EVALUATING THE MAGNITUDE AND SPATIAL EXTENT OF DISRUPTIONS ACROSS INTERDEPENDENT INFRASTRUCTURE

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MOTIVATION

Infrastructure networks are becoming increasingly interconnected and reliant on each other for normal operation. However, they are typically modelled in isolation without considering the flow on effects of outages beyond the studied system. This can lead to significant and often unforeseen societal and economic impacts. These inter-network connections are commonly referred to as **dependencies** and can represent a physical dependence, such as electricity supply to a pump, or through co-location, such as multiple utilities hosted by a bridge structure. Others may be more complex such as a wastewater treatment plant requiring a functional path through a road network to dispose of solid waste at a landfill.

This poster presents an application of Esri GIS technologies as a tool to simulate and further understand **the potential magnitudes and spatial extent of infrastructure outages** across inter-dependent national infrastructures. With an aim to **better inform decision makers** on resilience building measures, we seek to answer;

- Where are our most critical infrastructure assets?
- What areas are most vulnerable to disruption?
- To what extent do dependencies contribute to overall user disruptions?

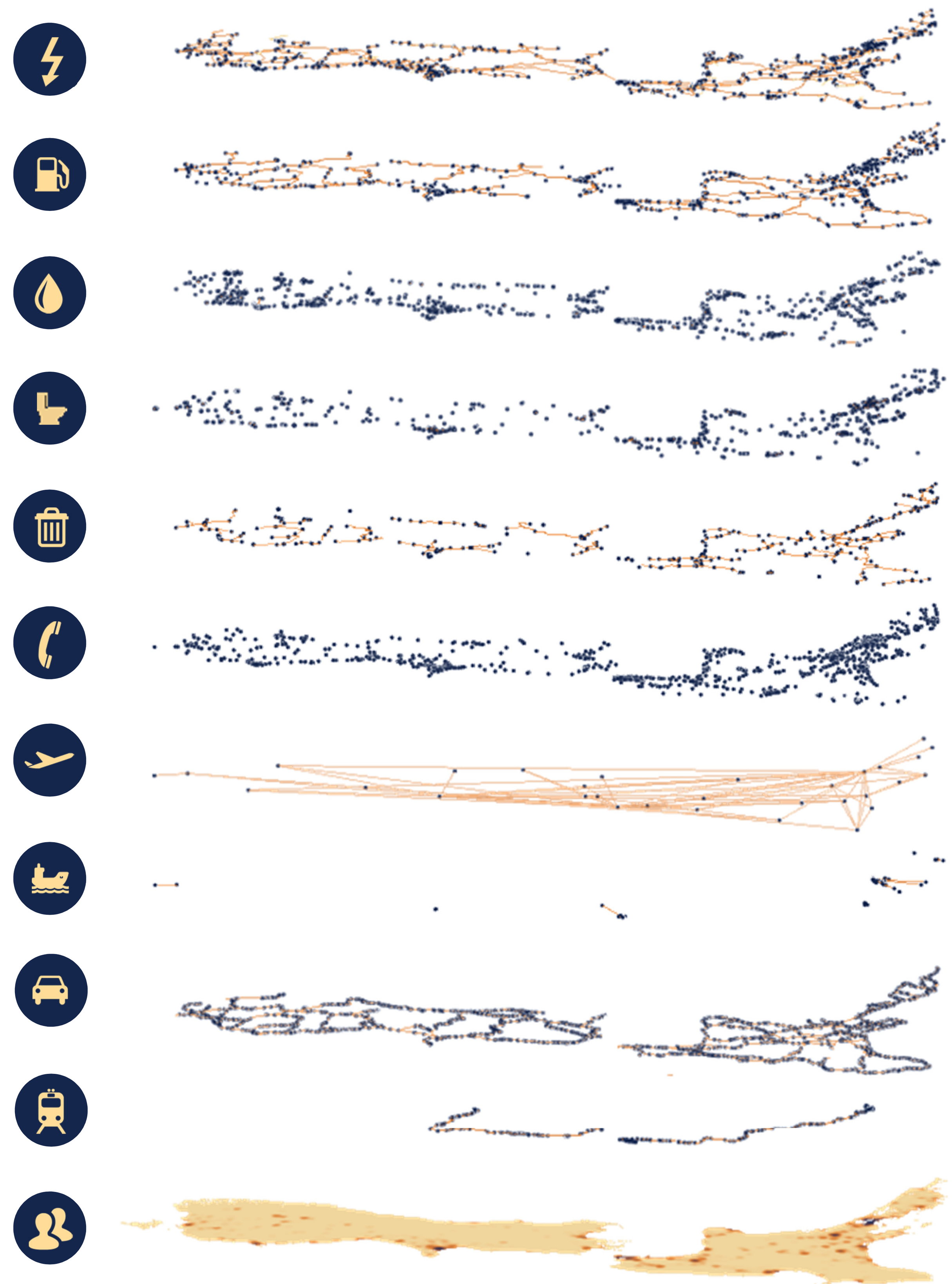

