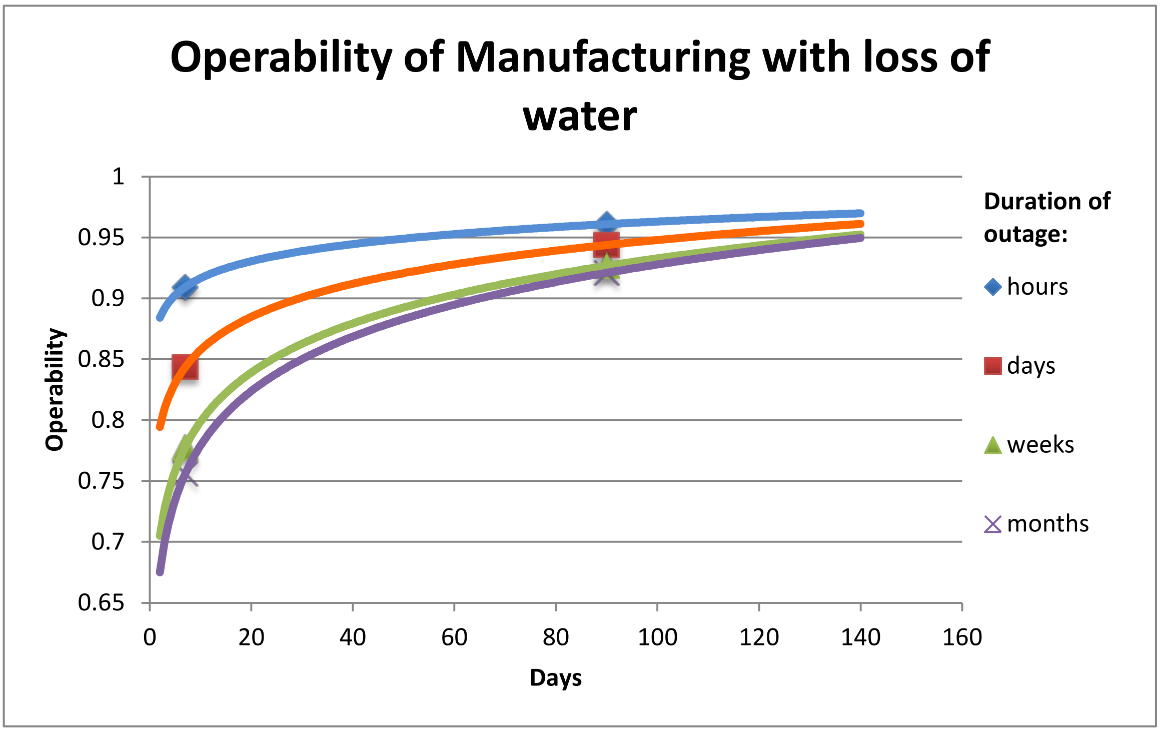

Figure 6 Example operability curve for manufacturing due to loss of water service (for varying periods).

Figure 7 shows how the same type of disruption affects sectors differently. The graph shows the effect of a total building loss and a month of water disruptions. The results show little difference between the sectors, but Financial and Insurance Services are least disrupted and Accommodation and Food Services are most disrupted as is expected due to the latter sector's high dependence on their premises and location.

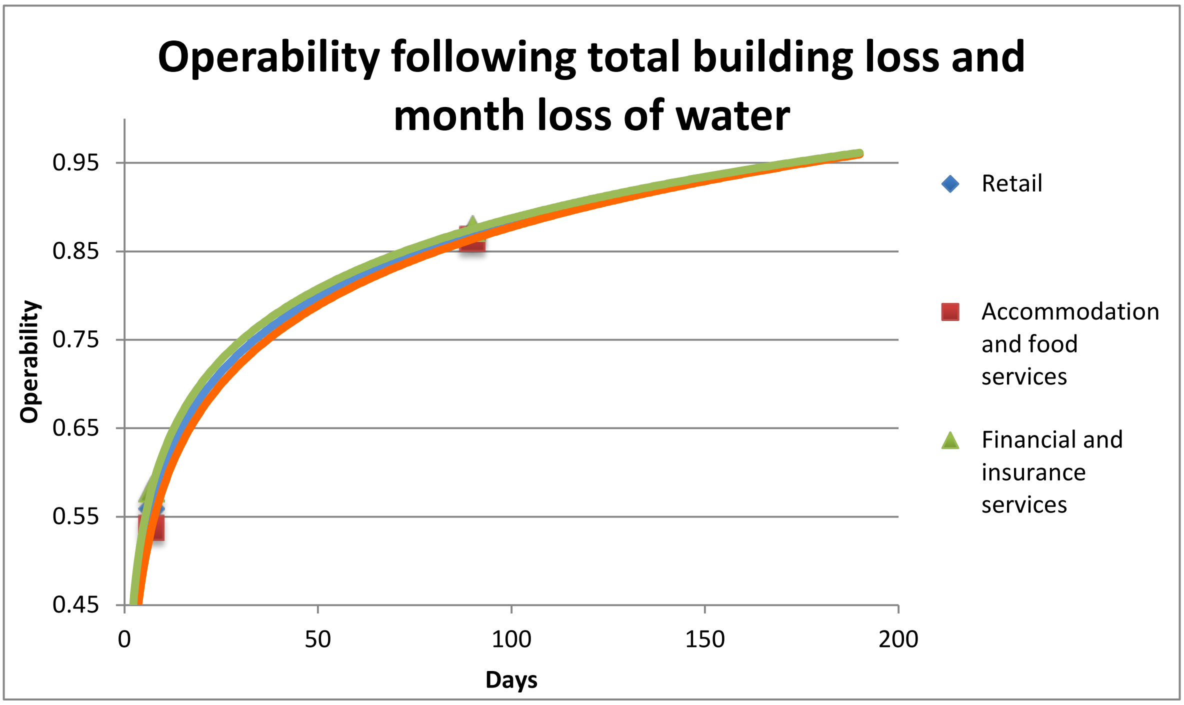

Figure 7 Example operability curves for different sector organisations due to loss of building and months of water disruption.

The operability function is the primary way the business behaviour module will link with the full MERIT model. The operability function translates the disruption scenarios impact information into a level of operability over time that can be applied, as an adjustment factor, to the economic module. The following sections identify other ways the business behaviours module could account for the ways organisations respond and adapt in the face of disruption.

The analysis used in the development of the operability function is in Appendix 2, ERI Results Bulletin 2015-K05-01.

3.3 SUPPLY CHANGE EFFECTS

As discussed in Section 3.2.5 'suppliers' ability to meet demand' has an impact on an organisation's ability to operate and deliver their products or service. When suppliers are disrupted, there is often a significant delay between an organisations' recognition that they need new suppliers and actually obtaining new suppliers. This needs to be reflected within MERIT.

In Canterbury, only 18.5% of organisations changed their suppliers. Even where organisations' usual suppliers were only 'somewhat capable' of supplying their needs, just 26% of organisations elected to change suppliers. And of the organisations that did change from their 'somewhat capable suppliers', they were statistically significantly less likely to be able to completely meet their demand within several months (49% compared to 68%).

This provides some evidence that when organisations are forced to change their suppliers, there is a negative impact on their operability. Generally, however, CGE models do not account for disruptions due to the need to change suppliers (including development of relationships and arrangements with new suppliers and delays in commodity availability). CGE models, which are normally used for regional/national level analysis, tend to model the operation of economic industries as a whole (i.e., there is one 'agent' representing each industry). This means that there is no identification of individual suppliers and consumers (firms/organisations) within an industry group. As a result, delays brought about by organisations needing to switch to new suppliers when the usual supplier is no longer able to satisfy demand are not easily captured within such models[5]. To account for this, we suggest incorporating a delay into the MERIT model whenever industries substitute commodities (see Figure 8).

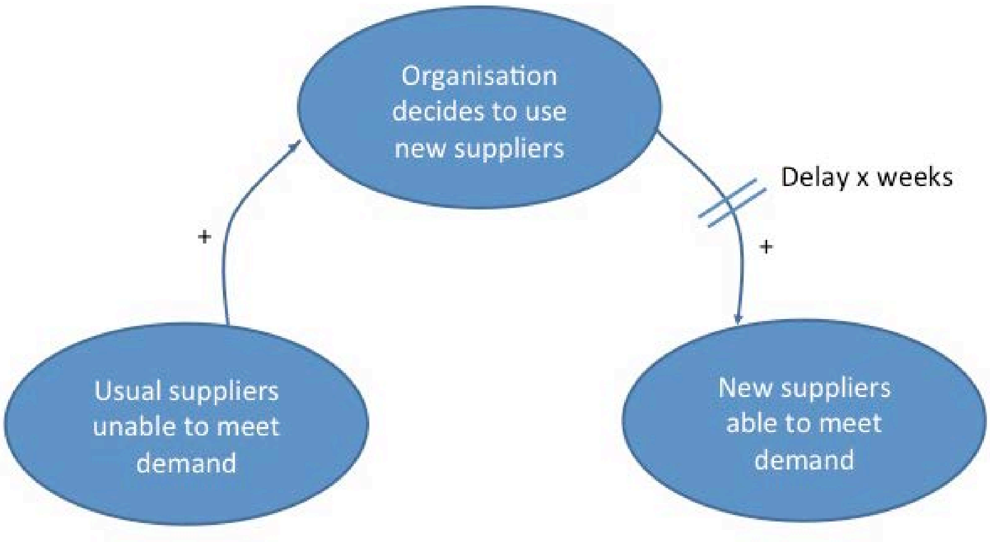

Figure 8 Effect of changing suppliers.

We will investigate the appropriate delay duration through our upcoming case study analysis, but sensitivity analysis will also be needed to determine whether or not the impact of supplier disruption is accounted for adequately, and to refine the length of the delay. During this process we will also consider whether changing suppliers would be better modelled as a disruption (an independent variable) in the operability model.

The analyses on productivity changes are included in Appendix 2, ERI Results Bulletin 2015-K06-01.

[5] Note, that if there is not enough supply of a particular commodity (in total) to meet total demand then this will create an impact in a normal CGE model.

3.4 PRODUCTIVITY CHANGES

Our analyses show that productivity increases are likely after a disruption and this phenomenon should be incorporated into MERIT. Here productivity is the efficiency of production, in other words, it is the ratio of output to inputs used. Just under 50% of organisations surveyed identified sustained productivity improvements following the earthquakes[6]. Productivity improvements have been identified by other authors, such as Park, Cho, and Rose (2010), as occurring within economies following disaster. Park, Cho and Rose (2010) describe how production levels increase to recover lost productivity and then return to the pre-disaster state after a period, as shown in Figure 9.

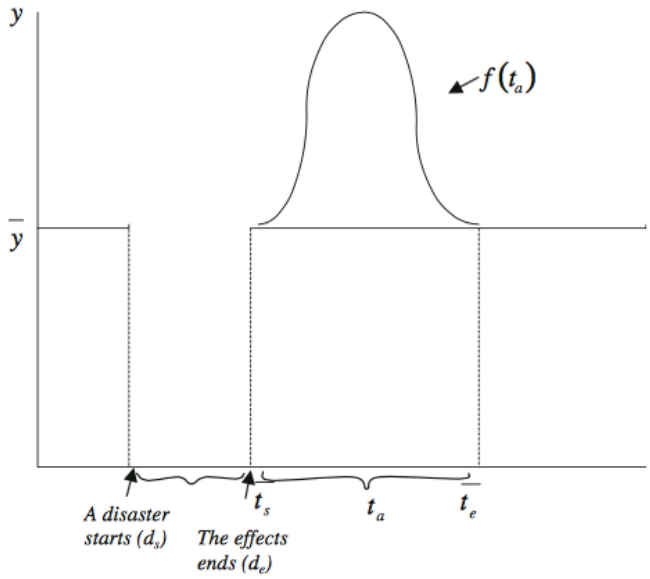

Figure 9 Time framework of ex-ante extreme event for an industry (Park, Cho and Rose (2010)).

The Canterbury dataset shows that organisational productivity levels were still surpassing pre-earthquake levels two and a half years after the earthquakes. Longer term productivity gains were particularly evident in industry sectors that experienced significant increases in demand such as Construction (43% reported productivity gains) and Accommodation and Food Services sectors (51% reported productivity gains).

Productivity gains were achieved through a variety of methods. Overall the methods with the highest correlation to productivity gains were organisations accessing new markets sectors, changing operational process, and integrating new technologies:

- 28% of organisations developed new market sectors (i.e. accessing new customers). Organisations in the construction sector and accommodation and food services were more likely to develop new customers; organisations in the Healthcare and Social Assistance, Education and Training and Professional, Scientific and Technical Service sectors were less likely to make this change.

[6] Note that the data obtained does not provide sufficient detail to determine whether or not this increase is in excess of baseline or counter-factual productivity increases. This is the areas of future research.

- Just under 20% of organisations significantly changed their operational processes.[7] There was no statistically significant differences in terms of which sectors changed their operational processes.
- 22% of organisations adopted new technologies. Professional, Scientific and Technical Services organisations were statistically more likely to adopt new technologies, compared to Accommodation and Food Services organisations, Electricity, Gas, Water and Waste organisations and Arts and Recreation organisations.

The factors affecting change in productivity are shown in Figure 10.

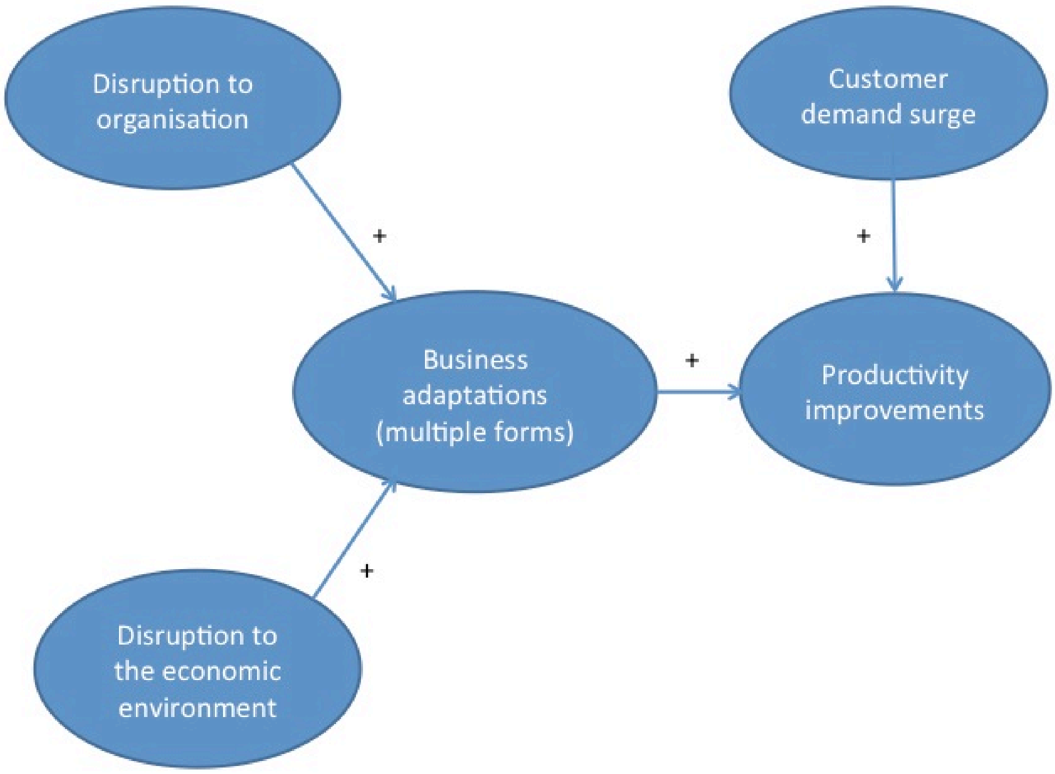

Figure 10 Factors affecting productivity changes.

To account for disruption induced productivity increases, we propose including a scenario specific factor in the model that adjusts the productivity formula for each sector within MERIT. The nature and scale of the productivity change factor requires further investigation. In particular the following need consideration:

- The <u>duration and nature of productivity increases</u> and potential for productivity decline over time. While the increase in productivity is evident after over two years, there could potentially be a return to lower production levels – particularly if some of the productivity increases are due to post-disaster demand surges.

[7] Operational processes transform inputs (e.g., materials, labour, information) into outputs (services, goods, level of customer satisfaction). Therefore, positive changes to operational processes can include a range of management decisions and actions that improve the organisations' outputs relative to inputs.

- The extent of productivity increases. The data from the Canterbury earthquakes only indicates an increase or decrease in productivity. The level of increases still needs to be determined.
- The relative efficacy of different strategies used for productivity improvements.
- The potential for and reasons behind productivity decline/return to normal level.
- The differences in productivity changes between sectors.

These will be explored during the case study component of the project (see Section 4.0).

The analyses on productivity changes (both from ERI study and a summary of literature) are included in Appendix 2, ERI Results Bulletin 2015-K07-01 and 2015-K08-01.

3.5 WORKFORCE INERTIA

A key dimension in understanding organisational recovery from disruption is understanding how organisations manage their workforce. And since labour is a key variable in the economic module of MERIT, it is important to understand post-disruption labour issues.

A schematic diagram of the factors affecting workforce changes is shown in Figure 11. The Canterbury earthquake data shows that, unsurprisingly, staff retention and hiring is significantly positively correlated with changes in demand.

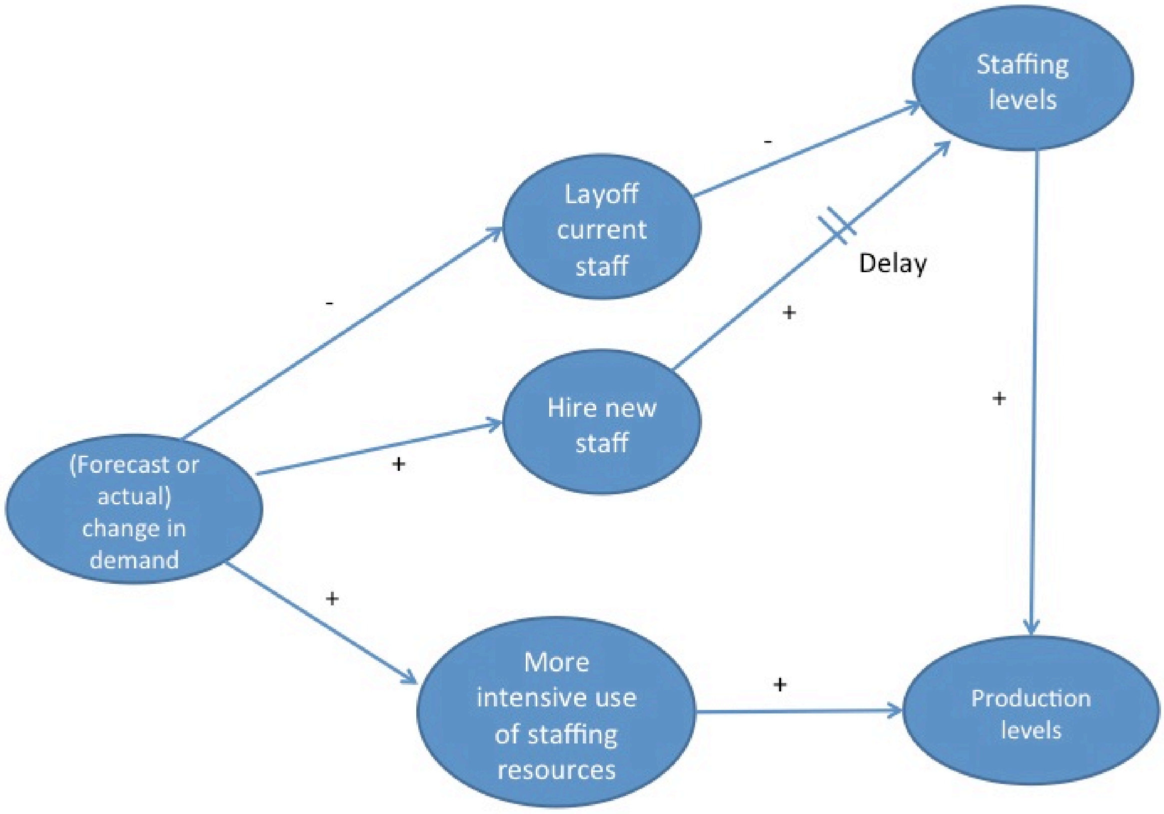

Figure 11 Factors affecting workforce changes.

Previous studies, such as Kachali (2013), indicate that some organisations will retain staff for as long as they can post-disaster, despite decreased income and demand. This is expected as there is a cost associated with bringing on new staff (recruiting, training etc.) and this must be balanced against needs to reduce payroll expenditure. Organisations need to be confident that the demand change will endure before they decide to hire or fire staff. Employers may also value the welfare of their staff and be reluctant to let staff go until absolutely necessary.

The qualitative data collected in the ERI survey showed that organisations found losing staff very challenging. 14 respondents indicated that having to make staff redundant or reducing staff numbers was a significant challenge for their organisation.

The Canterbury earthquake recovery was also constrained by workforce availability. 99 out of the 541 survey respondents said that finding qualified people with the right skills or who were suitable for their organisation was their main challenge. This resource constraint will be apparent in both of the community-wide disaster scenarios (the Alpine Fault and the Auckland Volcanic Field) used in the ERI project.

Consequently, MERIT will need to incorporate adjustments to account for labour constraints. Options for including this are:

- a limit on the ‘labour’ variable within the model: either as a cap on labour markets or a delay in securing additional labour
- an increase in productivity of existing workforce, reflecting that organisations will make more intensive use of their existing staff[8].

The appropriate approach will need to be determined in collaboration with the economic modelling team.

The analyses on workforce inertia are included in Appendix 2, ERI Results Bulletin 2015-K09-01.

3.6 GOVERNMENT GRANTS

The use of the government grants is an important consideration for interpreting and transferring the Canterbury earthquake data to the generalised MERIT model. It is also important for understanding the impact of government interventions on business behaviours as a potential lever within the MERIT model.

Following the Canterbury earthquakes the Government provided an earthquake support subsidy (ESS) in an effort to help businesses retain staff. The subsidy was available for up to eight weeks to any organisation in Christchurch facing hardship (loss of access to workplace, premises damage, delayed insurance payments) following the earthquakes. Small businesses experiencing a loss of trade were also eligible. The subsidy was not available to international or large national organisations (Ministry of Social Development, 2011a). The ESS was extended by another six weeks but under stricter criteria (Ministry of Social Development, 2011b). In total, the earthquake support subsidy contributed $185 million to over 10,000 sole traders and 8,000 employers (supporting nearly 47,000 employees) (Ministry of Social Development, 2011c) or 27% of the local workforce (Fischer-Smith, 2013).

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[8] Note that to some extent productivity increases may already be captured in the Operability function: enabling organisations to meet demand in the face of significant disruption. Further investigation is required.

The survey analysis results show that less than a fifth of sampled organisations used the ESS. The effect, therefore, of the ESS on the aggregated business recovery data analysis is likely to be quite small.

From an individual organisation point of view, those that received the ESS, in general, had poorer recovery outcomes compared to those that did not receive the subsidy. As shown in Table 1, the organisations that used the ESS were more highly impacted, were less able to meet their demand and were more likely to describe themselves as "worse off", "still surviving," or "recovering" more than two and half years after the earthquakes. However, since there is no baseline data for comparison (an equivalent event where no ESS was available) it is unclear to what extent the ESS changed individual business behaviours and outcomes.

Some analyses suggest that the ESS had a significant impact on business survival. For example, Recover Canterbury believed many businesses would have closed without ESS:

> "The overwhelming response we [Recover Canterbury] had from businesses that received this subsidy is that it was one of the most critical pieces of support they received following the February earthquake, with some businesses going so far as to say it was the subsidy that saved their business from certain closure." (cited in Fischer-Smith (2013))

While, in our dataset, those that received the subsidy had poorer recovery outcomes compared to those that did not, the outcomes could have been worse if there was no subsidy at all. Poorer individual organisational outcomes could have had flow on effects for the wider economy as well, including: increased unemployment, depopulation, reduced business confidence and supply chain disruption for other organisations.

Table 1 Effect of using the earthquake wage subsidy (only includes statistically significant values, $p<0.05$)

	Used ESS	Did not use ESS
Percent of sample	17%	83%
Percent Small Medium Enterprises (SME) (<20 full time equivalent staff)	21% (note that 86% of ESS users were SMEs)	79%
Level of overall impact (where 0 is not disrupted and 1 is very disrupted)	0.76	0.62
Unable to meet demand immediately after the earthquake	24%	11%
Completely able to meet demand several months after the earthquake	60%	74%
Significantly worse off (two and a half years after the earthquake)	29%	12%
Survival mode (two and a half years after the earthquake)	14%	6%
Still recovering from the earthquake (two and a half years after the earthquake)	40%	28%
Found the earthquakes positive	16%	30%
Poor cashflow	13.6%	7.3%

The authors propose that recipient organisations of the ESS likely fell into three main categories (as depicted in Figure 12):

- **The ESS delayed the inevitable.** If a business was fundamentally unviable (with or without the earthquake), the effect of the ESS was to delay staff moving onto the unemployment benefit (or into other employment) and potentially damped population 'flight' from Christchurch by allowing time for employees to look for new jobs.
- **The ESS was a 'life saver'**. For some organisations the ESS would have prevented staff being laid off in the short term (due to cashflow issues). Maintaining staff would have increased their chances of recovery. It also gave business owners time to make critical business decisions. From a regional economy perspective, saving these businesses would have reduced supply chain disruption within the economy and prevented a temporary 'spike' in the number of unemployed in Christchurch. In doing so it potentially damped 'flight' of population from Christchurch.
- **The ESS was a nice to have**. For some organisations, that were otherwise viable, the ESS was likely a 'nice to have' but not a necessity. If the ESS had not been available, the organisation would have found other ways to overcome the short-term issues they were facing, such as approaching their bank for a loan. While the data in Table 1 indicates that the ESS was not effective at improving the recovery of recipient organisations, it is likely to have contributed to a 'sense of support' for affected organisations, which may have created a more positive outlook by these business owners.

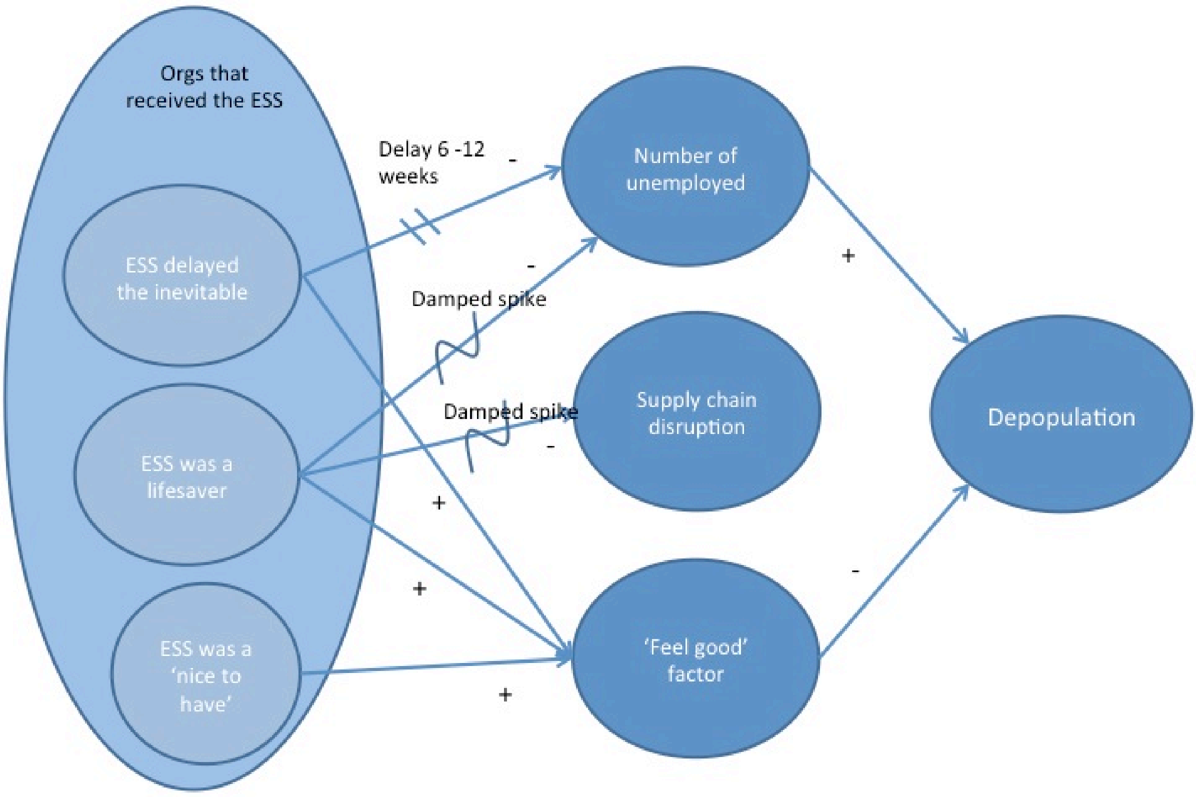

Figure 12 Effect of Earthquake Support Subsidy.

