Modelling the impact of lifeline infrastructure failure during natural hazard events

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How prepared are we for extensive lifeline failure, and can graph theory aid in disaster mitigation?

1. Current gaps in disaster mitigation

The cascading nature of lifeline failures represents an emergent risk, in that natural hazard events 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.

It was found that although some countries have endeavoured to include lifelines into disaster management plans there are still a number of barriers which limit the extent of this inclusion, namely:

- **inadequate community education and engagement about lifeline failure in a disaster**
- **limitations of local government to strengthen lifeline infrastructure and mitigate service failure**
- **inaccessibility of sensitive lifeline information**
- **a lack of holistic disaster scenarios**

2. Research aim

The aim of this PhD research was to provide a better understanding of the impacts of lifeline failure during natural hazard events, with graph theory being the tool to help achieve this.

This research sought to go beyond natural hazard exposure and vulnerability by modelling lifeline disruption to investigate how the loss of essential services can impact disaster response and recovery. This study combined ash dispersal modelling and graph theory techniques to assess the exposure of major roads to volcanic ash from future eruptions at Fuji volcano, Japan, and to understand the impact road closures could have on emergency response and recovery.

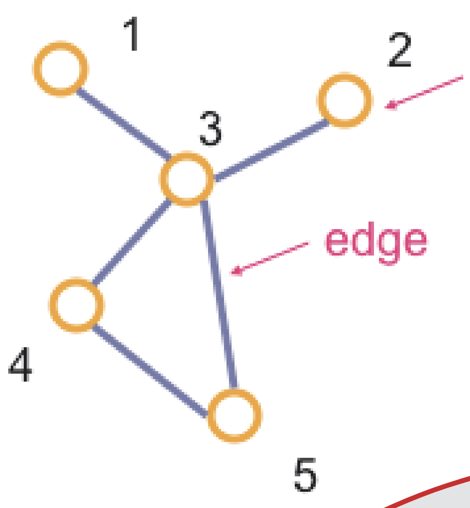

Figure 1: Example of a graph with five nodes and five edges.

3. Graph theory

Limited research has been undertaken on the impact of natural hazard events on lifeline systems and the flow-on effects from failure. This study used graph theory tools to analyse and predict service disruption during lifeline network failure caused by a spatially-distributed disaster footprint.

Graph theory is the study of networks represented as graphs. Graphs are mathematical structures consisting of nodes and edges that are used to describe the building blocks of many physical networks and other interactions (Fig.1).

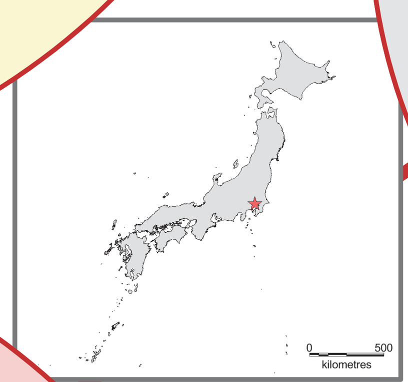

Figure 2: Location of Mount Fuji, Japan.

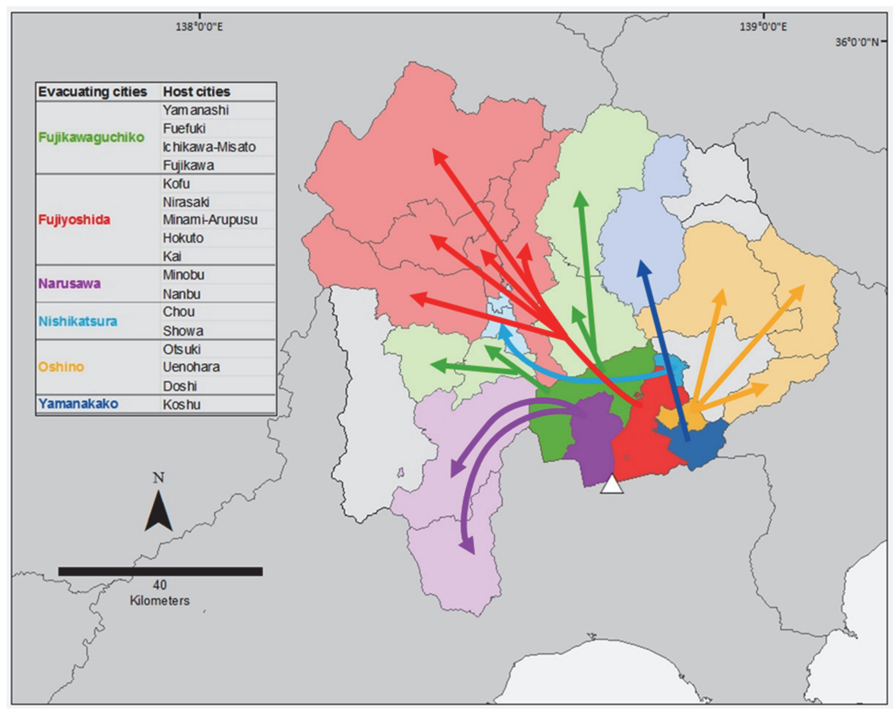

Figure 3: Mount Fuji wide evacuation plan for Yamanashi Prefecture. Legend lists the six evacuating cities and associated host cities. White triangle marks the location of Mount Fuji.

