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Supply chain impacts during the January 2023 Kimberley, Western Australia, floods

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Abstract

Until recently, the capacity to quantify and understand disruptions to Australian domestic supply chains due to external events (e.g., natural hazards) as they occur was very limited. This is an important capability as it enables emergency managers to direct resources to improve response and recovery times during supply chain disruptions to greater effect, and to better understand and quantify the potentially far-reaching community and economic impacts likely to be felt during such events. The Transport Network Strategic Investment Tool (TraNSIT, CSIRO) was recently adapted in partnership with the Australian Climate Service (ACS) to fill this information gap. Specifically, a decision support service was stood up to supply a daily snapshot on the current state of the national supply chain network to emergency management agencies during natural hazard events, particularly flood events.

In this paper, we present some of the key capabilities of this service in the context of a recent major flood event which occurred in the Kimberley region of northern Western Australia (WA) during January 2023. This event caused extensive damage to major freight routes and communities within northern WA and left several communities completely cut-off from the broader transport network. TraNSIT modelling during the event indicated that significant immediate-term supply chain impacts were likely to be felt, including detours of several thousand kilometres for some cross-country freight, and substantial blockages of essential food and fuel to several population centres within the region. Such impacts were substantiated by observations during the event.

From an emergency management perspective, the ACS TraNSIT service is a powerful, one-of-a-kind decision support tool able to provide near real-time intelligence on the likely state of the national supply chain network during flood events. Operationally, it has successfully supported national and state and territory emergency management agencies through several recent events, of which the Kimberley event is one example. Importantly, it has assisted managers in deciding where to best direct resources for effective near-term impact mitigation during disruption events.

Planned improvements will address current model limitations, as well as bring significant new capabilities to the ACS TraNSIT service. This includes a supply chain impact forecasting capability, which will help emergency managers to make better-informed preparations for flood events before they occur.

1. Introduction

Until recently, the capacity to quantify and understand disruptions to Australian domestic supply chains due to external shocks as they occur was limited. From an emergency management perspective, such a capability is important as it can enable managers to more effectively direct immediate remediation efforts towards the most critically impacted components of the supply chain network, and improve response and recovery times. As the impacts of climate change continue to intensify, and natural hazard events become more frequent and more severe (e.g. Tabari 2020), such a capability will inevitably become an increasingly valuable and important component of the national emergency management framework.

The Transport Network Strategic Investment Tool (TraNSIT), developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), was recently adapted, in partnership with the Australian Climate Service (ACS), to fill this information gap. Through ACS, TraNSIT currently provides a near real-time decision support service to emergency managers, consisting of a comprehensive overview of current supply chain impacts due to natural hazard-induced disruptions to the transport network. This service has already been in operation for two Australian severe weather seasons commencing late 2021, and has provided supply chain intelligence to Commonwealth and state/territory agencies responsible for emergency management during several major flood events.

In this paper, we present some of the key capabilities of the ACS TraNSIT service in the context of a recent flood event over the Kimberley region of northern Western Australia (WA), during early January 2023. We also outline the significance of these new capabilities in the context of emergency management during natural hazard-induced supply chain disruptions.

2. Background

TraNSIT is a freight and supply chain planning model developed by the CSIRO with the support of government and industry. Since its inception in 2012, it has primarily been used as a research tool, and has informed significant freight investment decisions for a range of industries, including the livestock, horticulture, and forestry sectors (Higgins et al. 2018).

Currently, the TraNSIT model stores information on several million unique road, rail, and sea freight movements which occur each year across the country, and which move over 180 distinct commodity types across over 750,000 supply chain legs. These supply chains span primary production stages, all the way to domestic and export markets. This data is regularly updated to remain concurrent with actual supply chains operating within Australia, and the acquisition of this data is facilitated through ongoing partnerships between CSIRO and a range of industry and government bodies.