If the use and effect of government grants, such as the earthquake support subsidy, is going to be integrated into MERIT, it will be necessary to determine the proportion of recipients of the ESS that fall into each of the three categories above. The case studies are an opportunity to understand this further (see Section 4.0).

The analyses on the earthquake wage support subsidy are included in Appendix 2, ERI Results Bulletin 2015-K10-01.

3.7 RELOCATION EFFECTS

Organisations may need to relocate in response to large scale and long duration infrastructure disruptions – a response which may be necessary to consider and model in MERIT. Data from the Canterbury earthquakes shows that organisations do not choose to relocate lightly in the face of disruptions and take time to do so once decided. There was a median lag time of approximately three months between the February 2011 earthquake event and organisations' actual relocation.

The decision to relocate is dependent on a number of factors. First, the decision to relocate is dependent on the impacts on the organisation. Following the Canterbury earthquakes, those that relocated suffered more severe structural damage and longer duration infrastructure disruptions than those that didn't relocate. Other studies by the researchers (Stevenson, 2014) indicate that the feasibility of relocation and perceived and actual location dependence can also influence the decision to relocate. Furthermore, the decision to relocate can be delayed due to factors such as market conditions and business requirements (such as finding new premises, fitting out premises, acquiring licences / consents where necessary).

If organisations relocate, there are likely effects on an organisation's ability to operate and, consequently, their economic performance. The Canterbury dataset shows that those that relocated after the earthquakes were significantly less likely to be able to meet demand both immediately and several months after the earthquakes. However, it should be noted that this may be due to a higher level of impact being sustained by these organisations. A schematic diagram of the factors affecting relocation and the effects of relocation are shown in Figure 13.

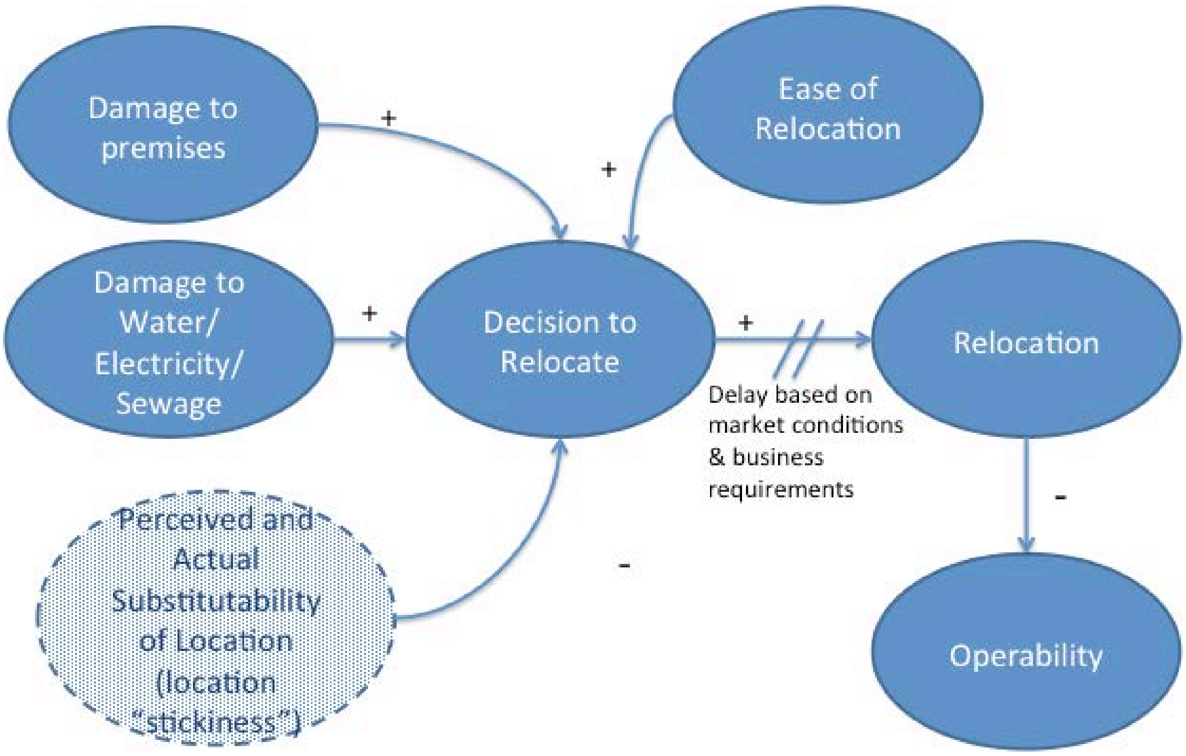

Figure 13 Factors affecting decision to relocate.

If relocation is included in the MERIT model, both a delay in relocation decisions and a reduction in 'operability' during the relocation period should be considered. However, the current ERI survey data does not provide enough evidence to quantify these effects. The relocation model will be further developed, using the case studies for data collection (see Section 4.0).

The analyses on the workforce inertia are included in Appendix 2, ERI Results Bulletin 2015-K11-01.

4.0 FUTURE WORK – CASE STUDIES

The next step for the ERI business behaviours team is to test the transferability of the relationships developed using the Canterbury earthquake data to other geographic and socio-economic contexts, and to different infrastructure disruption events. To do this a series of paired case studies in two study regions, Canterbury and Auckland, will be carried out. 6-10 organisations that completed the ERI Canterbury business behaviours survey will be selected. These organisations will represent a range of sectors, business sizes and types. For each Canterbury case study a corresponding organisation in Auckland with similar demographic features will be selected.

The case studies will concentrate on the following:

1. For Canterbury organisations: confirming the interpretation of the survey responses. For example, what does it mean to an organisation to be 'slightly disrupted' and to be able to continue functioning?
2. Discussing the levels of and effectiveness of mitigation measures in place (particularly for critical infrastructure disruption).
3. Understanding the level of disruption due to reduced levels of infrastructure service – e.g., impact of rolling electricity outages compared to no electricity and impact of increased travel times.
4. Determining the level of non-infrastructure experienced disruption for the volcanic field scenario.
5. Determining the applicability of the operability curves to short duration outage events.
6. Discussing the issues associated with disruptions to the supply chains, including the reasons or triggers for changing suppliers (e.g., percentage of needs met) and potential delays or other penalties from changing supplier.
7. Exploring changes in productivity following disruption (particularly with Canterbury organisations). Including,
    a. Duration and nature of productivity increases
    b. Extent of productivity increases
    c. Strategies used for productivity increases
    d. Productivity decline or return to normal (timing, nature, reasons)
    e. Differences in productivity changes between sectors and
    f. Tipping point (scenario size / nature) for changes in productivity.
8. Determining how organisations make staffing decisions. For example, identifying the scale and nature of events that change business confidence and how far ahead workforce needs are determined.
9. For Canterbury organisations: Understanding the role and effectiveness of the Earthquake Wage Subsidy.
10. Understanding the triggers that will cause relocation, the factors affecting the relocation destination, and the effects of the relocation.
11. Other MERIT levers, as agreed with full ERI team.

The case study findings will be used to calibrate and rationalise the relationships and functions developed through the survey data analysis. As noted by Chang et al. (2002), organisations that have not suffered a disruption may under-estimate their capacity to function. Analysis of the Canterbury survey data agreed with this finding but also provided a new insight. Even if organisations have faced adversity, they are still likely to under-estimate their capacity in the face of similar disruption. Specifically, the Canterbury business behaviour survey asked questions both about how organisations were affected by infrastructure disruption following the earthquakes, as well as questions about how they could operate in the face of future infrastructure disruption. Organisations consistently under-estimated their ability to function during infrastructure disruption – often signalling they could sustain less disruption (in terms of duration of loss of service) than they sustained following the earthquakes.

Many organisations indicated they ‘could not function’ following an infrastructure disruption that was in fact shorter than the one faced following the Christchurch earthquakes. And in the case of the earthquakes they were still able to meet approximately 50% of their demand immediately after the earthquakes and 80–90% several months after (see Appendix 2 ERI Results Bulletin 2015-K12-01 for more details). This disparity between perceived operability and actual operability will need to be taken into account when analysing and applying the case study data.

5.0 SUMMARY

The Canterbury earthquake business behaviours data has provided an effective platform for developing quantitative and qualitative business behaviour models. First, an operability model has been developed that can be integrated into MERIT. The data allowed for both infrastructure and non-infrastructure impacts to be translated into experienced disruptions for businesses. These impacts in turn can then be used to determine an organisation's operability over time. This operability model will allow the economic model to adjust for actual business behaviour.

Second, a series of additional integration points have also been identified for MERIT. These include:

- A delay or other adjustment for changes to supply chain
- Adjustments for post-disaster productivity gains
- A delay in movement of labour within the economy
- The effect of Government grants
- Relocation triggers and effects

The next step in the project, the case studies, will allow for the models developed here to be verified and adjusted and, where possible, further quantified. In addition, the business behaviours team will continue to work with the disruption scenario and economic modelling team to align and merge our findings into the MERIT model.

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7.0 ABOUT THE TEAM

7.1 ECONOMICS OF RESILIENT INFRASTRUCTURE (ERI) PROJECT

The Economics of Resilient Infrastructure (ERI) is a four year research project (2012–2016) funded by the New Zealand government.

The project aims to develop a new model (known as MERIT) which will:

- quantify the economic implications of vulnerabilities to infrastructure failure from both natural hazards and infrastructure-only events, and
- explore alternative infrastructure-related mitigation, adaptation and recovery strategies.
- enable a high resolution assessment across space and through time of the economic consequences of infrastructure failure, business response and recovery options.

The project team includes researchers from GNS Science, Market Economics Ltd, Resilient Organisations, and Research Institute for Knowledge Systems (RIKS). Auckland Council, Tony Fenwick (Wellington) and Simon Worthington (Christchurch) are also involved.

For more information on the ERI project see our website:
http://www.naturalhazards.org.nz/NHRP/Hazard-themes/Societal-Resilience/Economics-of-Resilient-Infrastructure

7.2 RESILIENT ORGANISATIONS (RESORGS)

The Business Behaviours strand of research within the ERI project is being undertaken by Resilient Organisations.

Resilient Organisations is a public good research programme based in New Zealand. We have been researching what makes organisations resilient to crises since 2004. Resilient Organisations is a collaboration between top New Zealand research universities, particularly the University of Canterbury and University of Auckland. We are a multi-disciplinary team of over 35 researchers, representing a synthesis of engineering, science, and business leadership aimed at transforming organisations into those that both survive major events and thrive in the aftermath.

In an increasingly volatile and uncertain world, one of the greatest assets an organisation can have is the agility to survive unexpected crisis, to find opportunity, and thrive in the face of potentially terminal events. This resilience is typified by world class organisational culture and leadership, strong and diverse networks that can be drawn on for support when needed, and an attitude and strategic positioning that is change-ready. More resilient organisations lead to more resilient communities and provide the honed human capital to address some of our most intractable societal challenges.

See www.resorgs.org.nz for further information.

APPENDICES

APPENDIX 1: EXPERIENCED DISRUPTION DUE TO INFRASTRUCTURE OUTAGES

Equation co-efficients

Sector	Water		Sewage		Electricity		Gas		Phone		Data		Road		Rail		Airport		Port		Fuel	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
All	0	0.2	0	0.3	0.1	0.3	0.0	0.3	0.2	0.2	0.1	0.3	0.2	0.2	0.0	0.2	0.0	0.2	0.0	0.2	0.1	0.2
Health Care and Social Assistance	0.1	0.3	0.1	0.3	0.1	0.3	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0.0	0.2	0	0	0.0	0.2
Professional, Scientific and Technical Services	0.1	0.2	0	0.3	0.1	0.2	0.0	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.0	0.1	0.0	0.2	0.0	0.1	0.0	0.2
Education and Training	0.0	0.3	0	0.3	0.1	0.2	0.0	0.3	0.2	0.2	0.3	0.2	0.2	0.1	0	0.7	0	0.3	0	0	0.0	0.2
Manufacturing	0.0	0.3	0	0.3	0	0.3	0.0	0.1	0.1	0.3	0.0	0.3	0.2	0.2	0	0.3	0	0.2	0.0	0.2	0.0	0.2
Transport, Portal and Warehousing	0.0	0.3	0	0.3	0	0.3	0.0	0.3	0.2	0.2	0.1	0.3	0.1	0.2	0.1	0.1	0.1	0.3	0.2	0.1	0.2	0.2
Construction	0.0	0.3	0	0.3	0	0.3	0.0	0.3	0.1	0.3	0.0	0.3	0.2	0.2	0	0.1	0.0	0.3	0	0.1	0.1	0.2
Retail	0.1	0.2	0.1	0.3	0.2	0.2	0.0	0.3	0.3	0.2	0.1	0.3	0.3	0.1	0.1	0.2	0.1	0.1	0.0	0.2	0.2	0.2
Agriculture, forestry and fishing	0.0	0.3	0	0.3	0	0.3	0.0	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.0	0.2	0.0	0.1	0.0	0.3	0.0	0.2
Accommodation and food services	0.0	0.3	0.1	0.3	0	0.4	0.0	0.3	0.1	0.2	0.1	0.2	0.1	0.2	0	0.2	0.1	0.3	0.0	0.2	0.0	0.3
Wholesale trade	0.0	0.2	0	0.3	0.1	0.3	0.0	0.3	0.1	0.3	0.1	0.3	0.2	0.2	0.0	0.2	0.0	0.2	0.0	0.3	0.0	0.2
Information, Media and Telecommunications	0.0	0.2	0	0.2	0	0.3	0	0	0.1	0.1	0.1	0.3	0.2	0.2	0.0	0.2	0.0	0.2	0	0	0.1	0.2
Electricity, Gas, Water and Waste Services	0.1	0.2	0.1	0.2	0.1	0.3	0	0	0.2	0.3	0.1	0.2	0.5	0.1	0.0	0.2	0	0.3	0	0.3	0.2	0.2
Financial and insurance services	0.0	0.2	0	0.2	0	0.2	0.0	0.2	0.2	0.2	0.1	0.2	0.3	0.1	0	0	0.0	0.3	0	0	0.1	0.1
Rental, Hiring and Real estate	0.0	0.3	0.1	0.2	0.1	0.3	0	0	0.1	0.3	0.1	0.3	0.4	0.1	0	0	0.0	0.3	0	0	0	0.3
Arts and Recreation Services	0.1	0.3	0	0.3	0	0.3	0	0.4	0.0	0.4	0.0	0.4	0.1	0.2	0	0	0	0.2	0	0.3	0.1	0.2

Theoretically A should be zero (no disruption for no outage of infrastructure). Where value is >0, we suggest the function is forced to zero where infrastructure outage duration is 0 (no outage). Also, maximum disruption is 1. So function must have maximum outcome of 1.

Experienced disruption values by sector and infrastructure outage duration

Table 1 of 3

Sector	Water				Sewage				Electricity				Gas			
	h	d	w	m	h	d	w	m	h	d	w	m	h	d	w	m
All	0.2	0.4	0.6	0.8	0.3	0.6	0.9	1	0.4	0.7	1	1	0.3	0.6	0.9	1
Health Care and Social Assistance	0.4	0.7	1	1	0.4	0.7	1	1	0.4	0.7	1	1	0.2	0.4	0.6	0.8
Professional, Scientific and Technical Services	0.3	0.5	0.7	0.9	0.3	0.6	0.9	1	0.3	0.5	0.7	0.9	0.2	0.4	0.6	0.8
Education and Training	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.3	0.5	0.7	0.9	0.3	0.6	0.9	1
Manufacturing	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.1	0.2	0.3	0.4
Transport, Portal and Warehousing	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.3	0.6	0.9	1
Construction	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.3	0.6	0.9	1
Retail	0.3	0.5	0.7	0.9	0.4	0.7	1	1	0.4	0.6	0.8	1	0.3	0.6	0.9	1
Agriculture, forestry and fishing	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.2	0.4	0.6	0.8
Accommodation and food services	0.3	0.6	0.9	1	0.4	0.7	1	1	0.4	0.8	1	1	0.3	0.6	0.9	1
Wholesale trade	0.2	0.4	0.6	0.8	0.3	0.6	0.9	1	0.4	0.7	1	1	0.3	0.6	0.9	1
Information, Media and Telecommunications	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.3	0.6	0.9	1	0	0	0	0
Electricity, Gas, Water and Waste Services	0.3	0.5	0.7	0.9	0.3	0.5	0.7	0.9	0.4	0.7	1	1	0	0	0	0
Financial and insurance services	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
Rental, Hiring and Real estate	0.3	0.6	0.9	1	0.3	0.5	0.7	0.9	0.4	0.7	1	1	0	0	0	0
Arts and Recreation Services	0.4	0.7	1	1	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.4	0.8	1	1
h = hours, d = days, w = weeks, m = months																

Experienced disruption values by sector and infrastructure outage duration

Table 2 of 3

Sector	Phone				Data				Road				Rail			
	h	d	w	m	h	d	w	m	h	d	w	m	h	d	w	m
All	0.4	0.6	0.8	1	0.4	0.7	1	1	0.4	0.6	0.8	1	0.2	0.4	0.6	0.8
Health Care and Social Assistance	0.4	0.6	0.8	1	0.4	0.6	0.8	1	0.4	0.6	0.8	1	0	0	0	0
Professional, Scientific and Technical Services	0.4	0.6	0.8	1	0.3	0.5	0.7	0.9	0.4	0.6	0.8	1	0.1	0.2	0.3	0.4
Education and Training	0.4	0.6	0.8	1	0.5	0.7	0.9	1	0.3	0.4	0.5	0.6	0.7	1	1	1
Manufacturing	0.4	0.7	1	1	0.3	0.6	0.9	1	0.4	0.6	0.8	1	0.3	0.6	0.9	1
Transport, Portal and Warehousing	0.4	0.6	0.8	1	0.4	0.7	1	1	0.3	0.5	0.7	0.9	0.2	0.3	0.4	0.5
Construction	0.4	0.7	1	1	0.3	0.6	0.9	1	0.4	0.6	0.8	1	0.1	0.2	0.3	0.4
Retail	0.5	0.7	0.9	1	0.4	0.7	1	1	0.4	0.5	0.6	0.7	0.3	0.5	0.7	0.9
Agriculture, forestry and fishing	0.3	0.5	0.7	0.9	0.3	0.5	0.7	0.9	0.3	0.5	0.7	0.9	0.2	0.4	0.6	0.8
Accommodation and food services	0.3	0.5	0.7	0.9	0.3	0.5	0.7	0.9	0.3	0.5	0.7	0.9	0.2	0.4	0.6	0.8
Wholesale trade	0.4	0.7	1	1	0.4	0.7	1	1	0.4	0.6	0.8	1	0.2	0.4	0.6	0.8
Information, Media and Telecommunications	0.2	0.3	0.4	0.5	0.4	0.7	1	1	0.4	0.6	0.8	1	0.2	0.4	0.6	0.8
Electricity, Gas, Water and Waste Services	0.5	0.8	1	1	0.3	0.5	0.7	0.9	0.6	0.7	0.8	0.9	0.2	0.4	0.6	0.8
Financial and insurance services	0.4	0.6	0.8	1	0.3	0.5	0.7	0.9	0.4	0.5	0.6	0.7	0	0	0	0
Rental, Hiring and Real estate	0.4	0.7	1	1	0.4	0.7	1	1	0.5	0.6	0.7	0.8	0	0	0	0
Arts and Recreation Services	0.4	0.8	1	1	0.4	0.8	1	1	0.3	0.5	0.7	0.9	0	0	0	0
h = hours, d = days, w = weeks, m = months																

Experienced disruption values by sector and infrastructure outage duration

Table 3 of 3

Sector	Airport				Port				Fuel			
	h	d	w	m	h	d	w	m	h	d	w	m
All	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.3	0.5	0.7	0.9
Health Care and Social Assistance	0.2	0.4	0.6	0.8	0	0	0	0	0.2	0.4	0.6	0.8
Professional, Scientific and Technical Services	0.2	0.4	0.6	0.8	0.1	0.2	0.3	0.4	0.2	0.4	0.6	0.8
Education and Training	0.3	0.6	0.9	1	0	0	0	0	0.2	0.4	0.6	0.8
Manufacturing	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
Transport, Portal and Warehousing	0.4	0.7	1	1	0.3	0.4	0.5	0.6	0.4	0.6	0.8	1
Construction	0.3	0.6	0.9	1	0.1	0.2	0.3	0.4	0.3	0.5	0.7	0.9
Retail	0.2	0.3	0.4	0.5	0.2	0.4	0.6	0.8	0.4	0.6	0.8	1
Agriculture, forestry and fishing	0.1	0.2	0.3	0.4	0.3	0.6	0.9	1	0.2	0.4	0.6	0.8
Accommodation and food services	0.4	0.7	1	1	0.2	0.4	0.6	0.8	0.3	0.6	0.9	1
Wholesale trade	0.2	0.4	0.6	0.8	0.3	0.6	0.9	1	0.2	0.4	0.6	0.8
Information, Media and Telecommunications	0.2	0.4	0.6	0.8	0	0	0	0	0.3	0.5	0.7	0.9
Electricity, Gas, Water and Waste Services	0.3	0.6	0.9	1	0.3	0.6	0.9	1	0.4	0.6	0.8	1
Financial and insurance services	0.3	0.6	0.9	1	0	0	0	0	0.2	0.3	0.4	0.5
Rental, Hiring and Real estate	0.3	0.6	0.9	1	0	0	0	0	0.3	0.6	0.9	1
Arts and Recreation Services	0.2	0.4	0.6	0.8	0.3	0.6	0.9	1	0.3	0.5	0.7	0.9

APPENDIX 2: ERI RESULTS BULLETINS

- ERI Results Bulletin 2015-K01-1 Analysing disruption by economic sector
- ERI Results Bulletin 2015-K02-1 Infrastructure loss – duration and experienced disruption
- ERI Results Bulletin 2015-K03-2 Modelling non-infrastructure disruption
- ERI Results Bulletin 2015-K04-1 Combining disruptions
- ERI Results Bulletin 2015-K05-1 Operability
- ERI Results Bulletin 2015-K06-1 Effect of changing suppliers
- ERI Results Bulletin 2015-K07-1 Productivity improvements from disruption
- ERI Results Bulletin 2015-K08-1 Assessing ability to meet demand in the context of other resiliency studies
- ERI Results Bulletin 2015-K09-1 Workforce inertia
- ERI Results Bulletin 2015-K10-1 Effect of the Earthquake Support Subsidy
- ERI Results Bulletin 2015-K11-1 Relocation
- ERI Results Bulletin 2015-K12-1 Organisation disruption – perception vs reality

Business Behaviours Following the Canterbury Earthquakes

Analysing disruption by economic sector

ERI Results Bulletin 2015-K01-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

Is sector the best lens to analyse and compare disruption and recovery from disasters?

A common grouping of organisations used in economic and disaster recovery studies is 'sector'. Sometimes this is broken down further into industry units. However, in our survey we restricted our groupings to sectors, as defined in ANZSIC.

We wanted to see if this was a suitable grouping for anlaysing the impact on and recovery from the Canterbury earthquakes. And if not, what might be a suitable alternative grouping?

Findings for MERIT:

The results indicate that there is some sector specific infrastructure dependence. For example, the most dependent sectors on water are Retail trade, Health Care and Social Assistance, Maunfacturing, Arts and Recreation Services, Accommodation and Food Services and Education and Training.

This indicates that for ERI, sectors should be taken into account when looking at the relationship between duration of outage (model from Aim 1) and level of disruption due to the infrastructure outage.

In terms of recovery, the anlaysis shows that sector does account for some variation in the 'ability to meet demand' / operability. However, there are a number of other factors that may influence recovery – including organisational size, national / international support, available resources, change in demand, location of customers, nature of work environment and services etc. Because of the large number of variables, one ability to meet demand / operability function will be produced for all organisations. Then, the factors that contribute to that function (see *Results Bulletin 2015-K05-1*) can be analysed at a sector level or based on organsiational size etc.

Analysis:

To answer this question there are two things that need to be considered: a) are there sector differences in level of disruption (given duration of outage) for sectors and b) are there sector differences in recovery (given level of infrastructure disruption).

First, we need to look at the relative disruption that infrastructure outages caused for organisations in different sectors. Based on the responses to question 45 'how long could you continue functioning without normal supply', there were significant differences between the different sectors and their dependence on infrastructure. The table below summarises the most and least dependent sectors on each of the infrastructure types.

Based on this evidence it is recommended that the infrastructure functions – those that translate duration of outage to level of disruption due to infrastructure loss – are sector based.

	Most dependent	**Least dependent**
Water	Education and training Accommodation and food services Manufacturing	Professional, Scientific and Technical Services Transportation, postal and warehousing Construction Retail Wholesale Electricity, Gas, Water and Waste Services Financial and Insurance services Rental, Hiring and Real Estate
Sewage	Education and training Accommodation and Food Services	Electricity, Gas, Water and Waste Services
Electricity	Education and training Manufacturing Retail	Construction Transportation, postal and warehousing Electricity, Gas, Water and Waste Services
Gas	Accommodation and food services Arts and recreation Services	Health care and social assistance Professional, Scientific and Technical Services Manufacturing Transportation, postal and warehousing Construction Retail Financial and Insurance services Rental, Hiring and Real Estate
Phone	Rental, Hiring and Real Estate	Health care and social assistance Manufacturing Construction Agriculture, forestry and fishing

	Most dependent	Least dependent
Data	Financial and Insurance services Rental, Hiring and Real Estate	Health care and social assistance Education and training Construction
Road	Education and training Manufacturing Transportation, postal and warehousing Construction Retail Accommodation and food services Wholesale trade Rental, Hiring and Real Estate	Professional, Scientific and Technical Services Agriculture, forestry and fishing
Rail	Manufacturing Retail Wholesale trade	Professional, Scientific and Technical Services Arts and Recreation Services
Airport	Accommodation and food services Wholesale trade Transportation, postal and warehousing	Health care and social assistance Professional, Scientific and Technical Services Financial and Insurance services Arts and Recreation Services
Port	Transportation, postal and warehousing Wholesale trade Manufacturing	Health care and social assistance Professional, Scientific and Technical Services Information media and telecommunications Arts and Recreation Services
Fuel	Manufacturing Transportation, postal and warehousing Construction Retail Agriculture, forestry and fishing Accommodation and food services Wholesale trade Rental, Hiring and Real Estate	Health care and social assistance Professional, Scientific and Technical Services Financial and Insurance services
Based on Games Howell post-hoc test – significance to 0.05 level.		

Accordingly, regression functions have been developed to see the relationship between the level of disruption and the duration of disruption experienced in Christchurch (by sector) (see Results Bulletin 2015-K02-1). These tell us how dependent each sector was on each infrastructure type (the higher the B value, the more important the infrastructure for that sector). The results show a similar dependence for water – however, it is noted that there are a number of other sectors that also show high dependence on water.

In terms of recovery, the variable ability to meet demand (AMD) / operability, was analysed to see if there were significant differences in the recovery of organisations. Without taking infrastructure outage into account, a Kruskal Wallis was carried out. This showed that there is some difference between AMD for sectors. However, this could be due to a range of different factors including, different impactedness and/or mitigation, or other external factors such as organisational size, national / international support, available resources, change in demand, location of customers, nature of work environment and services etc. Some of these factors will be sector dependent and some will not. Therefore it is suggested that the ability to meet demand analysis is not carried out by sector and instead the factors noted above, are all assessed for their effect separately and if necessary, variables themselves (rather than the whole model) can be tested for sector dependence.

