HAZARD NOTE

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CAN GRAPH THEORY HELP PREPARE FOR LIFELINE FAILURE DURING A DISASTER?

ABOUT THIS PROJECT

This research was a PhD study, *Modelling the impact of lifeline infrastructure failure during natural hazard events*, which was part of the Bushfire and Natural Hazards CRC project *Using realistic disaster scenario analysis to understand natural hazard impacts and emergency management requirements*.

AUTHORS

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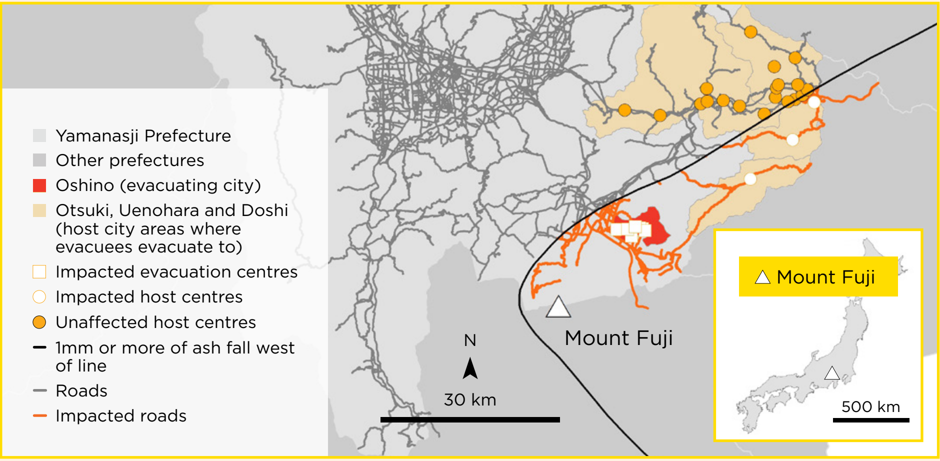

Above: THE POTENTIAL IMPACT OF 1MM OR MORE OF ASH FALL FROM A FUTURE 1707 TYPE ERUPTION AT MOUNT FUJI ON HOST CITIES (OTSUKI, UENOHARA AND DOSHI), THE EVACUATED LOCATION (OSHINO), AND ROAD ACCESS FOR EVACUATED RESIDENTS TO RETURN HOME (OSHINO) AFTER THE ERUPTION. NOTE ROAD INFRASTRUCTURE CAN BE IMPACTED BY LESS THAN 1MM OF ASH FALL ACCUMULATION, SUCH AS OBSTRUCTION OF ROAD MARKINGS AND REDUCED TYRE TRACTION.

SUMMARY

Not only is it important to make lifelines – infrastructure that communities rely on each day such as roads, bridges, power and water – more resilient to disruption from natural hazard shocks, there is also a need to better prepare communities and emergency services to cope with service outages. This research combined natural hazard modelling, GIS analysis and graph theory tools to gain a better understanding of the impacts of lifeline failure during natural hazards and assess the usefulness of graph theory techniques in aiding disaster mitigation, emergency response and community recovery. Mount Fuji in Japan was used as a case study as Australian data was not readily available, however the findings are still applicable to Australian emergency managers. Overall, with adequate information on lifelines and the populations that rely on their services, graph theory can be a useful tool for investigating lifeline failure in a disaster context by helping to envisage network exposure, the flow on effects of lifeline failure and network recovery.

CONTEXT

The continual and growing presence of populations and infrastructure within natural hazard prone areas, combined with climate change, has the potential to intensify the exposure and vulnerability of lifelines to natural hazard shocks. Consequently, future lifeline failure, of varying degrees of seriousness, may simply have to be expected. It is therefore necessary to understand how lifelines and their functionality may be impacted when subjected to disruption from disasters, and furthermore, the social and economic costs of lifeline failure for at-risk populations.

BACKGROUND

The cascading nature of lifeline failure represents an emergent risk, in that natural hazards can now have complex and far-reaching impacts due to our reliance on interdependent and interconnected systems. Although not entirely unforeseen, lifeline failure during disasters has yet to be fully incorporated into disaster plans. There is currently inadequate community education and engagement about what lifelines are, their failure in a disaster, limitations at the local government level to strengthen lifeline infrastructure and mitigate service failure, limited access to sensitive lifeline information, and a lack of holistic disaster scenarios including input from critical infrastructure sectors. Graph theory (see breakout box, page 2) could be used as a disaster planning tool to model and envisage future lifeline failure scenarios.