A cost model is applied to the national road network (obtained through HERE streets, www.here.com), which combines physical road properties and truck mass restrictions with representative truck operating costs (e.g., driver costs, repair costs, fuel costs etc.). Through this, per road segment total use costs for typical truck trailer configurations (semitrailer, b-double, two and three-trailer road trains) are derived. Using the output of this cost model, a graph of the entire road network is generated, where its edges are weighted by total traversal cost. Shortest (cheapest) paths in terms of overall total traversal cost are then calculated for the full set of national supply chain legs, represented via origin and destination points on the graph. These results are aggregated across all supply chains to provide information and statistics around freight transport costs, truck type and network usage, and other characteristics of the national supply chain network, under the assumption of optimal network usage. For further details of the TraNSIT model, the reader is referred to Higgins et al. 2018.

The Australian Climate Service (ACS) was established by the Australian Government in 2021, following recommendations from the Royal Commission on National Natural Disaster Arrangements (Commonwealth of Australia 2020). It is a multi-agency organisation consisting of partners from the Bureau of Meteorology, the CSIRO, the Australian Bureau of Statistics, and Geoscience Australia. Currently, the ACS directly supports the National Emergency Management Agency (NEMA) in its day-to-day operations.

One of the key roles of the ACS is to identify and quantify natural hazard-induced impacts on the national supply chain network, and to provide ACS stakeholders with a near real-time decision support service to assist with mitigating such impacts, particularly in the context of community preparedness and response. Due to its unique position as an established and reputable supply chain intelligence tool, the TraNSIT model was adapted to fill this role in the ACS. Specifically, by reflecting existing disruptions to the national transport grid into the model's network data, TraNSIT can be utilised to provide comprehensive information on the current state of the national supply chain network. This information can then be utilised by appropriate emergency management agencies to inform decisions around near-term impact mitigation.

Since being operationalised during the 2021/2022 Australian summer, the ACS TraNSIT service has supported emergency management operations through several major flood events. One such event is the recent Kimberley floods, which occurred in late December 2022/early January 2023. Between 29/12/2022 and 6/1/2023, up to 800 mm of rain fell over parts of the Kimberley and Pilbara regions in northern WA, as ex-Tropical Cyclone Ellie moved over the region. Extensive damage to infrastructure resulted from the ensuing flood event, including severe damage to the Great Northern Highway, which is the main freight route for the region. This resulted in several towns being completely cut-off from the broader transport network for several days.

3. Methods

Disruptions to the national supply chain network are modelled using a mix of near real-time and modelled information in TraNSIT. In the first instance, current road closures due to flooding are obtained from third party state and territory web services (see appendix) as GeoJSON format datasets. These represent extant (i.e., near real-time) road closures at the time of data extraction. Because these services are independent from one another, their underlying road network data typically also differ; in turn, the TraNSIT model's road network (HERE streets) typically differs from each of these. Therefore, after extraction, closed road segment geometries obtained from each state and territory are conflated with TraNSIT's road network via nearest-neighbour mapping.

The resulting road segments are then used as input to the TraNSIT model where they are marked as unpracticable in the road network. The TraNSIT model is subsequently run for all freight movements that would normally traverse these blocked roads in order to find alternative routes. Two main outcomes result from such a model run: 1) an alternative route exists, and freight can be re-routed, or, 2) there is no alternative route and freight is therefore blocked. In both cases, various metrics relating to the freight and trip characteristics are calculated. While TraNSIT's freight movement data are available at monthly resolution, these metrics are scaled to be representative of a single week of sustained, unchanging impacts on the transport network, which, following consultation with stakeholders, was decided as being representative of the duration of a typical disruption.

The impacts of the road and supply chain disruptions are then quantified by comparing these 'flood scenario' results to business as usual (BAU) results (a pre-existing dataset). Relative differences in freight movement features, such as trip cost, length, and duration, as well as information on freight blockages, are extracted. The resulting data is aggregable and separable over several dimensions; in particular, by commodity (e.g., unleaded fuel, bread, or cattle) and commodity sector (e.g., fuel, processed food, or livestock), or spatially, by Local Government Area (LGA) and/or freight destination enterprise type (e.g., supermarket, fuel station etc.), or by a combination of the above.