Ranks

	Sector	N	Mean Rank
Ability to meet demand immediately after the earthquakes	Health Care and Social Assistance	48	271.47
	Professional, Scientific ad Technical Services (including Admin and support and public admin)	66	285.07
	Education and Training	34	230.69
	Manufacturing	73	245.86
	Transport, Postal and Warehousing	28	272.23
	Construction	43	294.14
	Retail trade	43	211.60
	Agriculture, Forestry and Fishing	21	326.60
	Accommodation and Food Services	44	308.08
	Wholesale Trade	31	265.29
	Information Media and Telecommunications	8	355.88
	Electricity, Gas, Water and Waste Services	18	283.50
	Financial and Insurance Services	21	262.26
	Rental, Hiring and Real Estate Services	32	220.05
	Arts and Recreation Services	19	212.74
	Total	529	

Test Statistics[a,b]

	Ability to meet demand immediately after the earthquakes
Chi-Square	28.981
df	14
Asymp. Sig.	.011

a. Kruskal Wallis Test

b. Grouping Variable: Sector

Limitations:

The analysis for infrastructure dependence is based on organisations forward looking assessments. The analysis could be further enhanced through analysis of actual impact and disruption (e.g. as per results presented in Results Bulletin 2015-K02-1)

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015) Business Behaviours following the Canterbury Earthquakes: Analysing disruption by economic sector. ERI Results Bulletin 2015-K01-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Infrastructure loss – duration and experienced disruption

ERI Results Bulletin 2015-K02-1

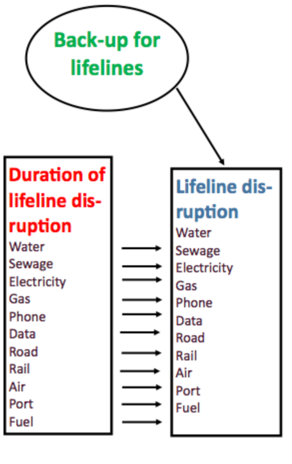
Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

Given the length of an infrastructure loss, what is the experienced disruption for an organisation?

The level of disruption an organisation experiences following an infrastructure outage is dependent on the duration of the outage, the nature of the disruption, the level of mitigation in place and the dependence on the infrastructure.

We wanted to create a function to model the relationship between the duration of infrastructure outage with the level of disruption caused to the organisation - for input into the MERIT model.



Findings for MERIT:

In the ERI model, the experienced disruption due to infrastructure loss will be estimated based on the duration of the infrastructure outage (as provided by Aim 1). These infrastructure disruption functions will then be used to populate the overall impact variable (as discussed in *Results Bulletin 2015-K04-1*), which in turn feeds into the operability (ability to meet demand) function.

Consequently, a series of functions have been developed using the ERI business behaviours survey data to link the duration of outage to the level of reported, experienced disruption. This has been done on a sector by sector basis (as discussed in *Results Bulletin 2015-K01-1)*

The function is in the form:

Experienced disruption = A + B x (length of disruption)

Experienced disruption is measured on a scale of 0 to 1 (not disrupted to very disrupted). (As noted above, this will feed into the overall impact variable).

Length of disruption is based the Canterbury survey data. It uses a 1,2,3,4 coding for duration of outage – linked to hours, days, weeks, months respectively. This is because this coding (compared to an equivalent hours based coding) returned higher R^2 values. We need to consider how we can translate the maps / functions from the ERI disruptions scenarios team into this same coding if these functions are adopted.

A and B are constants and are dependent on sector. The values for each infrastructure and sector are shown in the table below. Note that the function must range between 0 and 1. Therefore the function will need to have maximum and minimum constraints. Also note that the level of mitigation against infrastructure disruption was modelled but was not found to be significant.

	Water		Sewage		Electricity		Gas		Phone		Data		Road		Rail		Airport		Port		Fuel	
Sector	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
All	0	0.2	0	0.3	0.1	0.3	0.0	0.3	0.2	0.2	0.1	0.3	0.2	0.2	0.0	0.2	0.0	0.2	0.0	0.2	0.1	0.2
Health Care and Social Assistance	0.1	0.3	0.1	0.3	0.1	0.3	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0.0	0.2	0	0	0.0	0.2
Professional, Scientific and Technical Services	0.1	0.2	0	0.3	0.1	0.2	0.0	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.0	0.1	0.0	0.2	0.0	0.1	0.0	0.2
Education and Training	0.0	0.3	0	0.3	0.1	0.2	0.0	0.3	0.2	0.2	0.3	0.2	0.2	0.1	0	0.7	0	0.3	0	0	0.0	0.2
Manufacturing	0.0	0.3	0	0.3	0	0.3	0.0	0.1	0.1	0.3	0.0	0.3	0.2	0.2	0	0.3	0	0.2	0.0	0.2	0.0	0.2
Transport, Postal and Warehousing	0.0	0.3	0	0.3	0	0.3	0.0	0.3	0.2	0.2	0.1	0.3	0.1	0.2	0.1	0.1	0.1	0.3	0.2	0.1	0.2	0.2
Construction	0.0	0.3	0	0.3	0	0.3	0.0	0.3	0.1	0.3	0.0	0.3	0.2	0.2	0	0.1	0.0	0.3	0	0.1	0.1	0.2
Retail	0.1	0.2	0.1	0.3	0.2	0.2	0.0	0.3	0.3	0.2	0.1	0.3	0.3	0.1	0.1	0.2	0.1	0.1	0.0	0.2	0.2	0.2
Agriculture, forestry and fishing	0.0	0.3	0	0.3	0	0.3	0.0	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.0	0.2	0.0	0.1	0.0	0.3	0.0	0.2
Accommodation and food services	0.0	0.3	0.1	0.3	0	0.4	0.0	0.3	0.1	0.2	0.1	0.2	0.1	0.2	0	0.2	0.1	0.3	0.0	0.2	0.0	0.3
Wholesale trade	0.0	0.2	0	0.3	0.1	0.3	0.0	0.3	0.1	0.3	0.1	0.3	0.2	0.2	0.0	0.2	0.0	0.2	0.0	0.3	0.0	0.2
Information, Media and Telecommunications	0.0	0.2	0	0.2	0	0.3	0	0	0.1	0.1	0.1	0.3	0.2	0.2	0.0	0.2	0.0	0.2	0	0	0.1	0.2
Electricity, Gas, Water and Waste Services	0.1	0.2	0.1	0.2	0.1	0.3	0	0	0.2	0.3	0.1	0.2	0.5	0.1	0.0	0.2	0	0.3	0	0.3	0.2	0.2
Financial and insurance services	0.0	0.2	0	0.2	0	0.2	0.0	0.2	0.2	0.2	0.1	0.2	0.3	0.1	0	0	0.0	0.3	0	0	0.1	0.1
Rental, Hiring and Real estate	0.0	0.3	0.1	0.2	0.1	0.3	0	0	0.1	0.3	0.1	0.3	0.4	0.1	0	0	0.0	0.3	0	0	0	0.3
Arts and Recreation Services	0.1	0.3	0	0.3	0	0.3	0	0.4	0.0	0.4	0.0	0.4	0.1	0.2	0	0	0	0.2	0	0.3	0.1	0.2

Theoretically A should be zero (no disruption for no outage of infrastructure). Where value is >0, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage). Also, maximum disruption is 1. So function must have maximum outcome of 1.

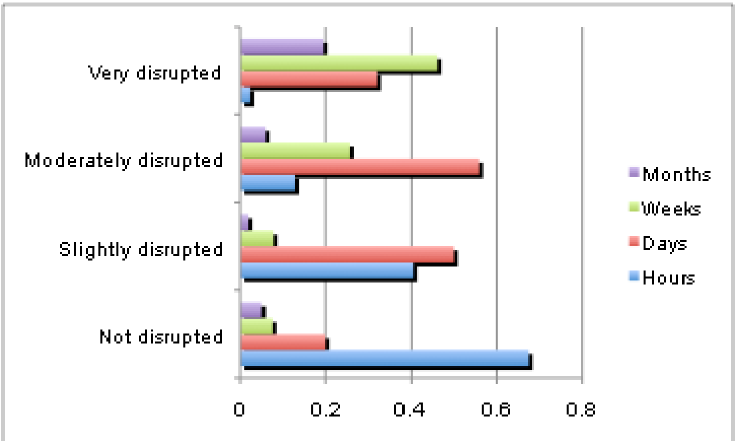
Analysis:

First, need to check whether there is a correlation between "length" and "extent" of disruption from the loss of infrastructure post-22nd Feb quake (question 12). The two survey questions are:

> *Q12d: With reference to the 22 February 2011 earthquake, how was your organisation disrupted by the loss of the following infrastructure services? (response options: not disrupted, slightly disrupted, moderately disrupted, very disrupted) (SPSS coding: impWat1 (0=not disrupted, 0.33=slightly disrupted, 0.66= moderately disrupted, 1= very disrupted)*

> *Q12e: With reference to the 22 February 2011 earthquake, for how long did your organisation experience disruptions to the following infrastructure services? (response options: hours, days, weeks, months) (SPSS coding: impWatD (1=hours, 2=days, 3= weeks, 4= months)*

In addition we need to consider the nature of the relationship between duration of outage and level of disruption. The analysis was carried out for water supply. The results showed that organisations that suffered higher level of disruption from the loss of water supply have been the ones experiencing the loss of the water supply service for a longer period of time. This relationship appears to be modeled best linearly: i.e. hours, days, weeks, months are a linear scale (rather than as equivalent hours).



Length of disruption (% of orgs per period time) experienced per different disruption levels

Next, the data set was split into sectors. For each sector a linear (step-wise) regression was carried out for each infrastructure type. The regression dependent variable was level of disruption (impWat1) and the independent variables were duration of outage (impWatD) and mitigation level for infrastructure (mitCritl). This is so that the infrastructure disruption scenarios (Aim 1) can be converted into level of disruption.

Residuals were tested and any variables where standardised residuals were greater than 3 or less than -3 were excluded from the analysis.

Note that we could either use a 1,2,3,4 coding for hours, days, weeks, months of duration of outage (impWatD). Or we could use the equivalent hours coding of the data (impWatD2). For water, sewage and electricity (the first three infrastructure types tried) and for all three the first coding option returned a higher R^2 value.

The results are in the form shown below. A, B and C differ for all sectors.

Experienced disruption = A + B x duration of water outage + C x mitigation against critical infrastructure disruption

(SPSS coded formula: impWat1 = A + B x impWatD + C x mitCritI (this is for the 1,2,3,4 coded data))

Note that C was found to be not significant in most cases (and where it was significant the correlation was negative – i.e. the more mitigation in place, the higher the disruption) and therefore has been excluded.

Water outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.101	0.234	0.631	<0.005	523
Health Care and Social Assistance	0.101	0.273	0.738	<0.005	47
Professional, Scientific and Technical Services	0.094	0.198	0.228	<0.005	65
Education and Training	-0.012	0.259	0.568	<0.005	35
Manufacturing	-0.006	0.276	0.727	<0.005	71
Transport, Portal and Warehousing	0.009	0.289	0.705	<0.005	28
Construction	0.002	0.265	0.722	<0.005	44
Retail	0.124	0.208	0.581	<0.005	43
Agriculture, forestry and fishing	-0.021	0.287	0.751	<0.005	17
Accommodation and food services	0.048	0.337	0.702	<0.005	44
Wholesale trade	0.048	0.235	0.650	<0.005	32
Information, Media and Telecommunications	0.032	0.241	0.818	<0.005	7**
Electricity, Gas, Water and Waste Services	0.076	0.205	0.521	<0.005	17
Financial and insurance services	0.021	0.204	0.505	<0.005	22
Rental, Hiring and Real estate	0.024	0.285	0.685	<0.005	32
Arts and Recreation Services	-0.089	0.307	0.753	<0.005	20

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is too small to accurately rely on proposed function. Suggest service is similar to professional, technical and scientific services – use this function to approximate.

Sewage outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.026	0.266	0.775	<0.005	525
Health Care and Social Assistance	0.081	0.264	0.694	<0.005	47
Professional, Scientific and Technical Services	0.010	0.264	0.757	<0.005	64
Education and Training	-0.013	0.263	0.741	<0.005	35
Manufacturing	0.022	0.273	0.726	<0.005	72
Transport, Portal and Warehousing	0.021	0.261	0.767	<0.005	28
Construction	0.009	0.275	0.754	<0.005	44
Retail	0.059	0.265	0.858	<0.005	42
Agriculture, forestry and fishing	0	0.249	0.956	<0.005	18
Accommodation and food services	0.056	0.292	0.738	<0.005	44
Wholesale trade	0.007	0.258	0.810	<0.005	32
Information, Media and Telecommunications	0.015	0.235	0.938	<0.005	7**
Electricity, Gas, Water and Waste Services	0.07	0.222	0.601	<0.005	17
Financial and insurance services	0	0.205	0.570	<0.005	22
Rental, Hiring and Real estate	0.055	0.240	0.703	<0.005	32
Arts and Recreation Services	-0.04	0.266	0.591	<0.005	20

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is small (or arguably too small) to accurately rely on proposed function.

Electricity outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.055	0.284	0.610	<0.005	525
Health Care and Social Assistance	0.104	0.3	0.584	<0.005	47
Professional, Scientific and Technical Services	0.104	0.214	0.425	<0.005	65
Education and Training	0.130	0.216	0.455	<0.005	35
Manufacturing	-0.006	0.340	0.721	<0.005	72
Transport, Portal and Warehousing	0.044	0.247	0.736	<0.005	26
Construction	0.002	0.308	0.592	<0.005	44
Retail	0.206	0.243	0.531	<0.005	43
Agriculture, forestry and fishing	-0.012	0.283	0.628	<0.005	18
Accommodation and food services	-0.019	0.380	0.692	<0.005	43
Wholesale trade	0.077	0.270	0.647	<0.005	32

Electricity outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
Information, Media and Telecommunications	-0.038	0.259	0.729	<0.005	7**
Electricity, Gas, Water and Waste Services	0.083	0.253	0.387	0.005	17
Financial and insurance services	0.023	0.227	0.539	<0.005	22
Rental, Hiring and Real estate	0.088	0.279	0.598	<0.005	32
Arts and Recreation Services	-0.025	0.338	0.538	<0.005	20

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is small (or arguably too small) to accurately rely on proposed function.

Gas outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.007	0.252	0.830	<0.005	475
Health Care and Social Assistance	0.005	0.239	0.845	<0.005	44
Professional, Scientific and Technical Services	0.014	0.242	0.684	<0.005	61
Education and Training	0	0.33	1	<0.005	30
Manufacturing	0.012	0.135	0.346	<0.005	67
Transport, Portal and Warehousing	0	0.33	1	<0.005	25
Construction	0.009	0.321	0.473	<0.005	39
Retail	0.020	0.327	0.899	<0.005	38
Agriculture, forestry and fishing	0	0.165	0.433	<0.005	17
Accommodation and food services	0.027	0.267	0.793	<0.005	43
Wholesale trade	0.002	0.265	0.984	<0.005	29
Information, Media and Telecommunications	0	0		<0.005	Not disrupted
Electricity, Gas, Water and Waste Services	0	0		0.005	16 – all but one case not disrupted
Financial and insurance services	0.013	0.156	0.510	<0.005	18
Rental, Hiring and Real estate	0	0		<0.005	30 - All but one case not disrupted
Arts and Recreation Services	-0.003	0.370	0.753	<0.005	19

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is small (or arguably too small) to accurately rely on proposed function.

Phone outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.164	0.234	0.396	<0.005	527
Health Care and Social Assistance	0.215	0.210	0.328	<0.005	48
Professional, Scientific and Technical Services	0.175	0.184	0.332	<0.005	65
Education and Training	0.237	0.184	0.326	<0.005	35
Manufacturing	0.061	0.274	0.557	<0.005	73
Transport, Portal and Warehousing	0.174	0.220	0.303	<0.005	27
Construction	0.142	0.298	0.412	<0.005	42
Retail	0.322	0.196	0.373	<0.005	43
Agriculture, forestry and fishing	0.109	0.178	0.358	<0.005	19
Accommodation and food services	0.135	0.242	0.195	<0.005	45
Wholesale trade	0.093	0.285	0.594	<0.005	30
Information, Media and Telecommunications	0.125	0.130	0.630	<0.005	7**
Electricity, Gas, Water and Waste Services	0.246	0.255	0.262	0.005	17
Financial and insurance services	0.158	0.193	0.260	<0.005	22
Rental, Hiring and Real estate	0.123	0.281	0.412	<0.005	32
Arts and Recreation Services	0.007	0.355	0.4	<0.005	20

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is small (or arguably too small) to accurately rely on proposed function.

Data outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.092	0.257	0.519	<0.005	517
Health Care and Social Assistance	0.244	0.158	0.218	<0.005	47
Professional, Scientific and Technical Services	0.105	0.215	0.460	<0.005	65
Education and Training	0.260	0.181	0.361	<0.005	35
Manufacturing	0.035	0.290	0.638	<0.005	73
Transport, Portal and Warehousing	0.059	0.322	0.529	<0.005	27
Construction	0.030	0.332	0.477	<0.005	44
Retail	0.093	0.255	0.528	<0.005	41
Agriculture, forestry and fishing	0.050	0.211	0.420	<0.005	16
Accommodation and food services	0.084	0.216	0.375	<0.005	44
Wholesale trade	0.063	0.272	0.587	<0.005	31
Information, Media and					Not significant**

Data outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
Telecommunications					
Electricity, Gas, Water and Waste Services	0.120	0.204	0.181	0.005	17
Financial and insurance services	0.139	0.226	0.340	<0.005	20
Rental, Hiring and Real estate	0.097	0.275	0.512	<0.005	31
Arts and Recreation Services	0.021	0.363	0.488	<0.005	20

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** Approximate using average regression function across all sectors.

Road network outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.185	0.173	0.545	<0.005	519
Health Care and Social Assistance	0.229	0.163	0.557	<0.005	47
Professional, Scientific and Technical Services	0.176	0.163	0.463	<0.005	62
Education and Training	0.237	0.148	0.410	<0.005	32
Manufacturing	0.164	0.177	0.550	<0.005	73
Transport, Portal and Warehousing	0.103	0.249	0.820	<0.005	26
Construction	0.199	0.176	0.549	<0.005	43
Retail	0.303	0.144	0.399	<0.005	43
Agriculture, forestry and fishing	0.092	0.166	0.465	<0.005	18
Accommodation and food services	0.081	0.184	0.561	<0.005	45
Wholesale trade	0.168	0.193	0.757	<0.005	32
Information, Media and Telecommunications	0.187	0.166	0.640	<0.005	7**
Electricity, Gas, Water and Waste Services	0.508	0.101	0.206	<0.005	15
Financial and insurance services	0.312	0.110	0.119	0.064	22 Not significant
Rental, Hiring and Real estate	0.405	0.092	0.239	<0.005	32
Arts and Recreation Services	0.051	0.213	0.660	<0.005	20

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is small (or arguably too small) to accurately rely on proposed function.

Rail outage

Sector	A*	B	Adjusted R^2	Significance	Number responses (with outliers removed)
All	0.011	0.189	0.649	<0.005	
Health Care and Social Assistance					No disruption**
Professional, Scientific and Technical Services	0.005	0.094	0.402	<0.005	
Education and Training	0	0.66	1	<0.005	***
Manufacturing	-0.001	0.292	0.938	<0.005	
Transport, Portal and Warehousing	0.065	0.103	0.122	0.041	
Construction	0	0.110	1	<0.005	
Retail	0.05	0.153	0.25	<0.005	
Agriculture, forestry and fishing					No disruption**
Accommodation and food services	-0.003	0.222	0.943	<0.005	
Wholesale trade	0.002	0.241	0.819	<0.005	
Information, Media and Telecommunications	0.010	0.227	0.972	<0.005	
Electricity, Gas, Water and Waste Services	0	0.330	1	<0.005	***
Financial and insurance services					No disruption**
Rental, Hiring and Real estate					No disruption**
Arts and Recreation Services					No disruption**

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is small (or arguably too small) to accurately rely on proposed function.
**These sectors experienced no disruption and no loss of service. May be due to limited disruption to service. Or lack of dependence. Assume no dependence except for agriculture and forestry (for this use average function)
*** Based on one point (rest of sector are at no disruption / no loss of service). Assume average function.

Airport outage

Sector	A*	B	Adjusted R^2	Significance	Number responses (with outliers removed)
All	0.019	0.23	0.744	<0.005	497
Health Care and Social Assistance					Not disrupted***
Professional, Scientific and Technical Services	0.018	0.22	0.814	<0.005	63
Education and Training	0	0.33	1	<0.005	30
Manufacturing	-0.004	0.176	0.697	<0.005	68
Transport, Portal and Warehousing	0.058	0.259	0.794	<0.005	26
Construction	0.008	0.328	0.705	<0.005	41
Retail	0.073	0.145	0.246	<0.005	39
Agriculture, forestry and fishing	0.036	0.085	0.191	0.04	18
Accommodation and food services	0.062	0.272	0.775	<0.005	43
Wholesale trade	0.006	0.246	0.760	<0.005	30
Information, Media and Telecommunications	0.010	0.227	0.972	<0.005	8
Electricity, Gas, Water and Waste Services	0	0.33	0.615	<0.005	15

Airport outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
Financial and insurance services	0.012	0.257	0.580	0.064	18
Rental, Hiring and Real estate	0.035	0.312	0.435	<0.005	31
Arts and Recreation Services	0	0.165	0.704	<0.005	19

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is small (or arguably too small) to accurately rely on proposed function.
**These sectors experienced no disruption and no loss of service. May be due to limited disruption to service. Or lack of dependence. Assume average function.

Port outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.006	0.232	0.855	<0.005	495
Health Care and Social Assistance	0	0			No disruption reported
Professional, Scientific and Technical Services	0.004	0.099	0.476	<0.005	63
Education and Training	0	0			
Manufacturing	-0.001	0.178	0.855	<0.005	71
Transport, Portal and Warehousing	0.221	0.138	0.259	<0.005	27
Construction	0	0.11	1	<0.005	40
Retail	0.038	0.168	0.445	<0.005	38
Agriculture, forestry and fishing	0.006	0.269	0.976	<0.005	16**
Accommodation and food services	0.001	0.245	0.987	<0.005	42
Wholesale trade	0.005	0.252	0.881	<0.005	28
Information, Media and Telecommunications	0	0			Results not significant – assume no disruption (see Results Bulletin K10)
Electricity, Gas, Water and Waste Services	0	0.330	1	<0.005	15**
Financial and insurance services	0	0			No disruption reported
Rental, Hiring and Real estate	0	0			No disruption reported
Arts and Recreation Services	0	0.25	1	<0.005	17**

* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage).
** This number is small (or arguably too small) to accurately rely on proposed function.

Fuel outage					
Sector	**A***	**B**	**Adjusted R^2**	**Significance**	**Number responses** (with outliers removed)
All	0.059	0.232	0.569	<0.005	504
Health Care and Social Assistance	0.026	0.231	0.713	<0.005	45
Professional, Scientific and Technical Services	0.049	0.236	0.682	<0.005	63
Education and Training	0.039	0.194	0.371	<0.005	31
Manufacturing	0.013	0.235	0.677	<0.005	70
Transport, Portal and Warehousing	0.154	0.246	0.384	<0.005	27
Construction	0.097	0.192	0.430	<0.005	44
Retail	0.172	0.195	0.285	<0.005	39
Agriculture, forestry and fishing	0.042	0.224	0.693	<0.005	20
Accommodation and food services	0.029	0.257	0.579	<0.005	44
Wholesale trade	0.041	0.290	0.827	<0.005	28
Information, Media and Telecommunications					Not significant. Assume average function
Electricity, Gas, Water and Waste Services	0.168	0.187	0.283	0.032	16
Financial and insurance services	0.138	0.12	0.064	0.067	20 Not sig to 0.05
Rental, Hiring and Real estate	0	0.332	0.734	<0.005	30
Arts and Recreation Services	0.107	0.227	0.371	<0.005	20
* Theoretically this value should be zero (no disruption for no outage of infrastructure). Most of the values can be rounded to zero. Where value is >0.05, suggest the function is forced to zero where infrastructure outage duration is 0 (no outage). ** This number is small (or arguably too small) to accurately rely on proposed function.					

Limitations:

Respondents were asked 'how long did your organisation experience disruptions to the following infrastructure services.' This could be interpreted as a severe disruption or as any kind of disruption (e.g. you have no water or you have water but need to boil it). It is unclear how respondents would have interpreted this question. This will have to be considered through case studies and when linking with the disruption scenarios team.

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015) Business Behaviours following the Canterbury Earthquakes: Infrastructure loss – duration and experienced disruption. ERI Results Bulletin 2015-K02-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Modelling non-infrastructure disruption

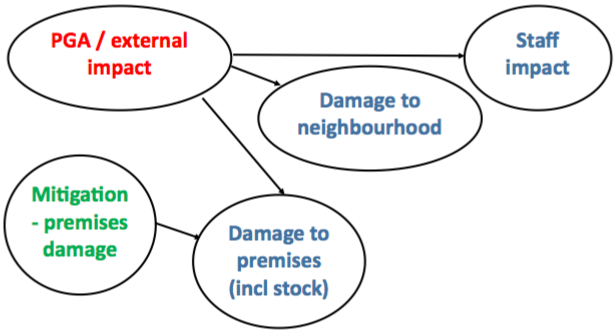
ERI Results Bulletin 2015-K03-2

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

How can we model non-infrastructure disruption?

Two of the scenarios being investigated in the Economics of Resilient Infrastructure project will have non-infrastructure related disruptions. The Canterbury earthquake data has shown us that non-infrastructure impacts are equally, and in some cases more, disruptive compared to infrastructure disruption. So, can we model the level of non-infrastructure damage?



Findings for MERIT:

For the Alpine fault scenario (earthquake) in MERIT, we could use PGA (peak ground acceleration) to estimate non-infrastructure disruption. Based on the Canterbury dataset the following relationships could be used to model non-infrastructure impacts:

$$\boldsymbol{ED_{premises} = 0.9\ x\ PGA} \qquad [\boldsymbol{if\ ED_{premises} > 1, then = 1}]$$

(note that mitigation against building damage was not a significant predicting factor for this)

$$\boldsymbol{ED_{neigh} = 1.1\ x\ PGA} \qquad [\boldsymbol{if\ ED_{neigh} > 1, then = 1}]$$

$$\boldsymbol{ED_{staff} = 0.2 + 0.5\ x\ PGA} \qquad [\boldsymbol{if\ ED_{staff} > 1, then = 1}]$$

Where $\boldsymbol{ED_{premises}}$ *is Experienced disruption due to damage to premises*

ED_{neigh} *is Experienced disruption due to neighbourhood damage*

ED_{staff} *is Experienced disruption due to staff impact*

PGA *is peak ground acceleration in g*

These results can also be expressed in terms of MMI (Modified Mercalli Index).

$ED_{premises}$ = 0.12 x MMI-0.56 *[if $ED_{premises}$>1, then =1]*

ED_{neigh} = 0.13xMMI-0.62 *[If ED_{neigh}>1, then =1]*

ED_{staff} = 0.07xMMI-0.11 *[if ED_{staff}>1, then =1]*

Note that these results include all organisations surveyed – including those affected by the cordon, the residential red zone a number of other significant external factors (as well as PGA). This analysis could be refined to separate out some of these major external factors so that they can be separately modelled.

An alternative approach to modelling non-infrastructure impacts will be needed for the volcanic scenario. A similar approach could be taken but instead using depth of ash or proximity to ash source. A function to model this will be developed during the case studies and in consultation with the disruption scenarios team in ERI.

Analysis:

First, non-infrastructure related impacts were combined into three different groups: damage to premises, damage to neighbourhood, and staff impact. The questions contributing to these factors are shown in the table below. A Cronbach's Alpha was derived for each of these categories and this confirmed that the groupings were appropriate (alpha >0.8).

Impact	Survey Question	Calculation description / Notes	SPSS variable name	Cronbach Alpha
Damage to premises	Q11 (part)	Combined, average impact of (Scaled 0-1): Difficult accessing IT Structural Damage to buildings Non-structural damage Machinery loss or damage Office equipment loss or damage Damage to inventory or stock	impPhys	0.84
Damage to neighbourhood	Q11 (part)	Combined, average impact of (scaled 0-1): Damage to or closure of adjacent buildings	impNeigh	0.882

Impact	Survey Question	Calculation description / Notes	SPSS variable name	Cronbach Alpha
		Damage to local neighbourhood Difficulty accessing premises		
Staff impact	Q11 (part)	Combined, average impact of (scaled 0-1): Health and safety issues for employees Availability of staff Perceptions of building safety Changes in staff emotional wellbeing	impStaff	0.81

Next, a linear regression was carried out for the three different types of impacts (see causal network below). The dependent variable is the impact type and the independent is PGA (peak ground acceleration). For damage to premises, the level of mitigation against building damage is also included as a dependent.