BUSHFIRE AND NATURAL HAZARDS CRC RESEARCH

Most methods for assessing the vulnerability of critical infrastructure systems have involved mathematical modelling approaches, such as graph theory. Although this area of research is not new, the majority of literature focused on network topologies, interconnections and robustness to random failure and targeted attacks. Limited work has been undertaken on the impact of natural hazards on lifeline systems and the flow on effects from failure on disaster response and recovery. This research sought to go beyond network exposure and vulnerability by modelling lifeline disruption in a real-world disaster context.

This research was unable to include an

Australian case study, as information on critical infrastructure networks and their vulnerabilities to natural hazards was not readily available. Instead data was sought from Japan. This project was able to collaborate with prefecture governments, research centres and lifeline companies in Japan to develop end-user driven research. Field visits uncovered that the potential disruption of road transportation from volcanic ash fall was currently under investigated.

To address this gap, this study combined ash dispersal modelling and GIS tools with graph theory techniques to assess the exposure of major roads to volcanic ash from a future eruption at Mount Fuji, Japan, and to understand what impact road closures could have on emergency response and recovery, with a focus on Yamanashi Prefecture.

RESEARCH FINDINGS

An in-depth description of all findings, including modelling results, from this research can be found in Singh (2019). In short, this study found that, in this particular scenario:

- Ash fall accumulation, only after a couple of hours from the onset of an eruption, may inhibit the ability of residents to evacuate safely or unassisted.
- Ash induced road closures cut off access to some evacuation centres and resulted in long detours for others, affecting current evacuation plans for Yamanashi Prefecture.
- Ash fall deposits can also impact the return of evacuees to their homes, once the eruption has ended, by either blocking roads or damaging buildings (see Figure 1, page 1).
- Approximately 700 km of roads in Yamanashi Prefecture would need to be cleared of ash and likely require repeated cleaning due to ash remobilisation.
- Apart from motorways, roads that connected different cities within Yamanashi Prefecture were found to be the most important for evacuation and resident return. These roads could be prioritised for clean-up.

HOW COULD IT BE USED?

Graph theory techniques are useful for identifying critical components important to the functioning of networks. With additional supporting information to appropriately weight network connections there is great potential for graph theory techniques to add value in the disaster management space when combined with other tools – such as natural hazard modelling and GIS – and integrated into holistic scenarios that incorporate inputs from all stakeholders.

The results of this study will be disseminated to the Japanese collaborators to better inform the prefecture government of the feasibility of their evacuation plans and to provide them with methods for further risk assessment.

Although this research had an overseas focus, the methods developed in this scenario can also be applied in an Australian context. Moreover, modelling lifeline disruption and the flow on affects of service outage can be of use throughout the entire disaster management process, from mitigation to response and recovery. Knowing what areas could be cut off from lifelines such as power or water would enable populations to prepare for service outages. Emergency services would be able to determine transportation access for emergency response and evacuation and, in the aftermath of a disaster, determine which routes to open first for optimal recovery.

FUTURE DIRECTIONS

This research could be applied in an all hazard context where lifeline exposure and potential failure could be examined and compared between hazard types. There is also scope to take this research further by including lifeline interdependences and modelling the potential propagations of service failure between lifeline networks. Another direction would be to include economic data to allow for a monetary value to be placed on lifeline disruption. In any case, any future research in this area will require the input and expertise of the lifeline sector. To become truly resilient to disruption from natural hazards, interagency collaboration is vital.

WHAT IS GRAPH THEORY?

Graph theory is the study of networks through graphical representations. Graphs are mathematical structures made up of nodes and edges, which are used to represent network components and the connections between them. Various algorithms can be used to investigate network structure, evolution and robustness.

END-USER STATEMENT

"The effects of climate change mean that Emma's work has important implications for the critical infrastructure sector. Australian organisations in the critical infrastructure sector regularly prepare for the potential impacts of natural hazards. Preparedness activities, such as exercising, allow organisations to simulate how they can maintain a continuation of supply to the community during and after a disaster. The ability for decision makers to enhance their visualisation of the possible network disruptions using graph theory will certainly add value to any type of future scenario modelling."

– Dr Steven Curnin, Member of the Resilience Expert Advisory Group for Critical Infrastructure Resilience

FURTHER READING

Singh, E. A. (2019) *Modelling the impact of lifeline infrastructure failure during natural hazard events*. Doctoral dissertation, Macquarie University, Faculty of Science and Engineering, Department of Environmental Sciences http://hdl.handle.net/1959.14/1268491.

The Bushfire and Natural Hazards CRC is a national research centre funded by the Australian Government Cooperative Research Centre Program. It was formed in 2013 for an eight-year program to undertake end-user focused research for Australia and New Zealand.