Fig. 1: *Representations of the studied infrastructure networks with population distribution (bottom) using ArcScene. Dependencies between networks are not mapped for clarity.*

SPATIAL NETWORK REPRESENTATIONS

Over 20,000 individual nodes and edges have been collected or digitised from network operators to build a geodatabase of national infrastructure network representations (Fig. 1) across;

- **energy sector** (electricity, petroleum supply)
- **water and waste** (water supply, wastewater, solid waste)
- **telecommunications** (mobile networks)
- **transportation** (rail, ferry, state highways, air)

Source – sink connectivity paths are mapped and modelled within each network using *Network Analyst* where nodes and edges are assigned a user dependence equivalent to the potential number of users disrupted over a given day. This dependence is calculated according to provided statistics in addition to the spatial intersections of census meshblocks with catchments, distribution zones, reception area buffers, or Voronoi Decomposition.

Finally, directed dependency edges are mapped across networked nodes where appropriate based on known physical connections, geographic proximities, or through shortest paths routing algorithms using other infrastructures (e.g. retail petroleum distribution via road networks).

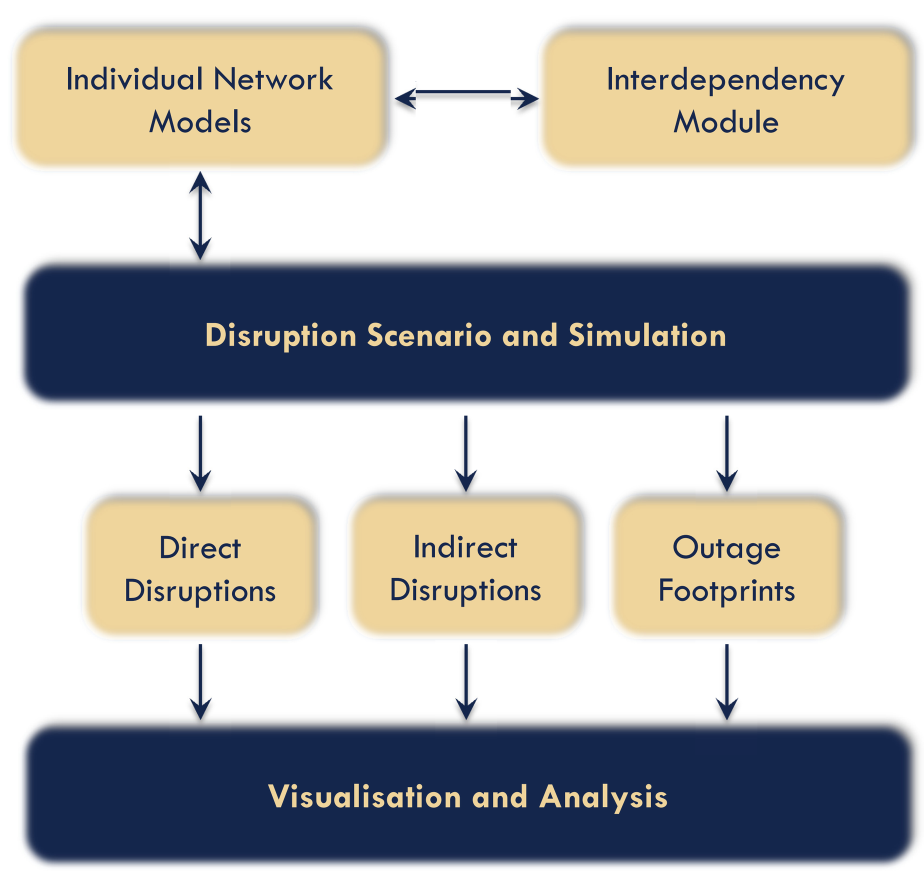

Fig. 2: *Modelling framework combining individual infrastructure models with an interdependency module to account for indirect network disruptions.*