The results are:

Damage to premises = 0.9 x PGA (note that mitigation was not a significant predicting factor)

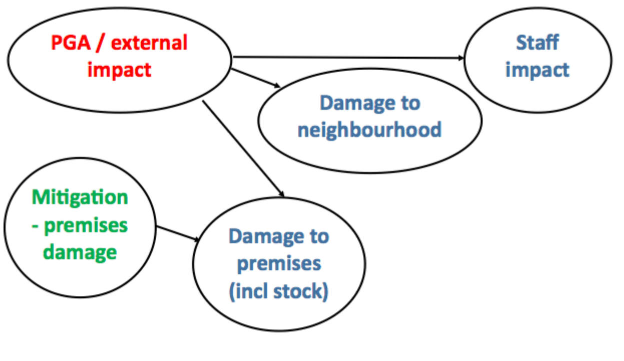
(R^2 = 0.149, p<0.005)

Neighbourhood damage = 1.1 x PGA

(R^2 = 0.135, p<0.005)

Staff impact = 0.2 + 0.5 x PGA

(R^2 = 0.048, p<0.005)



Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.386[a]	.149	.147	.268681

a. Predictors: (Constant), Peak ground acceleration

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.020	1	5.020	69.541	.000[b]
	Residual	28.587	396	.072		
	Total	33.607	397			

a. Dependent Variable: Physical impacts

b. Predictors: (Constant), Peak ground acceleration

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	.010	.044		.231	.818		
	Peak ground acceleration	.888	.106	.386	8.339	.000	1.000	1.000

a. Dependent Variable: Physical impacts

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.370[a]	.137	.135	.340558

a. Predictors: (Constant), Peak ground acceleration

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.174	1	7.174	61.852	.000[b]
	Residual	45.232	390	.116		
	Total	52.406	391			

a. Dependent Variable: Neighbourhood impacts

b. Predictors: (Constant), Peak ground acceleration

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-.026	.057		-.450	.653		
	Peak ground acceleration	1.087	.138	.370	7.865	.000	1.000	1.000

a. Dependent Variable: Neighbourhood impacts

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.223[a]	.050	.048	.266151

a. Predictors: (Constant), Peak ground acceleration

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.500	1	1.500	21.178	.000[b]
	Residual	28.547	403	.071		
	Total	30.047	404			

a. Dependent Variable: Staff impacts

b. Predictors: (Constant), Peak ground acceleration

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	.205	.043		4.748	.000		
	Peak ground acceleration	.482	.105	.223	4.602	.000	1.000	1.000

a. Dependent Variable: Staff impacts

Derivations of Expected Disruptions correlations ad a function of Mercalli Macroseismic Intensity – MMI

In order to derive the Expected Disruption equations as a function of Mercalli Macroseismic Intensity, MMI, we assumed a correlation between MMI and PGA.

PGA and MMI parameters are completely different, the first one being a physical measure of the ground motion, variable from point to point due to attenuation and the local soil conditions. And the latter being a subjective measure of the earthquake-induced damage to the built environment, averaged over a wide area. MMI implicitly includes the seismic vulnerability of the building stock. Because of that, MMI-PGA correlations available in the international literature are usually regional-specific and extremely scattered.

However, most of the PGA-MMI and therefore MMI-PGA correlations can be expressed in a similar format, i.e.

$$MMI=5+(1/LN(C_2))*(LN(PGA)-LN(C_1))$$

where PGA[g] while C_1 and C_2 are coefficients that could be specifically defined for the area of study, as follow: C_1 represents the PGA value corresponding to the reference intensity MMI=5; C_2 measures the rate of the peak ground acceleration increase with the intensity, e.g. for a one degree variation of macroseismic intensity ΔMMI=1, the corresponding acceleration multiplier factor is equal to C_2.

We assumed C_1= 0.03 and C_2=1.6 (Lagomarsino & Giovinazzi, 2006):

$$MMI=5+(1/LN(1.6))*(LN(PGA)-LN(0.03))$$

Table 1 reports the corresponding MMI-PGA values, according to the assumed correlation and values of the coefficients *(i.e Appendix2 –EQ2)*, and the resulting values of Expected Disruption to premises, and disruption to staff and neighbourhoods.

MMI	PGA(g)	$ED_{premises}$	ED_{staff}	ED_{neigh}
5.0	0.03	0.03	0.22	0.03
5.6	0.04	0.04	0.22	0.04
6.1	0.05	0.05	0.23	0.06
6.5	0.06	0.05	0.23	0.07
6.8	0.07	0.06	0.24	0.08
7.1	0.08	0.07	0.24	0.09
7.3	0.09	0.08	0.25	0.10
7.6	0.10	0.09	0.25	0.11

9.0	0.20	0.18	0.30	0.22
9.9	0.30	0.27	0.35	0.33
10.5	0.40	0.36	0.40	0.44
11.0	0.50	0.45	0.45	0.55
11.4	0.60	0.54	0.50	0.66
11.7	0.70	0.63	0.55	0.77
12.0	0.80	0.72	0.60	0.88
12.2	0.90	0.81	0.65	0.99
12.5	1.00	0.90	0.70	1.00

We could have derived the Expected Disruption equations as a function of Mercalli Macroseismic Intensity, MMI, by simply substituting the variable PGA with the analytic *function* above.

However, in order to avoid the complexity of having to deal with a logarithmic function, the Expected Disruption equations as a function of Mercalli Macroseismic Intensity were derived as a linear interpolation of the values in Table 1.

The resulting equations are as follow:

	$ED_{premises}$	ED_{staff}	ED_{neigh}
m	0.12	0.07	0.13
q	-0.56	-0.11	-0.62

$$ED_{premises} = 0.12 \times MMI - 0.56 \qquad [\text{if } ED_{premises}>1, \text{ then } =1]$$

$$ED_{neigh} = 0.13 \times MMI - 0.62 \qquad [\text{If } ED_{neigh}>1, \text{ then } =1]$$

$$ED_{staff} = 0.07 \times MMI - 0.11 \qquad [\text{if } ED_{staff}>1, \text{ then } =1]$$

Limitations:

The approach taken does not include for other external factors such as liquefaction and cordon areas that affect impact. The analysis approach could be further refined by removing organisations that suffered disruption due to being in the cordon and in areas of significant liquefaction (residential red zone areas) and adding these are additional factors.

Also note that the survey question asks for level of disruption due to the impact type. Therefore respondents likely answered this based on the degree of impact AND their dependence on the thing impacted.

References:

Lagomarsino, S., Giovinazzi, S., (2006). Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. Bulletin of Earthquake Engineering, 4,4,pp415-443. Kluwer Academic Publishers

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015) Business Behaviours following the Canterbury Earthquakes: Modelling non-infrastructure disruption. ERI Results Bulletin 2015-K03-2. Resilient Organisations www.resorgs.org.nz

Resilient ORGANISATIONS   ECONOMICS of RESILIENT INFRASTRUCTURE

Business Behaviours Following the Canterbury Earthquakes

Combining disruptions

ERI Results Bulletin 2015-K04-1

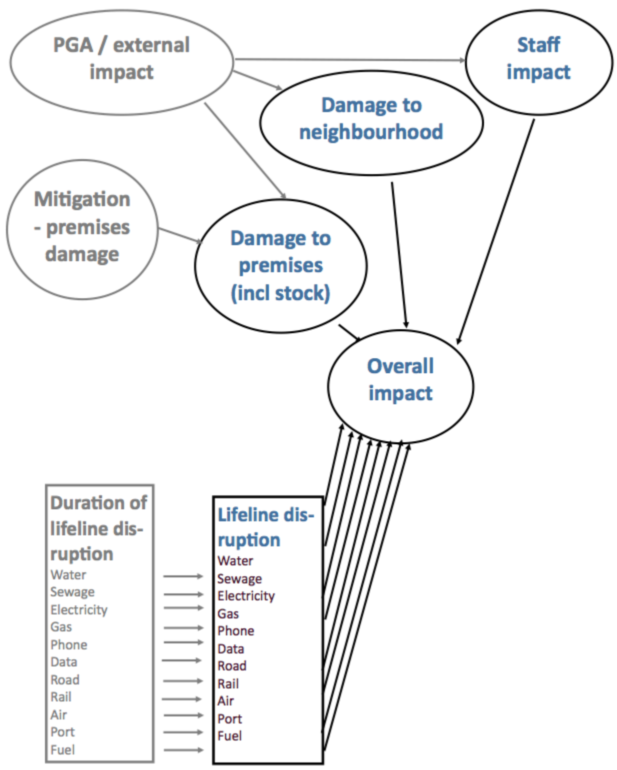
Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

What is the best way to combine multiple disruptions to determine an overall level of disruption on an organisation?

Following the earthquakes, organisations were impacted in a number of different ways – including physical damage, disruption to infrastructure, disruption to suppliers, customers and staff. For modelling and analysis purposes it is often necessary to combine impacts to represent an overall level of disruption. However, there are many different ways this can be done – e.g. taking the maximum, average or a weighted value.

We wanted to determine the best way to combine disruption for our dataset.



Findings for MERIT:

1. Disruption can be grouped into three categories:
   a) Non-infrastructure disruption (physical impacts, neighbourhood impacts, staff impacts),
   b) Network infrastructure disruption (electricity, water, sewage, phone, data, road and gas) and
   c) Node infrastructure disruption (Rail, Port, Airport, fuel).
2. For each of these groups, the maximum disruption within that group has been taken to represent the disruption of this kind.
3. These disruptions have then been further combined to generate an overall disruption variable for use in the regression (this is to reduce collinearity effects and reduce the number of variables in the regression). Both a regression analysis and a correlation analysis indicated that the best combination to model these impacts is an average of the top two impacts (taken two of the above three categories).

Analysis:

The ERI business behaviour survey asked businesses about the disruption caused by a wide range of impacts. These needed to be consolidated to enable the data to be processed.

First, the non-infrastructure impacts were grouped, theoretically, by 'like' impacts. Three broad categories emerged: damage to premises, damage to neighbourhood and impact on staff (see table below for questions). An average score for each grouping was calculated and a Cronbach's Alpha carried out to determine whether the scale / item grouping was reliable. The scales chosen were reliable – all returning Cronbach Alpha > 0.8. (see table below).

Impact	Survey Question	Calculation description / Notes	SPSS variable name	Cronbach Alpha
Damage to premises	Q11 (part)	Combined, average impact of (Scaled 0-1): Difficult accessing IT Structural Damage to buildings Non-structural damage Machinery loss or damage Office equipment loss or damage Damage to inventory or stock	impPhys	0.84
Damage to neighbourhood	Q11 (part)	Combined, average impact of (scaled 0-1): Damage to or closure of adjacent buildings Damage to local neighbourhood Difficulty accessing premises	impNeigh	0.882
Staff impact	Q11 (part)	Combined, average impact of (scaled 0-1): Health and safety issues for employees Availability of staff Perceptions of building safety Changes in staff emotional wellbeing	impStaff	0.81

Next, using these impact groupings and the infrastructure impacts a principle component analysis was carried out to determine if the factors could be further grouped. The analysis showed that the impacts fall into three categories:

- Non-infrastructure impacts (physical, neighbourhood and staff),
- Network infrastructure impacts (Electricity, water, sewage, phone, data, road and gas) and
- Transportation infrastructure impacts (Rail, Port, Airport, fuel).

Rotated Component Matrix[a]

	Component		
	1	2	3
Impact: Electricity	.840		
Impact: Water supply	.825		
Impact: Sewage	.814		
Impact: Phone networks	.741		
Impact: Data networks	.700	.356	
Neighbourhood impacts		.847	
Physical impacts		.844	
Staff impacts	.311	.690	
Impact: Road networks	.420	.490	
Impact: Rail			.765
Impact: Port			.757
Impact: Airport			.731
Impact: Fuel	.310		.616
Impact: Gas	.370		.371

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

To represent each of these categories, the maximum impact recorded within any one category was taken as the value for that category. This is described in the table below.

Model variable	Survey Question	Calculation description / Notes	SPSS variable name
Maximum network infrastructure impact	Q12d	Maximum impact from this group of variables a score from 0 to 1. impWat1 impSew1 impElec1 impGas1 impPh1 impData1 impRd1	impMxNet
Maximum transportation infrastructure impact	Q12d (part)	Maximum impact from this group of variables a score from 0 to 1. impRail1 impAir1 impPort1 impFuel1	impMxTra
Maximum non-infrastructure impact	Q11 (part)	Maximum impact of (scaled 0-1): Structural Damage to buildings Non-structural damage Machinery loss or damage Office equipment loss or damage Damage to inventory or stock Damage to or closure of adjacent buildings Damage to local neighbourhood Difficulty accessing premises Health and safety issues for employees Availability of staff Perceptions of building safety Changes in staff emotional wellbeing	impMxExt

Next it is necessary to understand whether or not these factors are additive (i.e. if you suffer each of these types of disruptions you are three times more disrupted than if you only suffer one) or if they are substitutable (disruption of one is equal to disruption of another) or another combination. Or alternatively, one type of impact is more impactful than another.

First, the average response to the level of disruption reported for each type of impact was generated, to help determine the relative importance of the different impact types.

	Maximum non-infrastructure impact	Maximum network infrastructure impact	Maximum transportation infrastructure impact
Mean	.5211	.6853	.2728
N	538	539	534
Std. Deviation	.31409	.33356	.33391

From this, it appears that damage to the transportation infrastructure was the least disruptive. However, as shown below, this is due to the lower damage on the transportation infrastructure and a lower dependence on this type of infrastructure (see analysis below).

It also appears that network infrastructure was more impactful than non-infrastructure damage, however, it is possible that this is because a number of organisations experienced minor non-infrastructure damage – bringing the average level of disruption down.

The average length of disruption for the infrastructure (following the earthquakes) is shown below.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Duration of water disruption - equivalent hours	358	.16749	.284812	.015053
Duration of sewage disruption - equivalent hours	298	.20206	.318737	.018464
Duration of electricity disruption - equivalent hours	383	.09557	.220320	.011258
Duration of gas disruption - equivalent hours	63	.16762	.308133	.038821
Duration of phone disruption - equivalent hours	414	.06418	.180297	.008861
Duration of data disruption - equivalent hours	357	.06950	.186198	.009855
Duration of road disruption - equivalent hours	346	.44855	.463454	.024915
Duration of rail disruption - equivalent hours	47	.15643	.275885	.040242
Duration of airport disruption - equivalent hours	91	.11240	.265767	.027860
Duration of port disruption - equivalent hours	66	.25658	.364376	.044852
Duration of fuel disruption - equivalent hours	172	.07931	.200106	.015258

Mean for network infrastructure (1=month) = 0.245

Mean for transportation infrastructure (1=month) = 0.151

The average dependence on infrastructure types, based on organisation self assessment of how long they could continue functioning without certain infrastructure is shown below (where the scale is 0 for months and 4 for could not function):

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Dependence on infrastructure: Water	532	2.23	1.344	.058
Dependence on infrastructure: Sewage	529	2.22	1.363	.059
Dependence on infrastructure: Electricity	536	2.97	1.322	.057
Dependence on infrastructure: Gas	408	1.12	1.545	.076
Dependence on infrastructure: Phone networks	530	2.69	1.173	.051
Dependence on infrastructure: Data networks	521	2.58	1.255	.055
Dependence on infrastructure: Road networks	517	2.47	1.347	.059
Dependence on infrastructure: Rail	435	.62	1.114	.053
Dependence on infrastructure: Airport	451	.75	1.142	.054
Dependence on infrastructure: Port	438	.68	1.156	.055
Dependence on infrastructure: Fuel	486	1.82	1.317	.060

Mean for network infrastructure (4=could not function, 0=months) = 1.336

Mean for transportation infrastructure (4=could not function, 0=months) = 1.18

To further assess the relative impact of the different infrastructure types, the dataset was split into groups that represented a range of external impact and infrastructure impacts; that is, only high non-infrastructure impacts, only high network infrastructure impacts and only high transportation impacts. Using these groupings, an assessment of the impacts and their impact on ability to meet demand was carried out. First the operability or average ability to meet demand (AMD) was calculated. Again, it appears transportation is the least disruptive. Non-infrastructure impact and network infrastructure impact seems to have similar affect on ability to meet demand. The fact that AMD for all organisations was lower than for the subsets, indicates that the impacts may have been somewhat additive.

Level of impact			**Average AMD**
impMxExt	**impMxNet**	**impMxTra**	
All	All	All	0.69
>0.5	<0.5	<0.5	0.81
<0.5	>0.5	<0.5	0.79
<0.5	<0.5	>0.5	0.9

In addition a regression was carried out to determine the relative importance of the impacts on predicting AMD. The results show that non-infrastructure and network infrastructure impacts are almost equally as important. Transportation impacts have less of a relationship with AMD.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.384[a]	.147	.142	.32492

a. Predictors: (Constant), Maximum transportation infrastructure impact, Maximum non-infrastructure impact, Maximum network infrastructure impact

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.460	3	3.153	29.870	.000[b]
	Residual	54.791	519	.106		
	Total	64.251	522			

a. Dependent Variable: Ability to meet demand immediately after the earthquakes

b. Predictors: (Constant), Maximum transportation infrastructure impact, Maximum non-infrastructure impact, Maximum network infrastructure impact

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.976	.034		28.351	.000
	Maximum non-infrastructure impact	-.250	.051	-.224	-4.855	.000
	Maximum network infrastructure impact	-.257	.052	-.243	-4.948	.000
	Maximum transportation infrastructure impact	.095	.046	.091	2.085	.038

a. Dependent Variable: Ability to meet demand immediately after the earthquakes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.193[a]	.037	.035	.35153
2	.362[b]	.131	.123	.33519

a. Predictors: (Constant), Peak ground acceleration

b. Predictors: (Constant), Peak ground acceleration, Maximum transportation infrastructure impact, Maximum non-infrastructure impact, Maximum network infrastructure impact

To test the best possible combination of the various impacts, five new variables were created and a correlation between impact and Ability to Meet Demand was carried out. The new variables were:

- Maximum impact (1 only)
- Average of Maximum external and network impacts *(note that this is not favoured because the model needs to include for non-road transportation impacts)*
- Weighted impact 2 variables ((1 x max impact + 0.5 x second highest impact (any type))
- Average of top two variables only
- Average of all three vairables

The weighting scheme that returned the highest correlation between AMD and impact was for the average of the top two imapcts (from the three categories).

This approach (averaging the top two impacts) is considered the best to allow the model to be applied to different disruption scenarios (e.g. one where non-road infrastructure is most disruptive).

		Ability to meet demand immediately after the earthquakes
Maximum impact out of impMxExt, impMxNet, impMxTra	Pearson Correlation	-.318**
	Sig. (2-tailed)	.000
	N	533
Impact - average of top two - impMxExt, impMxNet, impMxTra	Pearson Correlation	-.345**
	Sig. (2-tailed)	.000
	N	533
Maximum impact (weighted) 1 x top impact + 0.5 x second impact from impMxExt, impMxNet, impMxTra	Pearson Correlation	-.343**
	Sig. (2-tailed)	.000
	N	533
Average maximum impact from impMxExt, impMxNet,	Pearson Correlation	-.267**
	Sig. (2-tailed)	.000
	N	533
	Sig. (2-tailed)	
	N	533
Average of maximum impacts from mpMxExt, impMxNet, impMxTra	Pearson Correlation	-.303**
	Sig. (2-tailed)	.000
	N	533

Limitations:

This approach could be tested further by running a series of regressions – using groups of respondents from the survey – those that only experienced one type of impact and those that experienced multiple. The different impact combinations could be applied to these groups to see if the model holds steady for these different groups.

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015). Business Behaviours following the Canterbury Earthquakes: Combining disruptions. ERI Results Bulletin 2015-K04-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Operability

ERI Results Bulletin 2015-K05-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

How did operability (ability to meet demand) change following the earthquakes and what were the driving factors?

Following the earthquakes, organisations' operability (ability to meet demand) changed over time. The level to which they could operate, or meet demand, was likely influenced by a number of things e.g. level of impact, level of infrastructure damage, level of mitigation, ability of suppliers to meet demand, size, sector and resilience.

We wanted to see if we could determine the primary factors that influence ability to meet demand and produce a mathematical function that could represent this over time, for insertion into the MERIT model.

Findings for MERIT:

The equation to model operability or 'ability to meet demand (AMD)' is shown below for time step one (immediately after the earthquakes – say 1 week) and several months after the earthquakes (say three months)

> Operability (t1) = 1 – 0.4 x impAll
>
> Operability (t2) = 1 – 0.1 x impAll
>
> Where Operability is at t1 (1 week) and t2 (3 months)
>
> Where impAll is the overall impact and is a function of infrastructure and non-infrastructure impacts (see *ERI Results Bulletin 2015 K04-01* for this relationship).
>
> A logarithmic curve would then be set between these two points.

Note that this assumes the disruptions due to suppliers ability to meet demand are already accounted for within the economic model (through supply links).

Analysis:

This analysis is based on the causal network included at the end of this document.

One of the key questions in the ERI survey was 'To what extent was your organisation able to meet demand for your products and services a) immediately after the earthquakes, b) Several months after the earthquakes c) a year on from the earthquakes, d) two years on from the earthquake. This 'ability to meet demand' was considered similar to data needed to formulate an 'operability' curve often used in economic studies. This variable was chosen as the key link between the business behaviours model and the economic model for ERI.

MeetDem1
MeetDem2
MeetDem3
MeetDem4

First a conceptual model of the factors influencing operability (or ability to meet demand (AMD)) was created, see Figure 1. The factors that directly impacted operability or 'ability to meet demand' could all be generated from the questions in the survey. Some of the question responses were joined to make a single index, representing a factor in the model. This was done to reduce the number of variables in the model, and increase the reliability of the results. A Cronbach Alpha was generated for each variable to determine if this approach was appropriate.

Model variable	**Survey Question**	**Calculation description / Notes**	**SPSS variable name**
Overall impact	Q12d	see ERI bulletin K04-1 for rationale	impAll
Resilience - planned	Q44	Use combined index ResInd1 – ResInd5 and ResInd13	ResPlan **α = 0.874**
Resilience - adaptive		Use combined index ResInd6 - ResInd12	ResAdpt **α = 0.846**
Average level of mitigation	Q12a (part)	Assuming that N/A responses mean 'no mitigation in place' and 1 means 'mitigation in place. (Average level of mitigation) Relationships with suppliers Relationship with businesses in our sector Relationship with business advisor Relationship with staff Relationship with neighbours Business continuity, emergency management or disaster preparedness plan Backup or alternative site	mitAve **α = 0.830**

Model variable	Survey Question	Calculation description / Notes	SPSS variable name
		Practiced response to disaster Emergency kit Insurance Available cash or credit Spare resources (e.g. equipment or extra people)	
Feasibility of relocation	Q 19b	Multi-tick responses to this were divided into feasible = 1, or non-feasible = 0. Organisations were scored 1 if they responded to any 'feasible' option. The majority of my staff can work from home = 1 It is relatively easy for us to set up a new location = 1 We have multiple sites we can operate from = 1 We could potentially site-share with another organisation = 1 Others = 0	FeasRel
Post-event adaptation	Q 37 and 38	Average of total response to the following (yes =1 and no=0): Has your organisation initiated new collaborations? [newColla] Has your business adopted new technologies?[BusChng4] Has your business changed operational processes? [BusChng5] Has your business restructured? [BusChng6] Has your business closed unprofitable lines? [BusChng7] *(Note that New Production lines, new market sector and new delivery channels have been ignored because these affect demand and are in another part of the model)*	PostAdpt **α = 0.531** (this is an additive index – a higher number means most adaptation, therefore a low Cronbach's Apha is acceptable)
Change in demand	Q25a	As is. Match time period	ChngDem1 to ChngDem4
Ability of suppliers to meet demands	Q20	As is.	supAblty
Ownership – individual proprietorship	Q10	A Mann-Whitney U test was carried out to determine the significance of ownership on Ability to Meet Demand. The only type of ownership model that performed significantly different to others was individual proprietors / self-employed: they were statistically significantly less likely to be able to meet demand immediately after the earthquakes than other types of businesses (U=17800, p=0.012). 97	ownIndv

Model variable	Survey Question	Calculation description / Notes	SPSS variable name
		organisations reported themselves as self employed. Their average Ability to Meet Demand score was 0.642, compared to 0.719 for other ownership types.	
Locations outside Canterbury	Q14 (adjusted)	A yes/no variable was established indicating those that had organisations outside of Canterbury and those that didn't. (this indicates resources / support outside the affected area)	locOutCa
Did they relocate	Q18a	Yes / No	Relocate
Number of FTE employees	Q7	Based on 1 x full time + 0.5 x part time	NoEmpFTE
Earthquake wage subsidy	Q30 (part)	Yes / No	FinRec9

A step-wise linear regression was then carried out to determine which variables were predictors of operability or ability to meet demand. Note that analyses showed that operability or AMD was not dependent on sector (see *ERI Results Bulletin 2015-K03-1)* so operability or AMD regression was only carried out across all organisations (not by sector).

Initially the regression was carried out for all four time periods, however, the number of organisations that couldn't meet demand quickly reduced. By 1 and 2 years after the earthquakes, the data tells us that really only outliers couldn't meet demand – so it is not possible / useful to try to model. To determine the slope for how quickly organisations are able to recover ability to meet demand need to model both immediately after and few months after and do a logarithmic curve fitting to model the trajectory.

Change in demand appeared in the regression results but the results were questionable. Change in demand had a slight impact on the initial AMD but only significantly for change in demand immediately after the impact. It is unlikely that there would have been an immediate response between change in demand and ability to meet demand. In addition, the relationships was positive (those with increased demand were more able to meet demand). These results are counter-intuitive and suggests some anomalies, possibly related to how people answered the question. Therefore it is suggested that <u>Change in Demand be removed</u> from the model.

The regression results are shown below.

Operability (t1) = 0.767 + 0.125 x SupAblty – 0.414 x impAll (adjusted R^2 = 0.166, Sig =<0.005)

Operability (t2) = 0.836 + 0.072 x SupAblty – 0.088 x impAll (adjusted R^2 = 0.051, Sig =<0.005)

Where Operability = Ability to meet demand / operability at Time 1 (1 week) and Time 2 (3 months)

Where SupAblty = suppliers ability to meet demand (measured on a scale of 0 to 2 (completely incapable to completely capable)

Where impAll is overall impact and is a function of infrastructure and non-infrastructure impacts (see *ERI Results Bulletin 2015 K04-01* for this relationship).

A logarithmic curve would then be set between these two points. A logarithmic curve was selected because of the pattern generated when the AMD survey responses are plotted.

However, after discussions with Aim 3 (the economic modelling team), it was decided that the ability of suppliers to meet demand is already implicit in the model as organisations are linked together with their suppliers and these disruptions flow through the system. Therefore, this variable was excluded.

Therefore, we will assume remove suppliers ability to meet demand from the model and we get two new operability / AMD functions:

Operability (t1) = 1 – 0.4 x impAll (adjusted R^2 = 0.117, Sig =<0.005)

Operability (t2) = 1 – 0.1 x impAll (adjusted R^2 = 0.029, Sig =<0.005)

Where Operability = Ability to meet demand at Time 1 (1 week) and 2 (3 months)

Where impAll is overall impact and is a product of infrastructure and non-infrastructure impacts (see *ERI Results Bulletin 2015 K12-01* for this relationship).

A logarithmic curve would then be set between these two points, with an asymptote of 1.

During model development the degree to which MERIT reflects supply chain disruption needs to be tested. One way to do this might be to create an 'operability' stock variable. Then we could apply our normal operability function (the version without suppliers ability to meet demand) at time step 1, we will see a certain level of operability, then at time step two we should see some of the supplier disruptions coming through which should lower the operability stock. Obviously over this time step operability will also increase so we'd need to adjust for that. This would show us how much disruption is flowing through the MERIT model. Our linear operability model (when we include suppliers disruption) tells us the anticipated effect of supply chain disruption: If supply chains are unaffected (SupAblty = 2) then the operability should increase by about 25% (absolute of total potential operability). Conversely, if supply chains are not functioning fully (our data shows this organisations start making supply chain changes on average at around the 60% mark of suppliers ability to meet demand) then the operability would be around 25% less (absolute of total potential operability).

