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DISRUPTION OF CRITICAL INFRASTRUCTURE DURING PROLONGED NATURAL DISASTERS

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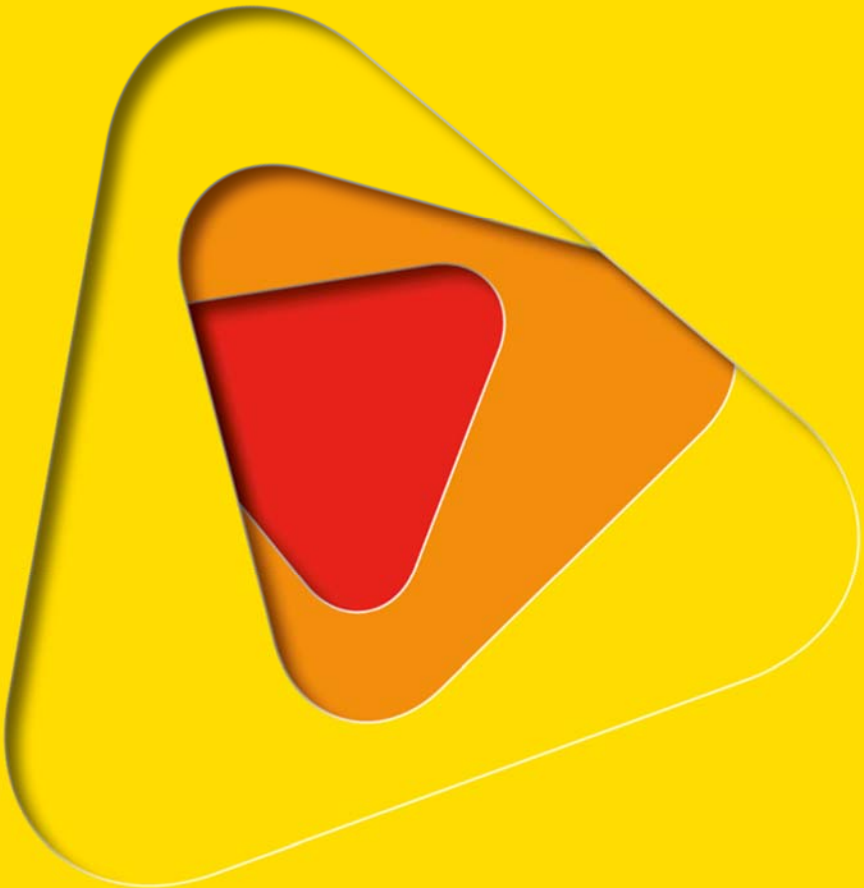

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ABSTRACT

Recent events such as the 2010 and 2011 Canterbury earthquakes, New Zealand; 2009 Southeast Australia heatwave; 2010 eruption of Eyjafjallajökull volcano, Iceland; and the 2011 Tohoku earthquake, tsunami and nuclear disaster in Japan, have highlighted the vulnerability of infrastructure and essential services to long-term disruption from prolonged and complex natural disasters. Prolonged natural disasters can impact surrounding areas for weeks to months after the initial event, causing vast and on-going disruption to utility, transport and communication networks; infrastructure that is vitally important for everyday living, the economy and emergency response. The quake-stricken Canterbury region of New Zealand endured thousands of disruptive aftershocks that continued for over two years following the initial earthquake in 2010. These aftershocks contributed to delays in repair and rebuilding, and caused significant additional damage. Our growing reliance on infrastructure and technology, along with the strong interdependent nature of these critical services, can potentially turn one failure into a cascading disaster. Local impacts to critical infrastructure can also lead to the interruption of essential services in regions that were not directly impacted by the physical hazard event. It has never been more important to understand network vulnerabilities and to analyse the cost of long-term disruption, both social and economic. Whilst significant work has gone into understanding the direct impacts from natural hazards, less emphasis has been placed on understanding the vulnerability of critical infrastructure, including indirect and long-term disruption.