Several key metrics and visualisations derived from the above data are presented in the form of a summary report. Metrics used were established through a thorough and iterative consultation process with end-users (NEMA and state and territory emergency management agencies), and are intended to be concise, easily understood, and 'actionable' in the sense that the supplied information can quickly and directly support emergency management decisions on the ground during an event. Some requirements which were borne out through this process, and which were subsequently incorporated into the report, include:

- Summary information on the current state of the national transport network
- Information on detour impacts due to disruptions
- Information on freight blockages due to disruptions
- Impact summaries at the state and LGA level
- Detailed information on critical goods not reaching communities due to disruptions

Complete TraNSIT model outputs for the scenario are also made available via the ACS TraNSIT web interface (not shown in this paper), which enables users to undertake further in-depth and self-guided analysis of the results, as required.

In the context of the operational ACS TraNSIT service, the entire workflow above is embedded within an automated scheduling pipeline, which is triggered at roughly 06:00 AEST each day. This pipeline handles all aspects of the service, including generation and distribution of the summary report to end-users, as well as uploading data to the ACS TraNSIT web interface.

4. Results

Key outputs of the service are summarised for a single day (7/1/2023) during which some of the peak impacts of the Kimberley flood event were experienced. Note that, due to space constraints, results presented are only a subset of the full set of outputs for the day but were chosen here to capture the most pertinent modelled supply chain impacts for the event.

Figure 1: National road closures and impacted LGAs on 7/1/2023

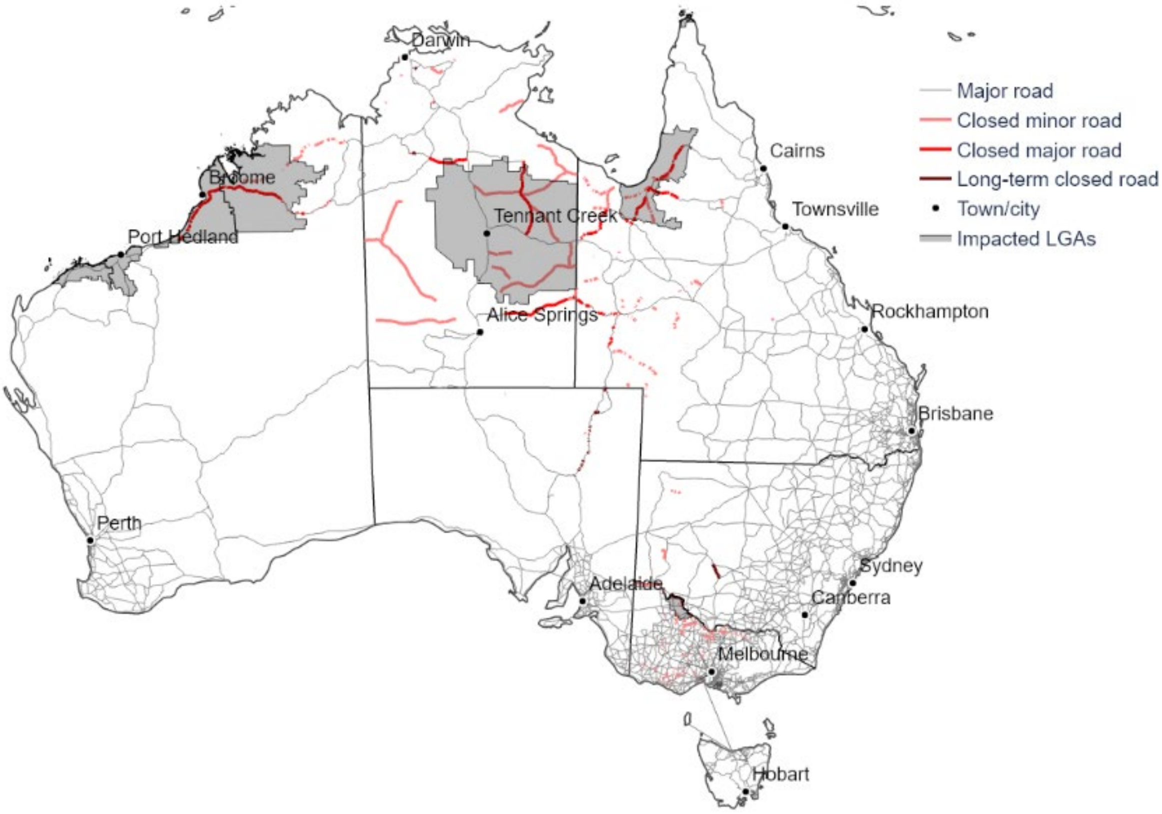


Figure 2: Modelled freight detours, relative to BAU, on 7/1/2023

Figure 3: Transport cost increases due to detours by commodity sector and relative to BAU, on 7/1/2023. Lighter bars indicate BAU costs (for affected trips only), while darker bars indicate modelled costs for the same trips during the flood event. Percentages show the change between the two.

