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Keeping goods moving in the wake of a disaster: a qualitative study of intermodal transport

Purpose – This paper examines what facilitates the swift reconfiguration of freight movements across transport modes in the wake of a major disaster.

Design/methodology/approach – A qualitative research approach focusing on the New Zealand domestic freight transport operations in the wake of the 2016 Kaikōura earthquake is used with data collected through 19 interviews with 27 informants. The interviews are thematically analysed by using the framework method.

Findings – The paper provides rich and detailed descriptions of the ability of a freight transport system to recover from a disaster through rapid modal shifts. It identifies nine factors enabling modular transport operations and highlights the critical role of physical, digital, operational, and inter-organisational interconnectivity in the aftermath of a disaster.

Originality – Although the management of freight disruptions has become a prevalent topic not only in industry and policy-making circles, but also in the academic literature, qualitative research focusing on the ability of commercial freight systems to adapt and recover from a disaster through rapid modal shifts is limited. This qualitative study sheds light on the mechanisms underlying the continuity of freight operations in the wake of a disaster and provides a comprehensive understanding of modular transport operations and the ability of freight systems to keep goods moving.

Keywords: freight transport, disaster response, disaster recovery, transport disruptions, modularity, intermodal transport, synchromodal transport, transport interfaces, redundancy, flexibility

Paper type: research paper

1. Introduction

Shocks, such as disasters or the COVID-19 pandemic, expose the fragility of supply chains and bring chaos to the movement of goods (Chowdhury *et al.*, 2021; van Hoek, 2020). With freight disruptions expected to occur more frequently and with increasingly severe consequences, supply chain risk management and resilience have become paramount issues (El Baz and Ruel, 2021; Fan and Stevenson, 2018). Among the events affecting freight operations, disasters have elicited research interest because they can substantially disrupt pre-existing transport networks and the deliveries of goods needed by businesses and individuals. When the damage is significant, re-establishing critical connections and prior transport capacity may not be an option in the short term. To ensure the continuity of their supply chains, businesses need to swiftly adjust their freight operations. In particular, the use of alternative transport routes and modes (road, rail, sea, and air) is a critical factor of transport resilience and the ability of freight operators to mitigate disruptions in the aftermath of a disaster (Ertem *et al.*, 2017). Quantitative approaches and mathematical modelling are commonly used to examine intermodal transport and the creation of resilient freight networks. However, little qualitative research delves into and provides rich and detailed descriptions of the ability of freight transport systems to recover from a disaster through rapid modal shifts (Wan *et al.*, 2018). In addition, practical studies focusing on the post-disaster response and recovery of a freight transport system are limited (Mattsson and Jenelius, 2015). Therefore, the purpose of this qualitative study is to examine what facilitates the swift reconfiguration and recovery of freight movements across transport modes when a natural hazard causes severe transport disruptions. The research is guided by the theoretical concept of modularity and the following question: *what are the key factors enabling modular and flexible freight operations across transport modes in the aftermath of a disaster?* To address this question, a qualitative study focusing on the New Zealand (NZ) domestic freight operations in the wake of the 2016 Kaikōura earthquake is used with data collected through 19 interviews with 27 key informants.

The remainder of this paper is structured as follows. Section 2 reviews the literature on resilience (flexibility and redundancy), intermodal transport, and modularity. Section 3 focuses on the methodological approach and the presentation of the Kaikōura earthquake. Section 4 reports the qualitative analysis of the interview data. These findings are discussed in Section 5. Sections 6 and 7 respectively identify the contributions and limitations of this research. Section 8 provides concluding comments.

2. Literature review and theoretical grounding

2.1. Resilience (redundancy and flexibility)

Since the seminal paper by Christopher and Peck (2004), the concept of supply chain resilience has been widely discussed in the literature. It refers to the ability of a supply chain to respond to disruptions, including unexpected and uncontrollable events, and rapidly recover from them in order to maintain the continuity of operations (Ponomarov and Holcomb, 2009). As explained by Sheffi and Rice Jr. (2005), recovery is determined by the level of redundancy and flexibility built into the supply chain system. Redundancy is defined as the extra resources and excess capacity kept as a buffer against uncertainty and disruptions. Flexibility is commonly defined as the ability to swiftly respond to disruptions along the supply chain by reconfiguring operations (Sheffi, 2019). The concepts of resilience, flexibility and redundancy are widely discussed in the supply chain management literature (Pettit *et al.*, 2010; Tukamuhabwa *et al.*, 2015) and in the more specific context of freight transport (which is the focus of this paper). For example, Ta *et al.* (2009) conceptualise freight transport resilience by defining the concept along three dimensions (the physical infrastructure, the organisations overseeing infrastructure maintenance/performance, and the users). They also identify the components of a resilient freight transport system, including redundancy, collaboration between organisations, and smooth interconnections between the parts of the system. Going one step further, Tamvakis and Xenidis (2012) highlight the importance of the information technology supporting the system's operations.