INTRODUCTION

Lifeline networks are the critical infrastructure and essential services that we rely on for day-to-day living, economic output and emergency response. These include, transportation, telecommunication, power and water networks. Continuing increases in population and urbanisation puts increasing pressure on these essential services. With this comes a growing reliance on infrastructure and technology, some of which has strong interdependencies, meaning one failure could potentially turn into a cascading disaster. Lifeline networks are particularly vulnerable to disruption from natural hazards and recent events around the world, including Australia and New Zealand, have highlighted this:

- In June 2014, Northland was hit by a severe storm; strong winds impacted the area and much of the North Island of New Zealand. At the height of the storm, there were over 90,000 power outages across Auckland and widespread power cuts in Tauranga, South Waikato and Coromandel; 30,000 residential and business customers lost power (NZ Newswire, 2014a). Most of the damage was caused by trees falling across lines, which the Electricity Networks Association (ENA) stated affected all suppliers (NZ Newswire, 2014b). Most power was restored the next day, but some residents were without hot water for up to a week (MediaWorks TV, 2014).
- In May 2014, Darwin airport was closed for around 24 hours after an ash cloud from Sangeang Api volcano in Indonesian blew over the Northern Territory. All flights in and out of Darwin were cancelled and flights around the country bound for Bail were also disrupted (Dmytryshchak, 2014).

Although disruptive, and not without cost, these events were relatively short lived and functionality was restored within days. However, this research project is particularly interested in prolonged and multi-hazard events.

A prolonged event is defined in this study as a natural hazard event with an extended duration (a week or more) or a series of events that occur in quick succession. The 2009 Southeast Australia heatwave and 2010 volcanic eruption in Iceland would therefore be classified as prolonged natural hazard events:

- The January/February 2009 southeast Australia heatwave caused localised power outages of various lengths throughout Adelaide and Melbourne over a period of 16 days (Australian Bureau of Statistics, 2013). On the 30th January nearly 500,000 residents in Melbourne City, northern suburbs, Geelong and western Victoria were without power (ABC, 2009). This loss of power resulted in evacuations from the Crown Casino and the Victorian Arts Centre, traffic light failures, and people requiring rescue from lifts. Train and tram services in Melbourne were cancelled not only due to the power outages, but also due to buckling of rail lines and air conditioner failures (McEvoy et al., 2012; ABC, 2009). As at 1 February 2009, the heatwave was estimated to have cost the Victorian economy $100 million (Houston and Reilly, 2009).
- The 2010 eruption of the Eyjafjallajökull volcano, Iceland, caused extensive air travel disruption due to a seven day closure of large areas of European airspace, affecting the travel arrangements of hundreds of thousands of people. This affected economic, political and cultural activities in Europe and across the world and resulted in an estimated total loss for the airline industry of US$1.7 billion (IATA, 2010).

A multi-hazard event is defined as an event that is associated with additional or secondary hazards (e.g. earthquakes causing liquefaction, landslides, fires and tsunami):

- The Canterbury region of New Zealand endured thousands of disruptive aftershocks that continued for more than two years following the initial 7.1 quake in 2010, including the M6.3 quake in February 2011 that killed over 180 people. Larger earthquakes in the sequence triggered soil liquefaction and rock falls, which caused widespread power outages, the disruption of wastewater services, the closure of the international airport and damage to roads and bridges. These additional hazards disrupted rescue and rebuilding efforts (Parker and Steenkamp, 2012). ANZ chief economist Cameron Bagrie estimated that it will take the New Zealand economy 50-100 years to fully recover (MediaWorks TV, 2013).

Prolonged and multi-hazard natural disasters are of interest as they can cause vast and on-going disruption to utility, transport and communication networks, which are critical services for rescue and recovery. While various network vulnerability models have been developed (Murray, 2013; Moon and Lee, 2012), most models were not created specifically to look at shocks from natural disasters, and certainly not prolonged and/or multi-hazard events. There is currently a lack of comprehensive modelling to investigate indirect and on-going lifeline network disruption from complex natural disasters. Therefore, the aim of this project is to describe and quantify the impacts of prolonged and multi-hazard natural hazard events on lifeline networks and to also understand the interconnectedness of these critical services. Key research questions include:

- How does the interconnectedness of critical services lead to a cascade of failures?
- What influences network recovery and how long can they take to rebuild?
- How long can impacts from a natural hazard event remain and what is the cost of long-term network disruption?
- What scenarios could generate a potentially catastrophic disruption in the future?

