DISRUPTION OF CRITICAL INFRASTRUCTURE DURING NATURAL DISASTERS

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CAN GRAPH THEORY TECHNIQUES HELP WITH EMERGENCY RESPONSE AND OPTIMAL LIFELINE NETWORK RECOVERY?

1. Background

To better prepare for future hazard events, potential impacts on critical infrastructure need to be included in scenario development and vulnerability assessment. There is a need to understand the behaviour and interconnectedness of critical infrastructures and to identify populations and services that rely on their operation. Therefore, critical infrastructure vulnerability needs to be considered alongside social dimensions that take into account the ability of populations to adapt or cope with infrastructure disruption.

This study combines 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.

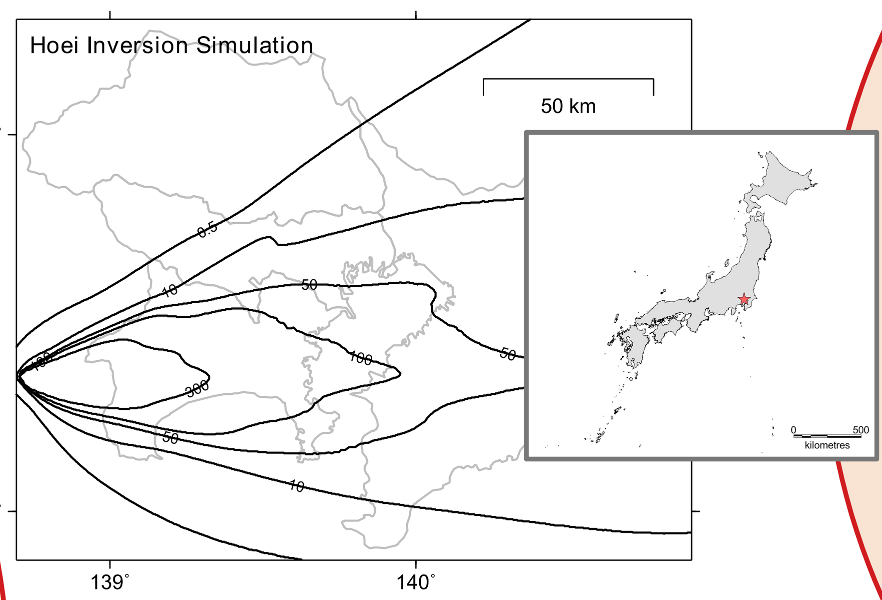

Figure 1: Inversion modelling results combining 17 phases describing the entire 1707 Hoei eruption sequence (Magill et al., 2015). Ashfall isopachs in millimetres.

2. Modelling ashfall from a future eruption at Mount Fuji

The 1707 Hoei eruption is one of the most violent eruptions that Fuji volcano has produced. The eruption produced wide-spread ashfalls covering most of the south Kanto plain to the east of the volcano. Ash from this eruption has also been found 280 km from source in deep sea cores in the Pacific Ocean (Miyaji et al 2011; Miyaji 2002). Although the 1707 eruption is maybe the worst-case scenario from Mount Fuji in terms of ashfall hazard, it would be inapt not to plan for the worst.

The 1707 Hoei eruption from Mount Fuji was replicated using *Tephra2*, an analytical tephra advection-diffusion model (Bonadonna et al., 2005), which calculates particle diffusion, transport and sedimentation. Magill et al. (2015) used high-resolution data describing 17 phases of the Hoei eruption (Miyaji et al., 2011) and inversion techniques to estimate the physical parameters of the Hoei eruption (Fig.1).

3. Impact of volcanic ash on roads

The impact of volcanic ash on road transportation has been documented during recent eruptions such as Mount St Helens (1980), Pinatubo (1991), Sakurajima (1955 onwards), Pacaya (2010) and Shinmoedake (2011) (Fig. 2). Falling or remobilised ash has been found to significantly reduce driver visibility. Fine ash can make road surfaces slippery, especially if wet, and ash fall thicknesses of 0.5mm can obscure road markings. Fine ash can also abrade vehicle components and clog air and oil filters (Nairn 2002; Magill et al 2013; Wilson et al 2012; Wilson et al 2014; Hayes et al 2015).

The disruption of transport networks during a disaster can result in the isolation of populations, and hinder evacuation and rescue operations. After a disaster, road closures could dramatically increase travel time, disrupt supply chains and hamper recovery efforts such as stopping access to other critical infrastructure for maintenance.

Figure 2: Road closure during the 2011 Shinmoedake eruption in Japan (Magill et al., 2013).

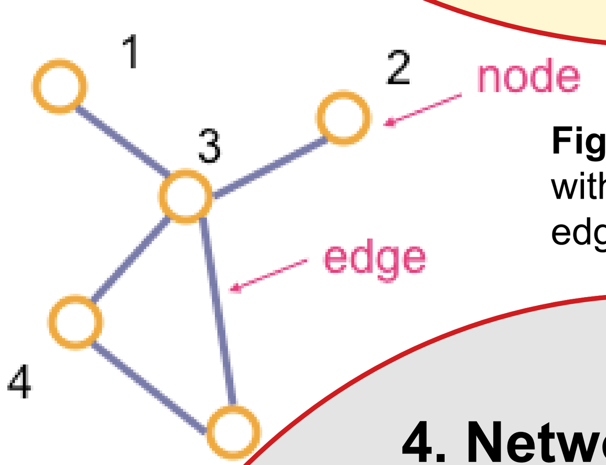

Figure 3: Example of a graph with five nodes and five edges.