In their review of the literature on transport resilience, Wan *et al.* (2018) show that most academic studies in this area are quantitative studies based on mathematical modelling and simulation (accounting respectively for over half and one third of the reviewed studies). For example, mathematical modelling is used to optimise freight flows (Hosseini and Al Khaled, 2021), measure and increase recovery performance (Chen and Miller-Hooks, 2012), and assess the value of resilience drivers, such as the structure of the transport network (Zhang *et al.*, 2015) and real-time decision making (Hrušovský *et al.*, 2021). Wan *et al.* (2018) also argue that transport resilience can take different forms and that context is a key differentiating factor. For example, transport resilience has been studied in the context of different infrastructures, such as seaports (Becker and Caldwell, 2015) and inland ports (Hosseini and Barker, 2016), different modes, including maritime (Omer *et al.*, 2012) and rail transport (Bešinović, 2020), as well as different events, such as disasters or the COVID-19 pandemic (Schofer *et al.*, 2022).

Focusing more specifically on the concepts of redundancy and flexibility, the literature shows that resilient transport requires redundant connections, namely alternative roads or alternative modes between the origin and the destination of the goods. These alternative connections bypass disrupted areas, enable the re-routing of freight movements (Ishfaq, 2013) and, therefore, mitigate the impact of disruptive events (Uddin and Huynh, 2016). Going one step further, Xu et al. (2015) and Jansuwan et al. (2021) argue that two dimensions are needed to increase transport flexibility and prevent traffic bottlenecks when shipments are re-routed. These two dimensions are the availability of alternative travel options (routes and modes) and sufficient redundant capacity to handle varying freight volumes.

2.2. Intermodal transport

Intermodal transport is defined as the transport from origin to destination using the same load unit, usually a shipping container (SteadieSeifi *et al.*, 2014). By increasing the number of transport options, an intermodal network creates a flexible freight system (Naim *et al.*, 2006). Flexible transport generates operational benefits and customer value, including on-time deliveries and higher product availability (Dong *et al.*, 2018). The literature also argues that intermodal transport brings economic (Agamez-Arias and Moyano-Fuentes, 2017), social (Ertem *et al.*, 2022), and environmental benefits (Lammgård, 2012). Despite these benefits, the implementation of intermodal transport presents multiple challenges. For example, intermodal operations require a significant level of integration because modes operate differently and typically control only a part of the transport chain (Bontekoning *et al.*, 2004). Therefore, various actors need to work together in order to coordinate their actions, sometimes over different time horizons. Actors include transport operators (across all modes and distances, namely short and long hauls), terminal operators (in charge of the transhipment operations), and governmental agencies responsible for infrastructure planning and development (Macharis and Bontekoning, 2004).

Another challenge is the complexity inherent in the combination of transport modes with different volume and time constraints, different norms and practices, and different service contracts (Bontekoning *et al.*, 2004). Therefore, intermodal operations require the various transport modes to be tightly integrated through the development of interfaces. Interfaces determine how the components of a system interact and fit together, thereby enabling the seamless movements of goods between routes, modes, and/or actors.

To some extent, intermodal transport has been investigated in the context of disasters. For example, Ertem *et al.* (2017) discuss the use of multiple modes of transport to increase resilience in humanitarian logistics operations, but note the lack of academic studies on this topic. Addressing this gap, Ertem *et al.* (2022) develop an intermodal transport model supporting the delivery of emergency supplies in Turkey and find that using multiple modes (road/rail/sea) increases the resilience of humanitarian systems and the probability of reaching those affected by a disaster. Suzuki and Li (2012) focus on the 2011 earthquake in Japan and discuss the valuable contribution of redundant intermodal freight connections to the flexible movements of relief items and fuel in the aftermath of this event. Hosseini and Al Khaled (2021) also show that adding redundancy to the transport infrastructure (including routes and intermodal terminals) facilitates the re-rerouting of shipments, enhances the continuity of freight movements and, ultimately, increases the ability of a transport system to mitigate the impact of disasters.

Beyond the above studies, the literature discussing both intermodal transport and disaster response/recovery is scarce and qualitative research providing a rich and in-depth understanding of the multifaceted factors enabling the post-disaster reconfiguration of freight operations across modes remains limited. To address this gap, the theoretical concept of modularity is used in this paper.

2.3. Modularity

Modularity derives from the study of complex systems and the interconnections between the multiple elements that hold the systems together (Ackoff, 1971). A system is said to be modular if it is built from subsystems (or modules) that have been independently designed but, when put together, operate as a whole and contribute to the system's overall function (Baldwin and Clark, 1997). Thus, modularity refers to the extent to which the system can be broken up into modules and recombined into a different system, thereby allowing for more variety in end configurations (Schilling, 2000). According to Baldwin and Clark (1997, 2000), a modular system needs an architecture and interfaces. The architecture determines what modules are integrated into the system and what function each of them performs. Interfaces facilitate the interactions between the modules and determine how they fit together and interconnect. Ultimately, interfaces allow the components of a system to become non-specific and to be recombined effectively, namely with no or little loss of functional performance (Peters et al., 2018).