4. Mount Fuji eruption scenario

The well studied 1707 Hoei eruption from Mount Fuji, Japan, was used as a case study scenario.

Interviews with a number of representatives from prefecture governments, research centres and lifeline companies highlighted that the impacts of volcanic ash fall from a future eruption of Mount Fuji were yet to be fully addressed, in terms of both clean-up and disruption to emergency response operations.

Ash fall dispersal modelling, GIS and graph theory techniques were used to assess the impact that ash induced road closures could have on current evacuation plans for Yamanashi Prefecture (Fig. 3).

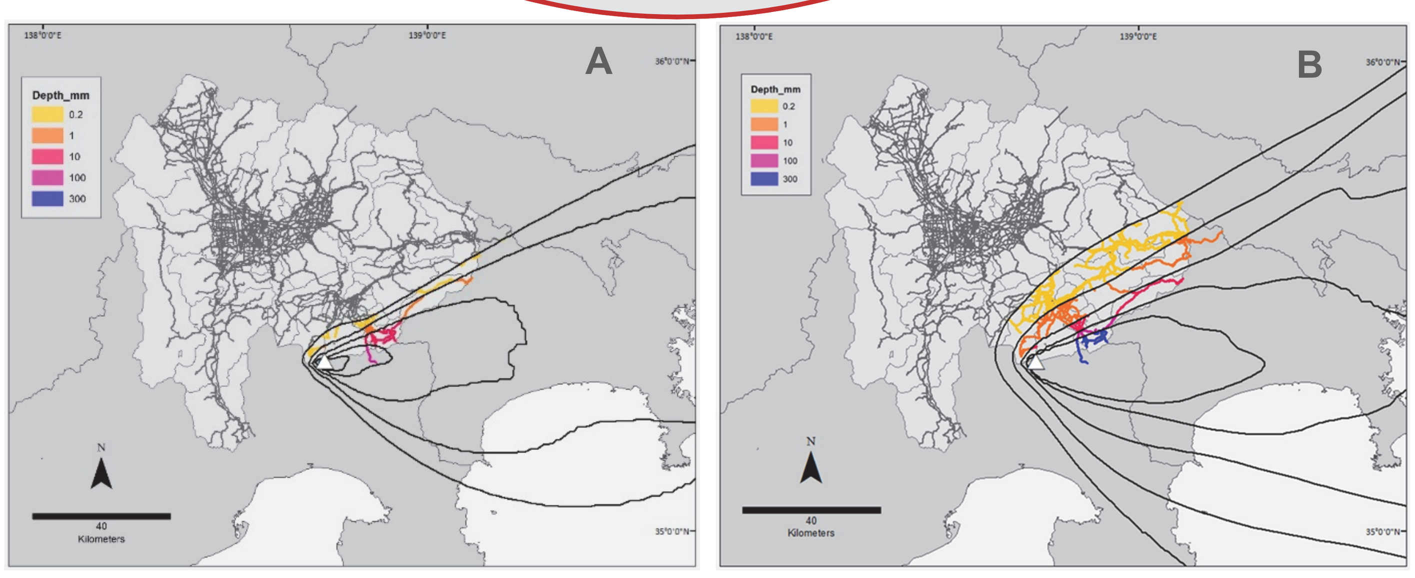

Figure 4: Exposure of prefecture roads to ash fall during the first 1.5 hrs of the eruption (A), which is likely to coincide with evacuation, and the entire eruption (B), which will impact recovery. Isopachs outlined in black and roads coloured with ash fall depths (mm).

