DISRUPTION OF CRITICAL INFRASTRUCTURE DURING NATURAL DISASTERS

bushfire&natural HAZARDS CRC

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

BACKGROUND

Critical infrastructure and essential services, such as: transportation, communication, power and water, are heavily relied upon by today's modern society for day-to-day living, the movement of goods and services, and disaster response and recovery. Currently there is limited quantitative research on the impact natural hazard events have on these systems and the flow on effects from their failure. To estimate the impact of lifeline network disruption during a disaster there is a need to better understand network behaviour and interconnectedness, as well as exposure and vulnerability to potential natural hazards.

PROJECT OBJECTIVES

- Utilising mathematical graph theory tools to analyse lifeline network behaviour and the impedance of services during network disruption.
- Overlaying natural hazard footprints onto network representations to simulate potential impacts of realistic disaster scenarios

GRAPH THEORY

Graph theory is the study of networks represented as graphs (Fig. 1). 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). Current applications of graph theory looking at infrastructure networks focus on network structure and robustness to random failure and targeted attack (Albert et al., 2004; Crucitti et al., 2004; Koç et al., 2014; Angeloudis and Fisk, 2006; Derrible and Kennedy, 2010; Cardillo et al., 2013). This research aims to add to this work by looking at natural hazard shocks, cascading lifeline failures and dynamic flow through weighted networks.

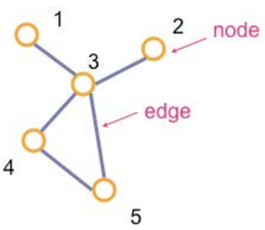

Fig. 1 Example of a graph with five nodes and five edges.

SIMULATED DISRUPTION TO THE TOKYO SUBWAY

The Tokyo Subway network was used as a case study example to show how graph theory techniques can be applied to assess transport system disruption during natural disasters. The subway network was subjected to a hypothetical inundation scenario based on an area prone to flooding. All components (56 stations) within the hazard footprint were deemed to have failed (Fig. 2). Over 5 million daily passengers across 9 of the 23 Special Wards of the Tokyo Metropolitan Prefecture would be impacted.

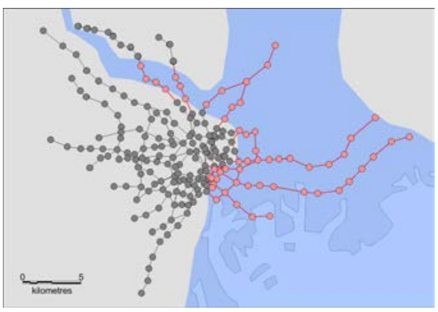

Fig. 2 Graph representation of the Tokyo Subway. Hypothetical inundation hazard footprint is indicated in blue ( ) and network components that coincide with the footprint are highlighted in red ( ).

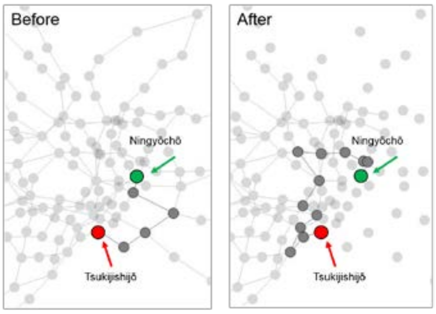

Fig. 3 Change in shortest path between Tsukijishijō and Ningyōchō stations after inundated stations and connections were deleted. Travel time between these two stations increased by 13 minutes.

Graph theory can be used to navigate networks and determine shortest paths between two nodes (Fig.3). This could help determine accessibility for emergency responders and routes for evacuation. Other common graph theory measures can determine a node's importance or centrality (Fig. 4). These could be used to identify which infrastructure components should be protected and/or rebuilt.

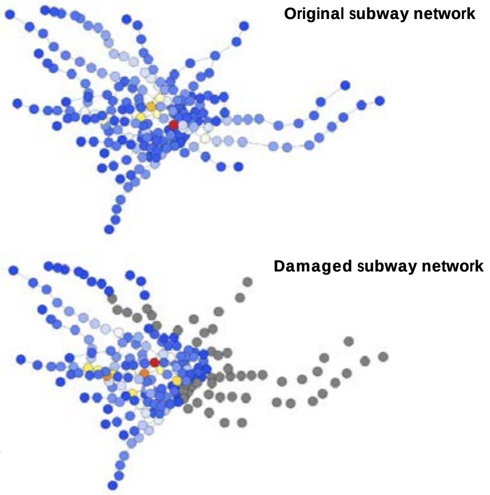

Fig. 4 Station 'betweenness' before and after deletion of inundated components. Betweenness is a measure of how many times a station is a connector along the shortest path between two other stations. Warmer colours indicate high scores and cooler colours indicate low scores.

FUTURE WORK

- Determine highway exposure to volcanic ashfall in Japan and identifying implications for evacuations and clean up
- Apply learnings to Australian case studies, contributing to the 'Using realistic disaster scenario analysis to understand natural hazard impacts and emergency management requirements' project, part of the BNHCRC 'Scenario and Loss Analysis' cluster

COMMENTS FROM THE END USERS

" Management of natural hazards, their impacts and their interactions in communities using structured mathematical and information system approaches is a critically important evolution of disaster management. Other sectors of industry and commerce use a variety of computational network and information modelling approaches to solve large and complex interconnected problems. These need to be applied to disasters. So the next few years will see disaster managers developing more formally adopted approaches to network, agent-based and least cost based methodologies and the research outlined in this poster will be part of the groundswell which will assist in understanding the adaption and innovation of these approaches to disasters," (NSW SES).

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