Lessons from the 2016 Kaikoura Earthquake: Understanding the Impacts of a Potential Alpine Fault Earthquake on Government Productivity in Wellington

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Charlotte Brown
Nick Horspool
Garry MacDonald
Kaylene Sampson
Erica Seville
Nicola Smith
Joanne Stevenson

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Executive Summary

Currently little is known about how government entities respond and adapt to disruption. Similarly, little is known about how these disruptions affect the delivery of government services and how those impacts flow through the regional and national economy. Because of the way government services are priced (or not priced) and consumed in the economy, interruptions in the provision of government services produce different economic outcomes when compared to disruptions in the provision of other sectors' goods and services. A better understanding of the behaviour of government entities in the face of these disruptions will improve our ability to model the economic impacts.

This report summarises the initial findings of a project jointly conducted by Resilient Organisations, M.E Research, and GNS Science, to enhance our understanding of the changes in national government productivity in Wellington associated with an Alpine Fault earthquake scenario. This project employed a three-stage approach. The first stage examined the impacts of the 14 November 2016 Kaikōura earthquake on four New Zealand government departments based in Wellington. In the second stage, the hazard impact and loss modelling tool, RiskScape generated probable damage and loss estimates from an Alpine Fault earthquake on the greater Wellington metro area. In stage three, these outputs were incorporated into the Measuring the Economics of Resilient Infrastructure Tool (MERIT) to estimate the economic losses that could transpire from government disruptions following an Alpine Fault earthquake scenario. There is a previous report available with more information on the Kaikōura case studies in a report published by Sampson et al. 2017.

Stage One Results

The main aim of stage one was to understand the experiences of government departments in relation to the 2016 Kaikōura earthquakes, to provide context and estimate some parameters used in the subsequent modelling of earthquake disruptions on government productivity. Phase one engaged 12 staff from seven different New Zealand government agencies. Results from stage one indicated that:

- The primary mechanism for disruption faced by case study agencies in Wellington was building disruption.
- Demand for critical government functions, such as social support payments, health services, and civil protection often increased following the disruption, while non-critical functions often experienced reduced demand.
- The government's ability to meet demand will depend on the disruption to critical services and buildings, the ability of the agency to reprioritise staff, and other resources toward demand increases, and the capacity of agency offices based outside of Wellington to absorb additional demand or house staff displaced from Wellington.

Phase one also provided useful insights into the length of time government agencies may need to operate from temporary locations, the loss of effective employee hours due to building disruptions, and how government agencies adapt to deal with the loss in effective employee time or productivity.

Stage Two

The second stage of this project estimated the potential building damage and subsequent consequences of an Alpine Fault earthquake using the RiskScape multi-hazard loss modelling tool. For this study we selected an earthquake scenario with a fault rupture that included both the Alpine Fault and a subsequent rupture of the Wairau Fault, which is the northern extension to the Alpine Fault. We deliberately selected a hazard scenario with potentially severe impacts for Wellington to enable in-depth analysis of the relationship between government productivity and impacts on both government and other buildings in the city. It is important to keep in mind when interpreting the results, that the chosen scenario is near to an Alpine Fault event worst case scenario for Wellington.

The RiskScape model produces different impact results for different runs of the same hazard scenario model. To capture a range of outputs, we produced 10 runs of the Alpine-Wairau fault rupture scenario, each producing different impacts for the Wellington metro areas.

Across all the model runs, the number of buildings in Wellington subject to the greatest damage (damage state 5 - collapse) was generally low (0-3 buildings). The number of buildings subject to irreparable structural damage (damage state 4) varied quite significantly (ranging from 3 to 45 buildings). We were able to match specific government tenants with the RiskScape building stock and damage information using the results of a recent survey of Wellington building occupancy and data from the NZGPP group on employee numbers at each location. This allowed us to translate the building disruption outputs to estimated impacts on government productivity in stage three.

Stage Three

Outputs of stages one and two were incorporated into the Measuring the Economics of Resilient Infrastructure Tool (MERIT) to estimate the economic losses that could transpire as a result of government disruptions following an Alpine Fault earthquake scenario. The core task for the MERIT modelling in this project was to design a new module or series of mathematical steps that could translate physical damage information into inputs for the economic model.

Overall the Government Organisations Module developed through this research estimates how building damage alters the productivity of government staff. While the initial disruption is to capital stocks (buildings), the way we implement and model the economic consequences of the disruptions is focused on the labour implications. There are three steps in the newly created Government Organisations Module:

1) Calculate the expected number of days each government organisation in the Wellington CBD is without a building or working in a temporary location (e.g. from home or sharing office space with another government organisation).
2) Calculate the hours of employee lost productivity due to building disruptions.
3) Assign adaptation measures taken by government agencies to deal with the loss in effective employee time or productivity.

In this study the adaptations focused on labour tactics to recapture lost productivity either through staff working harder and longer hours without extra pay, or by the agency paying overtime to staff or employing extra labour (either by contract or as additional staffing). We then selected parameters to adjust in the Dynamic Economic Model component of MERIT in order to best simulate the system-wide implications of a change in government productivity.

Results

The Government Organisations Module has been run 200 times providing some useful insights into the ranges of results that might be expected for the Alpine-Wairau scenario. It also provides some output indicators relating to non-market impacts (namely unpaid overtime) while the Dynamic Economic Model produces outputs relating only to the market economy.

Displacement

Initially, at day one after the event, all model runs report that the entire population of 28,000 government employees in the CBD (i.e. 100% of employees) are working at a temporary location. Over the next two weeks, the numbers of CBD employees in temporary working locations fall rapidly but are still at 13,000 or 46% according to the median of the model runs. By six months the equivalent figures for the median run are 1,500 or 5%. On first inspection these results may seem high, however, it is important to keep in mind that the modelling also incorporates buffer areas or cordons placed around buildings of damage states 4 and 5, and the assumed length of time of these cordons is relatively long. Interestingly, for all RiskScape runs, the number of government employees impacted by these cordon areas is higher than the number of employees impacted through occupancy of buildings directly impacted. These results serve to highlight that for government continuity planning there is strong importance not only in the structural resilience of buildings directly occupied by government staff, but also the neighbouring buildings, as these also have significant potential to create disruption.

Government Productivity Losses

Next, we quantified the losses in government productivity due to employees not being as productive following building disruptions. Here productivity losses are measured in the effective loss of 'as normal' employee hours. The event the losses in productivity vary quite substantially between the model runs. Summing over all days for the first year after the event, the total losses in hours are calculated across the 200 model runs as ranging from 1.56 to 2.57 million hours, with a median of 1.98 million hours (25 percentile = 1.83 million, 75 percentile =2.13 million).

Government Adaptations

We quantified the adaptation measures taken by government organisations to recover losses in productivity. It is assumed that there will a time for which the costs will be borne entirely by employees simply through working extra time or harder, without corresponding extra remuneration. The module calculates that these effects will be greatest just over one week after the event. We also calculated the number of additional paid employee hours generated to recover productivity. Under the median model run, the total additional number of paid employee time is around 21,000 hours per day shortly after the event and is maintained at higher than 10,000 hours per day for the entire first month after the event. For the entire first year after the event, and over the set of 200 hundred model runs the median time required was 1.10 million hours.

Gross Domestic Product

Finally, the simulation of the Dynamic Economic Model, utilised the single selected median run from the Government Organisations Module as the relevant input data. We calculated cumulative impact

on Gross Domestic Product (GDP) at three categories of spatial aggregation: Wellington Region, rest of New Zealand, and total New Zealand.

- At the national level the absolute impact is less than $1 million over the first two months, over six months there is a relatively small cumulative change of $1million in GDP, and over the entire first year the absolute impact is back down to less than $1 million.
- At the sub-national level, Wellington GDP increases by $11 million, but conversely GDP for the rest of New Zealand decreases by $11 million.
- The largest losses occur in the aggregated industry 'government, education, and health' in the rest of New Zealand, reflecting that it is expenditure on services from this industry group from which the largest pool of public funding has been withdrawn.

The relatively small changes at the national level reflect that to a large extent the outcomes are transfers in income and spending from one agent to another. When we look at the sub-national results we can see that transfers occur within the country.

Limitations and Discussion Points

- **Hypothetical event:** The event that has been modelled is hypothetical and focused almost exclusively on building damage in Wellington. In an Alpine fault rupture is quite likely that there will be damage to other built environment services necessary for a well-functioning economic system.
- **Economics and Systems-Analysis**: Our MERIT analysis and modelling has helped to illustrate the counter-balancing relationships that exist in economic systems. Additionally, in the government sector 'sales' of services and incomes generated do not fall despite the lack of supply and 'sector output' does not get sourced from alternative suppliers as this is generally not possible. As a result, the impacts on GDP are relatively minor. In this scenario analysis of a rupture event on the Wairau-Alpine fault, the economic modelling has produced an overall neutral impact on GDP.
- **Regional changes:** The funding of additional labour is ultimately sourced from all over New Zealand, there are differences in impacts at a regional level, with Wellington receiving a net increase in incomes and GDP, and the rest of New Zealand a net loss. In this study, we have not included any consideration of supply-side constraints on labour resources in the MERIT modelling, and therefore positive gains produced by the modelling may, to some extent, be over-estimated.
- **GDP/Value added versus other metrics.** A full consideration of welfare implications is likely to require other considerations and metrics. Although GDP impacts may be relatively neutral, welfare impacts may be quite high. Indeed, by its very nature, the government sector tends to be involved in the provision of goods and services that are poorly priced in markets relative to their social welfare benefits. Hence changes in GDP/value added from the education/ health sectors are not necessarily the best way to conceptualise the impacts that occur.

The results of this demonstrate that although such an event would cause significant disruptions to the operations of government agencies in terms displacement and labour hours lost, the impact on New Zealand's GDP is minimal. This work is a first attempt at quantifying the impact of a significant earthquake event on New Zealand's government productivity, and we note a number of areas for ongoing development in the full report.

Acknowledgements

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1.0 Introduction

New Zealand's capital city of Wellington experienced significant disruptions from a magnitude 7.8 'Kaikōura' earthquake that occurred on November 14th, 2016 at 12:02am local time. Although Wellington is 60km north of the northernmost causative faults (Litchfield et al. 2016; Bradley, Wotherspoon and Kaiser, 2017) several buildings were damaged, capacity was reduced in the main seaport, and water, electricity, and telecommunications services were temporarily disrupted (Giovinazzi et al. 2017; Hughes et al. 2017). Almost a month on from the quakes, approximately 11% of Wellington office spaces remained closed due to damage (Bradley, Wotherspoon and Kaiser, 2017). As the nation's capital, Wellington houses a concentration of government agencies. As such, the loss of productivity, and associated disruptions that were felt by organisations across the affected areas (Stevenson et al. 2017) were equally an issue for government. At least nine of the buildings requiring closure as a result of the earthquake housed government agencies, which required the temporary or permanent relocation of thousands of staff (Stevenson et al. 2017).

Currently, little is known about how government entities respond and adapt to disruption. Similarly, little is known about how these disruptions affect the delivery of government services and how those impacts flow through the regional and national economy. A better understanding of the behaviour of government entities in the face of these disruptions will improve our ability to model the economic impacts.