Modularity has been studied in the context of operations management (Baldwin and Clark, 2000) and, to some extent, supply chain operations (Jayaram and Vickery, 2018). In regard to freight transport, the concept of modularity underpins the development of academic research on synchromodality. An extension of intermodal transport, synchromodality is the real-time planning of freight movements and rapid shifting between modes and routes to create efficient flows of goods (SteadieSeifi *et al.*, 2014). In a synchromodal system, freight movements are booked mode-free, allowing for the modal split and travel route to be optimised for each shipment (Pfoser et al., 2016). Figure 1 compares intermodal and synchromodal transport. It shows that synchromodality creates an extremely adaptable system with the transport modes being the elements of a modular and highly adaptable system. By increasing modularity and adaptability, synchromodal transport can be used to mitigate the effects of transport uncertainty (Delbart *et al.*, 2021).

Figure 1. Intermodal and synchromodal transport (adapted from Farahani *et al.* (2018))

[Figure 1]

Synchromodal transport requires a high level of interconnectivity among the various actors and modes involved in freight movements. There is general agreement in the literature (e.g. Giusti *et al.*, 2019; Pfoser *et al.*, 2017) that interconnectivity comes from physical, digital, and operational interfaces. Physical interfaces create a highly efficient infrastructure enabling seamless flows of goods through hubs and modes. Digital interfaces include interoperable and interconnected digital platforms enabling information sharing and rapid re-routing decisions.

Operational interfaces facilitate the alignment of transport operations through operational standards, protocols, and procedures across modes.

The benefits of synchromodal transport identified in the literature include flexibility, speed, and cost reductions. Flexibility is the result of the increased number of route options and combinations, as well as integrated and dynamic routing planning (Dong *et al.*, 2018). Seamless and flexible movements of goods are also due to the availability of real-time transport data that enable transport operators to swiftly identify arising risks or opportunities along the transport chain and proactively adjust their plans to avoid disruptions and delays (Ambra *et al.*, 2019). Ultimately, seamless and flexible transport generate customer benefits (e.g. higher product availability due to rapid and on-time deliveries), operational benefits (e.g. reduced lead times and the better utilisation of the available transport resources through consolidation), and financial benefits (e.g. reduced transport costs). The environmental advantages of synchromodality have also been discussed in the literature. By switching transport to more environmentally friendly modes (e.g. rail or barge), synchromodal transport reduces carbon emissions (Dong *et al.*, 2018).

Although synchromodal transport is seen as a freight system able to deal with uncertainties and rapidly respond to constraints and disruptions (Delbart *et al.*, 2021), it remains a concept in its infancy (Pfoser *et al.*, 2022) and has not been specifically studied as a way of managing severe freight disruptions in the wake of a disaster. This paper uses the above-mentioned theoretical principles underlying synchromodal transport (physical, digital, and operational interconnectivity) to investigate what factors enable modular freight operations and rapid transport adjustments in the wake of a disaster.

3. Materials and methods

3.1. Qualitative data collection and analysis

An interview study was selected to cover a broad area of topics related to the reconfiguration of transport operations in the wake of a disaster and collect detailed narrative insights on the interviewees' experiences. Interviews were, therefore, expected to provide an in-depth understanding of the mechanisms underlying modular and flexible freight operations. 19 semi-structured interviews with 27 key informants were conducted by the main author from May to July 2020. Three interviews included more than one participant.

We opted for purposive sampling, a non-random technique based on the deliberate choice of the participants expected to provide the most relevant insights and commonly used in qualitative research (Etikan *et al.*, 2016). The potential respondents were approached directly via an email presenting the research or via intermediate contacts. The interview participants included various domestic actors representing different roles and transport activities in order to capture the diversity of their views and/or convergent thoughts. Nine freight transport users (freight owners including producers, distributors, and retailers), six transport operators (carriers across all modes, namely road, rail, coastal shipping, and air), four seaport managers (both in the North and South Islands of NZ), four industry representatives, and four governmental officials (including central authorities in charge of transport policy development and public actors responsible for the maintenance and performance of the transport network) were interviewed. As such, the participants represented the main categories of actors identified by Crainic *et al.* (2018). The interviewees were transport managers, heads of supply chain, operations managers, logistics managers, shipping managers, order fulfilment managers, etc. Table 1 provides information about the interviews.

Table 1. Interview details

[Table 1]

Semi-structured interviews were selected because they provide an overall direction to the discussions without obstructing the natural flow of the conversation and because they allow for follow-up questions that elicit more specific information. The average duration of the interviews was 50 minutes. As illustrated in Table 2, clear, generic, and open-ended questions were used to elicit a variety of responses and to avoid bias and distortion in the collection of data.

Table 2. Interview questions

[Table 2]

The interviews were recorded, transcribed verbatim, and analysed qualitatively using the framework method. The framework method is a systematic approach to the management and analysis of qualitative data. It is based on the identification of categories and codes that are used to provide a new structure to the data and help investigators address the research questions (Gale *et al.*, 2013). Gale et al.'s (2013) seven steps were followed in order to provide a clear audit trail and enhance the transparency of the research process (Gammelgaard, 2017), from the collection of the original data to the presentation and interpretation of the findings. In particular:

1. The 19 interviews were transcribed;
2. The researchers familiarised themselves with the interview data (by listening to the recordings and reading the transcripts);

3. To ensure the reliability of the coding process and avoid bias, six of the 19 interviews (i.e. over 30% of the interviews) were coded separately by two different researchers;
4. The researchers discussed and compared their coding and, ultimately, agreed on a working analytical framework for the coding categories;
5. All transcripts were coded in NVivo by applying the coding system agreed on;
6. The coded data was aggregated by category;
7. The data was analysed and interpreted around the theoretical concept of modularity and the different types of transport interfaces.