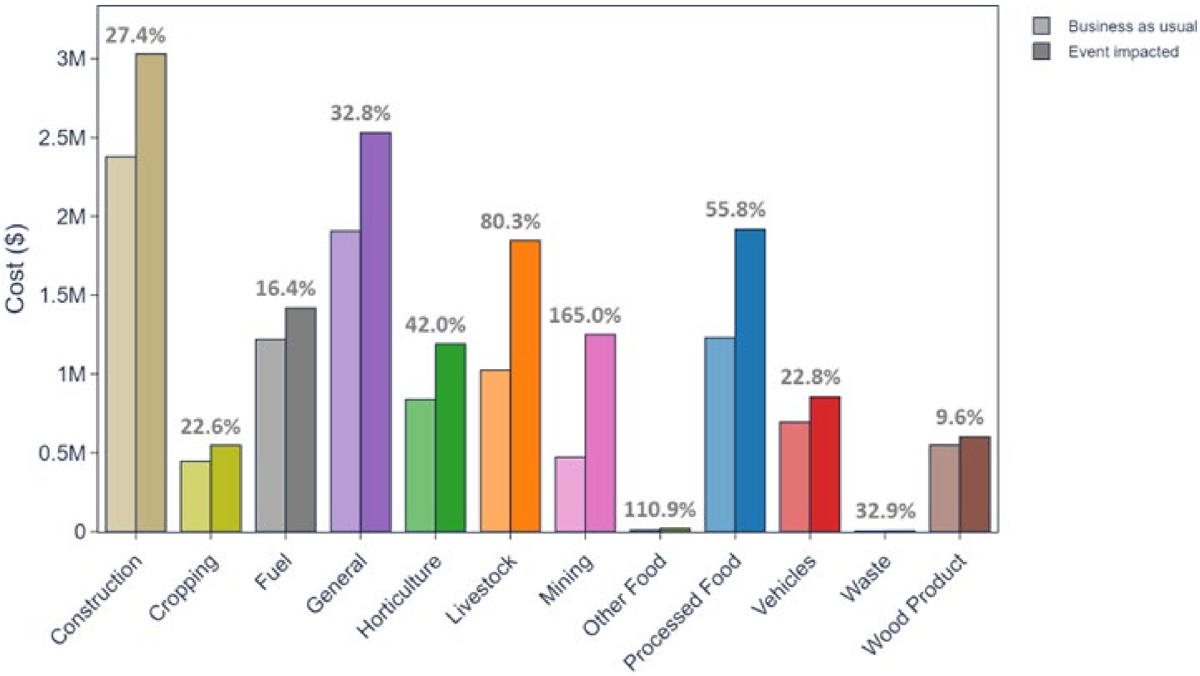
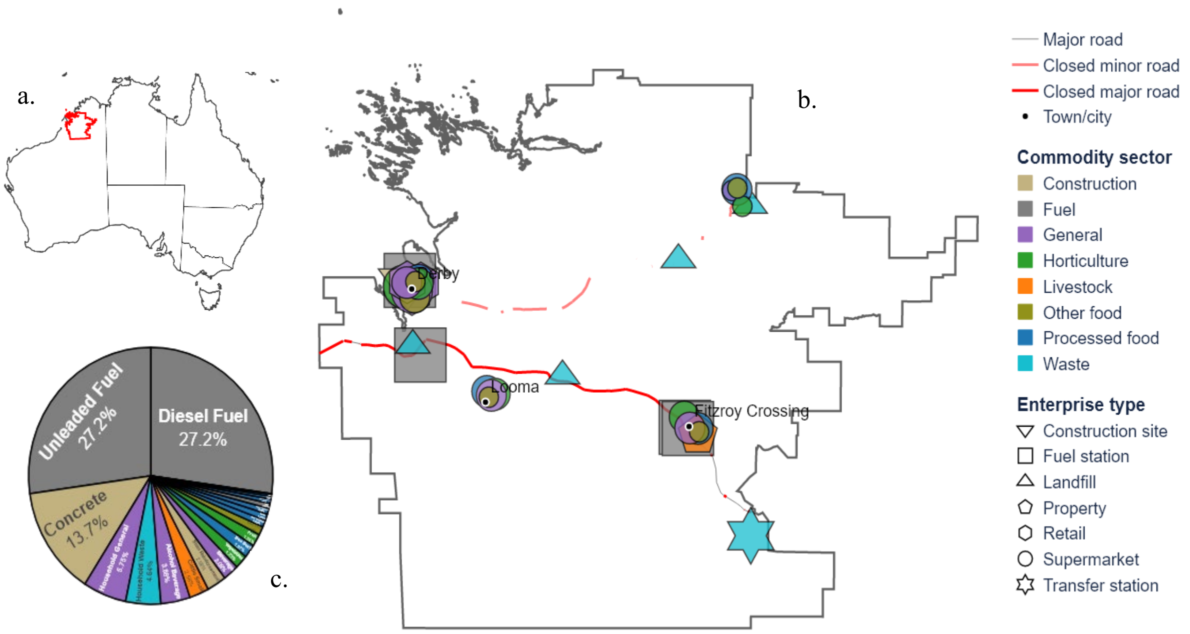