This report summarizes the initial findings of a project being jointly conducted by Resilient Organisations, M.E Research and GNS Science, to enhance our understanding of the changes in government productivity associated with an Alpine Fault earthquake scenario. This research combines observations of the changes to government productivity resulting from the Kaikōura earthquake and a desktop scenario of a probable damage and loss estimates from an Alpine Fault earthquake generated by the hazard impact and loss modelling tool, RiskScape. These outputs are then incorporated into the Measuring the Economics of Resilient Infrastructure Tool (MERIT) to estimate the economic losses that could transpire as a result of government disruptions following an Alpine Fault earthquake scenario.

2.0 Measuring Productivity

2.1 Productivity

Productivity is calculated as a ratio between outputs and inputs. It is used to assess how efficiently inputs, such as labour and capital, are used to produce outputs, such as goods and services, to achieve a given outcome. Measures of productivity can be used to compare a system to itself over time or to compare different organisations or economies. Figure 1 illustrates the relationship between four distinct aspects of the production process: inputs, process, outputs, and outcomes.

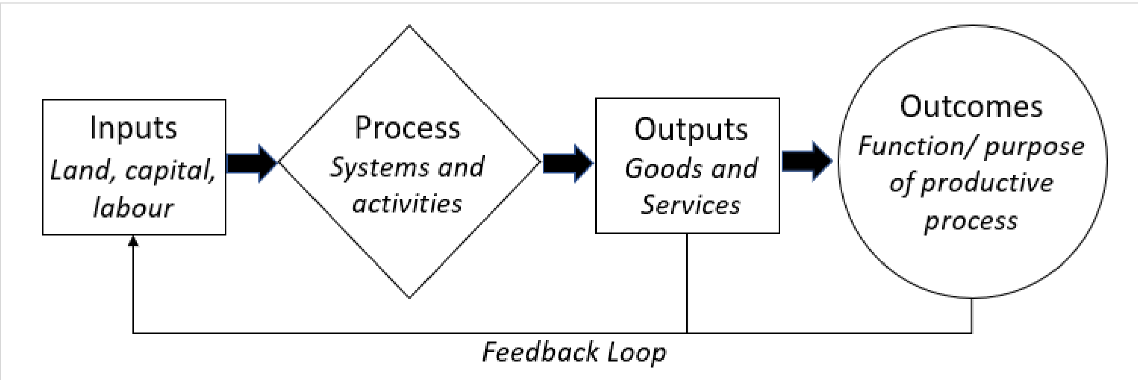

Figure 1: A simple representation of a production process (Sampson et al., 2017)

2.2 Measuring Government Productivity

Measuring government productivity is not straight-forward. The marginal or added value that is created through the process stage of production can be difficult to quantify. This is particularly true where government services are subsidised or provided free to the public or 'consumer'. Though in some cases the services provided by the state do have equivalence in the private sector (i.e. education); while in other cases, such as the services provided by Inland Revenue, there are no private sector equivalents from which to draw estimates of relative productivity (Douglas, 2006).

Government agencies perform a range of functions.[1] The outputs of some functions are more difficult to monetize or quantify than others. For example, the *All Right?* Wellbeing public awareness campaign jointly run between Canterbury District Health Board and the Mental Health Foundation of New Zealand was designed to increase the emotional and psychological resilience of Christchurch residents in the period after the 2010/11 earthquakes (Sampson et al., 2017). Measuring the effectiveness of such campaigns relies on intermediate measures or indicators as proxies for latent, diffuse, or longer-term outcomes (Douglas, 2006). In contrast, metrics that capture government activity that is directly outward facing or provides services directly to individuals, such as call centre support or hospital stays, are easier to capture (Douglas, 2006).

[1] Functions are the categories of activities performed and the statutory duties and procedures associated with carrying-out those activities.

Each agency also performs a variety of functions, typically divided into critical and non-critical subcategories. This categorisation is based on the assessment of whether a service, activity, or product must be maintained for an agency to meet its primary responsibilities and obligations. There is no consistent definition of criticality, and agencies apply the term to functions at their own discretion. Criticality will often determine how activities are prioritised during a disruption event. So, productivity at the agency level is a product of resource sharing and prioritisation at the function level.

In addition, some agencies provide 'emergency functions' in significant community-wide disruption events, for example, administering funding or other support services to disrupted populations. These activities are conducted in addition to business-as-usual (BAU) services, and often displace BAU activities during a response. This provides a challenge when measuring productivity change, as the nature of the service outputs are different before and after an event.

2.3 Capturing Productivity Changes for MERIT Modelling

Because the types of outputs and the ability to measure or quantify outputs varies so significantly across the government sector, we have chosen to describe and measure productivity change with metric that does not require any quantification of *outputs*. That is, we assume that for each government organisation there is a given level of output achieved per hour by an average (i.e. non-disrupted) staff member. When the organisation is disrupted, we can think of the productivity losses as the 'effective hours of normal staff output lost' per hour of staff time worked, meaning that a disrupted labour hour is less productive than a BAU labour hour.

3.0 Building a Government Organisation Productivity Model

This project employed a three-stage sequential approach to assess the impacts of an Alpine Fault earthquake on government productivity. The first stage examined the impacts of the 14th of November 2016 Kaikōura earthquake on four New Zealand government departments based in Wellington. This stage provided a conceptual foundation for building a model of earthquake impacts on government productivity. In the second stage, we modelled a potential future earthquake associated with the Alpine Fault and its potential impacts on buildings in the greater Wellington metro region. In the third stage of the project, the Measuring the Economics of Resilient Infrastructure Tool (MERIT) incorporated elements of stages one and two to evaluate the consequences of such a disruption to government productivity in Wellington.

3.1 Stage 1: Observations from the Kaikōura Earthquake

The main aim of stage one was to understand the experiences of government departments in relation to the 2016 Kaikōura earthquakes, to provide context and estimate some parameters used in the subsequent modelling of earthquake disruptions on government productivity. In this stage, we first conducted a focus group meeting with participants from five separate agencies who are part of a cross-government business continuity management (BCM) working group. All participants contributed to business continuity management or similar in their organisation. The focus group was conducted first to enable a cross-government view of the issues government organisations faced because of the 2016 earthquake event. The focus group discussion addressed post-Kaikōura earthquake operational environments, vulnerabilities, and adaptive strategies.

The focus group was followed by a series of one-on-one interviews with representatives from four different government agency 'case studies'. Two BCM working group participants offered their own agencies for inclusion in the interviews that followed, and that captured a more in-depth exploration of government productivity changes. Two additional agencies were recruited through contacts established in the focus group discussion. Between September and October 2017, we interviewed nine representatives from four government agencies with physical bases in Wellington, each of which provides a range of functions across New Zealand.

In total stage one engaged 12 staff from seven different agencies. The functions of these agencies varied considerably. The broad range of services included public facing functions such as call centres and service counters, revenue collection and distribution, document and records management, policy development and delivery, as well as leadership, strategy, and ministerial support services amongst others. Data for both the interviews and the earlier focus group was voice recorded and notes taken by two members of the research team. Anonymity and confidentiality was assured to all agencies that participated. The study was approved by the University of Canterbury Human Ethics committee.

3.1.1 Disruptions

The case study organisations experienced different levels of disruption following the 2016 Kaikōura event. Our case studies of four agencies reported performing 19 separate functions, of which six were considered critical. All critical functions related to services directly provided to the public.

Government organisation disruptions were largely caused by damaged buildings and temporary loss of access due to safety concerns about buildings. In one case, while two thirds of staff were able to return to work the day after the earthquake, the remaining third were unable to return and were relocated elsewhere on the North Island. Another agency was required to move premises on three separate occasions, within the space of a few weeks. In the third case, the occupation of multiple dwellings meant that staff were able to return to work at varying rates from within a few days up to 16 weeks (112 days). The fourth agency operated from a single building, which experienced damage and the building was closed to most staff for approximately 10 weeks. Because of the nature of this organisation's core function, limited direct access to building and contents led to a substantial loss of productivity for a subset of staff who could neither use the premises nor work from home.

The ability to occupy any buildings was contingent on the continued functioning of critical infrastructure services such as transport networks and the quick resumption of electricity services.

Time to reoccupy some government buildings was reliant on third party service providers, such as qualified engineers, to carry out safety inspections. We expect that in a larger event such as an Alpine fault rupture, it is likely that demand for engineering services would greatly surpass supply. Other significant vulnerabilities that would severely hinder the ability to deliver agency function included:

- IT and data hosting
- Access to specialist staff
- Coordinating services with other government agencies
- Third party suppliers, especially banking and telecommunications

3.1.2 Changes to Inputs

Two kinds of inputs are discussed herein; labour inputs and capital inputs. Figure 2 illustrates the level of labour input for each agency for both critical functions and non-critical agency work relative to 'business as usual' (BAU) inputs. As can be seen, Agency 1 returned to about 38 per cent of BAU staff hours worked by a week after the earthquake and 100 per cent of business as usual (BAU) staff hours worked within two weeks of the disruptive event. This recovery of input was more rapid for critical functions within the organisation which had about 75 per cent of BAU labour input within a day of the event. Agency 2 returned to 90 per cent of staff hours as a proportion of BAU for both critical and non-critical functions within a week of the event and 100 per cent within two weeks.

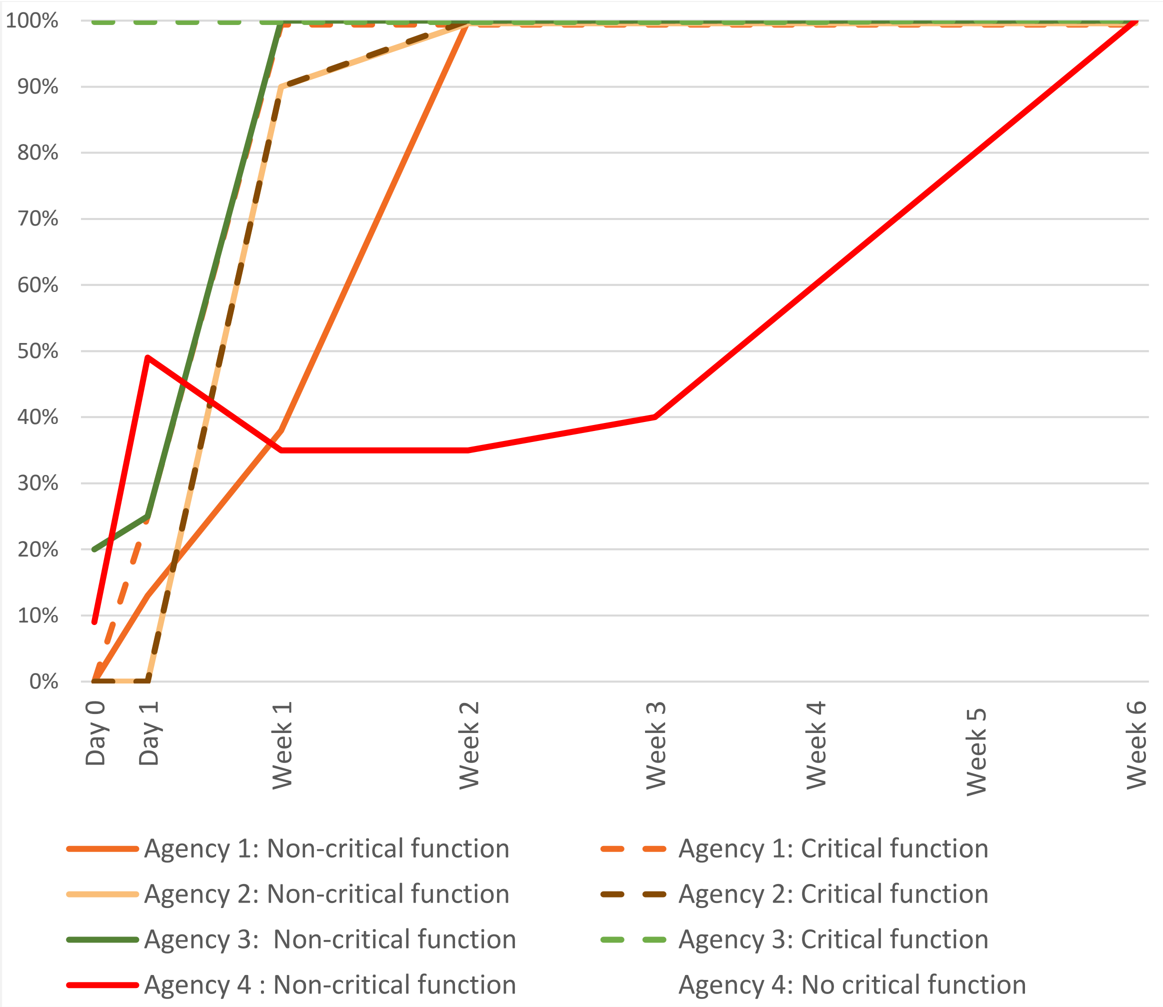

Figure 2: Labour inputs (staff hours) as a proportion of BAU labour inputs for non-critical function outputs (solid line) and critical function outputs (dotted line).