3.2. Research context

To collect meaningful qualitative data, the selection of an appropriate context expected to provide rich information on the subject under investigation is critical (Gammelgaard, 2017). NZ is prone to natural hazards and its geography (two long, narrow, and mountainous islands) increases the vulnerability of transport networks. As a result, severe disruptive events are likely to cause transport bottlenecks and freight disruptions for extended periods of time (Aghababaei *et al.*, 2020). As such, NZ provides an excellent setting for the empirical analysis of post-disaster transport disruptions.

In order to ground this research in the reality of a specific disaster, the interviews focused on the 2016 Kaikōura earthquake. This selection is justified by the major transport adjustments required after the event (Davies et al., 2017). The remainder of this section presents the NZ transport system and the Kaikōura earthquake.

3.2.1. The NZ transport system

An overview of the NZ transport system is presented in Figure 2. The system is dominated by road transport, with 92.8% of the total tonnage carried by trucks (Paling and King, 2019). The national State Highway network provides road linkages between NZ regions and cities. State Highway 1, which runs from the North to the South of the country, is often described as the backbone of the NZ transport system.

Figure 2. Overview of the NZ transport system with a focus on State highways, the rail network, and the main ports (OpenStreetMap, 2022)

[Figure 2]

The NZ rail network is owned and operated by the government through KiwiRail, NZ's sole rail operator for freight. Railways link the main cities in NZ and are used for large volumes of bulk commodities (e.g. logs) and containerised freight. Rail transport represents 5.6% of the total tonnage transported (Paling and King, 2019).

Five RO-RO ferries form a 'bridge' across the Cook Strait (93 kilometres) between Wellington in the North Island and Picton in the South Island (Figure 2). These ferries are operated by Interislander (run by KiwiRail) and StraitNZ (a privately-owned company run under the Bluebridge brand). They provide both passenger and freight services. By carrying freight in commercial trucks and wagons, the Cook Strait ferries link the road and rail networks between the North and the South Islands. In addition to the ferries, coastal shipping services transport bulk commodities (cement, fertiliser, grain, etc.) and containers around NZ. Pacifica Shipping is the only domestic shipping operator moving containerised cargo. Coastal shipping represents 1.6% of the total tonnage transported (Paling and King, 2019). In NZ, domestic flights are mostly for passenger movements, with only a small percentage of the total tonnage of domestic freight transported in the holds of passenger aircraft. NZ's flag carrier airline, Air New Zealand, does not operate any dedicated freighter aircraft domestically.

The prevailing freight flow pattern in NZ is from North to South. A large proportion of the imported containers are unloaded in Tauranga and Auckland, NZ's largest seaports with a yearly container throughput of 1.25 million Twenty-foot Equivalent Units (TEUs) for Tauranga and close to 900,000 TEUs for Auckland. Lyttelton Port, near Christchurch, handles some 450,000 TEUs per year and is the South Island gateway port (Deloitte, 2021). International trade represents some 60% of NZ's total economic activity (MFAT, 2022).

3.2.2. Kaikōura earthquake

On 14th November 2016, a magnitude 7.8 earthquake occurred in the South Island, followed by ongoing aftershocks. This earthquake caused the rupture of multiple faults, generating significant ground shaking, landslides, and land deformations (Hamling *et al.*, 2017). The upper South Island experienced the most severe infrastructure damage and transport disruptions after roads, railways, bridges, and tunnels were destroyed (Wotherspoon *et al.*, 2017). Waka Kotahi (2018), the NZ Transport Agency, reported 5,000 landslides along transport routes and identified 3,300 road and rail sections in need of repair in the South Island. Major freight routes between Picton and Christchurch were closed immediately after the event, including sections of State Highway 1 and the Main North Line railway. Figures 3 and 4 show the locations of the major road and rail closures in the aftermath of the earthquake, as well as the alternative routes used.

Figure 3. NZ road network on Day 16 following the Kaikōura earthquake (Davies et al., 2017)

[Figure 3]

Figure 4. NZ rail network on Day 16 following the Kaikōura earthquake (Davies et al., 2017)

[Figure 4]

The Main North Line railway reopened in September 2017, some 10 months after the earthquake. State Highway 1 was rebuilt and fully reopened in December 2017. Until the full reopening of the roads and of the railway, the damage from the Kaikōura earthquake significantly disrupted NZ's domestic freight operations and, in particular, the movements of goods between the two islands and around the upper South Island (Davies *et al.*, 2017). As a result of the unavailability of State Highway 1 and of the Main North Line railway, the use of coastal shipping and air transport increased. Road movements were also substantially affected since alternative inland routes were used and some of the goods carried by rail before the earthquake switched to road. This significantly extended the delivery times and intensified the demand for trucks. For example, trucks travelled some 250 additional kilometres between Picton and Christchurch, increasing the delivery time from 4.5 hours to 8 hours (Stevenson *et al.*, 2016).

