# THE DEPENDENCE OF NATIONAL TRANSPORTATION INFRASTRUCTURE ON ELECTRICITY

**Conrad Zorn**[a], Dr. Scott Thacker[b], Dr. Raghav Pant[b], Assoc. Prof. Asaad Shamseldin[a]

[a] Dept. of Civil and Environmental Engineering, University of Auckland; [b] Environmental Change Institute, University of Oxford, UK

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## OUR INFRASTRUCTURE NETWORKS

New Zealand's infrastructure networks are becoming increasingly interconnected and dependent on each other for normal operation. While typically studied as isolated systems, disruptions can rapidly propagate across networks with widespread effects for both society and the economy. It is the nature and magnitude of these dependencies which are generally not well understood.

With interactions between separate networks and a common reliance on electricity supply, the wider transportation sector and electricity distribution networks have been identified as having major potential as contributors to cascading failures.

Through a system-of-systems based analysis, this poster presents the dependencies between electricity and passenger transportation networks comprising; airports, ferries, rail, and petroleum distribution across the State Highway (SH) network.

## BUILDING NETWORK REPRESENTATIONS

Spatial representations of those selected infrastructures are presented in Fig. 1 as separate networks of nodes and edges, i.e. ferry terminals and routes, rail stations and tracks, and airports and flight connections. Fuel and electricity networks are represented through multi-level hierarchal structures where petrol stations are dependent on bulk fuel distribution points via the shortest path routes across the SH network of roads and crossings, and lower voltage distribution substations are dependent on transmission substations allowing complete network connectivity.

Further functional dependencies are mapped between electricity dependent transportation nodes and edges based on the known or the geographically closest substation of an appropriate voltage, thus creating a network-of-networks.

The criticality of each asset is assumed equivalent to the summed number of users directly and indirectly affected by the failure of each network component. Directly affected users are assigned according to operator provided counts if made available, or where commercially sensitive, estimated using a range of publically available statistics, passenger loadings, and the proximity to an asset. Indirectly affected users are then determined through inter and intra-network connections.

In applying this interdependent network structure, those electricity and passenger transportation assets with the greatest disruptive potential to business-as-usual can be identified while examining system level dependencies on electricity supply.

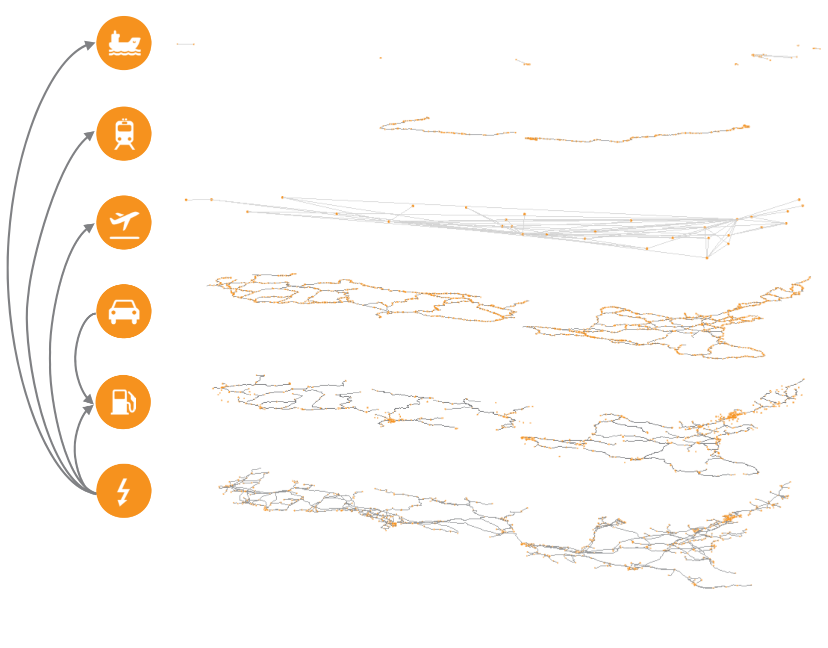

*Fig. 1.* *Network overviews of selected transportation and electricity infrastructures used with arrows indicating service flow for normal operation.*

## IDENTIFYING VULNERABILITES

Continuous surfaces are presented in Fig. 2 representing; (i) co-located transportation networks, (ii) areas with the most significant disruptive potential for transportation users, and (iii) the most critical sub-transmission substations to maintain normal transportation sector functionality. Contrasts between co-located and potential disruptions in part depict the significant dependence placed on fuel supply radiating out of the countries 11 bulk distribution points. As could be expected, the critical distribution substations for transportation infrastructures largely correlates to population densities at this scale.