Agency 3 maintained 100 per cent of labour inputs for their one critical function from the day of the earthquake, while total staff labour input did not return to 100 per cent of BAU until a week after the earthquake. Agency 4 did not identify any critical functions and therefore has a single measure for total labour input (non-critical functions) as a proportion of BAU labour input. The day after the earthquake some staff from Agency 4 began to reoccupy their building and work, but staff were notified later that week that the building was unsafe. Thus, labour input decreased between 15 November and 21 November 2016. It did not reach 100 per cent of BAU labour input until late December, around 6 weeks after the event.

Capital inputs are the second kind of input examined. As noted above, building damage was an issue to a greater or lesser degree for all case study agencies. The New Zealand Government Procurement and Property (NZGPP) group was established with the objective of ensuring "efficient and effective management of the Crown estate" (MBIE, 2016). The GPG played a significant role in helping affected agencies find spaces to occupy after the Kaikōura event. Their approach focused on filling space needs with existing buildings in the Government stock, facilitating temporary sharing agreements, and enabling hot-desking. Departments with less disruptions contributed to space sharing arrangements, with more than one respondent noting the high level of cooperation within the public service.

An interesting observation to make here is the discrepancy between the time taken to return to BAU function and the rate of return to buildings. As noted above, at least one agency took around 16 weeks to get back to full usage of their building, though returning to full function took considerably less time (about 6 weeks) for even the slowest agency. This highlights the success of the numerous adaptive strategies that were employed immediately after the Kaikōura event, which were aimed to reduce workflow disruption while meeting both BAU and emergency function requirements. Some of these strategies included:

- Paying overtime to pick up lost productivity
- Awarding time in lieu for overtime hours
- Redeploying staff from non-critical functions to meet critical functions or more urgent BAU
- Putting non-critical work on hold or removing it altogether from the work schedule.

It is interesting to note that one agency indicated that the built-in excess capacity in staffing as part of standard practice meant that no additional staffing hours were required to catch-up on work backlogs the weeks and months following the earthquakes. For a fuller discussion of specific agency action and approaches refer Sampson et al. (2017).

3.1.2 Changes to Outputs

The case study agencies reported on the effects the Kaikōura earthquake had on their service delivery in the days, weeks, and months following the event. Just as damage experienced was different for each agency, so too was the impact on output capacity. Outputs comprise three types of activity: emergency response, critical BAU, and non-critical BAU. These activities were engaged in at different rates across the four case study agencies, with one agency only having BAU output flow to manage, while others were juggling all three types of activities following the Kaikōura event.

Figure 3 is intended to illustrate one of the four patterns of output activity experienced by the case study agencies. As can be seen in this schematic (Figure 3), non-critical functions were dropped to make time for the required emergency response. As the pressure on the immediate emergency response waned over time, some of the non-critical work was resumed. In this model, staff worked overtime (increasing outputs above BAU) to catch up on some of the work that had been put on hold. Concurrently, the critical functionality of this agency was able to be maintained throughout the recovery period. This schematic is intended to illustrate the changes to critical and non-critical outputs relative to business as usual status.

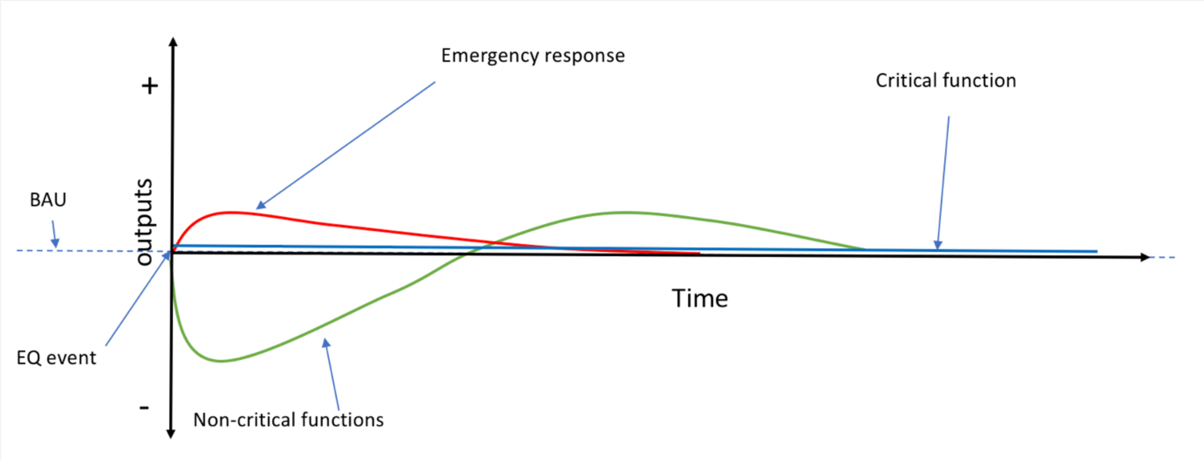

Figure 3: Schematic of approximate changes to critical, non-critical and emergency outputs over time.

Across the four agencies, some service outputs were continued through redirection of staff efforts, and others were suspended due to staff availability. The impacts of disruptions on outputs is summarised in Table 1.

Table 1: Changes to outputs for emergency functions, critical and non-critical BAU for the four case study agencies.

Agency	Emergency response function	Critical BAU	Non-critical BAU
1	None	Increased staff hours to meet two critical functions	Suspended some functions - redistributed staff to other agencies elsewhere in the North Island
2	None	Minimal interruptions – high level of online/automated output activity	Suspended functions intermittently for specific issues – i.e. building access, premises move
3	Yes – small increase in emergency functions	Stable without interruption - though staff were relocated to new premises outside of Wellington to perform this function	Five functions – a range of impacts from total suspension, significant reduction, or redistribution of work to other agencies
4	None	Nil – but increase in earthquake generated functions that became critical/urgent.	Reduced in line with staff input reduction – redirected efforts to earthquake generated recovery tasks.

Finally, as was noted by the BCM working group, and confirmed by our participants, government agencies in general are highly dependent on third party suppliers for critical functions. Following the Kaikōura event, there was one case study organisation's building re-entry was slightly slowed by the availability of structural engineers to check premises. Other than this instance, none of the agencies reported disruptions related to third party suppliers. In future events, however, it should be noted

that many third-party functions originate in Wellington and therefore are equally exposed to the types of earthquake generated disruptions as the government agencies they are serving. This interruption may additionally impact the capacity for effected agencies to return to full operation.

3.1.3 Stage 1 Results Summary

Figure 4 provides a system diagram of the relationship between the various aspects of disruption, government functions, and the communities that rely on government functions. As illustrated, the primary mechanism for disruption faced by our case study agencies in Wellington was building disruption. There were some very minor disruptions to infrastructure (electricity and related IT services), and it was clear that even with these minor disruptions, agencies' ability to function was compromised.

Demand for critical government functions, such as social support payments, health services, and civil protection often increases following a disruption. Non-critical functions may experience reduced demand, while people's energies are refocused on response and recovery priorities (as shown in Table 1). The government's ability to meet demand will depend on the disruption to critical services and buildings, the ability of the agency to reprioritise staff and other resources toward demand increases, and the capacity of agency offices based outside of Wellington to absorb additional demand or house staff displaced from Wellington (Figure 4).

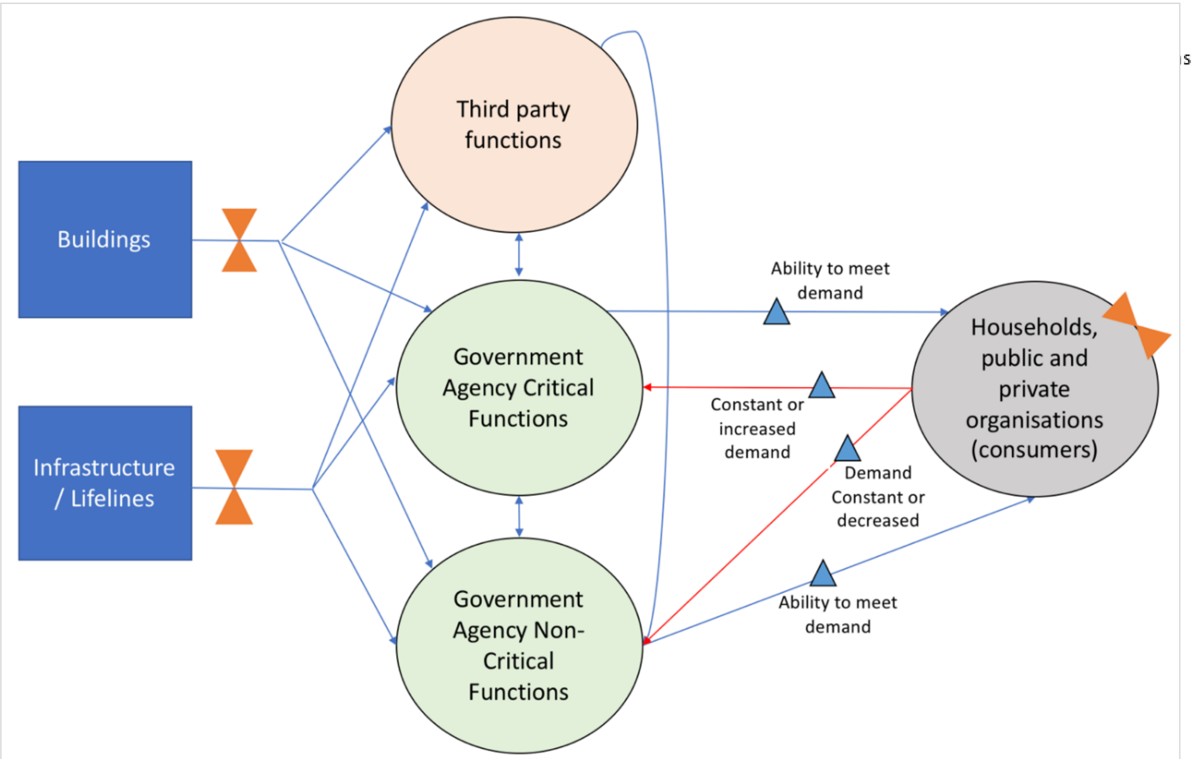

Figure 4: Relationships between elements influencing government productivity

3.2 Stage 2: RiskScape

The second stage of this project estimated the building damage and subsequent consequences of a potential Alpine Fault earthquake using the RiskScape multi-hazard loss modelling tool. RiskScape is a loss modelling tool designed to assist organisations and researchers with estimating asset impacts and losses from natural hazard events. The software is principally developed through collaboration between two New Zealand research organisations, GNS Science and NIWA, as well as other organisations affiliated with the Natural Hazards Research Platform. Further information on the tool can be found on the RiskScape website[2] and RiskScape Wiki.[3]

RiskScape operates by combining information or 'layers' relating to specific natural hazard scenarios and their hazard intensity, with asset locations and their characteristics, and vulnerability models. RiskScape then calculates asset damage and losses for each chosen scenario and outputs this information as individual asset impacts and losses (e.g. for each building RiskScape provides outputs indicators that include number of buildings by damage state, casualties estimated, time for reoccupation of building, and estimated reinstatement costs) or as aggregated asset impacts and losses over a geographic area.