MODELLING AND SIMULATION

Initially, each infrastructure network is modelled in isolation using Python language to utilise the *ArcPy* package and a range of *Spatial Analyst* and *Network Analyst* geoprocessing tools. This allows the complexities of each different network to be sufficiently detailed for determining reductions in service levels and user disruptions after considering redundancies and re-routing of service flows. This approach ensures models are easily updated with additional data, able to be studied at a variety of scales, and the underlying code transferable to other locations.

For a given hazard scenario, disruptions initially propagate throughout isolated models to quantify the **direct disruptions** within each network model. We then allow the interaction of networks through an interdependency module (Fig. 2) with the propagation of outages across networks quantifying the **indirect disruptions** – those disruptions that would not otherwise be captured if all infrastructure networks were modelled in isolation.

Combining the spatial extent of outages with the initiating infrastructure asset and the resulting population disrupted, we can identify the most vulnerable areas to disruption, the most critical assets, and the proportions of direct and indirect disruptions due to targeted asset damage or natural hazard scenarios.

VISUALISATION

GIS visualisations allow for the improved communication and validation of results with infrastructure operators and stakeholders. Using additional Esri Software *ArcScene* and *ArcReader*, users can track cascading outages and the relative effects on different networks as simulations progress in addition to constructing new outage scenarios of interest.

Using collated results, while kernel density mapping is applied at a national scale for identifying disruptive hotspots and pinch points, Fig. 3 presents an example of bivariate hex-bin mapping used to examine the spatial variability of risk – a function of the **likelihood of disruption** due to out of zone infrastructure damage (hex-bin size) and the **potential consequence of disruption** (hex-bin colour).

Through such visualisations, we can work with stakeholders to identifying priority areas for increasing resilience – predominantly the largest and darkest shaded hexagons. Beyond major urban centres, such instances include the apparent high reliance along a North-South running corridor in the north of Fig. 3 where a major state highway, electricity transmission lines, and a petroleum distribution pipeline are co-located.