This project has been partially funded by the Bushfire and Natural Hazard Cooperative Research Centre and is linked with the project “Using realistic disaster scenario analysis to understand natural hazard impacts and emergency management requirements” in the “Scenario and Loss Analysis” cluster. This project will develop realistic disaster scenarios utilising catastrophe loss models to identify vulnerable areas, utilities and assets within major Australian cities. As well as helping to create a better understanding of the implications of potential long-term lifeline network disruption, key outputs of this study will include:

- Review of key historical Australia, New Zealand and international natural disasters and the impact they had on lifeline networks
- Review of existing network vulnerability models
- Development of new approaches to quantify network vulnerability

PRELIMINARY STUDY – LATROBE VALLEY EARTHQUAKE

One example of a potential disaster that Australia could face is a damaging earthquake in the Latrobe Valley, Victoria, where ~80% of Victoria's energy is generated. The Latrobe Valley is located over the Morwell Hotspot earthquake source (Burbidge and Leonard, 2011) and is one of the more seismically active regions in Australia. Numerous historical earthquakes have been recorded in this region, the latest event being the Moe earthquake sequence that began with a 5.4 magnitude earthquake 10 km south of Moe, near Thorpdale, on 19th June 2012. Based on the earthquake source model defined in Burbidge and Leonard (2011), the most likely scenario for a damaging earthquake in the Latrobe Valley would be a magnitude 6 earthquake within the Morwell Hotspot.