Figure 1 summarises the condition of the national road network on the morning of 7/1/2023. Note that there are major road closures not only within the Kimberley region, but also disruptions through central Northern Territory and Queensland due to flooding associated with the same weather event. Also evident are disruptions in Victoria, primarily residual from the major flood event over southern states during late 2022. Overlain on this map are ‘impacted LGAs’ - LGAs with communities likely experiencing shortages in critical food and fuel products. The latter information is intended to quickly direct users’ attention to the currently worst-affected regions in terms of direct community impacts.

Figure 2 summarises detour impacts due to current road closures. It shows the modelled change in absolute road truck trailer numbers relative to the BAU scenario (for all commodities). Of note is the reduction in trailers along the Great Northern Highway in northern WA, corresponding to extensive closures on that and nearby alternative roads due to flooding. Correspondingly, there is an increase in traffic on the Eyre Highway in SA/WA, representing detours for freight whose origin/destination is southern WA, and which would use the Great Northern Highway under BAU conditions. Of note elsewhere is the large increase in trailers along the Stuart Highway in NT/SA. This is likely in part due to trucks taking the ‘long way around’ on their journey from/to WA. Due to the nature of this event - with substantial road disruptions to remote and sparsely connected parts of the country - freight detour lengths exceed 3,500 km for several modelled freight movements, corresponding to several days’ extra travel time.

Figure 3 provides a commodity sector-specific breakdown of increases in transport cost, relative to BAU and for affected trips only, resulting from detours during the event. Among the worst impacted sectors are livestock and mining (economically two of the largest sectors in the region), which are expected to experience, on average, 80% and 165% increases respectively in transport costs under the current state of disruption. Overall, additional freight

Figure 4: Incoming freight blockages for the Derby-West Kimberley LGA: a) location of the LGA; b) map of incoming freight blockages within the LGA; c) distribution of all blocked incoming freight for the LGA, in terms of absolute tonnes. Note that, due to plotting constraints, some commodities in the pie chart are illegible – these include general household goods, household waste, alcohol, and cattle.



costs due to detours are modelled to be on average 40% greater than BAU costs (again, for affected freight only).