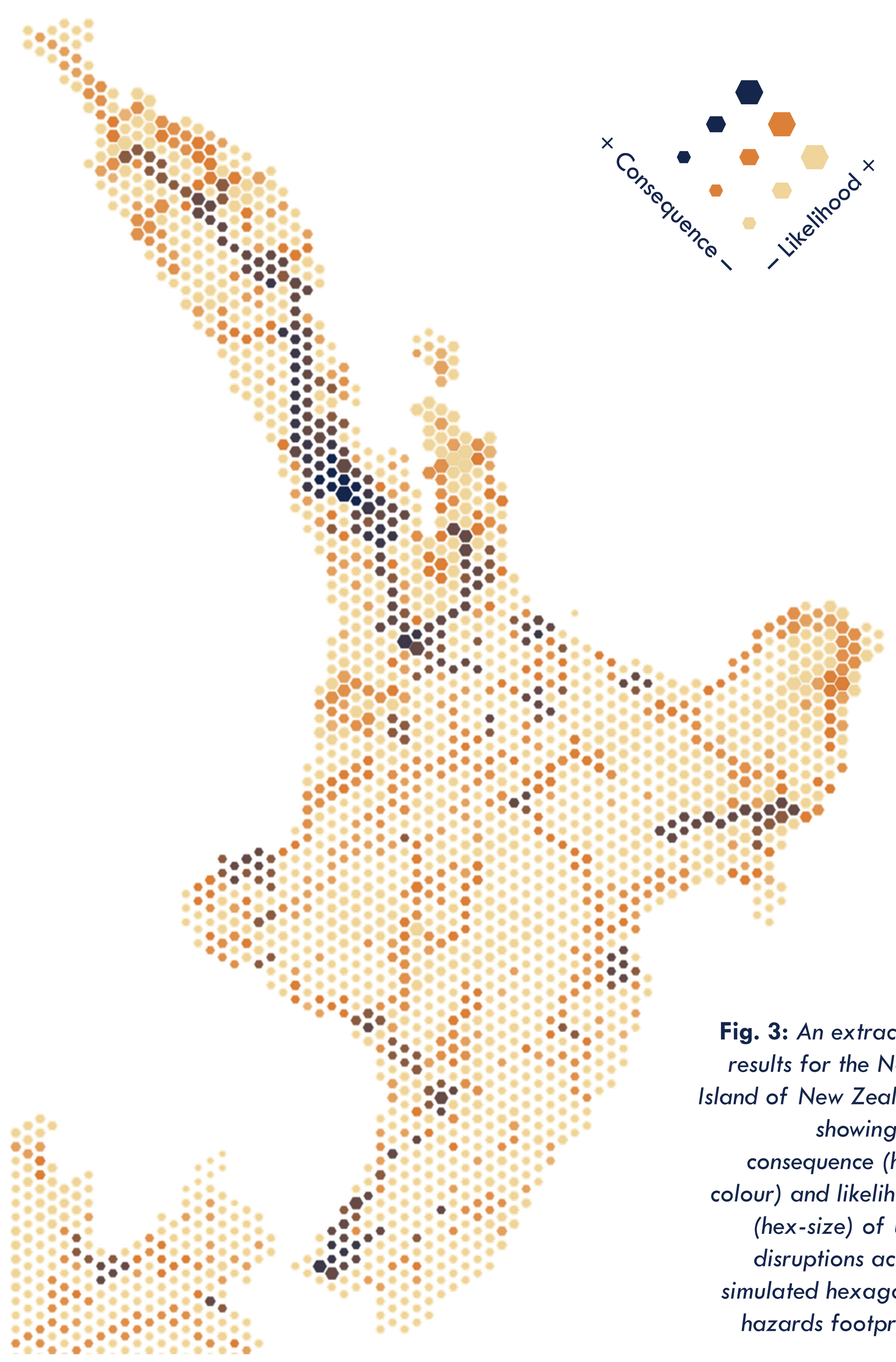

Fig. 3: *An extract of results for the North Island of New Zealand showing the consequence (hex-colour) and likelihood (hex-size) of user disruptions across simulated hexagonal hazards footprints.*

IMPACT OF DEPENDENCIES

Across the simulation data set depicted in Fig. 3, Fig. 4 suggests direct disruptions to individual networks only account for ~53% of the total number of user disruptions for a given hazard – the rest being a result of outages through infrastructure dependencies.

This observation strengthens the case for interdependent infrastructure modelling by considering reliant networks as opposed to simply those directly connected users – especially where a dependence on electricity or roading networks exists.

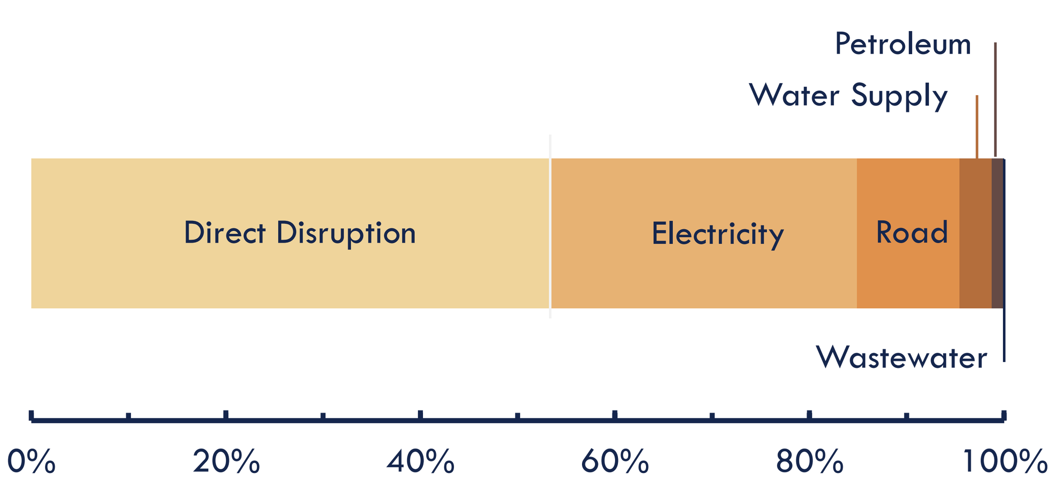

Fig. 4: *The proportion of direct disruptions to infrastructure networks compared to indirect disruptions initiated by the shown infrastructures. Those networks not shown contribute <1% towards cascading failures.*