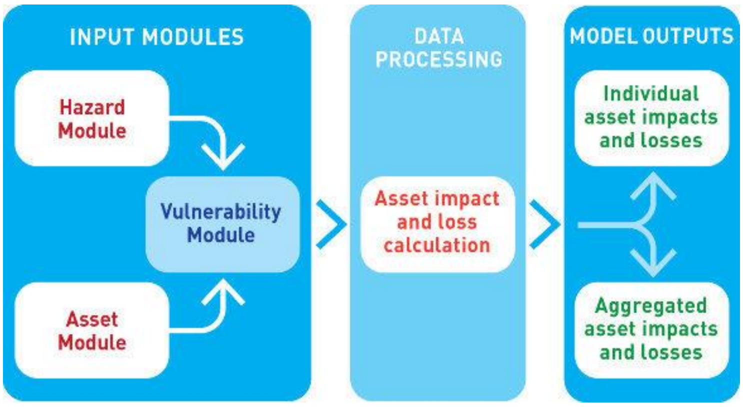

Figure 5: RiskScape modelling components and workflow (RiskScape, 2018)

3.2.1 Scenario

As mentioned earlier, the focus of this project is on estimating the impacts on government productivity of an Alpine Fault event. There are many potential scenarios of an Alpine Fault event that will have differing impacts for Wellington. Among the most important source of variation is the site for the initial fault rupture. For example, an initial rupture location at the northern end of the fault and propagating towards the south will likely produce significantly less ground shaking for Wellington compared with a rupture propagating north towards Wellington. Other plausible scenarios include the rupture of the Alpine Fault and other nearby faults in the Marlborough Fault System, much like occurred during the Kaikōura earthquake, which resulted in the rupture of over 14 faults. For this study, we have deliberately selected a hazard scenario that is at the upper or more severe end of the spectrum of Alpine Fault ruptures in terms of potential impacts for Wellington. The reason for choosing a scenario with significant impacts on Wellington was to enable in-depth

[2] https://www.riskscape.org.nz/
[3] https://wiki.riskscape.org.nz/index.php/Overview.

analysis of the relationship between government productivity and impacts on government buildings and other capital in the capital city.

The selected scenario is a fault rupture that includes both the Alpine Fault and subsequent rupture of the Wairau fault which is the northern extension to the Alpine Fault. Nevertheless, it is important to keep in mind when interpreting the results, that the chosen scenario is purposely severe for Wellington in terms of an Alpine Fault event. The ground motion maps for this scenario were developed by Professor Brendon Bradley from University of Canterbury for the AF8 project[4] which is developing a South Island wide response plan for an Alpine Fault earthquake.

3.2.2 Modelling

The RiskScape model is not deterministic. Impact results can be different for different runs of the same hazard scenario model, even when the input information and assumptions are unchanged.[5] Random variation will occur in the model results because the functions that are responsible for calculating building damage and structural failure include probability distributions; and each time the model is run it selects parameters from within those distributions. Another important aspect of the RiskScape modelling for this project is that only building assets were considered (i.e. infrastructure damage was excluded from the analysis). Based on the experience of the Kaikōura earthquake, building damage is likely to be the key driver of changes to government productivity. Figure 6 illustrates the types of outputs that can be generated by RiskScape.

Figure 6: Example of outputs that can be generated by RiskScape. Damage states are shown as damage state 1 (green), damage state 2 (yellow), damage state 3 (orange), damage state 4 (dark red), damage state 5 (black). Definitions are provided in Table 2 below.

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[4] http://projectaf8.co.nz/

[5] Detailed technical documentation for the RiskScape model is available at the following websites: https://www.riskscape.org.nz/ and https://wiki.riskscape.org.nz/index.php/Overview.

To enable the variation in potential building damage to be propagated through to the analysis of actual impacts on government productivity, the RiskScape model was run ten times, and the results for each run were provided separately to the MERIT modellers.

3.2.3 Outputs

The output provided to the MERIT modellers from RiskScape was essentially a set of GIS shapefiles. From these files it was possible to extract a matrix of building data. The rows of the matrix consisted of a list of all buildings. To keep the project tractable, only buildings located within Wellington central business district (CBD) were considered. For each building we then have within the matrix, several columns of attribute information (i.e. data that does not change when the model is run), the most important being: x and y co-ordinates that specify the building location, building use code, and number of building occupants (night and day). The other columns of the matrix contained the building damage state assigned to each building, for each of the ten runs. Table 2 details the damage state classification ranges from 1-5, with each state also corresponding to a range of expected time for re-occupation. Note that all buildings receive a Damage State of at least 1 for every model run (i.e. no 'non-damage' state).

Table 2: Building Damage States for RiskScape Model Runs

Damage State	Description	Expected Re-Occupation (days post-event)
1	Inspection and minor non-structural (fittings or services) repairs	1 to 7
2	Repairs to more severe non-structural damage	7 to 180
3	Repairable structural damage. Assessment and insurance delays, some buildings will be demolished and rebuilt rather than repaired	180 to 730
4	Non-repairable. Assessment, insurance negotiation, demolition, rebuild	730 to 1095
5	Building collapses	730 to 1095

A summary of the building damage states is provided in Table 3 below. Across all model runs, the number of buildings subject to damage state 5 (collapse) is generally low (0-3 buildings), while the number of buildings subject to damage state 4 (irreparable structural damage) varies quite significantly (ranging from 3 to 45 buildings). Run 1 exhibits relatively unusual results when compared to the other 9 runs, particularly in terms of many extra buildings subject to damage state 2 and a corresponding fall in the number classed as damage state 1. This could be due to this run sampling an extreme end of the vulnerability model distribution. Ideally, it would be optimal to include up to 1000 different runs to fully sample the probability distributions in RiskScape but due to the scope of this project and the need to pass this data on to MERIT, only 10 runs were included.

Table 3: Count of buildings by damage state for each RiskScape run of the Alpine-Wairau Fault scenario

Run	Damage State					Total
	1	2	3	4	5	
1	2,098	1,121	145	45	3	3,412
2	2,977	321	101	13	-	3,412
3	2,963	352	85	12	-	3,412
4	2,962	351	94	3	2	3,412
5	2,965	327	109	8	3	3,412
6	2,960	336	108	7	1	3,412
7	2,955	337	111	7	2	3,412
8	2,953	345	106	6	2	3,412
9	2,969	322	112	9	-	3,412
10	2,963	335	106	7	1	3,412

3.3 Stage 3: MERIT Modelling

MERIT (**M**easuring the **E**conomics of **R**esilient **I**nfrastructure **T**ool)[6] was initially developed in the 2012-16 MBIE funded Economics of Resilient Infrastructure (ERI) research programme by three partner organisations, M.E Research, Resilient Organisations and GNS Science. Further research and consultancy projects have since provided opportunities for ongoing development and application of this tool.

3.3.1 Background: Tasks Involved in MERIT Modelling

The core task faced in undertaking MERIT modelling is to translate descriptions of asset damage and other forms of physical disruption, derived for a specific disruption scenario or scenarios such as an earthquake event, into estimates of economic impacts. For the most part such information cannot be applied directly as inputs to an economic model. Instead, a variety of additional modelling steps, typically incorporating further information and assumptions are first undertaken to provide a set of time-dependent parameters that could be used directly as inputs to an economic model.

Figure 7 provides an example scheme of a MERIT modelling process undertaken recently for a Wellington Fault scenario (report currently unreleased). Arrows indicate where information flows between models (i.e. outputs from one model become an input to another model). Central to MERIT (and used in every modelling application) is a multi-sectoral, multi-regional, and fully dynamic economic model, termed the 'Dynamic Economic Model' (blue boxes) in the diagram below. This economic model is intentionally designed to imitate the core features of a Computable General Equilibrium (CGE) model. Unlike a typical CGE model, however, it is formulated as a System Dynamics simulation model using finite difference equations. This innovative extension is necessary to capture the transient nature of economic consequences following a disruption event. Further details of the economic model can be found in the technical report (Smith et al., 2016). Thus far, all

[6] www.merit.org.nz

MERIT applications have focused on reporting outcomes from the economic model in terms of impacts on GDP/ value added, although there is potential to also report other indicators which are either directly contained within the model or could be calculated from model variables. [7]

The nature and extent of the modelling necessary to generate inputs for the Dynamic Economic Model will vary depending on the information available and the questions under consideration. To date MERIT applications have primarily focused on the impacts of disruptions to *critical infrastructure* (i.e. roads, electricity, telecommunications, rail, ports, potable water, wastewater). Given that the core source of disruption examined in this project is building disruption, it is not necessary to undertake some of the infrastructure-related modelling that has occurred in other projects (e.g. the transport modelling shown in green boxes in Figure 7). Similarly, population relocation and tourism analysis are not a core focus of this project (e.g. grey and light blue models in Figure 7 not relevant).