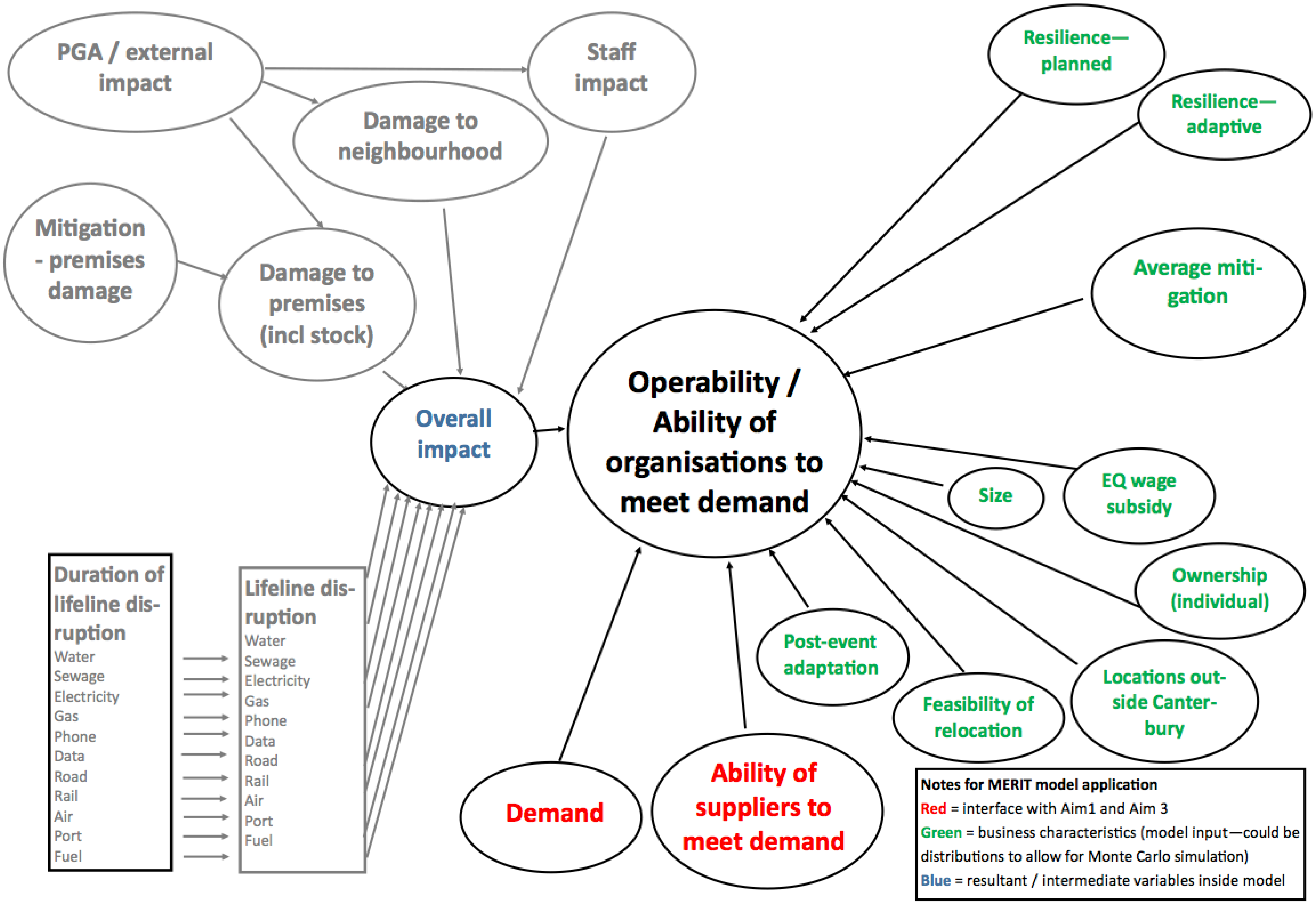
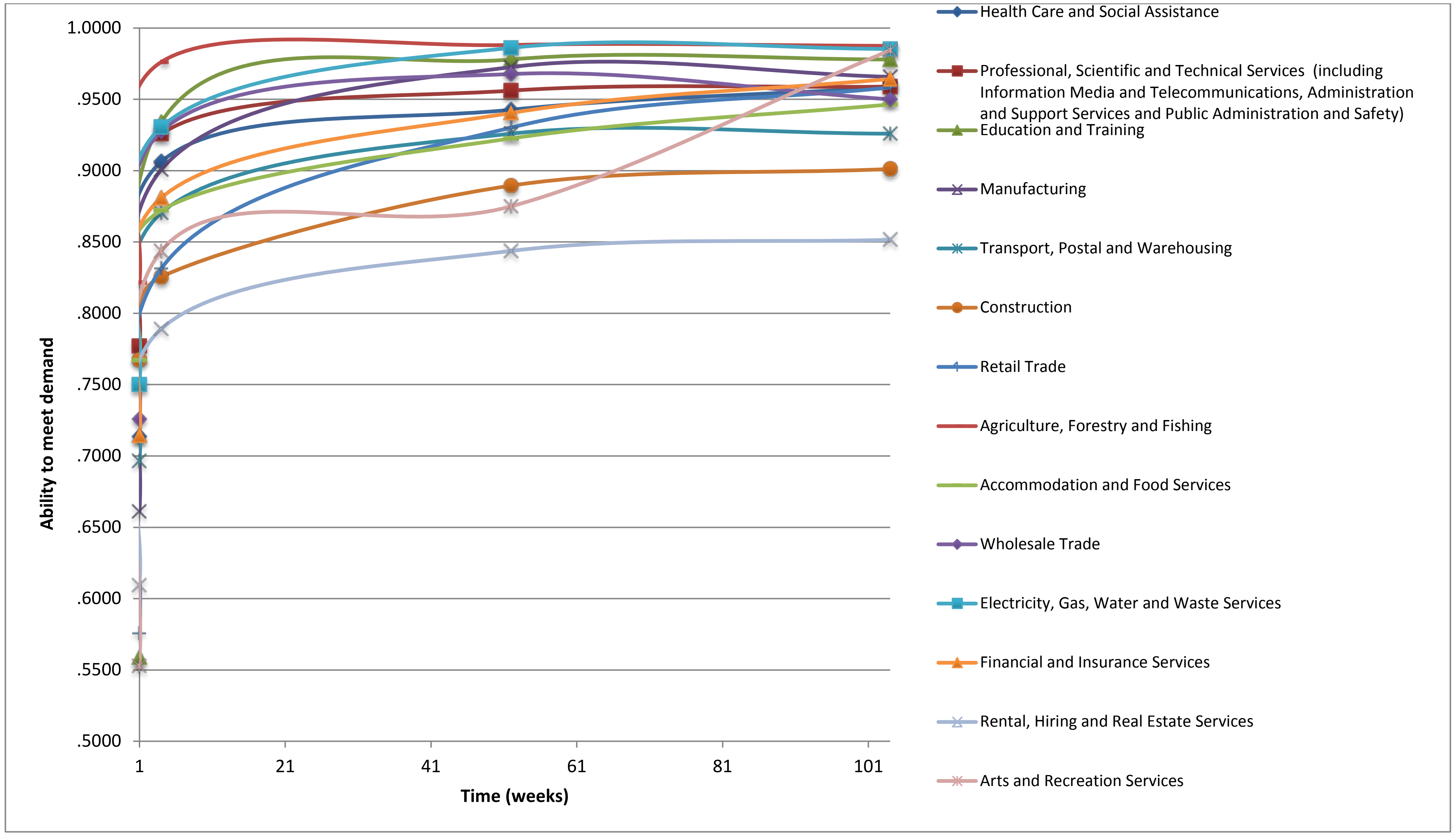

PGA / external impact
Staff impact
Damage to neighbourhood
Mitigation - premises damage
Damage to premises (incl stock)
Overall impact
Operability / Ability of organisations to meet demand
Resilience—planned
Resilience—adaptive
Average miti-gation
Size
EQ wage subsidy
Ownership (individual)
Locations out-side Canter-bury
Feasibility of relocation
Post-event adaptation
Demand
Ability of suppliers to meet demand
Duration of lifeline dis-ruption
Water
Sewage
Electricity
Gas
Phone
Data
Road
Rail
Air
Port
Fuel
Lifeline dis-ruption
Water
Sewage
Electricity
Gas
Phone
Data
Road
Rail
Air
Port
Fuel
Notes for MERIT model application
Red = interface with Aim1 and Aim 3
Green = business characteristics (model input—could be distributions to allow for Monte Carlo simulation)
Blue = resultant / intermediate variables inside model

Figure 1 – Conceptual 'Ability to meet demand' model



Limitations:

As with any analysis of survey data, the results are limited by the quality and interpretation of the respondents. The low R^2 values for the functions indicate the wide spread in organisational impact and behaviour. The results could potentially be improved by grouping the organisations by a certain factor. This analysis was carried out at sector level but the results were less reliable, in many cases due to the low number of responses in some of the sectors. Future analysis could attempt alternative grouping to try and improve the function reliability for example by size, by location, by customer location or service delivery method.

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015) Business Behaviours following the Canterbury Earthquakes: Operability. ERI Results Bulletin 2015-K05-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Effect of Changing Suppliers

ERI Results Bulletin 2015-K06-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

Is there a 'penalty' effect for organisations that change their usual suppliers during recovery?

Within economics there is a basic assumption behind supply/demand/price relationships that organisations can, and will, change suppliers to get the supplies that they need at the best price. But there is a level of disruption created for organisations from changing their suppliers; it takes time to establish a trusted relationship with new suppliers, potential teething problems setting up systems and processes between the two parties, and there may be a 'lead time' required from when supplies are ordered through to when they can be delivered.

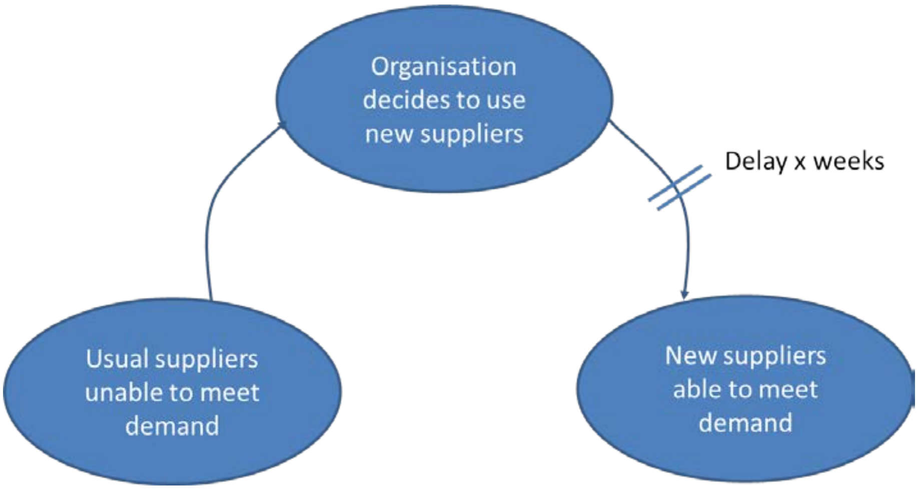
Following the Canterbury earthquakes a number of organisations experienced supply disruptions. We wanted to know what proportion of these organisations elected to change their suppliers, and if they did, whether this helped or hindered their recovery.

Findings for MERIT:

Changing suppliers did slow average resumption of full operability or Ability to Meet Demand (AMD), indicating that organisations likely experience changing suppliers as a form of 'disruption'. There are two ways we could model this disruption within MERIT depending on the outcome of discussions on whether supplier disruption should be included in the AMD/operability curve calculations:

Option A: include supplier disruption as a type of impact and include in the AMD calculation.

Option B: As a delay within the system model, representing time between an organisation choosing to switch suppliers, and their supply needs being met. We would need to play around with sensitivity to this delay. As an initial starting point, we suggest modelling a supplier change effect delay of 2 -4 weeks.



Analysis:

To explore the effect (and efficacy) of changing suppliers, we broke the sample into two groups – those organisations that elected to use new suppliers and those that didn't. First, we looked at the reported level of experienced disruption of those that changed suppliers against those that didn't.

Descriptives

Impact: Supplier Issues

Use of new suppliers	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No	361	.90	.935	.049	.80	1.00	0	3
Yes	90	1.51	.986	.104	1.30	1.72	0	3
Total	451	1.02	.975	.046	.93	1.11	0	3

ANOVA

Impact: Supplier Issues

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	26.879	1	26.879	30.104	.000
Within Groups	400.899	449	.893		
Total	427.778	450			

- **Those that changed suppliers indicated on average, a statistically significantly higher level of disruption due to supplier issues (50% disruption vs 30% disruption).**

Second, for each group we then subdivided them into whether their old suppliers were completely capable, somewhat capable, or completely incapable of meeting their needs. We analysed to see if there were any statistically significant differences in proportions between groups. We also compared average Ability to Meet Demand at different timesteps for each of the groups to see if changing suppliers helped or hindered organisations to meet their demand, given the same level of initial supplier disruption.

Suppliers ability to meet your needs * Use of new suppliers Crosstabulation

			Use of new suppliers		Total
			No	Yes	
Suppliers ability to meet your needs	Incapable	Count	5_a	2_a	7
		% within Suppliers ability to meet your needs	71.4%	28.6%	100.0%
	Somewhat capable	Count	165_a	59_b	224
		% within Suppliers ability to meet your needs	73.7%	26.3%	100.0%
	Completely capable	Count	231_a	30_b	261
		% within Suppliers ability to meet your needs	88.5%	11.5%	100.0%
Total		Count	401	91	492
		% within Suppliers ability to meet your needs	81.5%	18.5%	100.0%

Each subscript letter denotes a subset of Use of new suppliers categories whose column proportions do not differ significantly from each other at the .05 level.

- **Organisations did not elect to change suppliers lightly. Across the entire sample only 18.5% of organisations indicated that they used new suppliers following the Canterbury earthquakes.**

- **Even where their usual suppliers were 'incapable' or 'somewhat capable' of meeting their needs, only 26 - 28% of organisations switched to using new suppliers. Statistically significantly more organisations retained their suppliers.**

The sample of organisations whose suppliers were 'completely incapable of meeting needs' is too small to do much analysis, so we therefore focused on organisations whose suppliers were 'somewhat capable' of meeting their needs. Again, those that used new suppliers indicated a higher level of disruption due to suppliers issues.

Analysis also showed that of organisations that had suppliers 'somewhat capable of meeting demand' there was no statistically significant difference in their Ability to Meet Demand immediately after the earthquake between organisations that did or did not use new suppliers. But, a month after the earthquake, organisations that remained using their old suppliers were more likely to be completely able to meet demand one month after the earthquakes. One year and two years after the earthquake there was no statistically significant difference in organisation's ability to meet demand between those organisations that did or did not choose to use new suppliers; nor were there any statistically significant differences in their other recovery metrics.

Descriptives

Impact: Supplier Issues

Use of new suppliers	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean: Lower Bound	95% Confidence Interval for Mean: Upper Bound	Minimum	Maximum
No	151	1.28	.962	.078	1.13	1.44	0	3
Yes	59	1.75	.902	.117	1.51	1.98	0	3
Total	210	1.41	.966	.067	1.28	1.55	0	3

ANOVA

Impact: Supplier Issues

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.016	1	9.016	10.085	.002
Within Groups	185.941	208	.894		
Total	194.957	209			

Ability to meet demand one month after the earthquakes * Use of new suppliers Crosstabulation (NOTE THIS IS FOR ORGS WHOSE SUPPLIERS WERE SOMEWHAT CAPABLE OF MEETING DEMAND)

% within Use of new suppliers

		Use of new suppliers		Total
		No	Yes	
Ability to meet demand one month after the earthquakes	Unable (0-20%)	$3.1\%_a$	$n<5_a$	2.8%
	Limited (20-40%)	$3.1\%_a$	$8.8\%_a$	4.6%
	Partially (40-60%)	$3.7\%_a$	$n<5_a$	4.6%
	Mostly (60-80%)	$21.7\%_a$	$33.3\%_a$	24.8%
	Completely (80-100%)	$68.3\%_a$	$49.1\%_b$	63.3%
Total		100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Use of new suppliers categories whose column proportions do not differ significantly from each other at the .05 level.

- **Organisations that retained using their old suppliers were, on average, slightly faster to recovery full Ability to Meet demand / operability following the earthquakes, but this effect was temporary, affecting organisations for a period of weeks to months.**

To find out whether or not these supplier relationships were sector dependent, and ANOVA was carried out. There were no significant differences between sectors for supplier disruption, ability of suppliers to meet demand or the use of new suppliers (either when considering only organisations that had suppliers 'somewhat capable' or all organisations) .

ANOVA (suppliers somewhat capable of meeting demand)

		Sum of Squares	df	Mean Square	F	Sig.
Impact: Supplier Issues	Between Groups	8.174	14	.584	.602	.862
	Within Groups	193.985	200	.970		
	Total	202.158	214			
Suppliers ability to meet your needs	Between Groups	.000	14	.000	.	.
	Within Groups	.000	215	.000		
	Total	.000	229			
Use of new suppliers	Between Groups	1.418	14	.101	.506	.928
	Within Groups	41.429	207	.200		
	Total	42.847	221			

ANOVA (all orgs)

		Sum of Squares	df	Mean Square	F	Sig.
Impact: Supplier Issues	Between Groups	19.073	14	1.362	1.431	.135
	Within Groups	424.710	446	.952		
	Total	443.783	460			
Suppliers ability to meet your needs	Between Groups	6.420	14	.459	1.678	.057
	Within Groups	132.269	484	.273		
	Total	138.689	498			
Use of new suppliers	Between Groups	1.879	14	.134	.929	.528
	Within Groups	72.423	501	.145		
	Total	74.302	515			

MERIT already includes for supplier disruptions (in terms of commodities being available etc). However, MERIT does not include for the disruptions from have to change suppliers. So it is necessary to include a disruption function due to those organisations that must change suppliers. There are several ways this could be modelled within MERIT.

- This could be modelled as a delay – if an organisation needs to change suppliers then there would be a delay in supply of that commodity. The challenge will be to determine when this delay is applied (ie what sort of feedback inside MERIT is needed to determine the level of suppliers ability to meet demand is low enough to require a new supplier) and how long the delay will be. This will need to be investigated further in the case studies.

- Another option would be to include supplier's ability to meet demand or disruption to suppliers in the operability model for organisations that need new suppliers. A Pearson correlation show that both disruption to suppliers ('impact: supplier issues' in table below) and Suppliers ability to meet demand are significant predictors of ability to meet demand. It is suggested that the variable 'suppliers ability to meet demand' is a slightly better predictor based on the correlation results and should be used to create any function linking suppliers ability to meet demand and organisational ability to meet demand (see ERI Results Bulletin 2015-K05-1).

Correlations

		Impact: Supplier Issues	Suppliers ability to meet your needs	Ability to meet demand immediately after the earthquakes	Ability to meet demand one month after the earthquakes
Impact: Supplier Issues	Pearson Correlation	1	-.397**	-.251**	-.133**
	Sig. (2-tailed)		.000	.000	.004
	N	465	448	459	459
Suppliers ability to meet your needs	Pearson Correlation	-.397**	1	.267**	.207**
	Sig. (2-tailed)	.000		.000	.000
	N	448	503	496	494
Ability to meet demand immediately after the earthquakes	Pearson Correlation	-.251**	.267**	1	.525**
	Sig. (2-tailed)	.000	.000		.000
	N	459	496	533	527
Ability to meet demand one month after the earthquakes	Pearson Correlation	-.133**	.207**	.525**	1
	Sig. (2-tailed)	.004	.000	.000	
	N	459	494	527	528

**. Correlation is significant at the 0.01 level (2-tailed).

So the key thing to determine is: what drives the use of new suppliers? Here we looked at the ability of suppliers to meet demand as well as the location of suppliers. The only predictors appear to be those discussed above (ability of suppliers to meet demands and disruption due to supplier impact). So we need to determine the level of supplier's ability to meet demand that new suppliers are sought. The ANOVA analysis and means included below show that the mean for sticking with existing suppliers is '75%' and for those that choose new suppliers, the mean is '65%'. So as a starting point in the model we could have a feedback in the model to determine the capacity of connected organisations / sectors. This could trigger the use of either a delay or a disruption function.

ANOVA on Use of new suppliers

		Sum of Squares	df	Mean Square	F	Sig.
Suppliers ability to meet your needs	Between Groups	4.857	1	4.857	18.028	.000
	Within Groups	132.013	490	.269		
	Total	136.870	491			
Impact: Supplier Issues	Between Groups	26.879	1	26.879	30.104	.000
	Within Groups	400.899	449	.893		
	Total	427.778	450			
Suppliers pre-earthquake: Local(Canterbury)	Between Groups	758.967	1	758.967	.614	.434
	Within Groups	545439.250	441	1236.824		
	Total	546198.217	442			
Suppliers pre-earthquake: elsewhere in NZ	Between Groups	68.475	1	68.475	.081	.776
	Within Groups	373284.812	441	846.451		
	Total	373353.287	442			
Suppliers pre-earthquake: outside NZ	Between Groups	270.745	1	270.745	.627	.429
	Within Groups	189877.490	440	431.540		
	Total	190148.235	441			
Suppliers pre-earthquake: don't know	Between Groups	150.648	1	150.648	1.337	.248
	Within Groups	50158.605	445	112.716		
	Total	50309.253	446			
Suppliers post-earthquake: local (Canterbury)	Between Groups	789.859	1	789.859	.635	.426
	Within Groups	540765.495	435	1243.139		
	Total	541555.355	436			
Suppliers post-earthquake: elsewhere in NZ	Between Groups	152.568	1	152.568	.174	.677
	Within Groups	381420.691	435	876.829		
	Total	381573.259	436			
Suppliers post-earthquake: outside NZ	Between Groups	187.705	1	187.705	.413	.521
	Within Groups	198111.301	436	454.384		
	Total	198299.007	437			
Suppliers post-earthquake: don't know	Between Groups	270.974	1	270.974	1.716	.191
	Within Groups	69633.292	441	157.899		
	Total	69904.266	442			
	Within Groups	9974.364	85	117.345		
	Total	10013.057	86			

Descriptives

Suppliers ability to meet your needs

Use of new suppliers	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No	401	1.56	.521	.026	1.51	1.61	0	2
Yes	91	1.31	.510	.053	1.20	1.41	0	2
Total	492	1.52	.528	.024	1.47	1.56	0	2

ANOVA

Suppliers ability to meet your needs

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.857	1	4.857	18.028	.000
Within Groups	132.013	490	.269		
Total	136.870	491			

Limitations:

Whether an organisation choses to switch suppliers is likely to be highly dependent on an organisation's perception of how quickly the supplier is expecting to be able to resume supply. Our survey did not collect any information on this perception (nor how accurate this perception was). Teasing this out, along with more analysis of what level of 'delay' should be incorporated into the model to reflect time for new suppliers to be able to meet demand, will be a feature of the case studies.

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015) Business Behaviours following the Canterbury Earthquakes: Effect of Changing Suppliers. ERI Results Bulletin 2015-K06-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Productivity Improvements from Disruption

ERI Results Bulletin 2015-K07-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

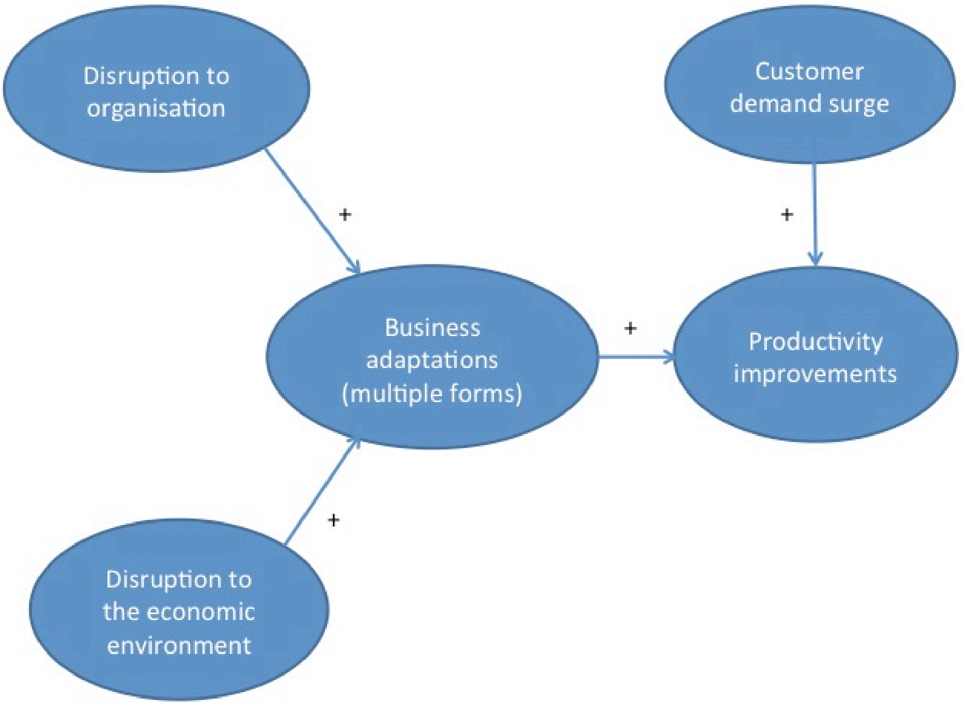
Is there a 'productivity effect' that arises from disruption?

We know that many organisations managed to achieve productivity gains from the earthquakes. This could be evidence of a "productivity effect"; the notion that when disasters destroy productive capital it often results in capital replacements using the most recent technologies, or the creation of new technologies, both of which potentially increase productivity and performance.

We wanted to see if there was any evidence for a 'productivity effect' occurring following the Canterbury earthquakes, and if so, was this affect related to the level of disruption an organisation experienced?

Findings for MERIT:

1) The disruption created overall by the Canterbury earthquakes DID result in productivity improvements for Canterbury organisations.
2) Productivity improvements occurred right across the economy, not just for the most impacted organisations. Organisations that experienced strong customer demand two years on from the earthquakes were those most likely to report greatly increased productivity.
3) There are sector differences between those most likely to see productivity gains:
   a. Organisations in the Education and Training sector were significantly more likely to enter into collaborations.
   b. Organisations in the Accommodation and Food Services sectors and wholesale were significantly less likely (than Education and Training) to enter into new collaborations.
4) Productivity gains were related to a whole raft of business changes. Certain sectors tended to use certain types of change strategies more than others.



Analysis:

Nearly 50% of organisations identified they experienced a productivity gain (slightly increased or greatly increased productivity), while just under 20% of organisations experienced productivity decline (slightly decreased or greatly decreased productivity).

	Frequency	Valid Percent	Cumulative Percent
Greatly decreased	32	6.0	6.0
Slightly decreased	68	12.7	18.7
The same	170	31.8	50.5
Slightly increased	173	32.3	82.8
Greatly increased	92	17.2	100.0
Total	535	100.0	

We found no major patterns (though some noise) between organisations that experienced greater or lesser direct impact from the earthquakes and their level of productivity gain or loss.

Current productivity * MaxImp Crosstabulation

% within MaxImp

		MaxImp				Total
		.00	1.00	2.00	3.00	
Current productivity	Greatly decreased		1.4%$_{b}$	4.3%$_{a, b}$	8.0%$_{a}$	6.0%
	Slightly decreased		8.6%$_{a}$	10.0%$_{a}$	15.3%$_{a}$	12.7%
	The same	63.6%$_{a}$	38.6%$_{a, b}$	35.7%$_{a, b}$	27.2%$_{b}$	31.6%
	Slightly increased	9.1%$_{a}$	30.0%$_{a}$	30.7%$_{a}$	34.5%$_{a}$	32.4%
	Greatly increased	27.3%$_{a}$	21.4%$_{a}$	19.3%$_{a}$	15.0%$_{a}$	17.2%
Total		100.0%	100.0%	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of MaxImp categories whose column proportions do not differ significantly from each other at the .05 level.

Looking across different sectors, we ran a cross-tabulation, looking to see if there were any statistically significant differences, between how organisations in that sector compared to the average across the economy. This identified that the Construction sector organisations as well as those in the Accommodation and Food Services sector were more likely to have seen their productivity *greatly increased* since the earthquakes.