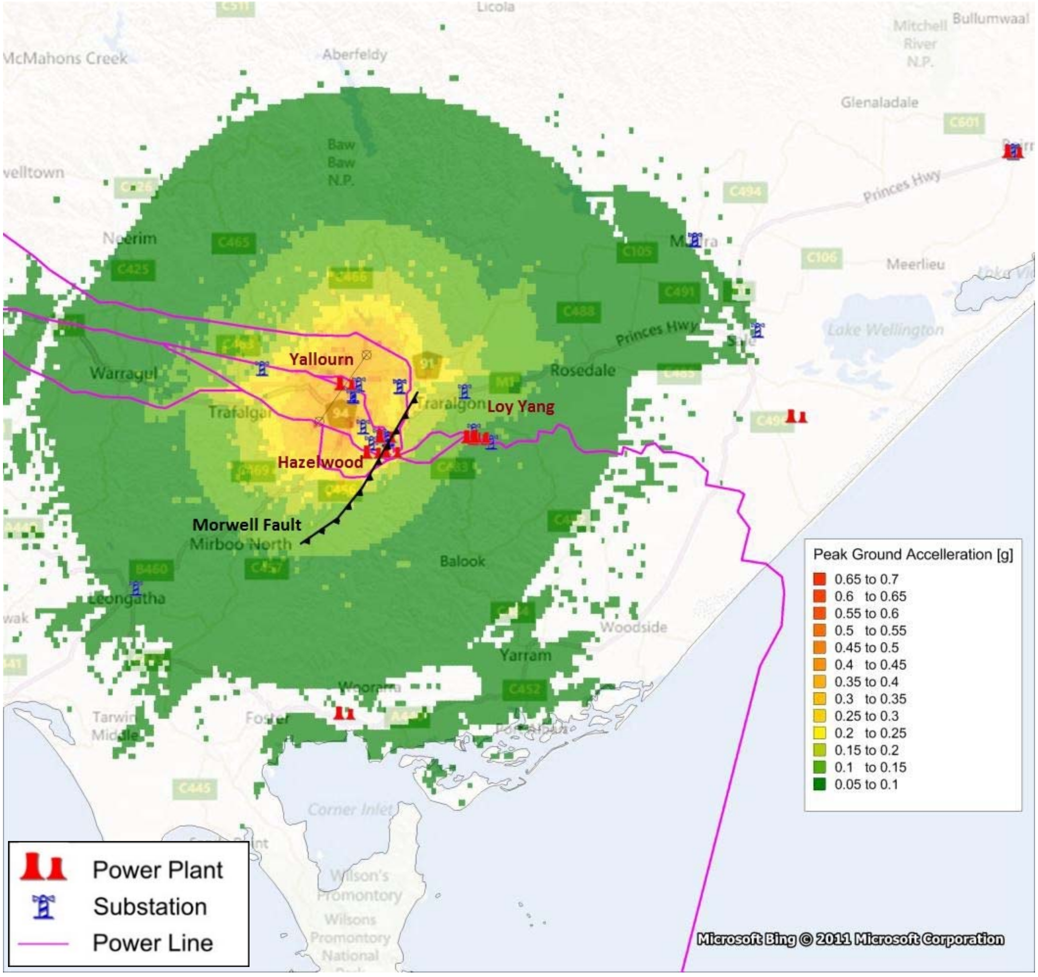

Figure 1: Peak ground acceleration in units of gravitational acceleration (g) for a M6.0 earthquake scenario along the Morwell Fault in the Latrobe Valley, VIC, and locations of main power infrastructure.

A preliminary scenario modelling exercise was commissioned by the Victorian Country Fire Authority (CFA) for emergency response planning purposes. The scenario we considered was a M6.0 earthquake occurring on the Morwell Fault (Figure 1). Loss and damage estimates were made from the ground shaking map shown in Figure 1, which was based on a ground motion prediction equations for bedrock conditions and took into account the quantifying efforts of the overlying soil. Losses to property and infrastructure were calculated using the methodology developed by the US Federal Emergency Management Agency (FEMA), through the HAZUS model. This methodology is based on deriving statistical models for a functional relationship between physical earthquake parameters such as peak ground acceleration (PGA), velocity (PGV), displacement (PGD) and response spectrum and a building's response to shaking.

Six power stations (Yallourn, Hazelwood, Jeeraland, Loy Yang A, Loy Yang B and Valley Power) could potentially be impacted by a M6.0 earthquake along the Morwell Fault. The HAZUS model defines four types of damage states (slight, moderate, extensive and complete damage) for generation plants and the probability of damage (Table 1). See Table 2 and Figure 2 for estimated PGA at each power station and the probability of damage.

If any number of these power stations, their substations and/or the power lines supplying the State were damaged, there would undoubtedly be major disruption and wide-spread impacts. A significant seismic event in this region could potentially impact infrastructure that is responsible for producing 90% of Victoria's required electricity. The true impact of a major power failure in Victoria cannot be fully described without understanding the ability of emergency services to conduct rescue operations with limited power supply; the length of time Victorian businesses will be able to operate without electricity; and the capacity of peaking facilities throughout the State to restore power to the grid in case of a major power failure.

Table 1: HAZUS definitions of damage states for generation plants

Damage state	Damage to generation plants
Slight/Minor Damage (ds_2)	ds_2 is defined by turbine tripping, or light damage to diesel generator, or by the building being in minor damage state
Moderate Damage (ds_3)	ds_3 is defined some by the chattering of instrument panels and racks, considerable damage to boilers and pressure vessels, or by the building being in moderate damage state
Extensive Damage (ds_4)	ds_4 is defined by considerable damage to motor driven pumps, or considerable damage to large vertical pumps, or by the building being in extensive damage state
Complete Damage (ds_5)	ds_5 is defined by extensive damage to large horizontal vessels beyond repair, extensive damage to large motor operated valves, or by the building being in complete damage state.

Table 2: Estimated PGA at power station site and each power station's contribution to power production.

Power station	PGA (g)	Power generation
Yallourn	0.36	supplies approximately 22 percent of Victoria's electricity needs and approximately eight percent of the National Electricity Market (NEM) (EnergyAustralia, 2014).
Hazelwood	0.26	supplies between 20 and 25 percent of Victoria's energy requirements and 5.4 percent of Australia's energy demand (GDF SVEZ Australian Energy, 2014a).
Jeeralang	0.21	The station is a peaking facility which is utilised only during periods of peak demand, it is also used as a black start facility to restore power to the grid in the event of major system failure.
Loy Yang A	0.1	Supplies approximately 30 percent of Victoria's power requirements (AGL, 2014).
Loy Yang B	0.09	supplies about 17 per cent of Victoria's energy needs (GDF SVEZ Australian Energy, 2014b).
Valley Power	0.09	Peaking facility