4. Findings

This section presents the thematic analysis of the interview data. Representative direct quotations are extensively used to provide narrative support to the analysis, a conventional approach in the presentation of qualitative research findings (Anderson, 2010). The reference attached to the quotations reflects the number allocated to each interview and the categories of respondents presented in Table 1. The categories of respondents are abbreviated as follows: TO for transport operator, TU for transport user, IR for industry representative, SM for seaport manager, and GO for government official.

4.1. Physical interfaces

4.1.1. Transport routes

The interview data illustrates the important role played by alternative transport modes and adequate linkages in the rapid reconfiguration of freight operations. According to most interviewees, the road and railway closures forced businesses to find alternative arrangements, including modal shifts from rail to road, from rail to coastal shipping, from road to coastal shipping, and from road to air. As explained by a business established in the upper South Island, "prior to the earthquake, the majority of the cargo that came out of our plant went south via rail and was loaded at Lyttelton Port [close to Christchurch]. Obviously with the rail down, we moved to all of the cargo going north. Essentially, we weren't able to get anything south, so our whole supply chain shifted to a north-facing model" (TU4).

NZ being highly reliant on road transport, alternative inland roads were used "through the centre of the South Island to get into Christchurch" (TO9). However, the use of inland roads proved challenging and created "transport congestion and road wearing issues" (IR7). "Suddenly, instead of having 200 trucks a day going down that route, there were a thousand a day. […] And we were competing for the space on the roads with the day-to-day public traffic, cars, motor homes, and all that stuff" (TO9). As a consequence, safety was an issue: "trucks put their wheels onto a soft shoulder or just outside the shoulder. And we had rollovers. That would close the highway for a wee while" (GO17). "A big lesson is that, if we have an event like Kaikōura, our main highway network, State Highway 1, really has to be designed with significant alternative routes" (TO9).

If a level of redundancy exists in the road network, the situation is different for rail: "when you look at rail, we only have, pretty much, the one rail network and its main arterial runs north to south" (SM8). "So rail became a non-modal option" (TO9) in the upper South Island following the Kaikōura earthquake. To mitigate this risk, one interviewee suggests "that government investments should create more services that branch off the main trunk line" (TO9).

The interviews also highlight the valuable contribution of the normally under-utilised coastal shipping capacity. "The earthquake happened at midnight and the next morning, the amount of coastal cargo that arrived in Auckland had doubled" (IR2). In addition to Pacifica's domestic coastal services, international shipping lines transporting import and export cargo to and from various NZ ports (including Blue Water, Maersk, MSC) were used for domestic inter-island operations. "Typically, they drop the imports in Auckland or Tauranga and then go south and fill up with exports. So that's why they've got all the spare capacity" (IR11). However, reliability issues were observed because international shipping lines serve their own commercial interests and do not see NZ (a remote location with a limited population) as a key destination. "Pacifica is the domestic provider, they had a very set shipping schedule and shipping capacity. […] The big shipping lines were more fickle and off window. If they were running late or they had their own capacity constraints, they could leave cargo on the wharf and just picked it up the next week. This is not useful when you try to run a domestic supply chain" (TO3).

Around one third of the freight normally transported by rail shifted to sea (TO3) but due to the longer delivery times and the low service frequency, NZ businesses commonly see coastal shipping as a non-attractive transport option. "The challenge with coastal is that it is a very slow service" (TO3). These service quality issues affected the post-disaster reconfiguration of transport operations in the wake of the Kaikōura earthquake: "It was hard to go from what you could effectively do as a 48-hour service on road from Auckland to Christchurch to a five-day service with coastal shipping" (TO16).

Therefore, airfreight was used for some of the time-sensitive products transported by road before the event. "Christchurch to Auckland, airfreight typically operates around 85-90% volume load factor […]. During that period, it would have operated at a 100%, just to keep things going. […] Without airfreight capacity, a number of businesses "would've run out of supply pretty quickly" (TO14).

4.1.2. Vehicles and carrying capacity

The interview data illustrates how the use of appropriate vehicles enhances interconnectivity between transport modes. Participants mention various vehicles (trucks, trains, coastal ships, ferries, aircraft) and the fact that these vehicles are not fully integrated. For example, the NZ truck fleets are mainly composed of curtain-siders rather than container trailers: "NZ businesses are quite wedded to the curtain-side assets […]. They side-load rather than end-load" (TO3). This does not support rapid movements of goods between trucks and other modes, as will be further explained in the next section discussing standard loads units.

Rapid modal shifts require not only the use of suitable vehicles, but also sufficient vehicle capacity to handle increased freight volumes. In the aftermath of the Kaikōura earthquake, the trucking capacity became an issue "because everyone was trying to get in extra trucks" (TO16). "Then, once we got the truck problem sorted out, the issue became getting enough drivers. […] Because of the diversion [through the inland route], you could not go from Spring Creek to Christchurch and back on one shift. We had to set up drivers in a hotel at a midway point" (TO16).