4. Network analysis

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 (Van Steen, 2010) (Fig. 3). In a road network, nodes represent road junctions and edges the road lengths.

Mathematical graph theory tools will be utilised to navigate highway and local road networks of Japan to determine the shortest paths, detours and optimal network recovery in the case of an eruption.

Table 1: Approximate road lengths impacted by various ranges of ashfall accumulation.

Ashfall (mm)	Length of highway (km)
0.5-10	369.9
10-50	379.6
50-100	200.1
100-300	181.1
>300	55.7

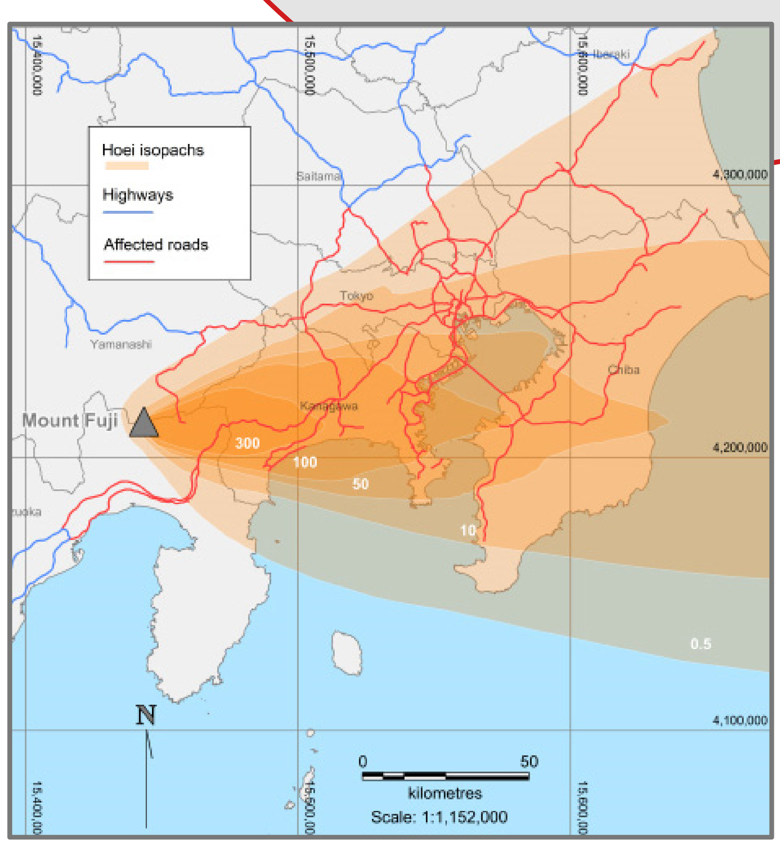

Figure 4: Inversion simulation of Hoei eruption sequence overlain onto the Nexco East and Central Nippon Expressway network. Impacted road segments marked in red.

5. Preliminary results

Isopachs from the Hoei inversion simulation (Fig. 2) were overlain onto expresssway data (Fig. 4). In this scenario 20% (1186 km) of the combined Nexco East and Central Expressway networks would be impacted by 0.5 mm or greater of ash (Table 1). The minimum ashfall threshold of 0.5 mm represents the depth needed to cover road markings and therefore when road clean-up would need to commence.

6. Next steps

Graph theory techniques will be used to assess the impacts of ash fall on the evacuation plans for Yamanashi Prefecture with regards to a future 1707 Hoei type eruption at Mount Fuji.

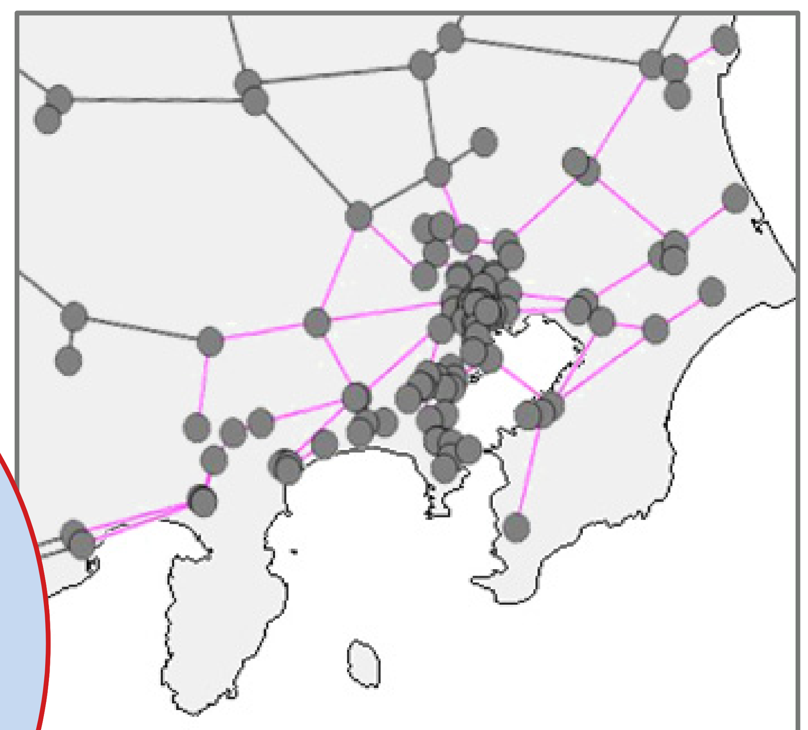

Figure 5: Graph representation of a portion of the highway system in Japan. The pink edges represent the sections of highway impacted by ≥0.5 mm of ashfall from the Hoei eruption from Mount Fuji

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