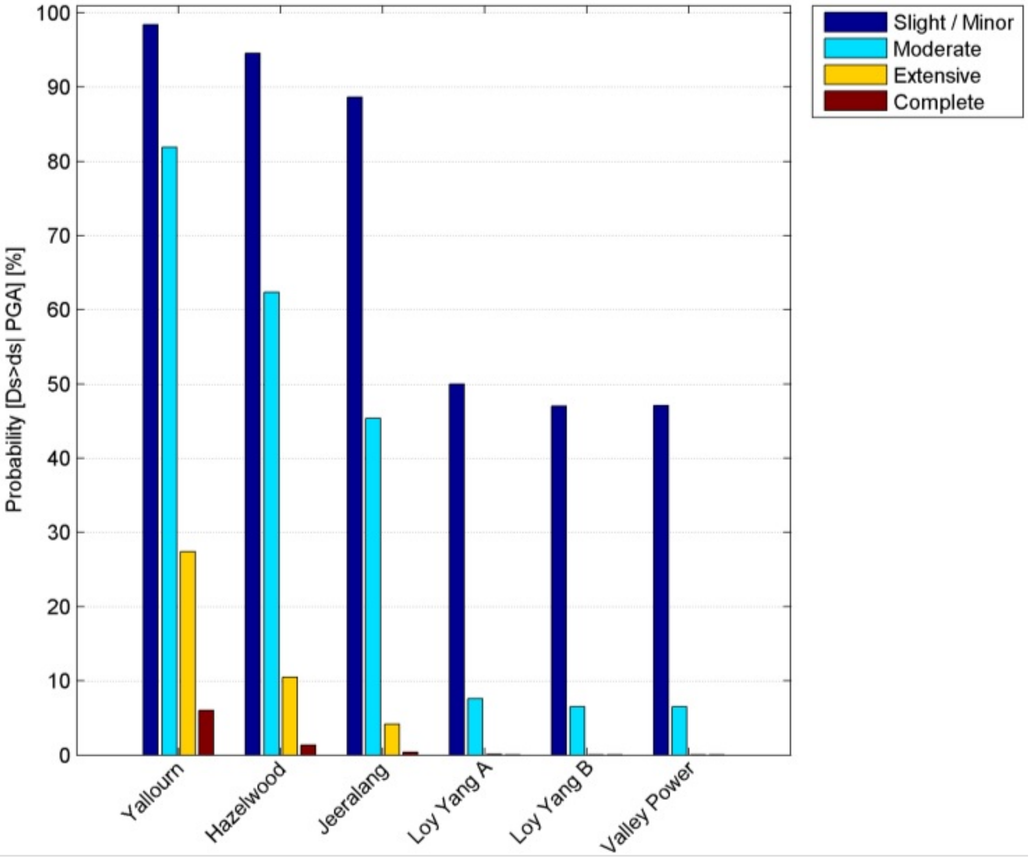

Figure 2: Probability of damage to power stations during at M6.0 earthquake on the Morwell Fault.

CONCLUDING REMARKS

In the preliminary work carried out for Victoria CFA, we considered losses and disruptions to lifelines in isolation, not taking into account the interactions between different elements, and only in a very general manner addressed the long-range/long-term impacts of natural disasters.

The current research project will create a model that can help answer questions such as:

- which areas of Victoria would most likely be blacked out? and
- which hospitals and fire stations would be most under-pressure?

This integrated analysis will also shed light on the increased costs and travel times of transportation; how this could affect emergency response, and what would be the economic impacts both state- and Australia-wide. To be able to do so, this project will require the following steps:

1. Collection of data describing infrastructure networks, such as roads, power and water
2. Modelling as a connected network considering the interactions between different lifeline elements
3. Overlaying this modelling with event hazard layers, and developing vulnerability functions to estimate losses to nodes and/or links between nodes
4. Analysing the post-event network to establish its efficiency, possible bottlenecks and impact to hubs

Such realism in modelled scenarios can help emergency and planning agencies better prepare and allocate resources more effectively.

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