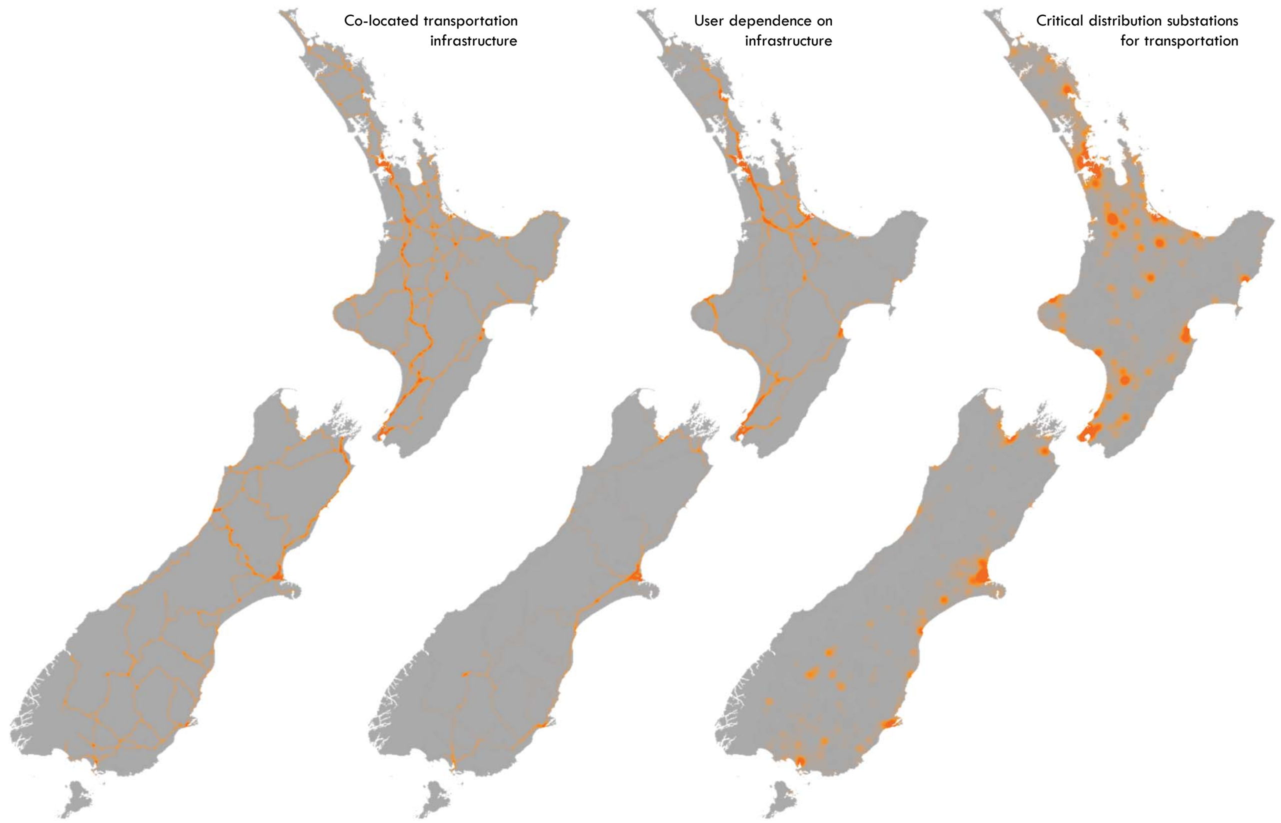


*Fig. 2.* *National representations of co-located transportation infrastructures, the user dependence on transportation network components, and the dependence placed on distribution substations based on a quartic smoothing function.*

## SYSTEM LEVEL DEPENDENCIES

Disruptions to transportation network users resulting from substation removals are presented in Fig. 3. Through separate exhaustive simulations of random ordered transmission and distribution substation failure scenarios, system level dependencies are identified.