Although building redundant vehicle capacity is mentioned as a possible solution, the interviewees acknowledge that doing so is costly: “nobody wants to pay for assets that aren't going to be utilised, just sitting there for a what-if situation” (TU15). Therefore, long-term equipment decisions need to be supported by government funding: “if you're going to have latent capacity, somebody's going to have to pay for that, and that's going to have to be central government” (TU4).

4.1.3. Transhipment hubs

The interview data provides insight into the essential role played by a number of nodal points after the Kaikōura earthquake. This includes seaports, inland ports (hinterland extensions of seaports), and the Spring Creek freight terminal located some 20 kilometres South of Picton (Figures 2, 3, and 4). In regard to seaports, the severe infrastructure damage caused by the Kaikōura event increased the volume of domestic port operations. Therefore, having port infrastructure with sufficient capacity and the ability to cater for a rapid influx of domestic freight was essential: “there was more demand for [port] services, what we saw virtually overnight given that the rail link and the road link were cut off, and because the ferries were closed for a couple of days. [...] The risk that you have is that you get a flood of inbound coastal containers. If those containers sit on the port for a long time, then that causes a capacity issue on our yard. […] Once you reach a certain level of congestion, then it goes downhill very quickly. If the earthquake had happened when we were full, it would have been enough to tip us over the congestion level. As it turned out, we had enough space and we were able to deal with it” (SM12). In this context, inland ports played an important role after the Kaikōura earthquake. They were used to free up yard capacity, “like a safety valve […]. When we have issues with capacity on the main port, we can use the inland port to store containers that we would normally store on the main port. It provides extra capacity” (SM12).

In addition to maintaining capacity, seaports need to be able to withstand the impact of disasters. According to multiple interviewees, the infrastructure of the NZ domestic ports is not sufficiently resilient: “port infrastructure tends to be done in the cheapest way possible and in an emergency. That really impacts on your resilience” (IR2). Robust port infrastructure is particularly important on both sides of the Cook Strait to support inter-island freight movements. There is a need for “really resilient, reliable infrastructure in Wellington and in Picton […] because we live on a fault line, you know, Wellington is on a fault line” (TO3).

When asked what facilitates the rapid movements of goods between modes, the role played by the Spring Creek intermodal freight terminal is mentioned by multiple interviewees. Before the earthquake, this terminal was a small container transit site operated by KiwiRail. Following the earthquake, it rapidly became a larger freight hub servicing up to 100 trucks a day (7 days a week, 24 hours a day) and facilitating the reconfiguration of transport operations. “The whole freight market realised that Spring Creek as a staging point for freight between the islands was pretty critical” (TO3). In particular, Spring Creek was used “as a transfer point, to take containers and freight off trains, and put them on trucks. […] Spring Creek was a key lifeline” (TO6).

4.1.4. Standard load units

The interview data highlights the critical role of shipping containers in the aftermath of the Kaikōura earthquake. “The only way you could move freight successfully between the islands was containerisation” (TO9) because “containers being containers, they can change modes very easily” (SM12). “The worst way is to unload all the freight out of a railway wagon, then reload it into a conventional truck” (TO9).

However, several interview participants discussed the lack of container capacity in the aftermath of the Kaikōura earthquake. In NZ, containers are mostly used for international trade.

Since curtain-siders (rather than containers and container trailers) are used for domestic freight movements, containers are in short supply when domestic freight has to be containerised, like in the aftermath of the Kaikōura earthquake. "Inter-island, we had to containerise all the products. So, we had to find containers. There was a shortage of containers. […] So, the first thing we had to do was to source as many containers as we could. We bought every available container that we could find in NZ, all within 48 hours. We also bought a hundred containers in China, brand new ones, but you've got to get them here and that takes five weeks" (TO9). Building this capacity requires a significant capital investment. "If we spend hundreds and hundreds of thousands of dollars buying that equipment, how long is this for? I mean, will we be using them for the next five years, which gives us a return on that investment? Or is it just during the duration of the event itself, as a temporary solution? And after that, what do we do with all these containers that are going to sit around for years, waiting for the next event that might not come?" (TO9).

4.2. Digital interfaces

The interview data shows that rapidly formulating a new transport plan in the wake of a disaster requires information and technology.

4.2.1. Information availability

As recounted by the interviewees, a variety of information was needed in the wake of the Kaikōura event. First, post-earthquake information about the accessibility of the transport network was critical: "you need information from the government, like how long the railway and the State Highway are going to be out of commission for. As I recall, it took a little bit of time for people to actually work out how long it was going to take to repair the road and the railway. […] Initially, it was treated as a short-term problem and then, when people assessed the damage and understood the scale, it became a long-term problem. […] Had we got better quality information at the start, we probably would have made different decisions and had different conversations earlier" (TO16).

In addition, in the event of a disaster and the subsequent re-routing of freight movements, advance demand information is essential to plan resources and swiftly respond to changing demand for freight transport: "we need to know what we're going to be receiving […]. This communication flow is absolutely vital. Without it, you're flying blind and you just don't know what you're going to be coping with" (SM13). Collecting and sharing that information becomes extremely complex when the number of customer interfaces increases. An interviewee compares rail and road operations: "If you think about my Auckland to Christchurch train that leaves at 9:30pm. I've got 10 wagons of freight on it for a trucking company. We look at it as freight for one customer. They look at those wagons as the freight for 3,000 customers" (TO3).