Figure 4b provides an overview of modelled incoming freight blockages in the Derby-West Kimberley LGA (an impacted LGA). Enterprises not receiving usual freight due to supply chain disruptions are marked on the map and are colour-coded based on the commodity sector that their blocked freight belongs to. Relative enterprise marker size provides a qualitative indication of the absolute amount (in tonnes) of freight blocked for that enterprise. For the LGA overall, modelling suggests that 96% of usual food inflows are unable to reach supermarkets, and 100% of usual fuel inflows are unable to reach fuel stations (these statistics are not indicated by the figure). Unsurprisingly, these blockages are particularly concentrated within the LGA's more highly populated towns of Fitzroy Crossing and Derby, which, for prolonged periods of the flood event, were completely cut-off from the broader transport network. Figure 4c depicts the overall distribution of BAU incoming commodities that are blocked during the event (in terms of absolute tonnes). Evidently, over half of the total blocked tonnes in the Derby-West Kimberley LGA consists of unleaded and diesel fuel. The information contained in these figures enables emergency managers to quickly identify which communities within a given impacted region are likely worst-affected, and therefore in most need of immediate assistance, during flood events.

Several remote impacts due to flooding in the Kimberley are also captured by the model. For example, access to Barramundi farms along the Kimberley coast (which are responsible for a large percentage of Australia's Barramundi production) is cut off. As a result, supermarket distribution centres in most capital cities are likely not receiving their usual Barramundi stock during the event.

5. Discussion

The results presented above highlight some of the key modelling capabilities of the current ACS TraNSIT service. This service runs daily and provides two products to emergency management end-users, namely, a report summarising the current impacts likely on the national supply chain network over the coming week, and an interactive web interface for users to further explore impacts beyond summary metrics. This service is of particular importance during natural hazard events, and provided ongoing support to emergency managers during the recent Kimberley flood event. Succinct and targeted metrics and visualisations assist emergency managers in quickly identifying and quantifying worst-affected regions and communities during an event, thus enabling managers to direct resources for near-term impact mitigation to greater effect. For example, summary measures of food and fuel unable to reach supermarkets and fuel stations in communities (Figure 3) provide managers with direct information on likely near-term shortages of critical goods typically required to sustain communities. In turn, this assists managers in identifying what sorts of commodities may need to be transported into communities by alternate means (e.g., by air) in the immediate term. A thorough consultation process with end-users throughout the development of the service was crucial in ensuring that outputs are meaningful and actionable in the context of a real-time operational emergency management setting. This remains an ongoing process, and further evolution of this product set is likely in the future.

The results presented raise interesting questions regarding interpretation of community-centric impacts in the face of alternative commodity choices, and this warrants deeper consideration. As an example (and as mentioned in the results section), modelling indicates that the Kimberley floods would likely cause disruptions to barramundi supplies in many parts of the country during the event, due to the Kimberley region being a primary barramundi producer nationally. Whilst this implies that barramundi consumers throughout the country will be unable to satisfy their usual barramundi intake, it does not necessarily translate to a similar depletion of the dietary/nutritional benefit that barramundi affords them for the duration of the event: whilst barramundi remains unavailable, consumers can simply replace this with a similar alternative commodity (for example salmon in this case, the supplies of which are generally unaffected by the event). For consumers in communities which are only distantly affected by the event, this is entirely possible; on the other hand, for consumers in communities directly and extensively impacted by the event, this is not necessarily the case: due to widespread direct blockages of incoming goods, it's possible that no alternative commodities are available. From an emergency management perspective, this reiterates the importance of presenting information around freight blockages through a community-centric lens, to help direct mitigation efforts to best meet the most immediate and critical community needs (e.g., food). As discussed above, the ACS TraNSIT service currently addresses this by specifically presenting blockages in critical consumer goods (food to supermarkets and fuel to fuel stations) as a percentage of BAU incoming freight of these types; however, further 'contextualisation' of model outputs can be achieved, and work is currently underway to translate this information into even more actionable and readily consumable forms by emergency managers; for example as the 'percentage/absolute number of families within an impacted LGA that are currently not receiving food', or, 'the percentage/absolute number of cars unable to fill their tank with fuel'.