Primary Sector * Current productivity Crosstabulation

			Current productivity					Total
			Greatly decreased	Slightly decreased	The same	Slightly increased	Greatly increased	
Primary Sector	Health Care and Social Assistance	Count	5$_{a}$	9$_{a}$	13$_{a, b}$	19$_{a}$	2$_{b}$	48
		% within Primary Sector	10.4%	18.8%	27.1%	39.6%	4.2%	100.0%
	Professional, Scientific and Technical Services	Count	4$_{a}$	11$_{a}$	21$_{a}$	16$_{a}$	7$_{a}$	59
		% within Primary Sector	6.8%	18.6%	35.6%	27.1%	11.9%	100.0%
	Education and Training	Count	2$_{a, b}$	5$_{a, b}$	16$_{b}$	7$_{a}$	4$_{a, b}$	34
		% within Primary Sector	5.9%	14.7%	47.1%	20.6%	11.8%	100.0%
	Manufacturing	Count	3$_{a, b}$	11$_{a, b}$	30$_{b}$	22$_{a, b}$	7$_{a}$	73
		% within Primary Sector	4.1%	15.1%	41.1%	30.1%	9.6%	100.0%
	Transport, Postal and Warehousing	Count	2$_{a}$	2$_{a}$	5$_{a}$	13$_{a}$	6$_{a}$	28
		% within Primary Sector	7.1%	7.1%	17.9%	46.4%	21.4%	100.0%
	Construction	Count	1$_{a}$	2$_{a}$	8$_{a}$	14$_{a}$	19$_{b}$	44
		% within Primary Sector	2.3%	4.5%	18.2%	31.8%	43.2%	100.0%

	Retail trade	Count	$3_{a, b, c}$	$4_{a, b, c}$	10_{c}	21_{b}	$4_{a, c}$	42
		% within Primary Sector	7.1%	9.5%	23.8%	50.0%	9.5%	100.0%
	Agriculture, Forestry and Fishing	Count	$0_{a, b}$	$1_{a, b}$	11_{b}	$8_{a, b}$	1_{a}	21
		% within Primary Sector	0.0%	4.8%	52.4%	38.1%	4.8%	100.0%
	Accommodation and Food Services	Count	2_{a}	3_{a}	6_{a}	11_{a}	23_{b}	45
		% within Primary Sector	4.4%	6.7%	13.3%	24.4%	51.1%	100.0%
	Wholesale Trade	Count	$3_{a, b}$	$5_{a, b}$	14_{b}	$7_{a, b}$	2_{a}	31
		% within Primary Sector	9.7%	16.1%	45.2%	22.6%	6.5%	100.0%
	Information Media and Telecommunications	Count	1_{a}	0_{a}	3_{a}	2_{a}	2_{a}	8
		% within Primary Sector	12.5%	0.0%	37.5%	25.0%	25.0%	100.0%
	Electricity, Gas, Water and Waste Services	Count	0_{a}	1_{a}	7_{a}	9_{a}	1_{a}	18
		% within Primary Sector	0.0%	5.6%	38.9%	50.0%	5.6%	100.0%
	Financial and Insurance Services	Count	0_{a}	5_{a}	6_{a}	6_{a}	5_{a}	22
		% within Primary Sector	0.0%	22.7%	27.3%	27.3%	22.7%	100.0%
	Rental, Hiring and Real Estate Services	Count	4_{a}	6_{a}	7_{a}	10_{a}	5_{a}	32
		% within Primary Sector	12.5%	18.8%	21.9%	31.3%	15.6%	100.0%
	Administrative and Support Services	Count	1_{a}	$0_{a, b}$	0_{b}	0_{b}	$1_{a, b}$	2
		% within Primary Sector	50.0%	0.0%	0.0%	0.0%	50.0%	100.0%
	Public Administration and Safety	Count	0_{a}	0_{a}	2_{a}	3_{a}	0_{a}	5
		% within Primary Sector	0.0%	0.0%	40.0%	60.0%	0.0%	100.0%
	Arts and Recreation Services	Count	1_{a}	3_{a}	8_{a}	5_{a}	2_{a}	19
		% within Primary Sector	5.3%	15.8%	42.1%	26.3%	10.5%	100.0%
	Other	Count	0_{a}	0_{a}	2_{a}	0_{a}	1_{a}	3
		% within Primary Sector	0.0%	0.0%	66.7%	0.0%	33.3%	100.0%
Total		Count	32	68	169	173	92	534
		% within Primary Sector	6.0%	12.7%	31.6%	32.4%	17.2%	100.0%

Each subscript letter denotes a subset of Current productivity categories whose column proportions do not differ significantly from each other at the .05 level.

It is interesting to see that sectors that achieved greatest productivity improvements are also sectors that experience a surge in demand related to the post-disaster rebuild. To see if in fact there is a relationship between change in demand and productivity gains we ran correlations between productivity and customer demand. Statistically significant correlations are evident across all timesteps, but in particular organisations that experienced strong customer demand two years on from the earthquakes were those most likely to report greatly increased productivity.

			Change in demand: Immediately after event	Change in demand: several months after the event	Change in demand: a year on from the event	Change in demand: two years on from the event
Kendall's tau_b	Current productivity	Correlation Coefficient	.135**	.266**	.400**	.479**
		Sig. (2-tailed)	.000	.000	.000	.000
		N	526	523	521	523

Running a correlation between productivity gain or loss, and business changes questions, show that organisations that made changes, were generally more likely to achieve productivity gains. Using a one way ANOVA, the level of productivity of organisations that made each change vs those that didn't were compared. Organisations that made these changes observed both increased and decreased producitivty as well as no change, as summarised below. Note that no account for multiple strategies or exogenous effects were taken into account.

Increased productivity

- New production lines
- New market sector
- New delivery channels
- New technologies
- Operational processes significantly changed

Reduced productivity

- Restructuring

No change

- New collaborations
- Unprofitable lines closed

		Current productivity
New collaborations	Correlation Coefficient	.043
	Sig. (2-tailed)	.277
	N	527
Business changes: new production service lines	Correlation Coefficient	.096*
	Sig. (2-tailed)	.015
	N	535
Business changes: new market sector (change in customers)	Correlation Coefficient	.190**
	Sig. (2-tailed)	.000
	N	535
Business changes: new delivery channels	Correlation Coefficient	.079*
	Sig. (2-tailed)	.044
	N	535
Business changes: new technologies	Correlation Coefficient	.120**
	Sig. (2-tailed)	.002
	N	535
Business changes: operational processes significantly change	Correlation Coefficient	.129**
	Sig. (2-tailed)	.001
	N	535
Business changes: restructuring	Correlation Coefficient	-.041
	Sig. (2-tailed)	.296
	N	535
Business changes: unprofitable lines closed	Correlation Coefficient	-.024
	Sig. (2-tailed)	.536
	N	535
Business changes: other	Correlation Coefficient	-.014
	Sig. (2-tailed)	.724
	N	535

Descriptives

Current productivity

New collaborations	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
No	409	.40	1.065	.053	.30	.51	-2	2
Yes	118	.47	1.217	.112	.25	.70	-2	2
Total	527	.42	1.100	.048	.33	.51	-2	2

ANOVA

Current productivity * New collaborations

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.464	1	.464	.383	.536
Within Groups	635.859	525	1.211		
Total	636.323	526			

Descriptives

Current productivity

New production service lines	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
No	479	.38	1.097	.050	.29	.48	-2	2
Yes	56	.73	1.053	.141	.45	1.01	-2	2
Total	535	.42	1.097	.047	.33	.51	-2	2

ANOVA

Current productivity * New production service lines

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.072	1	6.072	5.086	.025
Within Groups	636.302	533	1.194		
Total	642.374	534			

Descriptives

Current productivity

New market sector	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No	380	.29	1.035	.053	.19	.39	-2	2
Yes	155	.74	1.178	.095	.56	.93	-2	2
Total	535	.42	1.097	.047	.33	.51	-2	2

ANOVA

Current productivity * New market sector

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	22.539	1	22.539	19.381	.000
Within Groups	619.835	533	1.163		
Total	642.374	534			

Descriptives

Current productivity

New delivery channels	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No	491	.39	1.087	.049	.30	.49	-2	2
Yes	44	.73	1.169	.176	.37	1.08	-2	2
Total	535	.42	1.097	.047	.33	.51	-2	2

ANOVA

Current productivity * New delivery channels

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.510	1	4.510	3.769	.053
Within Groups	637.864	533	1.197		
Total	642.374	534			

Descriptives

Current productivity

New technologies	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No	417	.35	1.093	.054	.24	.46	-2	2
Yes	118	.67	1.079	.099	.47	.87	-2	2
Total	535	.42	1.097	.047	.33	.51	-2	2

ANOVA

Current productivity * New technologies

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.381	1	9.381	7.899	.005
Within Groups	632.993	533	1.188		
Total	642.374	534			

Descriptives

Current productivity

Operational processes significantly changed	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No	430	.36	1.050	.051	.26	.46	-2	2
Yes	105	.67	1.246	.122	.43	.91	-2	2
Total	535	.42	1.097	.047	.33	.51	-2	2

ANOVA

Current productivity * Operational processes significantly changed

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.913	1	7.913	6.647	.010
Within Groups	634.461	533	1.190		
Total	642.374	534			

Descriptives

Current productivity

Restructuring	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No	412	.48	1.009	.050	.38	.57	-2	2
Yes	123	.24	1.337	.121	.00	.47	-2	2
Total	535	.42	1.097	.047	.33	.51	-2	2

ANOVA

Current productivity * Restructuring

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.454	1	5.454	4.564	.033
Within Groups	636.920	533	1.195		
Total	642.374	534			

Descriptives

Current productivity

Unprofitable lines closed	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No	472	.44	1.071	.049	.34	.53	-2	2
Yes	63	.30	1.278	.161	-.02	.62	-2	2
Total	535	.42	1.097	.047	.33	.51	-2	2

ANOVA

Current productivity * Unprofitable lines closed

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.011	1	1.011	.840	.360
Within Groups	641.363	533	1.203		
Total	642.374	534			

Descriptives

Current productivity

Other	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
No	482	.43	1.094	.050	.33	.53	-2	2
Yes	53	.36	1.128	.155	.05	.67	-2	2
Total	535	.42	1.097	.047	.33	.51	-2	2

ANOVA

Current productivity * Other

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.227	1	.227	.188	.665
Within Groups	642.147	533	1.205		
Total	642.374	534			

Looking at business changes by sector, there are distinct trends as to which types of business changes different sectors are likely to adopt.

- 22% of all organisations in our sample entered into new collaborations following the earthquakes.
- Organisations in the Education and Training sector were significantly more likely to enter into collaborations. (Games Howell post-hoc test, $p<0.05$)
- Organisations in the Accommodation and Food Services sectors and wholesale were significantly less likely (than Education and Training) to enter into new collaborations.

Primary Sector * New collaborations Crosstabulation

			New collaborations No	New collaborations Yes	Total
Primary Sector	Health Care and Social Assistance	Count	32_a	16_a	48
		% within Primary Sector	66.7%	33.3%	100.0%
	Professional, Scientific ad Technical Services	Count	40_a	18_a	58
		% within Primary Sector	69.0%	31.0%	100.0%
	Education and Training	Count	18_a	16_b	34
		% within Primary Sector	52.9%	47.1%	100.0%
	Manufacturing	Count	59_a	14_a	73
		% within Primary Sector	80.8%	19.2%	100.0%
	Transport, Postal and Warehousing	Count	20_a	6_a	26
		% within Primary Sector	76.9%	23.1%	100.0%
	Construction	Count	32_a	11_a	43
		% within Primary Sector	74.4%	25.6%	100.0%

	Retail trade	Count	37_a	5_a	42
		% within Primary Sector	88.1%	11.9%	100.0%
	Agriculture, Forestry and Fishing	Count	17_a	3_a	20
		% within Primary Sector	85.0%	15.0%	100.0%
	Accommodation and Food Services	Count	41_a	4_b	45
		% within Primary Sector	91.1%	8.9%	100.0%
	Wholesale Trade	Count	29_a	3_a	32
		% within Primary Sector	90.6%	9.4%	100.0%
	Information Media and Telecommunications	Count	6_a	2_a	8
		% within Primary Sector	75.0%	25.0%	100.0%
	Electricity, Gas, Water and Waste Services	Count	12_a	5_a	17
		% within Primary Sector	70.6%	29.4%	100.0%
	Financial and Insurance Services	Count	18_a	4_a	22
		% within Primary Sector	81.8%	18.2%	100.0%
	Rental, Hiring and Real Estate Services	Count	27_a	5_a	32
		% within Primary Sector	84.4%	15.6%	100.0%
	Administrative and Support Services	Count	2_a	0_a	2
		% within Primary Sector	100.0%	0.0%	100.0%
	Public Administration and Safety	Count	2_a	3_b	5
		% within Primary Sector	40.0%	60.0%	100.0%
	Arts and Recreation Services	Count	18_a	2_a	20
		% within Primary Sector	90.0%	10.0%	100.0%
	Other	Count	2_a	1_a	3
		% within Primary Sector	66.7%	33.3%	100.0%
Total		Count	412	118	530
		% within Primary Sector	77.7%	22.3%	100.0%

Each subscript letter denotes a subset of New collaborations categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

New collaborations

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.917	14	.423	2.542	.002
Within Groups	85.108	512	.166		
Total	91.025	526			

- 28% of organisations developed new market sectors (change in customers). Organisations in the construction sector and accommodation and food services were MORE likely to develop new customers; organisations in the Healthcare and Social Assistance, Education and Training and Professional, Scientific and Technical Service sectors were less likely to make this change. (Games-Howell post-hoc test, $p<0.05$)

Primary Sector * Business changes: new market sector (change in customers) Crosstabulation

			Business changes: new market sector (change in customers)		Total
			No	Yes	
Primary Sector	Health Care and Social Assistance	Count	43_a	5_b	48
		% within Primary Sector	89.6%	10.4%	100.0%
	Professional, Scientific ad Technical Services	Count	47_a	12_a	59
		% within Primary Sector	79.7%	20.3%	100.0%
	Education and Training	Count	32_a	3_b	35
		% within Primary Sector	91.4%	8.6%	100.0%
	Manufacturing	Count	53_a	21_a	74
		% within Primary Sector	71.6%	28.4%	100.0%
	Transport, Postal and Warehousing	Count	22_a	6_a	28
		% within Primary Sector	78.6%	21.4%	100.0%
	Construction	Count	23_a	21_b	44
		% within Primary Sector	52.3%	47.7%	100.0%
	Retail trade	Count	26_a	17_a	43
		% within Primary Sector	60.5%	39.5%	100.0%
	Agriculture, Forestry and Fishing	Count	15_a	6_a	21
		% within Primary Sector	71.4%	28.6%	100.0%
	Accommodation and Food Services	Count	22_a	23_b	45
		% within Primary Sector	48.9%	51.1%	100.0%
	Wholesale Trade	Count	24_a	9_a	33
		% within Primary Sector	72.7%	27.3%	100.0%
	Information Media and Telecommunications	Count	4_a	4_a	8
		% within Primary Sector	50.0%	50.0%	100.0%
	Electricity, Gas, Water and Waste Services	Count	11_a	7_a	18
		% within Primary Sector	61.1%	38.9%	100.0%
	Financial and Insurance Services	Count	18_a	4_a	22
		% within Primary Sector	81.8%	18.2%	100.0%
	Rental, Hiring and Real Estate Services	Count	23_a	9_a	32
		% within Primary Sector	71.9%	28.1%	100.0%
	Administrative and Support Services	Count	2_a	0_a	2
		% within Primary Sector	100.0%	0.0%	100.0%
	Public Administration and Safety	Count	5_a	0_a	5
		% within Primary Sector	100.0%	0.0%	100.0%
	Arts and Recreation Services	Count	13_a	7_a	20

		% within Primary Sector	65.0%	35.0%	100.0%
	Other	Count	3_a	0_a	3
		% within Primary Sector	100.0%	0.0%	100.0%
Total		Count	386	154	540
		% within Primary Sector	71.5%	28.5%	100.0%

Each subscript letter denotes a subset of Business changes: new market sector (change in customers) categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

Business changes: new market sector (change in customers)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.140	14	.653	3.384	.000
Within Groups	100.696	522	.193		
Total	109.836	536			

- 22% of organisations adopted new technologies. Professional, Scientific and Technical Services organisations were statistically more likely to adopt new technologies, compared to Accommodation and Food Services organisations, Electricity, Gas, Water and Waste organisations and Arts and Recreation organisations.

Primary Sector * Business changes: new technologies Crosstabulation

			Business changes: new technologies		
			No	Yes	Total
Primary Sector	Health Care and Social Assistance	Count	39_a	9_a	48
		% within Primary Sector	81.3%	18.8%	100.0%
	Professional, Scientific ad Technical Services	Count	39_a	20_b	59
		% within Primary Sector	66.1%	33.9%	100.0%
	Education and Training	Count	28_a	7_a	35
		% within Primary Sector	80.0%	20.0%	100.0%
	Manufacturing	Count	58_a	16_a	74
		% within Primary Sector	78.4%	21.6%	100.0%
	Transport, Postal and Warehousing	Count	20_a	8_a	28
		% within Primary Sector	71.4%	28.6%	100.0%
	Construction	Count	34_a	10_a	44
		% within Primary Sector	77.3%	22.7%	100.0%
	Retail trade	Count	36_a	7_a	43
		% within Primary Sector	83.7%	16.3%	100.0%

	Agriculture, Forestry and Fishing	Count	16_a	5_a	21
		% within Primary Sector	76.2%	23.8%	100.0%
	Accommodation and Food Services	Count	41_a	4_b	45
		% within Primary Sector	91.1%	8.9%	100.0%
	Wholesale Trade	Count	26_a	7_a	33
		% within Primary Sector	78.8%	21.2%	100.0%
	Information Media and Telecommunications	Count	4_a	4_a	8
		% within Primary Sector	50.0%	50.0%	100.0%
	Electricity, Gas, Water and Waste Services	Count	17_a	1_a	18
		% within Primary Sector	94.4%	5.6%	100.0%
	Financial and Insurance Services	Count	14_a	8_a	22
		% within Primary Sector	63.6%	36.4%	100.0%
	Rental, Hiring and Real Estate Services	Count	24_a	8_a	32
		% within Primary Sector	75.0%	25.0%	100.0%
	Administrative and Support Services	Count	1_a	1_a	2
		% within Primary Sector	50.0%	50.0%	100.0%
	Public Administration and Safety	Count	2_a	3_b	5
		% within Primary Sector	40.0%	60.0%	100.0%
	Arts and Recreation Services	Count	19_a	1_a	20
		% within Primary Sector	95.0%	5.0%	100.0%
	Other	Count	3_a	0_a	3
		% within Primary Sector	100.0%	0.0%	100.0%
Total		Count	421	119	540
		% within Primary Sector	78.0%	22.0%	100.0%

Each subscript letter denotes a subset of Business changes: new technologies categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

Business changes: new technologies

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.647	14	.332	1.969	.018
Within Groups	87.982	522	.169		
Total	92.629	536			

- Just over 10% of organisations offered new products or services following the earthquakes. There were no significant differences between sectors, in terms of likelihood of developing new production service lines.

Primary Sector * Business changes: new production service lines Crosstabulation

			Business changes: new production service lines		
			No	Yes	Total
Primary Sector	Health Care and Social Assistance	Count	43_a	5_a	48
		% within Primary Sector	89.6%	10.4%	100.0%
	Professional, Scientific ad Technical Services	Count	51_a	8_a	59
		% within Primary Sector	86.4%	13.6%	100.0%
	Education and Training	Count	33_a	2_a	35
		% within Primary Sector	94.3%	5.7%	100.0%
	Manufacturing	Count	60_a	14_b	74
		% within Primary Sector	81.1%	18.9%	100.0%
	Transport, Postal and Warehousing	Count	27_a	1_a	28
		% within Primary Sector	96.4%	3.6%	100.0%
	Construction	Count	38_a	6_a	44
		% within Primary Sector	86.4%	13.6%	100.0%
	Retail trade	Count	38_a	5_a	43
		% within Primary Sector	88.4%	11.6%	100.0%
	Agriculture, Forestry and Fishing	Count	20_a	1_a	21
		% within Primary Sector	95.2%	4.8%	100.0%
	Accommodation and Food Services	Count	43_a	2_a	45
		% within Primary Sector	95.6%	4.4%	100.0%
	Wholesale Trade	Count	29_a	4_a	33
		% within Primary Sector	87.9%	12.1%	100.0%
	Information Media and Telecommunications	Count	6_a	2_a	8
		% within Primary Sector	75.0%	25.0%	100.0%
	Electricity, Gas, Water and Waste Services	Count	15_a	3_a	18
		% within Primary Sector	83.3%	16.7%	100.0%
	Financial and Insurance Services	Count	22_a	0_a	22
		% within Primary Sector	100.0%	0.0%	100.0%
	Rental, Hiring and Real Estate Services	Count	30_a	2_a	32

		% within Primary Sector	93.8%	6.3%	100.0%
	Administrative and Support Services	Count	1_a	1_a	2
		% within Primary Sector	50.0%	50.0%	100.0%
	Public Administration and Safety	Count	5_a	0_a	5
		% within Primary Sector	100.0%	0.0%	100.0%
	Arts and Recreation Services	Count	19_a	1_a	20
		% within Primary Sector	95.0%	5.0%	100.0%
	Other	Count	3_a	0_a	3
		% within Primary Sector	100.0%	0.0%	100.0%
Total		Count	483	57	540
		% within Primary Sector	89.4%	10.6%	100.0%

Each subscript letter denotes a subset of Business changes: new production service lines categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

Business changes: new production service lines

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.692	14	.121	1.281	.214
Within Groups	49.257	522	.094		
Total	50.950	536			

- Just under 20% of organisations significantly changed their operational processes. There is no significant difference in which sectors adopted this strategy.

Primary Sector * Business changes: operational processes significantly change Crosstabulation

			Business changes: operational processes significantly change		
			No	Yes	Total
Primary Sector	Health Care and Social Assistance	Count	43_a	5_a	48
		% within Primary Sector	89.6%	10.4%	100.0%
	Professional, Scientific ad Technical Services	Count	50_a	9_a	59
		% within Primary Sector	84.7%	15.3%	100.0%
	Education and Training	Count	30_a	5_a	35
		% within Primary Sector	85.7%	14.3%	100.0%
	Manufacturing	Count	60_a	14_a	74
		% within Primary Sector	81.1%	18.9%	100.0%
	Transport, Postal and Warehousing	Count	22_a	6_a	28
		% within Primary Sector	78.6%	21.4%	100.0%

	Construction	Count	30_a	14_b	44
		% within Primary Sector	68.2%	31.8%	100.0%
	Retail trade	Count	34_a	9_a	43
		% within Primary Sector	79.1%	20.9%	100.0%
	Agriculture, Forestry and Fishing	Count	18_a	3_a	21
		% within Primary Sector	85.7%	14.3%	100.0%
	Accommodation and Food Services	Count	36_a	9_a	45
		% within Primary Sector	80.0%	20.0%	100.0%
	Wholesale Trade	Count	30_a	3_a	33
		% within Primary Sector	90.9%	9.1%	100.0%
	Information Media and Telecommunications	Count	6_a	2_a	8
		% within Primary Sector	75.0%	25.0%	100.0%
	Electricity, Gas, Water and Waste Services	Count	15_a	3_a	18
		% within Primary Sector	83.3%	16.7%	100.0%
	Financial and Insurance Services	Count	16_a	6_a	22
		% within Primary Sector	72.7%	27.3%	100.0%
	Rental, Hiring and Real Estate Services	Count	20_a	12_b	32
		% within Primary Sector	62.5%	37.5%	100.0%
	Administrative and Support Services	Count	1_a	1_a	2
		% within Primary Sector	50.0%	50.0%	100.0%
	Public Administration and Safety	Count	3_a	2_a	5
		% within Primary Sector	60.0%	40.0%	100.0%
	Arts and Recreation Services	Count	18_a	2_a	20
		% within Primary Sector	90.0%	10.0%	100.0%
	Other	Count	3_a	0_a	3
		% within Primary Sector	100.0%	0.0%	100.0%
Total		Count	435	105	540
		% within Primary Sector	80.6%	19.4%	100.0%

Each subscript letter denotes a subset of Business changes: operational processes significantly change categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

Business changes: operational processes significantly change

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.997	14	.214	1.371	.162
Within Groups	81.473	522	.156		
Total	84.469	536			

- 8% of organisations used new delivery channels following the earthquake. This was statistically significantly more present in the professional, scientific and technical services sector compared to the Electricity, Gas, Water and Waste and Arts and Recreation services (Games Howell post-hoc test, p<0.05).

Primary Sector * Business changes: new delivery channels Crosstabulation

			Business changes: new delivery channels		
			No	Yes	Total
Primary Sector	Health Care and Social Assistance	Count	44_a	4_a	48
		% within Primary Sector	91.7%	8.3%	100.0%
	Professional, Scientific ad Technical Services	Count	51_a	8_a	59
		% within Primary Sector	86.4%	13.6%	100.0%
	Education and Training	Count	33_a	2_a	35
		% within Primary Sector	94.3%	5.7%	100.0%
	Manufacturing	Count	67_a	7_a	74
		% within Primary Sector	90.5%	9.5%	100.0%
	Transport, Postal and Warehousing	Count	21_a	7_b	28
		% within Primary Sector	75.0%	25.0%	100.0%
	Construction	Count	44_a	0_b	44
		% within Primary Sector	100.0%	0.0%	100.0%
	Retail trade	Count	41_a	2_a	43
		% within Primary Sector	95.3%	4.7%	100.0%
	Agriculture, Forestry and Fishing	Count	20_a	1_a	21
		% within Primary Sector	95.2%	4.8%	100.0%
	Accommodation and Food Services	Count	43_a	2_a	45
		% within Primary Sector	95.6%	4.4%	100.0%
	Wholesale Trade	Count	28_a	5_a	33
		% within Primary Sector	84.8%	15.2%	100.0%
	Information Media and Telecommunications	Count	7_a	1_a	8
		% within Primary Sector	87.5%	12.5%	100.0%
	Electricity, Gas, Water and Waste Services	Count	18_a	0_a	18
		% within Primary Sector	100.0%	0.0%	100.0%
	Financial and Insurance Services	Count	20_a	2_a	22
		% within Primary Sector	90.9%	9.1%	100.0%
	Rental, Hiring and Real Estate Services	Count	31_a	1_a	32
		% within Primary Sector	96.9%	3.1%	100.0%
	Administrative and Support Services	Count	1_a	1_b	2
		% within Primary Sector	50.0%	50.0%	100.0%
	Public Administration and Safety	Count	4_a	1_a	5
		% within Primary Sector	80.0%	20.0%	100.0%

	Arts and Recreation Services	Count	20_a	0_a	20
		% within Primary Sector	100.0%	0.0%	100.0%
	Other	Count	3_a	0_a	3
		% within Primary Sector	100.0%	0.0%	100.0%
Total		Count	496	44	540
		% within Primary Sector	91.9%	8.1%	100.0%

Each subscript letter denotes a subset of Business changes: new delivery channels categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

Business changes: new delivery channels

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.095	14	.150	2.039	.014
Within Groups	38.300	522	.073		
Total	40.395	536			

- 23% of organisations restructured. Rental, Hiring and Real Estate Services sector organisations were most likely to have restructured. Comparatively, organisations in Agriculture, Forestry and Fishing sectors were least likely to have restructured (Games-Howell post-hoc test, p<0.05).