The range and stepping of ferry and air curves are indicative of the comparatively small number of ports compared to substation nodes. Similar observations are made for the rail network, where the reliance on two transmission substations for Auckland rail electrification ensure the median curve shows an earlier complete rail disruption compared to distribution removals.

The relatively consistent slopes of the lowest impact fuel supply disruptions suggest petrol stations are relatively well distributed nationally across substations. Similarly, the median electricity user disruptions show a reduced range of potential curves with the smallest variation in users allocated to both transmission and distribution substations.


*Fig. 3.* *Infrastructure network user disruptions as a function of transmission (– – –) and distribution (—) substation removals with corresponding upper and lower limits resulting from 500 simulations.*

## COMPARISONS TO EXPERT-DERIVED CURVES

The fuel supply - distribution electricity dependency curve is compared in Fig. 4 to the expert elicited 'petroleum sector - electricity sector' relationship from the Economics of Resilient Infrastructure (EoRI) project (Buxton 2016, pers. comm.).

Assuming analogous definitions of system functionality, the simulated curves of Fig. 3 are translated to match the EoRI expert perceived redundancies. The approaches show similarities up to 80% electricity network inoperability. Beyond 80%, the EoRI curve is unchanged such that at 100% electricity inoperability, the effect to fuel supply is just below the projected simulation results. In comparison the median simulated curve suggests an increase from 85–96% across this same period.

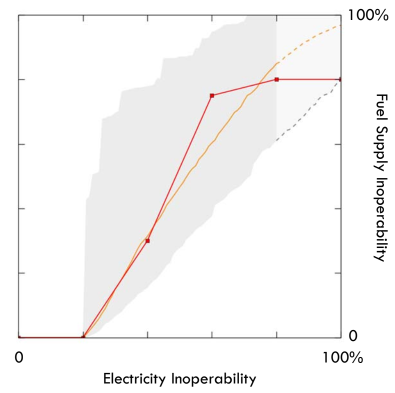


*Fig. 4.* *Comparisons of expert-elicited (—) and simulated (—) dependencies of fuel supply on the electricity sector.*

## CRITICAL SUBSTATIONS

The most critical transmission and distribution substations for normal operation of the transportation sector are ranked in Fig. 5 where for comparison, a simplified indication of direct economic losses is shown based on sectorial reductions in demand and corresponding industry level transactions.

The hierarchal representation of the electricity network ensure transmission substations show greater disruptive potential in terms of sector disruptions and economic impacts. These metrics show variability based on the specific infrastructure networks supplied and the corresponding user dependencies. However, substations supplying Wellington, Christchurch, and Auckland airports (appearing left to right for both parts of Fig. 5) show significantly larger potential economic impacts and thus reliable electricity infrastructure should be of importance in conjunction with those with the greatest user disruption potential.

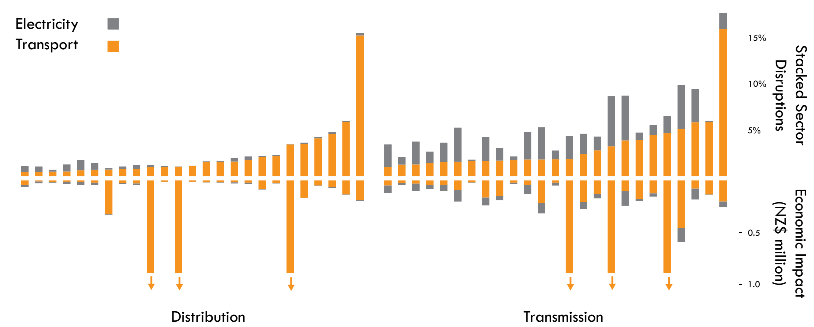


*Fig. 5.* *Electricity distribution and cumulative transportation sector disruptions relative to the complete disruption of individual networks resulting from substation removals.*

## CONTRIBUTIONS

Through the representation of national interdependent networked infrastructures across New Zealand and various failure scenario simulations this project;

- demonstrates the potential for widespread disruptions to transportation users and the sectors economy due to a loss in electricity,
- identifies where redundancies in the electricity network should be focused to minimise these potential disruptions, and
- highlights the differences between expert opinion and network based analysis for deriving system level dependency curves.