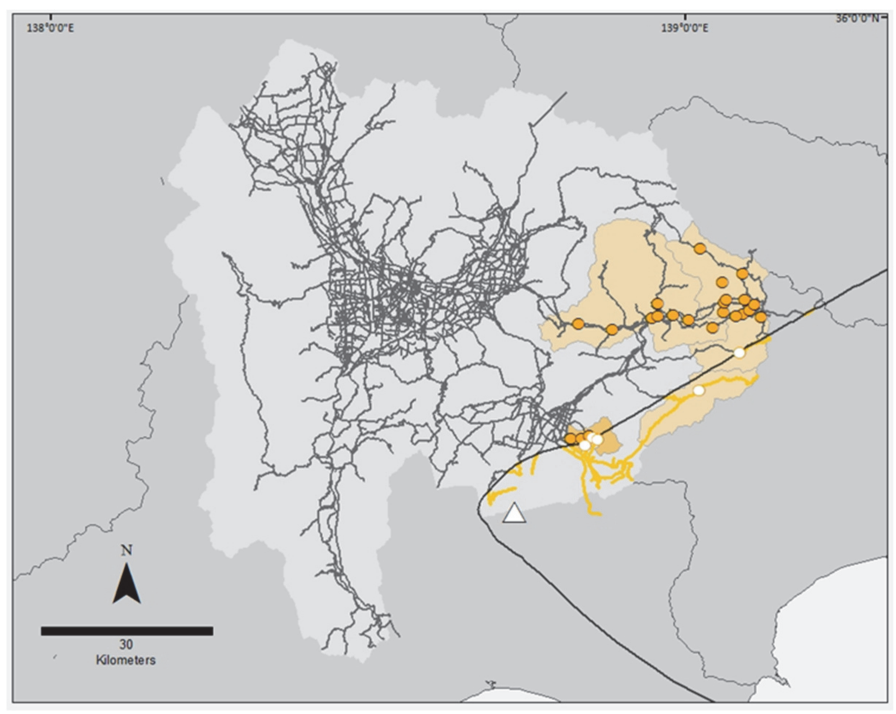

Figure 5: Part A - Impact of road closures at 0.2 mm of ash fall on Oshino City evacuation routes. Impacted roads are in yellow and isolated evacuation centres in white.

5. Results

The initial 1.5 hrs of the eruption would result in the exposure of ~150 km of roads to the east of the volcano to 0.2 mm or more of volcanic ash (Fig. 4A). If road closures occurred at ash fall thicknesses between 0.2 to 10 mm **current evacuation plans for Oshino and Yamanakako cities would be impacted.** A number of evacuation centres would be cut off and detours would be needed to reach others (Fig. 5).

The entire ash fall accumulation of this eruption scenario (14 days) resulted in 2.29×10^5 m^3 of ash being deposited on ~770 km of roads in Yamanashi prefecture (Fig. 4B).

With ash fall clean-up likely to commence at accumulations as low as 0.2 mm a **number of residents from all six evacuated cities may not be able to return home until roads reopen** (Fig. 6). Moreover, areas which are likely to receive high ash loads (≥ 300 mm), such as Yamanakako City, would also have to clean rooves of ash to avoid collapse and ensure resident safety.

In this scenario host cities to the east, especially Doshi, Otsuki and Uenohara, would receive up to 10 mm of ash fall and therefore be impacted themselves. Therefore **these locations might not make the best environments to evacuate to.**

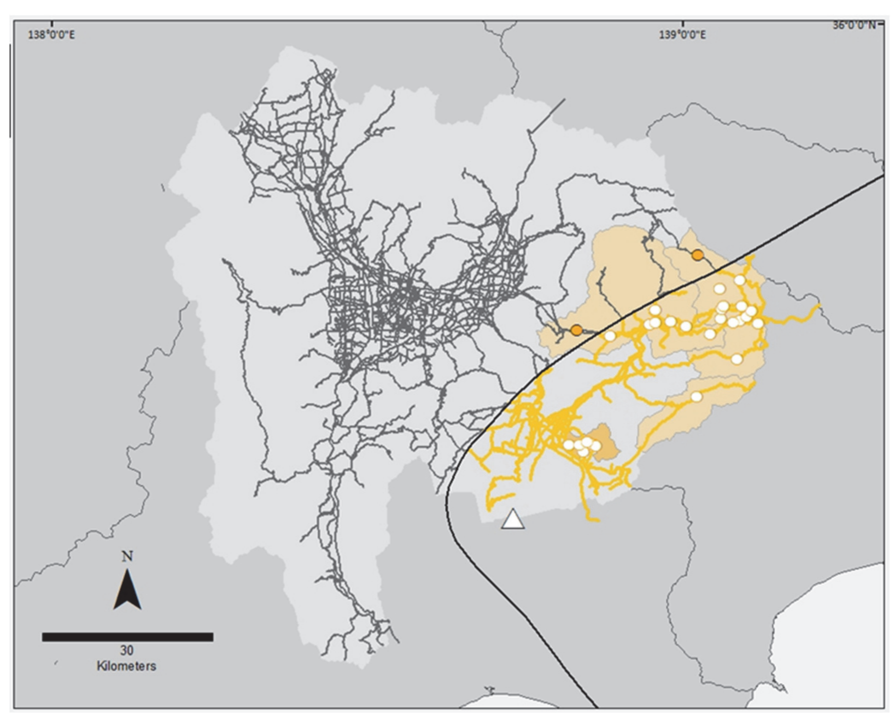

Figure 6: Part B - Impact of road closures at 0.2 mm of ash fall on Oshino City evacuation routes. Impacted roads are in yellow and isolated evacuation centres in white.

6. Implications

When combined with hazard modelling and GIS tools, **graph theory can be useful for both understanding and visualising lifeline failure in a natural hazard context.**

These techniques can be extended to all hazards and all lifelines.

Methods outline in this study can be of use throughout the entire disaster management process, from mitigation to response and recovery.

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