Primary Sector * Business changes: restructuring Crosstabulation

			Business changes: restructuring		
			No	Yes	Total
Primary Sector	Health Care and Social Assistance	Count	35_a	13_a	48
		% within Primary Sector	72.9%	27.1%	100.0%
	Professional, Scientific ad Technical Services	Count	46_a	13_a	59
		% within Primary Sector	78.0%	22.0%	100.0%
	Education and Training	Count	26_a	9_a	35
		% within Primary Sector	74.3%	25.7%	100.0%
	Manufacturing	Count	57_a	17_a	74
		% within Primary Sector	77.0%	23.0%	100.0%
	Transport, Postal and Warehousing	Count	23_a	5_a	28
		% within Primary Sector	82.1%	17.9%	100.0%
	Construction	Count	32_a	12_a	44
		% within Primary Sector	72.7%	27.3%	100.0%
	Retail trade	Count	33_a	10_a	43
		% within Primary Sector	76.7%	23.3%	100.0%
	Agriculture, Forestry and Fishing	Count	20_a	1_b	21
		% within Primary Sector	95.2%	4.8%	100.0%

	Accommodation and Food Services	Count	41_a	4_b	45
		% within Primary Sector	91.1%	8.9%	100.0%
	Wholesale Trade	Count	26_a	7_a	33
		% within Primary Sector	78.8%	21.2%	100.0%
	Information Media and Telecommunications	Count	4_a	4_a	8
		% within Primary Sector	50.0%	50.0%	100.0%
	Electricity, Gas, Water and Waste Services	Count	13_a	5_a	18
		% within Primary Sector	72.2%	27.8%	100.0%
	Financial and Insurance Services	Count	20_a	2_a	22
		% within Primary Sector	90.9%	9.1%	100.0%
	Rental, Hiring and Real Estate Services	Count	19_a	13_b	32
		% within Primary Sector	59.4%	40.6%	100.0%
	Administrative and Support Services	Count	0_a	2_b	2
		% within Primary Sector	0.0%	100.0%	100.0%
	Public Administration and Safety	Count	1_a	4_b	5
		% within Primary Sector	20.0%	80.0%	100.0%
	Arts and Recreation Services	Count	17_a	3_a	20
		% within Primary Sector	85.0%	15.0%	100.0%
	Other	Count	3_a	0_a	3
		% within Primary Sector	100.0%	0.0%	100.0%
Total		Count	416	124	540
		% within Primary Sector	77.0%	23.0%	100.0%

Each subscript letter denotes a subset of Business changes: restructuring categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

Business changes: restructuring

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.258	14	.304	1.743	.044
Within Groups	91.109	522	.175		
Total	95.367	536			

- 11% of organisations closed unprofitable lines, with Manufacturing organisations most likely to use this change strategy. The least likely sectors were Health Care and Social Services, Electricity, Gas, Water and Waste Services, Financial and Insurance services and Arts and Recreation (Games-Howell post-hoc test, $p<0.05$).

Primary Sector * Business changes: unprofitable lines closed Crosstabulation

			Business changes: unprofitable lines closed		
			No	Yes	Total
Primary Sector	Health Care and Social Assistance	Count	46_a	2_a	48
		% within Primary Sector	95.8%	4.2%	100.0%
	Professional, Scientific ad Technical Services	Count	53_a	6_a	59
		% within Primary Sector	89.8%	10.2%	100.0%
	Education and Training	Count	33_a	2_a	35
		% within Primary Sector	94.3%	5.7%	100.0%
	Manufacturing	Count	55_a	19_b	74
		% within Primary Sector	74.3%	25.7%	100.0%
	Transport, Postal and Warehousing	Count	25_a	3_a	28
		% within Primary Sector	89.3%	10.7%	100.0%
	Construction	Count	35_a	9_a	44
		% within Primary Sector	79.5%	20.5%	100.0%
	Retail trade	Count	36_a	7_a	43
		% within Primary Sector	83.7%	16.3%	100.0%
	Agriculture, Forestry and Fishing	Count	20_a	1_a	21
		% within Primary Sector	95.2%	4.8%	100.0%
	Accommodation and Food Services	Count	41_a	4_a	45
		% within Primary Sector	91.1%	8.9%	100.0%
	Wholesale Trade	Count	30_a	3_a	33
		% within Primary Sector	90.9%	9.1%	100.0%
	Information Media and Telecommunications	Count	7_a	1_a	8
		% within Primary Sector	87.5%	12.5%	100.0%
	Electricity, Gas, Water and Waste Services	Count	18_a	0_a	18
		% within Primary Sector	100.0%	0.0%	100.0%
	Financial and Insurance Services	Count	22_a	0_a	22
		% within Primary Sector	100.0%	0.0%	100.0%
	Rental, Hiring and Real Estate Services	Count	28_a	4_a	32
		% within Primary Sector	87.5%	12.5%	100.0%

	Administrative and Support Services	Count	1_a	1_a	2
		% within Primary Sector	50.0%	50.0%	100.0%
	Public Administration and Safety	Count	5_a	0_a	5
		% within Primary Sector	100.0%	0.0%	100.0%
	Arts and Recreation Services	Count	20_a	0_a	20
		% within Primary Sector	100.0%	0.0%	100.0%
	Other	Count	3_a	0_a	3
		% within Primary Sector	100.0%	0.0%	100.0%
Total		Count	478	62	540
		% within Primary Sector	88.5%	11.5%	100.0%

Each subscript letter denotes a subset of Business changes: unprofitable lines closed categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

Business changes: unprofitable lines closed

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.263	14	.233	2.359	.004
Within Groups	51.579	522	.099		
Total	54.842	536			

- Just under 10% of organisations used another form of business change. There were no significant differences in likelihood of adoption between sectors.

Primary Sector * Business changes: other Crosstabulation

			Business changes: other		Total
			No	Yes	
Primary Sector	Health Care and Social Assistance	Count	46_a	2_a	48
		% within Primary Sector	95.8%	4.2%	100.0%
	Professional, Scientific ad Technical Services	Count	54_a	5_a	59
		% within Primary Sector	91.5%	8.5%	100.0%
	Education and Training	Count	29_a	6_a	35
		% within Primary Sector	82.9%	17.1%	100.0%
	Manufacturing	Count	70_a	4_a	74
		% within Primary Sector	94.6%	5.4%	100.0%
	Transport, Postal and Warehousing	Count	25_a	3_a	28
		% within Primary Sector	89.3%	10.7%	100.0%
	Construction	Count	39_a	5_a	44

		% within Primary Sector	88.6%	11.4%	100.0%
	Retail trade	Count	42_a	1_a	43
		% within Primary Sector	97.7%	2.3%	100.0%
	Agriculture, Forestry and Fishing	Count	19_a	2_a	21
		% within Primary Sector	90.5%	9.5%	100.0%
	Accommodation and Food Services	Count	40_a	5_a	45
		% within Primary Sector	88.9%	11.1%	100.0%
	Wholesale Trade	Count	29_a	4_a	33
		% within Primary Sector	87.9%	12.1%	100.0%
	Information Media and Telecommunications	Count	7_a	1_a	8
		% within Primary Sector	87.5%	12.5%	100.0%
	Electricity, Gas, Water and Waste Services	Count	16_a	2_a	18
		% within Primary Sector	88.9%	11.1%	100.0%
	Financial and Insurance Services	Count	16_a	6_b	22
		% within Primary Sector	72.7%	27.3%	100.0%
	Rental, Hiring and Real Estate Services	Count	29_a	3_a	32
		% within Primary Sector	90.6%	9.4%	100.0%
	Administrative and Support Services	Count	2_a	0_a	2
		% within Primary Sector	100.0%	0.0%	100.0%
	Public Administration and Safety	Count	5_a	0_a	5
		% within Primary Sector	100.0%	0.0%	100.0%
	Arts and Recreation Services	Count	17_a	3_a	20
		% within Primary Sector	85.0%	15.0%	100.0%
	Other	Count	2_a	1_a	3
		% within Primary Sector	66.7%	33.3%	100.0%
Total		Count	487	53	540
		% within Primary Sector	90.2%	9.8%	100.0%

Each subscript letter denotes a subset of Business changes: other categories whose column proportions do not differ significantly from each other at the .05 level.

ANOVA

Business changes: other

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.530	14	.109	1.256	.231
Within Groups	45.435	522	.087		
Total	46.965	536			

Limitations:

There is likely to be a tipping point – where a certain level of disruption is needed, before organisations adapt beyond 'business as usual' type thinking. Talking through each of the MERIT scenarios is probably the best way to think through what those thresholds might be.

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015) Business Behaviours following the Canterbury Earthquakes: Productivity Effect of Disruption. ERI Results Bulletin 2015-K07-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Assessing Ability to Meet Demand in the Context of Other Resiliency Studies

ERI Results Bulletin 2015-K08-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

How does our Ability to Meet Demand survey data compare with the literature in terms of resiliency factors ?

What are the factors used define or measure business resilience in other studies?

What are the assumptions that other studies make about business performance following disruptions and what do other studies indicate about an organisation's operability post-disaster?

There are several assumptions and observations about the degree to which organisations are able to maintain functionality following disruptions, and the factors that influence the speed and efficacy of their efforts to do so. Here we identify some of these.

How do the organisations in our study confirm or refute these assumptions and findings?

Findings for MERIT:

These findings can be used to 'reality-check' common assumptions that inform business behaviours in economic model development.

1 MERIT should not assume ceased operations across the board in the event of significant lifeline outages. About 30% of organisations did not close following the February 22, 2011 earthquakes, despite experiencing sewage, water, or electricity outages.

2 MERIT should not assume decreased business operability across the board even for organisations that experience severe disruptions. About 33% of organisations that reported an impact above 75% (Maximum Impact Experienced) were completely able to meet demand immediately following the earthquakes.

- Not all organisations experienced reduced productivity or reduced ability to meet demand even if they experienced lifeline outages following the February 2011 earthquakes. Ability to meet demand in our sample does not fit the classic S-shaped production level curve (showing reduced production levels, followed by increased levels to recapture lost productivity, and an eventual normalisation).

Analysis:

Assumptions & Findings from Other Studies

What are the factors used define or measure business resilience in other studies?

Table 1 sumarises some of the ways resilience is understood and measured in other studies of business and economic recovery. This review allowed us to conclude that resilience is commonly conceptualised as the ability to and speed at which organisations are able to regain their desired level of production, function, or operability following a disruption of some kind.

Ability to meet demand as used in the Business Behaviours component of the ERI study is generally equivalent to organisational assessments of their operability at a given time or over a given period. Another related way that studies assess similar measures is the extent to which the organisation is able to fulfil the expectations of service delivery for their product.

Table 1: Interpretations of resilience in economic modeling

Concept	***Definition/ Measurement Factor***	***Citation***
Static economic resilience	"The ability of a system to maintain function when shocked."	Rose and Krausmann (2013)
Dynamic economic resilience	"Hastening the speed of recovery from a shock," (p.74)	Rose and Krausmann (2013)
Business resilience	"ability…to reschedule, or recapture, lost production after the event," (p.163).	Park, Cho, and Rose (2011)
Seismic resilience (of communities including organisations)	"Reduced failure probabilities…Reduced consequences from failures…Reduced time to recovery," (p.733) "Loss of resilience, R, with respect to [a] specific earthquake, can be measured by the size of the expected degradation in quality (probability of failure), over time (that is, time to recovery)." $R = \int_{t_0}^{t_1} [100 - Q(t)]dt$	Bruneau et al. (2003)
	"Another type of in-built counteractions is the so-called economic resilience, 'which refers to the inherent ability and adaptive response that enables firms and regions to avoid maximum potential losses' (Rose and Liao, 2005, p. 76)."	Okuyama (2007)
Inherent Resilience	the ability to substitute inputs and/or reallocate resources under normal circumstances	Rose and Liao (2005)
Adaptive Resilience	the ability in crisis situations with extra effort, is set as the changes in the parameters	Rose and Liao (2005)
Inoperability	"The extent to which a system deviates from its intended or planned performance level…Inoperability takes on values between 0 and 1, where 0 corresponds to the 'as planned' performance level and 1 corresponds to a completely inoperable system." (p.186-187)	Anderson et al. (2007)

Concept	*Definition/ Measurement Factor*	*Citation*
Business Resilience	“The ability to reduce losses under external unpredictable disturbances such as natural disasters,” (p.757)	Kajitani and Tatano (2009)
Resilience Factor	“Quantitiative measurement of lifeline impacts, which focuses on the production output of some industrial sectors during lifeline disruptions,” (p. 755). Kajitani and Tatano (2009) consider three resilience “options” to reduce business interruption losses: production level under lifeline disruptions, speed of recovery, and recovery of loss after restarting work.	Kajitani and Tatano (2009)
Resilience	“The ability of an entity to recover from an external disruptive event."	Henry and Ramirez-Marquez (2012)

In the next part of this analysis, several findings or assumptions about business performance post-disruption are evaluated and ‘reality-checked’ against the Canterbury dataset.

(A) **Recapture can start immediately after a disruptive event:** *“From the end point of the disaster stimulus (e.g., after the groundshaking from an earthquake or bomb blast from a terrorist attack), the recapturing process may start,” (Park, Cho, and Rose 2010).*

- Yes, this is true for some organisations. We found that 30%, 29%, and 27% of organisations stayed open and operational following the February 22, 2011 earthquakes despite experiencing electricity, water, and/or sewage outages respectively.
- Of all of the organisations that did not close following the Feb 2011 earthquake about 20% employed one or more productivity resilience tactic (i.e. more intensive use of staffing resources; more intensive use of existing resources; or replaced or upgraded technology) to recapture productivity. Again confirming that organisations are capable of starting the recapture process almost immediately.
- About 44% of sampled organisations were completely able to meet demand “immediately” following the earthquakes. Even organisations that reported an impact above 75% (Maximum Impact Experienced) were completely able to meet demand immediately after the earthquakes 33% of the time and 66% were completely able to meet demand several months after the earthquakes.

(B) **Organisations increase production levels to recapture lost productivity and then return to normal on an “S-Shaped Path” as in figure 1 below from Park, Cho, and Rose (2010).** *“We expect that the additional recaptured output increases following a normal distribution. This translates into a cumulative S-shape path; i.e., the marginality in the output increase is positive to a point and negative after that point.” (Park, Cho and Rose 2010)*

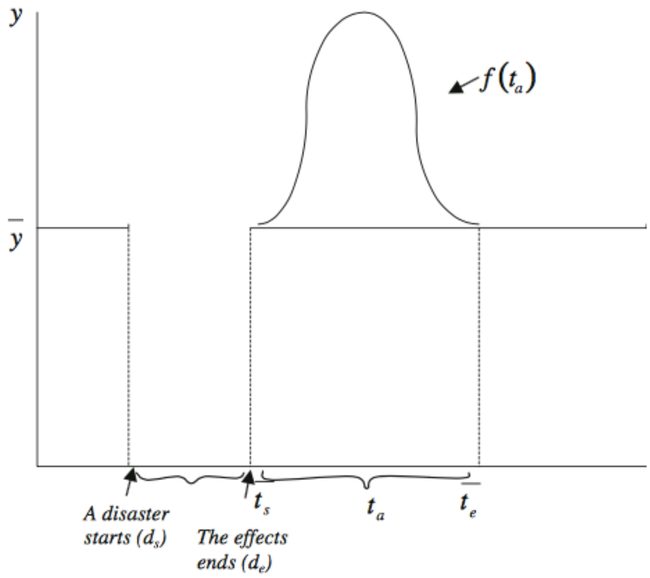


Fig. 1 Time framework of ex-ante extreme event for an industry

The Canterbury dataset showed that many organisations do not follow the "S-Shaped Path":

- Not all organisations experienced reduced productivity or ability to meet demand even if they experienced lifeline outages following the February 2011 earthquakes.
  - About 17% of organisations reported no productivity losses despite loss of water supply for days, weeks, or months.
  - About 16% of organisations reported no productivity losses despite loss of sewage supply for days, weeks, or months.
  - About 10% of organisations reported no productivity losses despite loss of electricity supply for days, weeks, or months.
  - About 36% of organisations were completely able to meet demand for their products or services despite water, sewage, or electricity outages for any length of time.
- There are some indications that some organisations readjusted to an improved level of functioning post-disaster as indicated by their answers on the survey issued over two years after the earthquakes. **See Bulletin: 2015-K07-1: Productivity Improvements from Disruption.

(C) **Ability to operate with lifeline disruptions is important for reducing losses:** *Kajitani and Tatano's (2009) study focusses on on two "resilience characteristics": production level under lifeline disruptions (reflecting only lifeline importance) and tolerable production (lifeline) stoppage periods. The study indicates that these two factors are important for reducing business interruption losses.*

- It is not clear that operating despite lifeline disruptions increases an organisations' ability to meet demand.
  - The Canterbury dataset showed that organisations that continued operating (i.e. did not close) following the February 2011 earthquakes, despite experiencing disruptions to electricity, water, and/or sewage did not have a significantly different ability to meet demand compared to organisations that closed or did not experience these disruptions.

(D) The more important electricity is to an organisations' ability to operate, the less resilient they are. (Rose and Lim 2002)

- We found essentially no relationship between electricity dependence and an organisations' ability to meet demand. An organisations' dependence on electricity was significantly, but very weakly negatively correlated with their ability to meet demand immediately after the February earthquake (*r= -0.097, p=0.05*) and not significantly correlated with their ability to meet demand any time after.

Limitations:

In our analyses we use ability to meet demand over time following the earthquakes, which is not perfectly comparable to metrics used in other studies such as level of production or organisational functionality. We also do not have data about when organisations employed resilience tactics and cannot measure the speed at which organisations recaptured productivity using various resilience tactics.

Reference List

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Rose, A. and Liao, S.Y. (2005). Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions. Journal of Regional Science. 45 (1): 75-112.

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015) Assessing Ability to Meet Demand in the Context of Other Resiliency Studies. ERI Results Bulletin 2015-K08-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Workforce inertia

ERI Results Bulletin 2015-K09-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

Do organisations try to retain their workforce in the face of disruption?

A number of our other studies on the Canterbury Earthquakes identified how organisations went out of their way to hold on to staff, even when normal business logic may have indicated it was better to lay staff off. Does our survey data support this theory, and if so, how might MERIT be adapted to reflect this behaviour by organisations?

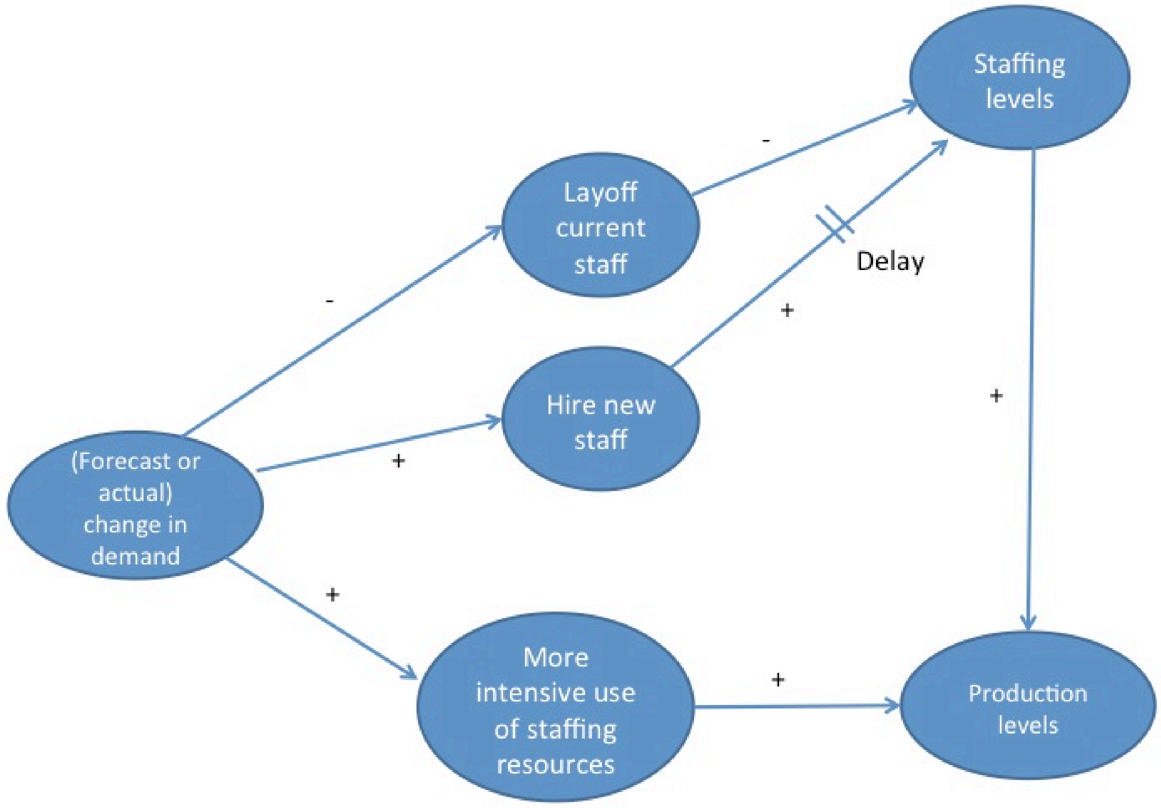
Findings for MERIT:

1. Organisations take a longer term view of staffing requirements rather than simply laying off and rehiring as demand fluctuates. We will use the case studies to estimate of how forward looking organisations are (1 month, 6 months, 1 year…) in establishing their workforce needs.

2. A disrupted economy is resource constrained. Organisations that need to grow are unlikely to be able to meet all their staff requirements in a post-disaster environment; they also need to use their existing workforce more intensively. In MERIT this could be reflected as:

    - a delay between deciding to take on staff, and their becoming available (we would need the case studies to see what length of delay is reasonable), and

    - an increase in productivity of existing workforce, reflecting that organisations will make more intensive use of their existing staff.



Analysis:

We undertook this analysis by running cross-tabs between change in staff and change in demand (over various timesteps) to see if any clear patterns emerged.

- **We found clear and statistically significant differences patterns showing that if an organisation experienced decreased demand, it was more likely to reduce staff. This pattern holds for change in demand across all timeframes.**

Unfortunately though we don't have fine grained enough data to work out if organisations didn't shed as many staff as they perhaps should have, nor do we have data on turnover (i.e. indicating if they worked hard to ensure that they didn't lose and then have to rehire).

Answers to open questions (see discussion at end of this section) do indicate that organisations found losing staff and making staff redundant very challenging. There is also a cost associated with bringing on new staff (recruiting, training etc.) so it could be expected that organisations would want to balance the needs to reduce payroll expenditure with the negative impacts of staff turnover. If organisations sense that a reduction in customer demand is likely to be only short-term, they may seek to hold on to staff, to be ready for when customer demand improves.

Staff changes * Change in demand: several months after the event Crosstabulation

% within Change in demand: several months after the event

		Change in demand: several months after the event			Total
		decreased demand	about same	increased demand	
Staff changes	Reduced significantly (less than -20%)	12.9%$_a$	5.6%$_b$	1.8%$_b$	6.7%
	Reduced (between -20% and -5%)	19.4%$_a$	9.4%$_b$	9.4%$_b$	12.7%
	Stayed about the same (between -5% and +5%)	50.0%$_a$	65.0%$_b$	42.1%$_a$	52.6%
	Grown (between +5% and +20%)	12.9%$_a$	15.0%$_a$	28.1%$_b$	18.6%
	Grown significantly (greater than 20%)	4.7%$_a$	5.0%$_a$	18.7%$_b$	9.4%
Total		100.0%	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Change in demand: several months after the event categories whose column proportions do not differ significantly from each other at the .05 level.

We found that staff changes are positively correlated with change in demand at all timesteps, but change in demand one and two years on from the earthquakes is more strongly correlated with staff changes than short term change in demand. This makes sense, as the question about staff changes was asking organisations to reflect on the number of staff they had at the time of the survey (2 ½ years after the earthquakes) compared with before the earthquakes.

Correlations

			Staff changes	Change in demand: Immediately after event	Change in demand: several months after the event	Change in demand: a year on from the event	Change in demand: two years on from the event
Kendall's tau_b	Staff changes	Correlation Coefficient	1.000	.200**	.275**	.335**	.334**
		Sig. (2-tailed)	.	.000	.000	.000	.000
		N	533	524	521	519	521

- **More interesting was that organisations that grew their staff numbers significantly found 'more intensive use of staffing resources' to be moderately or very important for recapturing lost production/delivery/output. This implies that organisations that found they had a greater workforce requirement, met this requirement through <u>both</u> recruitment and more intensive use of staff, perhaps reflecting a resource constrained economy.**

Staff changes * Product recapture: More intensive use of staffing resources Crosstabulation

			Product recapture: More intensive use of staffing resources				Total
			Not important	Slightly important	Moderately important	Very important	
Staff changes	Reduced significantly (less than -20$)	Count	10_{a}	9_{a}	5_{a}	7_{a}	31
		% within Staff changes	32.3%	29.0%	16.1%	22.6%	100.0%
	Reduced (between -20% and -5%)	Count	13_{a}	9_{a}	19_{a}	13_{a}	54
		% within Staff changes	24.1%	16.7%	35.2%	24.1%	100.0%
	Stayed about the same (between -5% and +5%)	Count	65_{a}	$44_{a, b}$	$44_{b, c}$	25_{c}	178
		% within Staff changes	36.5%	24.7%	24.7%	14.0%	100.0%
	Grown (between +5% and +20%)	Count	16_{a}	$13_{a, b}$	15_{a}	21_{b}	65
		% within Staff changes	24.6%	20.0%	23.1%	32.3%	100.0%
	Grown significantly (greater than 20%)	Count	4_{a}	4_{a}	16_{b}	$6_{a, b}$	30
		% within Staff changes	13.3%	13.3%	53.3%	20.0%	100.0%
Total		Count	108	79	99	72	358
		% within Staff changes	30.2%	22.1%	27.7%	20.1%	100.0%

Each subscript letter denotes a subset of Product recapture: More intensive use of staffing resources categories whose column proportions do not differ significantly from each other at the .05 level.

- **The concept of a resource constrained post-disaster environment is supported by answers to our open question on what were the greatest staffing challenges following the earthquakes, in which the most identified challenge was finding qualified or suitable staff.**

Top three staff challenges were found to be:

1. Finding qualified or suitable staff (99 refs)
2. Managing and supporting staff going through issues (53 refs)
3. Staff being stressed, emotionally drained and burnt out (48 refs)

One sixth of respondents said that finding qualified people with the right skills or who were suitable for their organisation was their main challenge (*99 refs*). This was due to the skills shortage in Chch post-EQ, and respondents even said that even if there were qualified people about, it was finding them that was difficult. Retaining staff was another challenge (*11 refs*); as was replacing good employees (*8 refs*) and the fact that competition for staff made them hard to find (*4 refs*) < these both relate to the challenge of finding suitable staff to employ. Increasing staff numbers (*4 refs*), needing staff (*3 refs*), needing more staff immediately to meet demand (*3 refs*), but having limited ways of attracting new staff to Christchurch (*3 refs*) also posed difficulties as well as the fact that staff were at risk of being poached by other companies (*3 refs*).

A major challenge to companies was their staff leaving due to personal issues (*33 refs*) (e.g. needing to escape Christchurch, or because they had family and housing matters to deal with). Similarly staff turnover (*6 refs*) and staff becoming increasingly unavailable (*2 refs*) for personal reasons as stated above were also difficulties.

In addition, a number of organisations identified having to make staff redundant/reducing staff numbers as a challenge (14 refs) most likely because of the toll it took on business owners having to let staff go of their people and the residual impact on remaining staff and the organisation; the then rehiring of staff made redundant was a lesser but still unpleasant challenge (3 refs). Finding enough work for staff was the second biggest challenge (11 refs), as was managing changing work supply and staff requirements (10 refs) where the business struggled to give staff enough to do when there was little work supply or struggled to maintain reasonable work hours where work supply was too much. Having to reduce staff's hours because of the lack of work experienced was also a challenge < most likely because people needed some stability and an income as they dealt with the EQ aftermath.

Limitations:

Our quantitative data is not particularly fine-grained with regards to staff numbers, and we are therefore drawing on our findings from other research, in addition to the survey data, for some of these findings. The survey data provides a snapshot of the number of employees for an organisation at the time of the survey, and also asks if staff numbers have grown or decreased since before the earthquakes. It does not reflect turnover of staff (staff leaving and staff being hired).

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015) Business Behaviours following the Canterbury Earthquakes: Workforce inertia. ERI Results Bulletin 2015-K09-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Effect of the Earthquake Support Subsidy

ERI Results Bulletin 2015-K10-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

Did the earthquake support subsidy have any great effect on the recovery of organisation?

There evidence in the international literature, particularly from US experience, indicating the 'aid' to businesses to support business recovery following disasters is not particularly effective at supporting recovery, and can sometimes hinder recovery. In their studies of small business recovery after the Northridge Earthquake, Dahlhamer and Tierney conclude that business assistance played a minimal role in assisting with recovery.

The Earthquake Support Subsidy (ESS) was used by over 8,000 businesses, accounting for almost 47,000 employees, and involved the distribution of $185 million of public funds, and is widely cited as being a highly successful policy. But what does our data tell us about the effectiveness of the earthquake support subsidy in supporting business recovery?