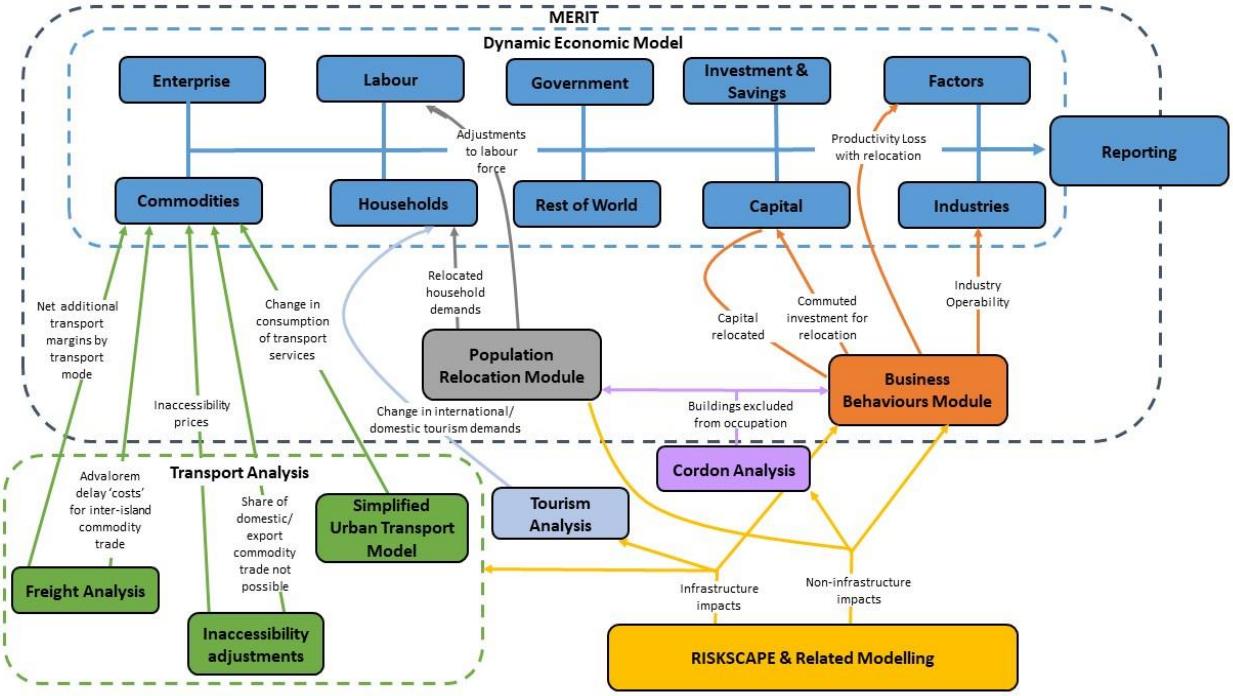


Figure 7: Example of a MERIT Modelling Scheme

To date, all MERIT applications have applied the Business Behaviours Module (BBM). It translates information on physical disruptions into estimates of industry 'operability' over time. Operability parameters vary between 0 (no operability) and 1 (non-disrupted or normal operability) and are closely related to the concept of productivity loss. When operability reduces to less than 1, industry output is scaled down from the level that might otherwise be expected from a given quantity of inputs to production. Importantly, the BBM is constructed mainly out of data from the Canterbury

[7] To assist in the conceptualisation, the mathematical procedures that make up the modelling process have been grouped into a series of 'models', some of which have underlying sub-components or 'modules'. For example, the Dynamic Economic Model is the core economic model constructed within the System Dynamics modelling language, and it is underpinned by several modules that cover Enterprises, Factors, Capital, Labour, and so on (see also Smith et al. (2016)).

earthquakes and as already discussed, the focus has mainly been on infrastructure damage.[8] It is also important to keep in mind that the structure and functions underpinning the BBM are designed to be generically applicable across all industries, rather than focused specifically on the nuances of the government sector. With this background, the core task for the MERIT modelling undertaken in this project is to design a new module or series of mathematical steps that, like the current BBM, can translate physical damage information into inputs for the economic model. The new module, termed the 'Government Organisations Module' can be considered an adaptation or extension to the BBM that addresses the following aims:

- *Propagation of uncertainty* –In this project we will seek to provide information on the potential *range of impacts* on government productivity, rather than provide a best guess of the most likely impacts. As outlined above, the RiskScape modelling provides some information on aleatoric uncertainty associated with an Alpine Fault event. For any given hazard event scenario, the model can produce a set of runs with differing outputs reflecting statistical uncertainty. A key goal of the Government Organisations Module will be propagation of this uncertainty through the equations that ultimately determine impacts on government productivity. Other key parameters incorporated in the Government Organisations Module are assigned probability distributions so that the associated uncertainty propagate through the module.[9]
- *Specifying disruptions from building damage* – For the Government Organisations Module the focus is specifically on the disruptions caused by interruptions in the ability to use buildings. We therefore sought to match specific government tenants with the RiskScape building stock and damage information. Fortunately for this project we have available the results of a recent survey of Wellington building occupancy (O. Filippova & N. Horspool, personal communication, 7 March 2018), as well as data from the New Zealand Government Procurement and Property (NZGPP) group under MBIE. The survey provides a list of all buildings in the Wellington CBD, including information about the tenants and space usage within the buildings.[10] The NZGPP data supplements this by also providing information on employee numbers at each location occupied by government agencies.
- *Incorporation of government-specific productivity implications and adaptations* – The government sector is relatively unique compared to other industry sectors in the economic model. Many of the functions of the government sector are of a public good nature, with sector 'outputs' not required directly as 'inputs' to production by other sectors. Also, while some government functions are time-critical, there also tends to be a relatively large

[8] The BBM does include consideration of non-infrastructure damage (e.g. disruptions to premises, neighbourhoods and staff). For earthquakes the levels of non-infrastructure disruptions are estimated based on ground shaking. To date no attempt has been made to consider how different building types (construction methods, materials etc) will also impact on the extent of premises disruption.
[9] Ideally, we would also do this within the Dynamic Economic Model, but the scale of the task is outside the scope of this project.
[10] Without this survey it would be very difficult to match buildings with occupiers classed according to specific industry groups. Although the RiskScape building attributes include a building use category, these are very aggregate groupings (e.g. 'commercial', 'residential') and only one use code is assigned for each building. Another option is to look at rating database information, but experience has shown it is difficult to match the use information to industry categories and furthermore the use categories are often inconsistently applied and infrequently updated.

component of activities that are relatively non time-critical. This provides some flexibility for adaptation measures that include reschedule and reprioritising. Another key feature is that some of the general market mechanisms for adapting to disruption supply of outputs from sectors (looking to alternative suppliers, increasing price to reduce demand) are not particularly relevant for the government sector. All of this has important implications for the way we seek to implement changes in productivity and adaptation responses in the economic model, and hence the parameters we seek to produce from the Government Organisations Module.

3.3.2 Structure of the Government Organisations Module

Overall the Government Organisations Module seeks to estimate how building damages alter the productivity of government staff. In other words, because government staff experience a disrupted working environment, the levels of production that can be achieved within an hour of work will be less than under normal circumstances. Interestingly, although the initial disruption is to capital stocks (buildings), the way we implement and model the economic consequences of the disruptions is focused on the labour implications.

From outside of the organisation, it may be the case that not all productivity losses caused by the building disruptions are apparent. This is because organisations implement adaptation measures that reduce the impact of the disruption. For example, staff may work harder and longer, an organisation may hire temporary contractors, or reschedule work to another time. Nevertheless, it is important to consider the full range of impacts immediately caused by the disruption, so that we can correctly assess the level of adaptation that occurs. Given that adaptation measures would not need to occur under normal circumstances, the costs of the adaptations are an important component of the overall economic impact.

The case studies undertaken during Phase 1 of this project highlighted that in addition to the disruptions driven by building damage, the ability of government organisations to undertake normal functions following an Alpine Fault event will also be highly influenced by the additional work that will be created for the government sector in responding to the event. This situation can be conceptualised as a fall in 'as normal' or BAU levels of productivity because organisations will be required to move resources away from normal functions to response functions. For the MERIT modelling no attempt has been made, however, to assess changes in government organisations functions and 'as normal' productivity due to the need to undertake response functions.[11]

The first step in the Government Organisations Module is to calculate the expected number of days each government organisation in the Wellington CBD are without a building or working in a temporary location (e.g. from home or sharing office space with another government organisation).

[11] In addition to the uncertainty associated with the types of response functions likely to be carried out by all government agencies, we do not have information on the specific community-wide damages likely to be encountered (particularly in the upper South Island) as a result of the specific Wairau rupture scenario and hence the extent of the disaster response required.

If we let $temp_{a,b}$ denote the number of days of temporary location for government agency a that normally (i.e. before the quake) resides in building b, it can be calculated as,

$$temp_{a,b} = \begin{cases} findtime_{a,b} & \text{for } findtime_{a,b} > 0 \text{ and } EMPLOY_{a,b} > 0 \\ builddowntime_b & \text{for } findtime_{a,b} = 0 \text{ and } EMPLOY_{a,b} > 0 \\ 0 & \text{for } EMPLOY_{a,b} = 0 \end{cases}$$

where $findtime_{a,b}$ is the number of days it takes agency a from building b to find and move to a new permanent location. $EMPLOY_{a,b}$ is the number of employees from government agency a originally working in building b, and $builddowntime_b$ is the number of days before reoccupation of building b is possible.

In turn, the elements $findtime_{a,b}$ are calculated simply by multiplying the expected number of days it would take an agency from building b to find a new location were it to be looking, $EXPFINDTIME_{a,b}$, by the variable $move_{a,b}$ which denotes whether the agency is indeed looking to move ($move_{a,b}$=1 when choosing to move and zero otherwise). Note that all parameters that are exogenous are denoted by capital letters:

$$findtime_{a,b} = EXPFINDTIME_{a,b} \times move_{a,b} .$$

An agency's choice to permanently leave a building depends on whether the expected time for reoccupation exceeds the time the agency is willing to wait for reoccupation ($MAXWAIT_a$). It is also assumed that agencies have foresight, so that the expected time for reoccupation is the same as the actual time for reoccupation, i.e. $builddowntime_b$:

$$move_{a,b} = \begin{cases} 1 & \text{for } builddowntime_b > MAXWAIT_a \\ 0 & \text{for } builddowntime_b \le MAXWAIT_a \end{cases} .$$

Finally, the number of days a building cannot be occupied is the maximum of number of days unable to be occupied due to direct damage to the building, $DIRECTDOWNTIME_b$, and the number of days a building cannot be occupied as it is cordoned due to its proximity to another damaged building, $cordontime_b$. The vector $CORDONON$ assigns a 1 to those buildings in a cordon and zero to all other buildings, while the vector $TCORDONTIME$ gives the number of days for a building cordon:

$$builddowntime_b = MAX\left(DIRECTDOWNTIME_b, cordontime_b\right)$$

$$cordontime_b = CORDONON_b \times TCORDONTIME_b .$$

Having determined the expected number of days each government organisation is subject to temporary accommodation; the **second step** is to calculate the effective employee hours of lost production due to building disruptions. The total hours of productive time lost for each day (t) after the event, $lostproductivetime_{a,}(t)$ is calculated as,

$$lostproductivetime_a(t) = \sum_b \left(HOURSPERDAY_a \times lostemploytemp_{a,b}(t)\right)$$

where $HOURSPERDAY_a$ is the average hours worked per employee in agency a during any day of the week. The variable $lostemployintemp_{a,b}(t)$ represents the number of effective employees lost while working in a temporary location during day t and is calculated as,

$$lostemployintemp_{a,b}(t) = (1 - prodindtemp_b(t)) \times noemploytemp_{a,b}(t)$$

$$prodindtemp_b(t) = 1 - 0.5^{\frac{t}{\alpha}} \times \beta \quad .$$

$$noemploytemp_{a,b}(t) = \begin{cases} EMPLOY_{a,b} & \text{for } t < temp_{a,b} \\ 0_{a,b} & \text{for t} \geq temp_{a,b} \end{cases}$$

The parameters α and β respectively represent the initial loss of productivity and the number of days for productivity to be half recovered (even when still working in temporary locations). Underpinning this formulation is the notion that productivity will return over time, even when organisations are working in temporary locations, due to the adaptations that will be put in place.

The **third step** of the module is concerned with assigning adaptation measures taken by government agencies to deal with the loss in effective employee time or productivity. For every hour of effective time lost, a proportion is assumed to be non-essential working time, the loss of which incurs no major consequences for the organisation (e.g. because unexpected events are to some extent part of normal activities and built into contingency planning). The proportion that is deemed non-essential for each agency is denoted by the parameter $NONESSENTIALRATIO_a$. Of the remaining lost time for each agency, it is assumed that a proportion, denoted by the parameter $IMMEDIATERECOVER_a$, will need to be caught up reasonably quickly by each agency, largely due to the time-critical nature of the services involved. Catch up will occur either through staff working harder and longer hours without extra pay, or by the agency paying overtime to staff or employing extra labour (either by contract or as additional staffing).