4.2.2. Interoperable technologies

The integration of information systems across the supply chain is another essential element of a digital transport system. However, different actors (users, seaports, transport operators, etc.) use different systems: "everyone's got its own system" (TO14) and "most of them are proprietary systems" (TO9). "Unfortunately, in the NZ context, we would like to believe that we are linked technology-wise pretty well but, in reality, we're not linked that well. […] Airfreight doesn't talk to sea freight, sea freight doesn't talk to road, and airfreight doesn't talk to road" (SM8). Because transport actors operate in a digitally disconnected environment, manual processes and verbal communication had to be used in the aftermath of the Kaikōura earthquake despite the fact that phone and mail communication is time-consuming and prone to errors: "in those times, it's such a fluid situation, it moves to a verbal line of communication […], via phone, text message, rather than system-generated, as we normally would" (TU15).

In other words, “we were on the phone using relationships to get capacity and yes, it was quite labour-intensive” (TO16).

Another interviewee explains how digital connections improve the management of rapid changes in operations: “one of our customers, their level of rebooking for containers went from being less than 2% of bookings to, at its peak, 85% of their bookings having to be reworked. […] With digital integration, all we have to do is pick up containers on the day and move them from A to B. If it’s linked up into our systems, we’re agnostic as to how many times they’ve changed the booking. So, there is a fundamental efficiency in that, which is why digital connections are important” (TO3).

4.3. Operational interfaces

The interview data shows that adjusting transport in the wake of a disaster requires organisations to reconcile their operational differences because road, rail, sea, and air operate differently and are subject to their own requirements and constraints. The interviews provide insight into these operational differences and the interfaces needed to create homogeneity in the transport system: “you’ve got to make sure that you are aligning your requirements around dangerous goods, weights, all those things” (TO3). Weight precision is particularly critical for airfreight: “the customer books 1,000 kilos and they turn up with 800 kilos. Or the other way: they book 1,000 kilos and they turn up with 2,000 kilos. That sounds good but it's a problem because we have to offload. We plan everything down to the kilo” (TO14).

Differences across modes also exist in the use of consolidated loads, for example when goods are palletised. Often, trucking companies carry pallets built to 1.8 meters high “whereas with airfreight, with the type of aircraft we've got around the country, our maximum height for a pallet is either 1.6 or 1.1 meters” (TO14). Booking requirements are also different from one mode to the next: “a trucking company just wants to know how many pallets need to be moved and the gross weight. [Airfreight] needs the volumetric weight" (TO14). Therefore, in the aftermath of the Kaikōura earthquake, operators had to clarify the transport characteristics and constraints associated with each mode: "we needed to educate customers not used to airfreight really quickly" (TO14). Education was also needed across the transport industry: "a lot of the trucking guys really don't have a good understanding of airfreight. And the same for us. Everyone is really good at what they do, but if you're asking what the trucking guys do, I actually wouldn't have a clue. I know they put stuff on a truck, but the timings and the requirements that they have, that one would be an education piece" (TO14).

Beyond these mode-specific characteristics, aligning scheduling arrangements was needed in the aftermath of the Kaikōura earthquake. Coordinating service timetables was critical due to "the perishable nature of some products" (TU4). For example, the Cook Strait ferries adjusted their timetables to accommodate the longer truck turnaround times between Picton and Christchurch, and retailers operated longer hours: "our distribution centres ran pretty much 24 hours for taking consignments in whereas, traditionally, it is from 6 in the morning till 6 at night. If there was a truck arriving at Christchurch at 2am in the morning, we would take that" (TU1).

4.4. Inter-organisational interfaces

The interview data illustrates the importance of inter-organisational relationships to manage freight disruptions and ensure transport continuity during a crisis. This includes the ability to rely on a well-established network of industry contacts: "in NZ, a lot of it is around relationships and knowing people and organisations, who to contact, who to talk to, where to get good information from. That is invaluable. And that allows you to react with whatever you need" (SM13). To this end, partnerships (rather than transactional relationships) are important: "what you need is the ability to go to one or two key partners and tap into that capacity" (TU4).

For some businesses, building relationships with multiple transport service providers is also a way of mitigating capacity issues: “we've got quite a large carrier network […] so we did have additional capacity through those carrier partners. But we also used a number of subcontractors that we wouldn't have normally used” (TU15).

Going one step further, an interviewee highlights the importance of “a coordinated response” across competitors (TU10). However, the data reveals that businesses are reluctant to share commercially sensitive information and engage with competitors as this might expose practices that competitors could take advantage of: “getting people to work together is difficult when they're all competing against each other” (TO5). In other words, trust is needed for the whole transport industry to work collaboratively: “we tried to facilitate a whole market solution, but we couldn't quite get the market to move in the same direction. That's where that competitiveness came into play, everyone wasn't sure whether they trusted the other party” (TO9). As summarised by a participant, collaboration cannot be fully effective “if you've got a competitive system where they all compete against each other, including across all forms of transport: shipping, rail, road, and air” (GO19).