There are current limitations to the TraNSIT model as a supply chain decision support tool. While the model provides insights on expected freight disruptions relative to BAU, there are no product inventories built into the model. Inventories are an important feature of realistic supply chain modelling: enterprises commonly maintain an inventory of reserve stock, and during supply chain disruptions, inventories may enable enterprises to continue operating under normal conditions for some period beyond the onset of the disruption (Atan and Snyder 2011). In its current implementation, TraNSIT effectively assumes that all freight moves through the supply chain network on a 'just-in-time' basis. This results in the immediate realisation of full potential impacts during a disruption, and therefore likely results in an overestimate in modelled impacts in many cases. Another limitation is the lack of 'alternate sourcing' of freight within the TraNSIT model, and, closely related to this, variable transport pricing and the impact this has on demand and choice of transport mode. In reality, enterprises will often seek alternate suppliers of product if their usual supply chain has been disrupted or transport costs become too expensive, thereby adding a degree of elasticity to the supply chain network (Colon et al. 2021). Conversely, in TraNSIT, suppliers for each enterprise are strictly fixed. This inelastic approach likely results, again, in modelled supply chain impacts being greater than what are experienced under a given scenario. It also fails to capture situations where transport costs exceed potential profits, thereby presumably resulting in delivery contracts not being completed. Finally, as previously mentioned, while the TraNSIT model does currently facilitate modelling of rail-based (and sea-based) freight in addition to road, integration of the two transport modes into a single adaptive multi-modal transport network has not yet been developed. This limits the current ACS TraNSIT service in that it is unable to seamlessly shift freight from road to rail in the event of road disruptions (or vice versa in the event of rail disruptions) without significant manual intervention, thereby rendering this feature ill-suited to an automated service.

Addressing the key limitations outlined above are priority improvements to the service under development. Other planned improvements include a supply chain impact forecasting capability, whereby near-term rainfall and flood forecasts, alongside physical road characteristics such as elevation data, are used to produce forecasts of probable road closures. This would be fed into the TraNSIT model to produce, in effect, a supply chain impact forecast at a given lead time. This capability would represent a significant improvement to the existing service, as it would enable emergency management and industry to act in advance of flood events, by shoring up likely impacted supply chains, and/or preparing communities for probable disruptions to the availability of essential products.

Finally, while this paper focusses specifically on road disruptions due to flooding, it should be emphasized that the TraNSIT model is not limited to this type of scenario in its application. Indeed, any scenario which can be adequately represented one or more disconnections in the physical transport network can be analogously captured by the TraNSIT model. Examples of this include train derailments, bushfires, or industrial disputes. Furthermore, TraNSIT is not limited to disruption modelling; it can also be used to model potential economic impacts and changes in network usage resulting from upgrades to the existing transport network. In this way, and as mentioned earlier in this paper, it can be used to inform and support optimal decision making around future transport infrastructure investment, such as improving network resilience in the face of increased stresses on the existing transport network arising from climate change.

6. Summary

In this paper, we have presented a novel tool - the ACS TraNSIT service - for monitoring and understanding real-time impacts on the national supply chain network due to disruptions during flood events. This service represents a major advancement in near real-time, national-scale supply chain monitoring, as well as in supply chain emergency response capabilities. We have presented some of the service's outputs and capabilities in the context of the recent Kimberley flood event in northern WA.

Since its inception during the 2021/2022 Australian severe weather season, the service has successfully supported emergency management through several major flood events around the country. Outputs are tailored to be easily consumed and rapidly actionable in critical and evolving emergency situations, and have assisted decision makers in appropriately allocating resources and supplies to worst-affected communities during flood events.

Current model limitations represent opportunities for development of additional capabilities and improvements to the existing service. These include incorporating enterprise inventories into the model, effectively enabling continued operation of enterprises for a time following an initial disruption (and therefore a more accurate representation of community resilience in the face of supply chain shocks); sourcing of freight by enterprises from alternate suppliers during disruption; and integration of other transport modes (e.g., rail) into the current service.

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Appendix

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Northern Territory road closures data: https://roadreport.nt.gov.au

Queensland road closures data: https://api.qldtraffic.qld.gov.au

South Australia closures data: https://maps.sa.gov.au

Tasmania road closures data: https://alert.tas.gov.au

Victoria road closures data: https://data-exchange-api.vicroads.vic.gov.au

Western Australia road closures data: https://www.mainroads.wa.gov.au