Overall, the unpaid extra time incurred by staff (measured in hours) to deal with short-term catch up after the disruption, $shortovertime_a(t)$, is calculated as,

$$shortovertime_a(t) = lostproductivetime_a(t-\delta) \times (1 - NONESSENTIALRATIO_a) \times IMMEDIATERECOVER_a \times IROVERTIMESH_a$$

Here the parameter δ denotes the average lag time (days) between lost time and when it is recaptured. Similarly, the hours of extra paid staffing required to deal with short-term catch up after the disruption, $shortpaidtime_a(t)$, is calculated as,

$$shortpaidtime_a(t) = lostproductivetime_a(t-\delta) \times (1 - NONESSENTIALRATIO_a) \times IMMEDIATERECOVER_a \times (1 - IROVERTIMESH_a) \times (1 + TEMPEFFECT_a)$$

The additional parameter $TEMPEFFECT_a$ is included to account for the fact that it may cost more/ require more hours to catch up if the work is undertaken by temporary or new staff (e.g. because of training, need to get up to speed and so on).

The balance of effective staff time lost is assumed to be recovered over the longer term. The Government Organisations Module simply spreads this extra staffing requirement over time, with parameter η_a denoting the day by which all is recovered. Once again, there is a share that is assumed to be made up by staff working unpaid, this time denoted by $LROVERTIMESH_a$.

3.3.3 Selection of Parameters for the Government Organisations Module

Table 3 provides a summary of the various parameters required for the new Government Organisations Module, and the values or probability distributions that have been assigned to each of these parameters for the purposes of the MERIT modelling. Note that although many of the parameters are structured so that different probability distributions can be applied to each individual government organisation, for the purposes of this modelling, all organisations have been assigned the same distributions for all parameters. It is possible that future work could look more closely at how the distributions may vary among different agencies. It is possible that such work would narrow the uncertainty in the overall outputs produced by the model. The building occupancy survey indicated that there are just over 100 different New Zealand government tenants located within buildings in the Wellington CBD. The identification of government organisations occurs through the ANZSIC industry use code assigned to each tenant. Central government and local government both have use codes beginning with 'OO'. We did, however, remove the local government tenants from our study population.

3.3.4 Running the Dynamic Economic Model

The Dynamic Economic Model is outlined in detail in other reports (e.g. Smith *et al*., 2016) and so only a brief description of the way the model is utilised for the scenario analysis, including the relevant input data or 'model shock', is provided here.

The first step in the analysis is to choose a single run from the Government Organisations Module that is a fair representation of the 'average' model run. We did this by taking model outputs for all 200 runs of the Government Organisations Module, specifically for the output variable that quantified the total extra number of hours required to be worked to recover losses in productivity (see Figure 8 below). We then calculated the mean result at each day over the first year following the event and selected the single model run with the smallest deviation from this series as the representative run.

The next challenge in the MERIT modelling is to decide which variables or parameters in the Dynamic Economic Model to alter in order to best simulate the system-wide implications of a change in government productivity. For this study we select the following:

Table 3 Parameters in the Government Organisations Module

Parameter Name	Description	Method for Derivation/ Assumptions/ Notes	Applied Distributions for Parameter
$EMPLOY_{a,b}$	Number of employees from agency a working in building b.	Estimated from floor area of tenancies and average numbers of employees per m^2	N/A
$EXPFINDTIME_{a,b}$	Number of days it would take an agency a from building b to find a new permanent location were it to be looking.	* There will be no movement for at least the first week * First month post event will be limited by access to building assessments for all buildings * Although it is likely that small agencies will move in less time than larger agencies, no attempt has been made at this stage to assign different distributions to agencies based on size	Absolute minimum time to relocate would be one week. 25% would relocate within one month. Median time to relocate = 3 months. 95% of government agencies will have relocated within one year
$MAXWAIT_{a}$	Maximum number of days agency a is willing to wait to reoccupy a building before choosing to instead find an alternative permanent location.	* For Damage State 2 and below, majority of organisations will not move * There is sufficient temporary accommodation * If an organisation chooses there is available space to relocate to * If government agencies are in long-term temporary accommodation their productivity will return to BAU levels. So long-term temporary accommodation is the same as 'permanent' relocation in terms of disruption to productivity * This may include organisations that choose to establish alternative working arragnmeents (online, working from home, etc) * 95% of government agencies would choose to relocate/establish alternative working arrangements if their building was going to be closed for 1 year or more * Will depend on whether agenices have specific ties to location. No attempt made at this stage to classify agencies into different groups based on location ties	5 percentile= 1 month, 95 percentile = 1 year, median = 6 months
$DIRECTDOWNTIME_{b}$	Number of days building b cannot be occupied because of direct damage.	* Derived from RiskScape damage states and the downtime assigned to each damage state	* Damage State 1: equal probability of 1 to 7 days * Damage State 2: beta distribution, median = 30 days, approximate minimum = 7 days, maximum = 180 * Damage State 3: beta distribution, median = 365 days, approximate minimum = 180 days, maximum = 730 days * Damage States 4 & 5: beta distribution, median = 800 days, approximate minimum = 730 days, maximum = 1095 days

Table 3 Parameters in the Government Organisations Module (continued)

Parameter Name	Description	Method for Derivation/ Assumptions/ Notes	Applied Distributions for Parameter
$CORDONON_b$	Value of 1 assigned to building b when located within a cordon, and zero assigned otherwise.	Buildings greater than or equal to three storeys and with a damage state of 4 or 5 identified. Buffer areas in proportion to 2.5m x number of storeys were created around these buildings. Any buildings intersecting these cordons were assumed to be subject to the cordon.	N/A
$TCORDONTIME_b$	Number of days building b is subject to a cordon because of location near to a severely damaged building.	* The time it takes to occupy is determined by the time it takes to demolish neighbouring building * Building in fall zone will be closed for length of time it takes for 'make safe' operations * Make safe operations could take about a year	The minimum closure time for buildings in the fall zone of another building is 365 days, the maximum closure for 95% of buildings is 1095 days, the mean is 730 days and the curve is normally distributed.
$HOURSPERDAY_a$	Average hours worked per day by an employee in agency a during any day of the week (Monday-Sunday).	* Assumed value of 5.58 for all agencies * Average hours per FTE is assumed to be 40/7 * Public Sector workforce data indicates 0.97 FTEs per employee	N/A
$NONESSENTIALRATIO_a$	The proportion of lost productive time for agency a that is non-essential and will not be recovered.	* Assume positively skewed distribution	Approximate minimum = 5%, approximate maximum = 80%, mean = 30%
$IMMEDIATERECOVER_a$	The proportion of lost productive time that will be prioritised for short term recovery (mainly time-critical functions).	* This will vary substantially for each organisation and a further sampling of government organisations is required to better understand the likely distribution	Minimum = 0%, maximum = 100%, median = 30%
$IROVERTIMESH_a$	The share of lost productivity that is recovered over the short term that will be recovered by staff working harder or longer (non-paid).	* Assume normal distribution	5 percentile = 20% 95 percentile = 30%
$TEMPEFFECT_a$	Percentage reduction in effective productivity of new/temporary staff compared to normal staff.	* Assume normal distribution	Minimum = 0, mean = 0.1, max = 0.2
$LROVERTIMESH_a$	The share of lost productivity recovered over the long term that will be recovered by staff working harder or longer (non-paid).	* Assume normal distribution	5 percentile = 5% 95 percentile = 10%
α_a	Initial loss of productivity for agency a. Can conceptualise as % reduction in effective hours per hour worked.	* Assume normal distribution	The minimum initial loss of productivity across all agencies is zero. The mean is 40% and maximum is approximately 80%.
β	The time (days) it takes for the initial loss of productivity to be half returned through general organisation adaptations.	* Assume normal distribution	Approximate minimum time to half return = 7 days. Approximate maximum time to half return is 60 days.
δ	The average lag time (days) between when productive time is lost and when it is recaptured.	* Assume 7 days	N/A
η_a	Day by which all lost work is recovered.	* Assume normal distribution	Approximte minimum = 30 days Approximate maximum = 365 days

Notes: Subscript a denotes government agency, while subscript b denotes a building.

- Wellington region's household income from provision of labour to the Central Government industry increases compared to the baseline. To ensure the value increase is consistent with the pricing utilised in base model, we translate all increases in hours worked to the relative increase in the *proportion* of government labour factor demanded.
- The additional costs of purchasing labour incurred by the Central Government industry depletes industry funds with a resulting change in capital income (i.e. not direct net change in value added for Central Government).
- It is assumed that additional 'within government' transfers will be needed to compensate for the extra spending on labour factors of production (implemented by adjusting the capital income account). To fund these transfers, it is also assumed that government shifts spending away from normal government consumption in the baseline scenario (i.e. depletion of government account that is allocated towards normal spending on healthcare, education, savings and so on).

Note that for the MERIT modelling, given the narrow focus on government sector productivity, and that the hazard impact scenario considers only impacts on buildings, we did not run other modules or components of the MERIT system (e.g., the Business Behaviours Model, Transport Analysis) to look at other wider economic implications of an Alpine Fault event scenario (e.g. disruptions to transport networks and other infrastructure in the South Island, potential infrastructure damages in Wellington and potential disruptions to all business activities, changes in tourism demands, funding and resourcing of repair and recovery).

3.4 Results: MERIT

This section of the report presents outputs from the MERIT modelling of the Alpine Fault scenario involving a rupture of the Wairau-extension. We believe it is informative to look separately at the results from the new Government Organisations Module, as well as from the Dynamic Economic Model itself. As the Government Organisations Module has been run many times, it provides some useful insights into the ranges of results that might be expected for the Alpine-Wairau scenario. It also provides some outputs indicators relating to non-market impacts (namely unpaid overtime) while the Dynamic Economic Model produces outputs relating only to the market economy.

3.4.1 Government Organisations Module

Figures 8 and 9 plot a series of outputs generated from the Government Organisations Module. To begin, Plots A and B in Figure 8 respectively summarise the total number of employees, and the share of employees, in Wellington CBD central government organisations that are working in temporary locations following the event. Note that although the Government Organisations Module calculates results daily, results are reported only at seven-day intervals for the first month, and at 28-day intervals thereafter. All 200 runs of the Government Organisations Module are also reported, so that it is possible to see the ranges in outcomes generated.

Initially, at day one after the event, all model runs report that the entire population of 28,000 government employees in the CBD (i.e. 100% of employees) are working at a temporary location.

This is because all buildings in the CBD receive a damage state of at least 1 where inspection of buildings is required. Over the next two weeks, the numbers of CBD employees in temporary working locations fall rapidly but are still at 13,000 or 46% according to the median of the model runs. By one month the numbers have fallen to 9,700 or 34% for the median, and for three months the figures are 5,700 or 20%. At six months the equivalent figures for the median run are 1,500 or 5%.