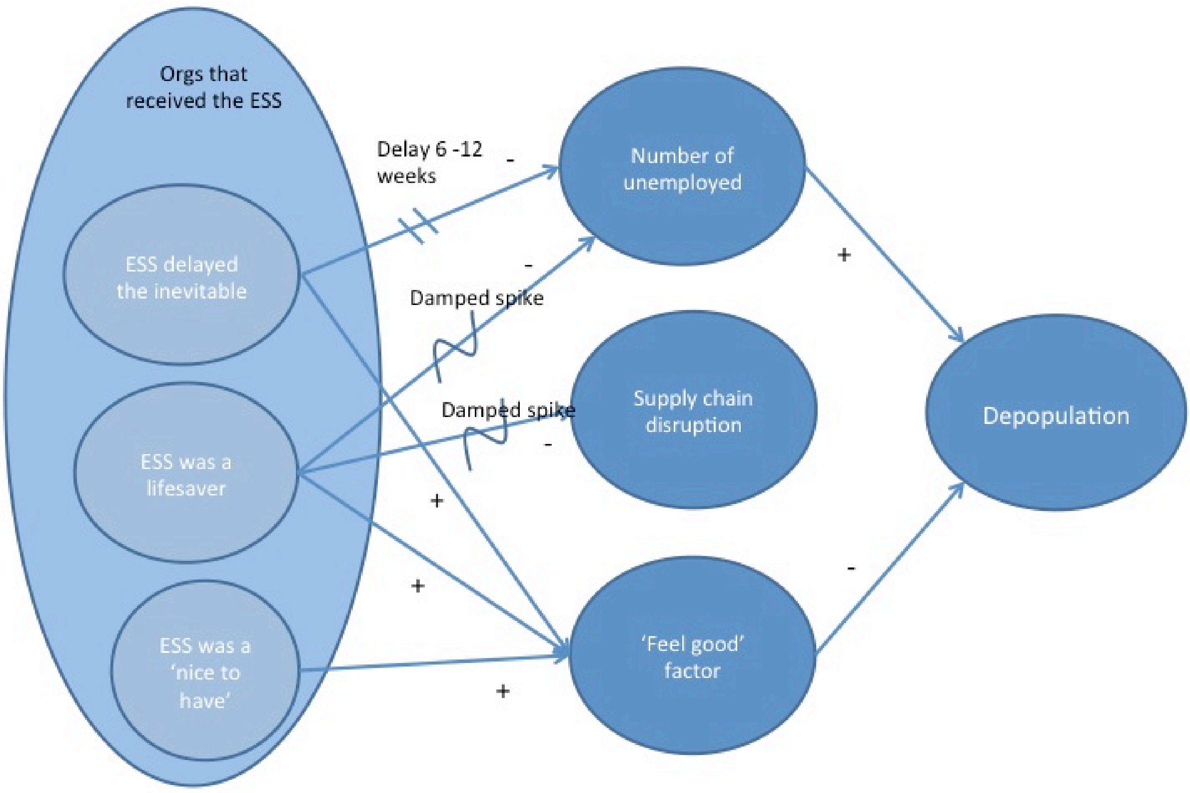
Findings for MERIT:

- The effect of the ESS was to give eligible organisations a delay in needing to make decisions on whether to layoff their employees. Recipient organisations of the ESS fall into three main camps:

o **The ESS delayed the inevitable.** The business was fundamentally unviable; organisations received the ESS but went on to fail anyway. The effect was a delaying of staff moving onto the unemployment benefit (or into other employment) and potentially damped 'flight' of population from Christchurch, if thousands were laid off during the immediate aftermath of the earthquake while people were still in shock.

  o **The ESS was a 'life saver'**. The earthquake support subsidy (ESS) was effective at preventing some SMEs from needing to layoff staff in the short term (to prevent cashflow problems). If they had have laid off staff, their chances of recovery would have been much reduced. The subsidy was well received by business owners as it gave them 'breathing space' to make critical business decisions. From an economy perspective, saving these businesses will have had several effects: it reduced the amount of supply chain disruption within the economy, that business failures may have contributed to; it prevented a temporary 'spike' in the number of unemployed in Christchurch and in doing so it potentially damped 'flight' of population from Christchurch.

- **The ESS was a nice to have**. For a number of organisations, that were otherwise viable, the ESS was possibly a nice to have (i.e. it was welcome support), but had it not been available, the organisation would have found other ways to overcome the short-term issues they were facing, such as approaching their bank for a loan etc. Our data indicates that the ESS was not effective at improving the recovery of recipient organisations. It is likely however that it contributed to a 'sense of support' by central government for the SME communities, which may have created a more positive outlook by these business owners.



- What we don't know, is what proportion of recipients of the ESS fall into each of the three categories above. We could use IRD data to look at the proportion of recipients that went on to fail anyway. Distinguishing between organisations for which the ESS was a life-saver vs a nice to have however is more difficult, and hard to establish quantitatively because there is no true counterfactual (without the ESS, potentially the banks would have stepped up with even more extensive support packages etc). We could however undertake further surveys or case studies of orgs that used the ESS to estimate this proportion – depending on how important it is seen for MERIT.

Analysis:

The Earthquake Support Subsidy is widely viewed as a very effective intervention for supporting businesses in Christchurch. Fischer-Smith (2013) identifies it as a 'deviant' policy in the sense of how well it was received by SMEs. This is how Recover Canterbury described the benefits of the policy:

> *Recover Canterbury had contact with around 8400 Canterbury businesses, many of whom received the Earthquake Support Subsidy. The overwhelming response we had from businesses that received this subsidy is that it was one of the most critical pieces of support they received following the February earthquake, with some businesses going so far as to say it was the subsidy that saved their business from certain closure. The key aspects of the subsidy that made it so highly effective was the fact it was implemented so quickly following the earthquake, and the simplicity and flexibility around the application process. The fact that the subsidy went to the business for them to pass on to staff also empowered employers and helped keep employment relations intact. The psychological impact of the subsidy can also not be underestimated. At a time of immense need and trauma, the subsidy demonstrated to the business community that the Government was right behind them, providing immediate support and encouragement to overcome the disaster we had all faced (Recover Canterbury, cited in Fischer-Smith (2013)).*

While it was an important policy measure, it is important to note that not all organisations were eligible for the ESS, nor took it up.

- **17% of our sampled organisations used the earthquake support subsidy to help finance their recovery; 21% of small and medium sized enterprises (SMEs) in our sample used it.**

Was the ESS well targeted in the organisations it supported?

- **On average those organisations that received the earthquake support subsidy were more highly impacted (0.76, where 0 is not disrupted and 1 is very disrupted) and than those that did not receive the subsidy (0.62).**

Report

Impact - average of top two - impMxExt, impMxNet, impMxTra

Financing recovery: Earthquake wage subsidy	Mean	N	Std. Deviation
No	.6153	447	.28059
Yes	.7593	94	.23844
Total	.6403	541	.27892

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Impact - average of top two - impMxExt, impMxNet, impMxTra * Financing recovery: Earthquake wage subsidy	Between Groups	(Combined)	1.610	1	1.610	21.478	.000
	Within Groups		40.401	539	.075		
	Total		42.011	540			

- **Organisations that used the earthquake wage subsidy were significantly more likely to be unable to meet demand immediately following the earthquakes (23.7% compared to 10.5%) and were also significantly less likely to be able to completely meet their demand (33.3% compared to 46.4%). They were less likely to be able to completely meet demand several months after the earthquakes (60.2% compared to 73.8%) – meaning the subsidy was well targeted at the organisations that were most impacted by the earthquakes.**

Ability to meet demand: immediately after the event * Financing recovery: Earthquake wage subsidy Crosstabulation

			Financing recovery: Earthquake wage subsidy		Total
			No	Yes	
Ability to meet demand: immediately after the event	Unable (0-20%)	Count	46_a	22_b	68
		% within Financing recovery: Earthquake wage subsidy	10.5%	23.7%	12.8%
	Limited (20-40%)	Count	38_a	11_a	49
		% within Financing recovery: Earthquake wage subsidy	8.6%	11.8%	9.2%
	Partially (40-60%)	Count	42_a	9_a	51
		% within Financing recovery: Earthquake wage subsidy	9.5%	9.7%	9.6%
	Mostly (60-80%)	Count	110_a	20_a	130
		% within Financing recovery: Earthquake wage subsidy	25.0%	21.5%	24.4%
	Completely (80-100%)	Count	204_a	31_b	235
		% within Financing recovery: Earthquake wage subsidy	46.4%	33.3%	44.1%
Total		Count	440	93	533
		% within Financing recovery: Earthquake wage subsidy	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Financing recovery: Earthquake wage subsidy categories whose column proportions do not differ significantly from each other at the .05 level.

Ability to meet demand: several months after the event * Financing recovery: Earthquake wage subsidy Crosstabulation

			Financing recovery: Earthquake wage subsidy		Total
			No	Yes	
Ability to meet demand: several months after the event	Unable (0-20%)	Count	7_a	3_a	10
		% within Financing recovery: Earthquake wage subsidy	1.6%	3.2%	1.9%
	Limited (20-40%)	Count	12_a	4_a	16
		% within Financing recovery: Earthquake wage subsidy	2.8%	4.3%	3.0%
	Partially (40-60%)	Count	21_a	5_a	26
		% within Financing recovery: Earthquake wage subsidy	4.8%	5.4%	4.9%
	Mostly (60-80%)	Count	74_a	25_b	99
		% within Financing recovery: Earthquake wage subsidy	17.0%	26.9%	18.8%
	Completely (80-100%)	Count	321_a	56_b	377
		% within Financing recovery: Earthquake wage subsidy	73.8%	60.2%	71.4%
Total		Count	435	93	528
		% within Financing recovery: Earthquake wage subsidy	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Financing recovery: Earthquake wage subsidy categories whose column proportions do not differ significantly from each other at the .05 level.

Did the ESS help the recovery of organisations that used it?

- **Organisations that used the earthquake wage subsidy are significantly more likely to be significantly worse off following the earthquakes (28.7% compared to 11.9%), are more likely to still be in survival mode (13.8% compared to 6.3%) or are still recovering from the earthquakes (40.4% compared to 28.1%), are less likely to have found the earthquakes positive (16% compared to 29.5%), and are more likely to now have poor cashflow (13.6% compared to 7.3%).**

Current situation * Financing recovery: Earthquake wage subsidy Crosstabulation

			Financing recovery: Earthquake wage subsidy		
			No	Yes	Total
Current situation	Significantly worse off	Count	53_a	27_b	80
		% within Financing recovery: Earthquake wage subsidy	11.9%	28.7%	14.9%
	Slightly worse off	Count	87_a	19_a	106
		% within Financing recovery: Earthquake wage subsidy	19.6%	20.2%	19.7%
	The same	Count	124_a	15_b	139
		% within Financing recovery: Earthquake wage subsidy	27.9%	16.0%	25.8%
	Slightly better off	Count	114_a	23_a	137
		% within Financing recovery: Earthquake wage subsidy	25.7%	24.5%	25.5%
	Significantly better off	Count	66_a	10_a	76
		% within Financing recovery: Earthquake wage subsidy	14.9%	10.6%	14.1%
Total		Count	444	94	538
		% within Financing recovery: Earthquake wage subsidy	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Financing recovery: Earthquake wage subsidy categories whose column proportions do not differ significantly from each other at the .05 level.

State of recovery * Financing recovery: Earthquake wage subsidy Crosstabulation

			Financing recovery: Earthquake wage subsidy		Total
			No	Yes	
State of recovery	We are no longer trading	Count	3_a	2_a	5
		% within Financing recovery: Earthquake wage subsidy	0.7%	2.1%	0.9%
	We are still in survival mode following the earthquake	Count	28_a	13_b	41
		% within Financing recovery: Earthquake wage subsidy	6.3%	13.8%	7.7%
	We are still recovering from the earthquakes	Count	124_a	38_b	162
		% within Financing recovery: Earthquake wage subsidy	28.1%	40.4%	30.3%
	We have fully recovered from the earthquakes	Count	92_a	25_a	117
		% within Financing recovery: Earthquake wage subsidy	20.9%	26.6%	21.9%
	The earthquakes were positive for our organisation	Count	130_a	15_b	145
		% within Financing recovery: Earthquake wage subsidy	29.5%	16.0%	27.1%
	The earthquakes never impacted our organisation	Count	64_a	1_b	65
		% within Financing recovery: Earthquake wage subsidy	14.5%	1.1%	12.1%
Total		Count	441	94	535
		% within Financing recovery: Earthquake wage subsidy	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Financing recovery: Earthquake wage subsidy categories whose column proportions do not differ significantly from each other at the .05 level.

Current cashflow * Financing recovery: Earthquake wage subsidy Crosstabulation

			Financing recovery: Earthquake wage subsidy		
			No	Yes	Total
Current cashflow	Very poor	Count	10_a	3_a	13
		% within Financing recovery: Earthquake wage subsidy	2.3%	3.4%	2.5%
	Poor	Count	31_a	12_b	43
		% within Financing recovery: Earthquake wage subsidy	7.3%	13.6%	8.4%
	Satisfactory	Count	124_a	36_b	160
		% within Financing recovery: Earthquake wage subsidy	29.1%	40.9%	31.1%
	Good	Count	134_a	21_a	155
		% within Financing recovery: Earthquake wage subsidy	31.5%	23.9%	30.2%
	Excellent	Count	127_a	16_b	143
		% within Financing recovery: Earthquake wage subsidy	29.8%	18.2%	27.8%
Total		Count	426	88	514
		% within Financing recovery: Earthquake wage subsidy	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Financing recovery: Earthquake wage subsidy categories whose column proportions do not differ significantly from each other at the .05 level.

The above could be due to the nature of the organisations that accessed the earthquake support subsidy so we therefore selected only cases of organisations that are SMEs.

- **Just looking at SMEs, SMEs that used the earthquake wage subsidy were more likely to be significantly worse off following the earthquakes (24.7% compared to 10.9%), to still be recovering (42% compared to 26.3%), and to not have found the earthquakes positive (16% compared to 31.3%) compared with SMEs that did not access the Earthquake Support Subsidy.**

Current situation * Financing recovery: Earthquake wage subsidy Crosstabulation

			Financing recovery: Earthquake wage subsidy		Total
			No	Yes	
Current situation	Significantly worse off	Count	33_{a}	20_{b}	53
		% within Financing recovery: Earthquake wage subsidy	10.9%	24.7%	13.8%
	Slightly worse off	Count	57_{a}	19_{a}	76
		% within Financing recovery: Earthquake wage subsidy	18.9%	23.5%	19.8%
	The same	Count	83_{a}	12_{b}	95
		% within Financing recovery: Earthquake wage subsidy	27.5%	14.8%	24.8%
	Slightly better off	Count	79_{a}	22_{a}	101
		% within Financing recovery: Earthquake wage subsidy	26.2%	27.2%	26.4%
	Significantly better off	Count	50_{a}	8_{a}	58
		% within Financing recovery: Earthquake wage subsidy	16.6%	9.9%	15.1%
Total		Count	302	81	383
		% within Financing recovery: Earthquake wage subsidy	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Financing recovery: Earthquake wage subsidy categories whose column proportions do not differ significantly from each other at the .05 level.

State of recovery * Financing recovery: Earthquake wage subsidy Crosstabulation

			Financing recovery: Earthquake wage subsidy		Total
			No	Yes	
State of recovery	We are no longer trading	Count	2_a	2_a	4
		% within Financing recovery: Earthquake wage subsidy	0.7%	2.5%	1.0%
	We are still in survival mode following the earthquake	Count	19_a	9_a	28
		% within Financing recovery: Earthquake wage subsidy	6.3%	11.1%	7.3%
	We are still recovering from the earthquakes	Count	79_a	34_b	113
		% within Financing recovery: Earthquake wage subsidy	26.3%	42.0%	29.7%
	We have fully recovered from the earthquakes	Count	60_a	22_a	82
		% within Financing recovery: Earthquake wage subsidy	20.0%	27.2%	21.5%
	The earthquakes were positive for our organisation	Count	94_a	13_b	107
		% within Financing recovery: Earthquake wage subsidy	31.3%	16.0%	28.1%
	The earthquakes never impacted our organisation	Count	46_a	1_b	47
		% within Financing recovery: Earthquake wage subsidy	15.3%	1.2%	12.3%
Total		Count	300	81	381
		% within Financing recovery: Earthquake wage subsidy	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Financing recovery: Earthquake wage subsidy categories whose column proportions do not differ significantly from each other at the .05 level.

Limitations:

Note though that our organisation under-represents failed businesses. Nor do we have accurate data on the financial status of our sampled organisations before the earthquakes. Supplementary analysis, using IRD data (if we can access it) would be beneficial.

References:

Fischer-Smith, R. (2013) The Earthquake Support Subsidy for Christchurch's small and medium enterprises: Perspectives from business owners. *Small Enterprise Research, Vol 20, Issue 1, 40- 54.*

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015). Business Behaviours following the Canterbury Earthquakes: Effect of the Earthquake Support Subsidy. ERI Results Bulletin 2015-K10-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Relocation

ERI Results Bulletin 2015-K11-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

1. **Did relocation actually mitigate the effects of the disruption for organisations in our study?**
2. **What kinds of 'relocation penalties' did organisations face?**

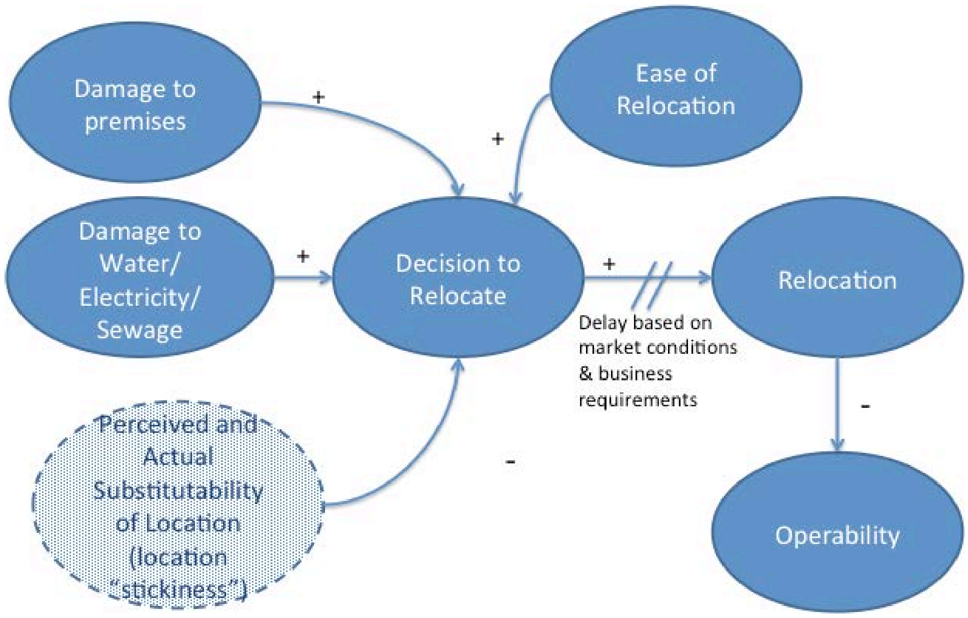
Findings for MERIT:

1 There needs to be a lag time component for organisations to receive signals that they need to relocate, to make the decision to relocate, and then to actually relocate. There was an average lag time of approximately 3 months between the February 2011 earthquake event and organisations' actual relocation.

2 Organisations tended to resist relocating even when their current location was compromised. There are (perceived) significant financial, social, and market costs to relocation that may outweigh the benefits. There is significant spatial inertia and relocation lag time that we need to consider when thinking about how to model relocation decisions.

3 There are potentially "relocation penalties." Organisations that did not relocate following the earthquake were significantly more likely to be able to meet demand immediately and several months after the earthquakes. But after one year there was no signifincat difference between their ability to meet demand.

   a. However, when only examining organisations that experienced lifeline disruptions (electricity, water, and sewage), there is not a significant difference between the organisations' that relocated and the organisations' that did not relocate's ability to meet demand.



Analysis:

- For this analysis we split the sample into three groups: (1) those that did not relocate following the February 2011 earthquakes, (2) those that relocated once, and (3) those that relocated more than once. Of the 541 organisations in our sample 60 organisations reported relocation once after February 2011, and 44 reported relocating more than once after the February earthquakes.
- **Organisations tended to resist relocating even when their current location was compromised.** It took organisations an average of 7.4 months (median 3) to relocate following the earthquake. A majority of organisations (60) of the 104 organisations that relocated relocated within three months. We assume that organisations that were able to relocate within three months of the earthquake were relocating to areas without electricity, water, and sewage infrastructure disruption. In case studies of 32 organisations we conducted in 2012, only one organisations of the 32 relocated outside of the region and less than half relocated within the region, despite the great majority suffering extensive damage to their buildings, surrounding areas, and lifeline outages.
- We then compared organisations that did not relocate but experienced water, sewage, or electricity disruptions for days, weeks, and months to organisations that relocated once within three months of the February earthquakes, and to those that relocated more than once following the earthquakes. Did those that had to relocate have different Ability to Meet Demand or recovery outcomes?
  - The preliminary analyses below show:
    - Organisations that experienced longer duration water, electricity, and sewage outages were all significantly more likely to relocate.
    - Organisations that experienced more disruptive structural damage to their buildings were more likely to relocate.

   - Organisations that had higher Maximum Experienced Impact scores were more likely to relocate.

- Organisations that did not relocate following the earthquake were significantly more likely to be able to meet demand immediately and several months after the earthquakes (note that this analysis does not control for impact).

The analysis below shows that organisations that experienced longer lifeline outages and experienced disruption to premises were more likely to relocate than those that had shorter duration outages.

Ranks

	Relocation after earthquakes	N	Mean Rank
Impact duration: Water supply	No	260	165.90
	Yes	96	212.64
	Total	356	
Impact duration: Electricity	No	284	175.91
	Yes	96	233.67
	Total	380	
Impact duration: Sewage	No	208	135.30
	Yes	88	179.69
	Total	296	
Impact: Structural damage to buildings	No	374	208.98
	Yes	120	367.55
	Total	494	
Maximum impact	No	409	247.51
	Yes	127	336.11
	Total	536	

Test Statistics[a,b]

	Impact duration: Water supply	Impact duration: Electricity	Impact duration: Sewage	Impact: Structural damage to buildings	Maximum impact
Chi-Square	16.090	22.944	18.343	121.511	36.847
df	1	1	1	1	1
Asymp. Sig.	.000	.000	.000	.000	.000

a. Kruskal Wallis Test

b. Grouping Variable: Relocation after earthquakes

The analysis below shows that organisations that did not relocate following the earthquake were significantly more likely to be able to meet demand immediately and several months after the earthquakes. After one year, there was no significant difference between those that relocated and those that didn't.

Ranks

	Relocation after earthquakes	N	Mean Rank
Ability to meet demand: immediately after the event	No	403	275.70
	Yes	125	228.39
	Total	528	
Ability to meet demand: several months after the event	No	398	269.41
	Yes	125	238.40
	Total	523	
Ability to meet demand: a year on from the event	No	397	263.61
	Yes	125	254.79
	Total	522	
Ability to meet demand: two years on from the event	No	393	259.82
	Yes	124	256.41
	Total	517	

Test Statistics[a,b]

	Ability to meet demand: immediately after the event	Ability to meet demand: several months after the event	Ability to meet demand: a year on from the event	Ability to meet demand: two years on from the event
Chi-Square	10.233	6.351	.775	.139
df	1	1	1	1
Asymp. Sig.	.001	.012	.379	.709

a. Kruskal Wallis Test

b. Grouping Variable: Relocation after earthquakes

Using the select cases feature in SPSS, I eliminated organisations that did not experience lifeline disruptions. When only examining organisations that experienced lifeline disruptions (electricity, water, and sewage) there is not a significant difference between organisations' that relocated and organisations' that did not relocate ability to meet demand.

Ranks

	RelocatePostFeb_Dummy	N	Mean Rank
Ability to meet demand immediately after the earthquakes	.00	187	135.44
	1.00	74	119.78
	Total	261	
Ability to meet demand one month after the earthquakes	.00	186	130.92
	1.00	74	129.43
	Total	260	
Ability to meet demand one year after the earthquakes	.00	185	130.08
	1.00	74	129.80
	Total	259	
Ability to meet demand two years after the earthquake	.00	185	130.05
	1.00	74	129.86
	Total	259	

Test Statistics[a,b]

	Ability to meet demand immediately after the earthquakes	Ability to meet demand one month after the earthquakes	Ability to meet demand one year after the earthquakes	Ability to meet demand two years after the earthquake
Chi-Square	2.429	.029	.002	.001
df	1	1	1	1
Asymp. Sig.	.119	.865	.969	.975

a. Kruskal Wallis Test

b. Grouping Variable: RelocatePostFeb_Dummy

Limitations:

These calculations are preliminary and need further analysis to ensure that important control variables are appropriately considered (e.g. sector, size, level of physical exposure, and whether the organisations was in a cordon).

Reference as:

Seville, E., Brown, C., Stevenson, J., Giovinazzi, S., Vargo, J. (2015). Relocation. ERI Results Bulletin 2015-K11-1. Resilient Organisations www.resorgs.org.nz

Business Behaviours Following the Canterbury Earthquakes

Organisation disruption – perception vs reality

ERI Results Bulletin 2015-K12-1

Findings from a survey of 541 organisations in the Greater Christchurch Urban area in late 2013

Question:

Do organisations accurately estimate their level of disruption to infrastructure outages (pre-event)?

Some studies and models rely on organisations to assess their ability to continue operations to model infrastructure disruption. However, previous studies (Chang et al. (2002)) have shown that organisations tend to under-estimate their ability to perform following crises.

We wanted to see whether organisations over or under-estimated their level of disruption to the earthquakes.

Findings for MERIT:

Organisations significantly under-estimate their ability to operate during infrastructure outages. Organisations that indicated they could not function following an infrastructure disruption shorter than the one faced following the Christchurch earthquakes, still managed to meet approximately 50% of their demand immediately after the earthquakes and 80-90% several months after.

This indicates that organisations are more adaptive than they think. This needs to be taken into account when ex-ante data is used to build models or estimate business recovery. It also may indicate that organisations' perceptions of 'not functioning' does not necessarily mean they are not meeting demand or are not economically active. For example, disrupted organisations may not be able to function as normal but they could use existing stock to service demand and will work to recapture lost production later. The distinction between operating and trading / meeting demand is an important one.

Analysis:

To analyse this, the responses to Q45 and Q12e were compared:

Q45: How long could your organisation continue functioning if normal supply to the following infrastructure services were disrupted (response options: could not function, hours, days, weeks, months) (SPSS coding: dpndWat, 0=months, 1=weeks, 2=days, 3= hours, 4 = could not function)

Q12e: With reference to the 22 February 2011 earthquake, for how long did your organisation experience disruptions to the following infrastructure services? (response options: hours, days, weeks, months) (SPSS coding: impWatD, 1=hours, 2=days, 3= weeks, 4= months)

Respondents that indicated they could not operate for a time shorter than the duration of outage they experienced were selected for analysis. (note that the selection criteria used in SPSS was – Select if (impWatD=2 and dpndWat >= 3) or (impWatD=3 and dpndWat >= 2) or (impWatD=4 and dpndWat >= 1)). Average Ability to Meet Demand was then calculated for the selected cases.
The results show that a) a large number of organisations under estimated how long they could operate for (despite recent experiences) and b) that they could meet almost half their demand when their answer to Q45 indicates that they could not continue functioning.

	Number responses	AMD (immediately after)	AMD (several months)
Water	143	0.549	0.863
Sewage	125	0.544	0.8433
Electricity	159	0.555	0.844
Gas	24	0.416	0.79
Phone networks	113	0.555	0.851
Data networks	109	0.54	0.848
Road	189	0.625	0.872
Rail	9	0.555	0.806
Airport	11	0.65	0.841
Port	16	0.672	0.938
Fuel	45	0.661	0.872

Limitations:

Some organisations may have indicated that they had a greater disruption to their infrastructure service than they actually had – due to the time between the event and the survey (2.5 years).

References:

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Contact details:

GNS Science
1 Fairway Drive, Avalon
Lower Hutt 5010
PO Box 30 368
Lower Hutt 5040
New Zealand
T +64-4-570 1444
F +64-4-570 4600