On first inspection these results may seem high, given that across the RiskScape runs the mean percentage of buildings in the CBD impacted by a damage state of 2 or more is only 15% (Table 3), and that buildings of damage state 1 are assumed to be able to be reoccupied within one week following inspection. It is important to note, that there was significant built environment disruption in Wellington caused by the Kaikoura earthquake, which had substantially lower levels of shaking than the projected shaking caused by an Alpine-Wairau fault rupture. An estimated 11% of Wellington's office space was closed due to damage in the month after the earthquake and there were two extended cordons affecting a total of 7 city clocks in Wellington CBD and Lower Hutt (Ellwood et al., 2016). It is also important to keep in mind that the modelling incorporates buffer areas or cordons placed around buildings of damage states 4 and 5, and the assumed length of time of these cordons is relatively long. Interestingly, for all RiskScape runs, the number of government employees impacted by these cordon areas is higher than the number of employees impacted through occupancy of buildings directly impacted (the mean across the RiskScape runs is 31% of government employees in the CBD impacted by cordons). Even accepting that relatively broad-brush assumptions have been used in the modelling of these cordon areas (see Table 3) and the resulting impacts created, this does serve to highlight that for government continuity planning there is strong importance not only in the structural resilience of buildings directly occupied by government staff, but also the neighbouring buildings, as these also have significant potential to create disruption. Furthermore, both the cordoning rules and the speeds at which damaged buildings are demolished or otherwise addressed to remove neighbourhood risks, are also likely to have quite significant impacts on the level of disruption experienced by government organisations (and also other agencies) following an event.

The next two plots in Figure 8, i.e. plots C and D, quantify the losses in government productivity due to employees not being as productive following building disruptions. Here productivity losses are measured in the effective loss of 'as normal' employee hours. Note that we are measuring the initial losses caused by the disruption, and not the final losses in production after adaptation measures take place to recover lost production (e.g. working longer hours).

At day seven after the event the losses in productivity vary quite substantially between the model runs, ranging from 44,000 hours per day to 80,000 hours per day with a median of 62,000 hours per day. At 8 weeks or approximately two months after the event, the equivalent calculations are 9,000 – 23,000 hours per day (median 15,000), and three months 1,200 – 9,000 hours per day (median 3,800). Summing over all days for the first year after the event, the total losses in hours are calculated across the 200 model runs as ranging from 1.56 to 2.57 million hours, with a median of 1.98 million hours (25 percentile = 1.83 million, 75 percentile =2.13 million).

The series of plots in Figure 9 now quantify the adaptation measures taken by government organisations to recover losses in productivity. As outlined in the sections above on the Government

Organisations Module, it is assumed that there will be some recovery of time for which the costs will be borne entirely by employees simply through working extra time or harder, without corresponding extra remuneration. The module calculates that these effects will be greatest just over one week after the event, for example, around 6,940 extra hours per day under the median run (Plot A). This is associated with the need to play catch-up on those government functions where timeframes for delivery are highly important. At around three months after the event the additional non-remunerated hours falls to less than 500 hours per day for the median run, reflecting not only that the level of disruption has reduced, but also that the hours being recovered are less time critical and are able to be more thinly spread over time.

Plot B in Figure 9 records the number of additional paid employee hours generated to recover productivity, as calculated by each of the 200 model runs. Like other plots, results are recorded at weekly and then monthly time slices. On this plot we have also included the median model run, indicated by the orange markers and a ‘best fit’ line. We have chosen to highlight this median run as it is this data that is used as an input to the MERIT Dynamic Economic Model. Under this median run, the total additional number of paid employee time is around 21,000 hours per day shortly after the event and is maintained at higher than 10,000 hours per day for the entire first month after the event. By around 8-9 months the daily extra time falls to around 1,000 hours. For the entire first year after the event, and over the set of 200 hundred model runs, the total additional time required to be worked ranges from 0.71 to 1.47 million hours, with a median of 1.10 million hours (Plot D).

3.4.2 Dynamic Economic Module Simulation

In this section of the results we report on the outputs from the simulation of the Dynamic Economic Model, utilising the single selected median run from the Government Organisations Module as the relevant input data.

To begin, Table 5 records the cumulative impact on Gross Domestic Product (GDP) at three categories of spatial aggregation: Wellington Region, rest of New Zealand, and total New Zealand. Note that all impacts are measured according to the difference from the baseline run of the model (i.e. simulation under normal conditions). The most obvious conclusion is that the results at the national level are only very small, i.e. the absolute impact is less than $1 million over the first two months, over six months there is a relatively small cumulative change of $1million in GDP, and over the entire first year the absolute impact is back down to less than $1 million. The relatively small changes reflect that to a large extent the outcomes are transfers in income and spending from one agent to another. Although the additional labour costs faced by government means that there are fewer funds available to spend elsewhere, there is also a compensatory effect whereby households (as providers of labour resources) receive greater labour income and hence increase spending. Spending by both agents has flow-on effects throughout the economy, and the model records the net changes that occur once all of these positives and negatives are taken into account.

When we look at the sub-national results we can see that transfers occur within the country. Overall, during the first year after the event, Wellington GDP increases by $11 million, but conversely GDP for the rest of New Zealand decreases by $11 million. Table 5 also provides more information on the impacts and transfers occurring at the level of specific industries. The largest losses occur in the aggregated industry ‘government, education, and health’ in the rest of New Zealand. This reflects

that it is expenditure on services from this industry group from which the largest pool of public funding has been withdrawn. Although extra household income will also create additional demands for these services, most of this additional income is concentrated in the Wellington region.

Figure 8: Impacts of building disruptions on productivity of Wellington CBD Central Government organisations

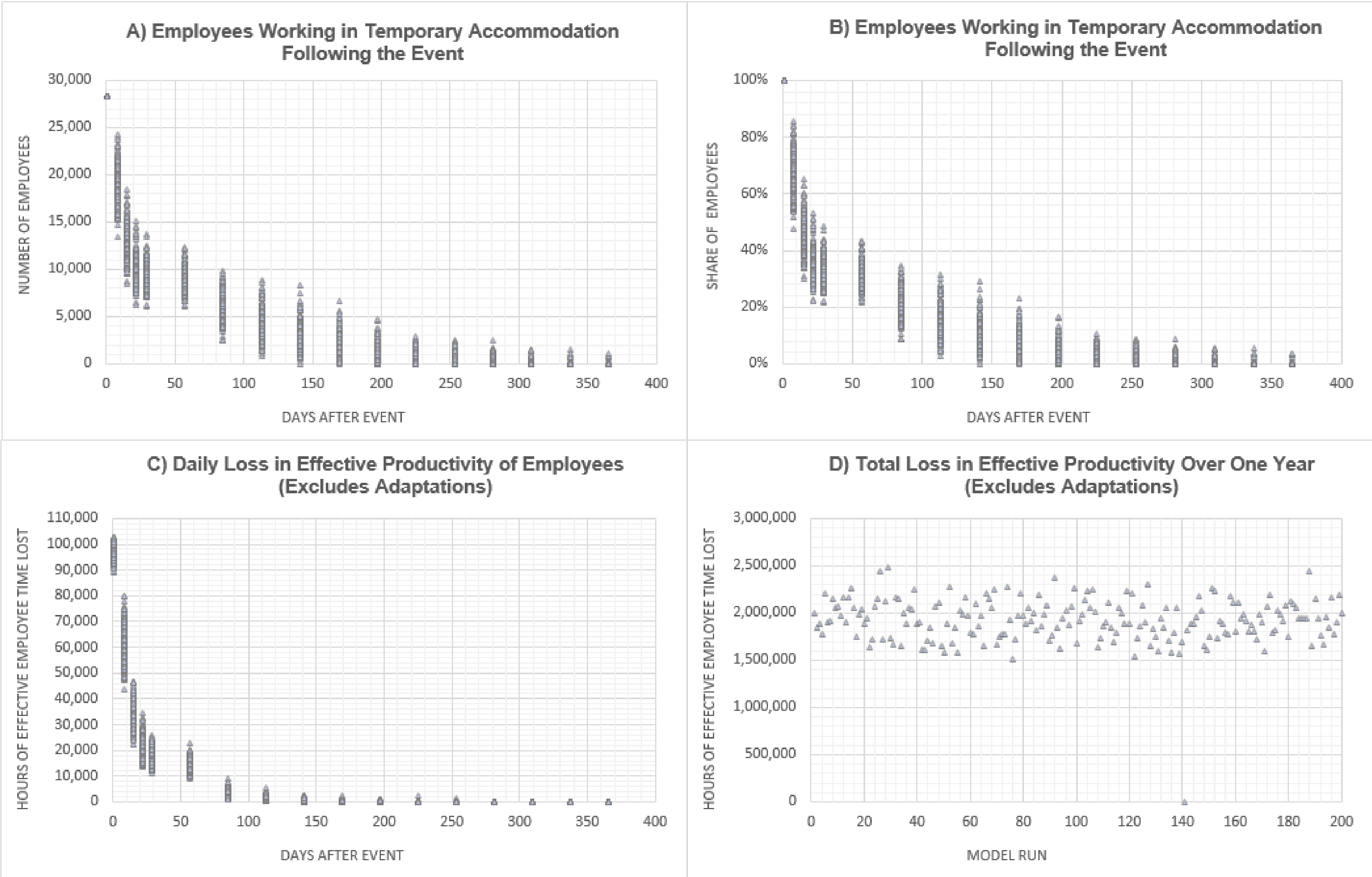
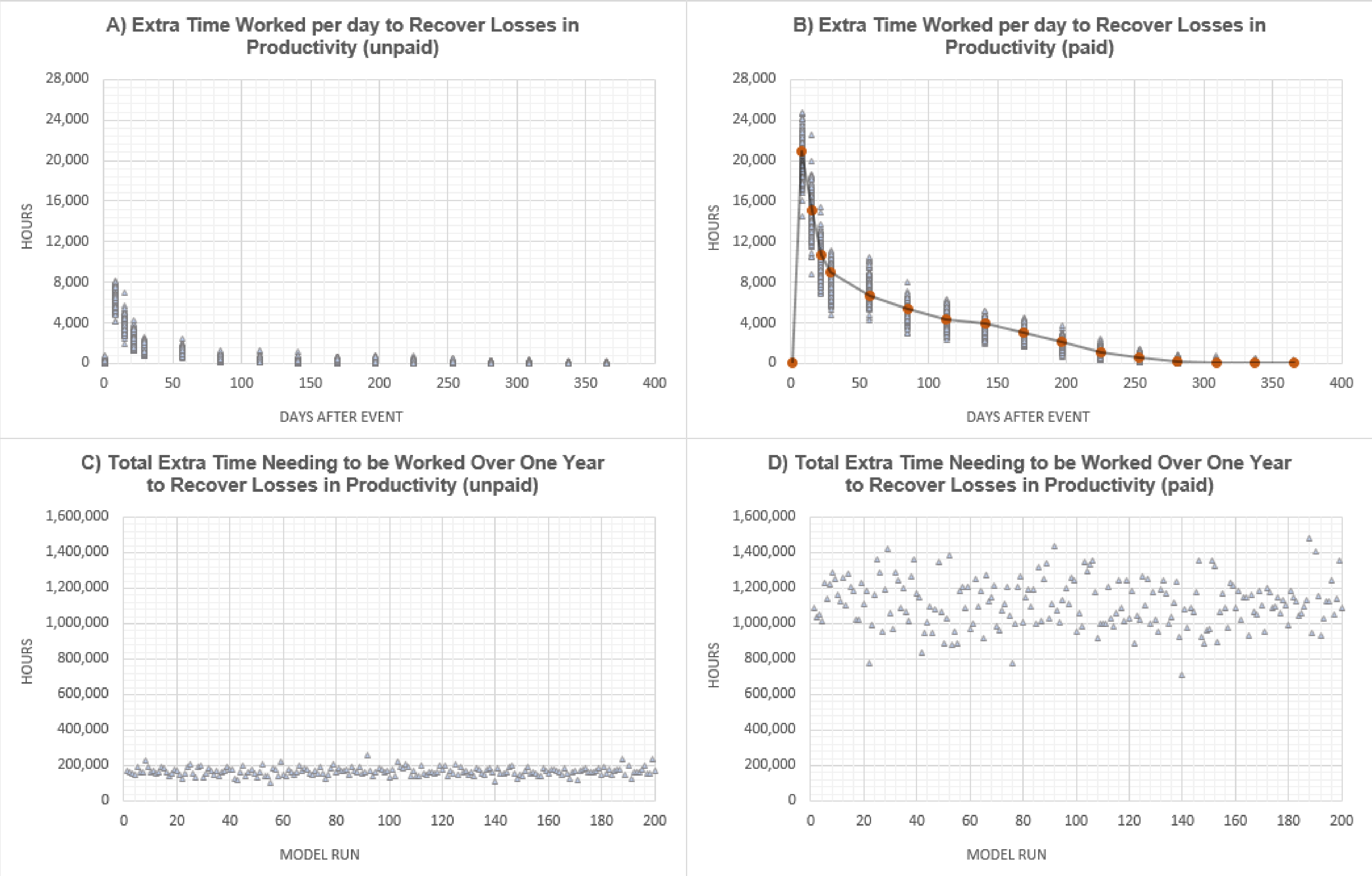


Figure 9: Costs to recover productivity for Wellington CBD Central Government organisations



Notes: For Plot B, no account is taken of the extra time it may take temporary/new/overworked staff to undertake tasks compared to normal staff (i.e. TEMPEFFECT =0)

Table 4: Impacts on Gross Domestic product[12]

Region	Cumulative Net Change in GDP from Baseline Scenario ($mil)			% change in GDP	
	2 months after event	6 months after event	1 year after event	0-6 months after event	6 months - 1 year after event
Wellington	3	9	11	0.1%	0.0%
Rest of New Zealand	-3	-8	-11	0.0%	0.0%
Total New Zealand	0	1	0	0.0%	0.0%

Table 5: Accumulated loss of industry value added ($mil)

Industry	2 Months			6 Months			1 Year		
	Wellington	Rest of NZ	Total NZ	Wellington	Rest of NZ	Total NZ	Wellington	Rest of NZ	Total NZ
1 Agriculture	0	0	0	0	0	0	0	0	0
2 Other primary	0	0	0	0	0	0	0	0	0
3 Manufacturing	0	0	0	1	0	0	1	0	0
4 Utilities & communications	0	0	0	1	-1	0	1	-1	0
5 Construction	-1	1	0	-1	2	0	-1	1	0
6 Trade and hospitality	1	0	1	2	-1	1	3	-1	1
7 Transport & storage	0	0	0	0	0	0	0	0	0
8 Financial & business services	0	0	0	1	-1	1	1	-1	1
9 Government, education and health	0	-2	-2	1	-4	-4	1	-6	-5
10 Other services	0	0	0	1	-1	0	1	-1	0
Other GDP components	1	-1	1	3	-2	1	4	-2	2
Total	3	-3	0	9	-8	1	11	-11	0

One limitation to keep in mind when interpreting these results is that we have assumed in the modelling that additional labour will be available to provide catch up on lost productivity. Due to the way we have shocked the model we have also not considered how the additional demands for labour may impact on other sectors (e.g. by increasing the general wage rate).[13] It is however possible that the gains for Wellington by additional demands for labour will be to some extent reduced by the pressure this puts on labour resources (this is often called "crowding out" impacts in economic modelling).

[12] All values reported for the MERIT Dynamic Economic model are in 2016 prices reflecting that the latest updates of price indices in the model.

[13] One reason for not considering supply constraints and price dynamics is that we were unable to determine the likely proportion of extra hours worked that is undertaken as overtime versus new/additional staff. Additional overtime worked is a relatively unusual situation where both supply for and demand of labour factors increase.

4.0 Discussion

In this final section of the report we highlight a few key points for discussion and further reflection:

- **Purely hypothetical event**: The event that has been modelled is hypothetical and highly stylised. Following the experience of the recent Kaikōura quake, we have focused this study on the impacts of building damage on government productivity. Nevertheless, it is worth noting that the scenario event itself (i.e. Alpine fault event including rupture on the Wairau extension) produces quite substantial shaking and damage. It is quite likely that there will be damage to other built environment services necessary for a well-functioning economic system. Although we have focused on buildings, a resilient economy needs mechanisms to adapt and deal with all these potential disruptions (including reducing the probability of occurrence where possible).
- **Economics and Systems-Analysis**: Our MERIT analysis and modelling has helped to illustrate the counter-balancing relationships that exist in economic systems, and that sometimes, indicators drawn from a system-wide analysis can provide counter-intuitive results. In this scenario analysis of a rupture event on the Wairau (Alpine) fault, the economic modelling has actually produced an overall neutral impact on GDP. Although a key outcome of the building disruptions is that the government organisations must fund additional labour to recapture lost productivity, and this depletes funds available for 'normal' government expenditure, from the perspective of net changes in GDP this is generally compensated by the fact that households receive additional income from their provision of additional labour. Additionally, because the funding of additional labour is ultimately sourced from all over New Zealand, there are differences in impacts at a regional level, with Wellington receiving a net increase in incomes and GDP, and the rest of New Zealand a net loss. We should however note a qualifier in that we have not included any consideration of supply-side constraints on labour resources in the MERIT modelling, and therefore positive gains produced by the modelling may to some extent be over-estimated. Furthermore, the temporary interruption in supply of government services may also have other flow-on impacts to the wider economy which are not captured, as is discussed further in the next bullet point.
- **Distinct Characteristics of the Government Sector**: A focus in this project has been on the distinct nature of the government sector, and how interruptions in the provision of government services may produce different economic outcomes when compared to disruptions in the provision of goods and services from other sectors. In our 'standard' economic modelling of other sectors, when there is a disruption in the ability to provide goods and services the relevant sector or sectors will face a loss of sales and a direct loss in GDP/Value added. At a system wide level there will also be a shift in demand for equivalent services provided from other regions and even from overseas. Furthermore, there will be some compensatory effects in that shortfalls in supply will raise relative prices for remaining goods/services. In the case of the government sector, however, we generally take a different approach: 'sales' of services and incomes generated do not fall despite the lack of supply.

Also, 'sector output' does not get sourced from alternative suppliers as this is generally not possible. As a corollary, the impacts on GDP are relatively minor. We do however, wish to acknowledge that there are likely to be impacts from interruptions in the supply of government services that are not captured by our modelling. Certainly, the government sector provides many economic benefits, such as reducing transaction costs from conflict, helping to reduce market failure through the provision of public goods, promoting efficiency gains and so on. Nevertheless, the nuanced nature of the role of government services in the economic system, and the difficulty in quantifying cause-effect relationships makes it extremely difficult to model how losses in provision of government services will impact on GDP and related metrics. We have therefore not attempted to do this in our MERIT modelling, focusing instead on the transfers in funding required to recapture productivity.

- **GDP/Value added versus other metrics.** Indicators such as GDP and value added are common in economic impact assessments. As is shown by this study, they can provide a helpful 'lens' with which we can start to envisage the system changes that may occur following an economic disruption. Nevertheless, these are not the only indicators available. A full consideration of welfare implications is likely to require other considerations and metrics. As an illustration, one of the possible outcomes demonstrated by this study of a fault event impacting Wellington is that there will be compensatory reductions in provision of normal government spending, e.g. on health care, education and so on. Although GDP impacts may be relatively neutral, welfare impacts may be quite high. Indeed, by its very nature, the government sector tends to be involved in the provision of goods and services that are poorly priced in markets relative to their social welfare benefits. Hence changes in GDP/value added from the education/ health sectors are not necessarily the best way to conceptualise the impacts that occur. On a related note, many of the functions provided by government are time-critical (e.g. welfare payments) and the welfare implications of lags in supply will not be well-captured by the typical metrics. Additionally, we have explained that a likely outcome of the disruption is employees facing unpaid additional work, and the related losses cannot be captured in GDP/ value added metrics. One recommended area for advancement of MERIT modelling is to extend the range of output metrics possible. It would be helpful to also include more-comprehensive welfare metrics, that for example include some consideration of time-loss impacts and changes in relative distributions of incomes.

5.0 Conclusions & Future Work

This multi-stage project combined focus group and case-study data with RiskScape hazard modelling outputs and Wellington building surveys and government property data to model the possible impacts of an Alpine Fault rupture on government productivity. Through this research the Government Organisations Module was developed and run as part of MERIT, allowing us to quantify the impact of a significant disaster event on government productivity and the propagation of those disruptions through the New Zealand economy. The results demonstrate that although such an event would cause significant disruptions to the operations of government agencies in terms displacement and labour hours lost, the impact on New Zealand's GDP is minimal. This work is a first attempt at quantifying the impact of a significant earthquake event on New Zealand's government productivity, and we note a number of areas for ongoing development below.

A significant challenge of this study was to develop a system that suitably translates information and relationships identified for individual case studies, into a framework that can be applied at the whole-of-government-sector level. The parameters included in the Government Organisations Module could be refined by more extensive data collection across government agencies. For example, future iterations of the module may be able to capture supply constraints and price dynamics affected by changing labour inputs.

In this study, we undertook multiple runs of the RiskScape and MERIT models helped to capture and communicate the likely variation in potential results. Unfortunately, developing uncertainty quantification abilities within the MERIT modelling system was outside the scope of this study, but there are plans in place to develop these extensions. One such extension could, for example, involve developing Mote Carlo techniques across the RiskScape-MERIT models to allow for better integration between the models and quantification of uncertainty in model outputs. In this study, we attempted to overcome that limitation by undertaking several model simulations, each time involving a different set of RiskScape results (i.e. model runs).

Following a disruption many government organisations will be called on to perform extra tasks that are critical to recovery. Thus, losses in productivity can potentially occur at a time when it is most important for government organisations to be operating fully. Capturing these implications in MERIT simulations is complex, not from a technical point of view but because of significant uncertainties around the exact cause-effect chain between changes in the provision of government response functions and economic recovery. These types of uncertainties are likely to be best addressed through 'what-if scenarios'. This would entail developing plausible narratives around how changes in government response functions impact on key drivers of recovery that are also 'levers' in the MERIT models. For example, we can adjust rates by which infrastructures can be reasonably restored (i.e. changes in infrastructure outages), or changes in business recovery (i.e. changes to operability curves).

Finally, we were unable to quantify the impact of disruptions to third party suppliers, which could be a significant source of disruption following a major earthquake. The development of a generic method for assessing the implications of supply disruptions is an important topic for research in modelling the economic consequences of disruption. In real world economic systems, many thousands of

transactions occur every day between economic activities; goods and services that may be critical to some operations may not be to others. To make matters more complicated business will have in place some measures that mitigate against disruptions, such as inventories in the case of manufacturers; however, the nature and level of such measures is likely to vary between businesses.

Supply-side impacts are not currently included in the MERIT Business Behaviours Model which calculates impacts of industry productivity, taking into consideration business adaptations. The incorporation of supply-side disruptions has, to date, been approached on an ad-hoc basis, with adjustments in productivity where disruptions that have significant impacts on production are identified. The project team had hoped that the Kaikoura event would provide some data and other information to expand the modelling of supply-side disruptions, potentially assisting in the move towards a genetic type of modelling approach. As it turned out, supply side impacts were not identified as significant across the organisations surveyed, apart from IT impacts for one organisation. We suspect that this may reflect, in part, the relative size of the Kaikoura event. We therefore note that the inclusion of supply side impacts on organisations' productivity remains an important topic for further research.

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