Table 3 summarises the above findings by presenting the key elements facilitating post-disaster transport adjustments, as reflected in the interview data.

Table 3. Summary of findings

[Table 3]

5. Discussion

5.1. Modular freight operations

Freight transport disruptions are to be expected in NZ. It is not a question of if, but when. In these circumstances, alternative transport plans are needed. This study shows that a modular transport system integrating multiple transport modes offers this flexibility. As mentioned in the literature review, a modular system needs an architecture (modules) as well as interfaces. Interfaces enable smooth interactions between the modules, make them operate as a whole, and increase the system's adaptability (Baldwin and Clark, 1997). As illustrated in Figure 5, transport modes are the modules to be recombined when a disaster makes parts of a freight system unavailable. Physical, digital, operational, and inter-organisational interfaces allow for interconnectivity between the transport modes and enable them to smoothly operate together.

Figure 5. Architecture and interfaces of a modular freight system

[Figure 5]

Going one step further, this study highlights the importance of building redundancies into the physical elements of the system. Figure 6 provides an overview of the four forms of redundancy discussed in the interviews. The importance of redundancy in freight transport aligns with the argument made in other academic disciplines (e.g. system thinking) and demonstrating that latent capacity improves the reliability of a system (e.g. Boland *et al.*, 1991).

Figure 6. Four forms of redundancy supporting post-disaster transport adjustments

[Figure 6]

Digital interfaces in the form of consistent information structures and interoperable systems, as well as operational interfaces that align modes working with different volume and time constraints are also critical elements of a modular transport system. These elements highlight the importance of standardisation in a modular transport system. To streamline movements across modes, standard physical, digital, and operational norms and practices are essential, including shipping containers, a common and consistent approach to data records, as well as standardised tracking numbers and documents (Bontekoning et al., 2004).

This research furthers the argument by showing that transport networks are more than physical, digital, and operational structures. Inter-organisational interfaces in the form of human networks, business connections, and longstanding relationships built up with transport operators support the reconfiguration and continuity of freight movements in the wake of a disaster. This echoes arguments found in organisation studies focusing on the building of modularity beyond organisational boundaries (Schilling and Steensma, 2001) and in supply chain management studies investigating the contribution of collaborative practices to supply chain resilience (Scholten and Schilder, 2015).

5.2. Barriers to implementing a modular transport system

Implementing a modular transport system in not without challenges. Fragmented information and technologies, as well as competitive behaviours significantly impede rapid modal shifts and the post-disaster reconfiguration of transport operations. More specifically, and in line with synchromodality studies (Pfoser *et al.*, 2016), this research shows that barriers include the lack of common processes and standards in the transport industry and the underuse of technologies that enable the collection and exchange of data. In addition, businesses are reluctant to work together and share information despite NZ’s small size and the close business relationships prevailing in this country.

Another barrier is the level of capital investment needed to build capacity. Long-term investment decisions are traditionally made after carrying out cost-benefit analyses (Eliasson and Lundberg, 2012). Accordingly, our findings show that private businesses are reluctant to commit to capital investments (e.g. carrying capacity, shipping containers, container trailers) without a level of certainty as to the value and viability of these investments.

Government departments can contribute to mitigating the above barriers and the impact of disruptive events on the commercial movements of goods. Firstly, they support the rapid recovery of freight operations by repairing the transport network and making it available as soon as possible after a disaster. Secondly, by identifying vulnerabilities in the freight system, establishing a transport contingency plan, and setting priorities for investment and transport upgrades, central authorities can reduce the impact of disasters and ensure the continuity of freight operations. In particular, they have a role to play in the funding and development of new transport infrastructure, and in the building of capacity and redundancy to ensure that alternative roads and/or transport options are available when parts of the network are damaged and inaccessible. Thirdly, a national freight strategy taking a system approach to freight transport and resilience (rather than a mode-specific focus), as well as long-term public investments and infrastructure developments (e.g. ports, road connections to the ports, coastal shipping) would give transport operators confidence that private capital investments will be recovered and that transport capacity developments will be profitable (e.g. shipping containers will be used). Finally, central authorities can act as an orchestrator in the development of a digitally integrated transport system by facilitating digital transformation and the development of data standards and interconnected platforms. In doing so, they create an interoperable environment where the multiple actors and modes involved in freight transport can communicate, manage disruptions, and continue to operate in the wake of a disaster.

5.3. Applicability to other contexts

Some of this paper's topics echo research conducted in the context of the COVID-19 pandemic, including discussions on the need for businesses to adjust their operations, the increased demand for sea transport and port services, resulting transport congestion issues, delayed deliveries, the shortage of shipping containers, and the importance of capacity building and redundancies. However, a global pandemic changing consumer consumption, leading to market supply and demand imbalances, causing border and business closures, and requiring the reconfiguration of supply chain networks is not fully comparable to a natural disaster causing severe infrastructure damage and triggering disruptions in the domestic movements of goods (Chang *et al.*, 2022). These differences in the challenges encountered emphasise the importance of understanding the context and the origin of disruptions when investigating the concepts of transport resilience and recovery. Similarly, external circumstances that can either support or prevent the recovery of transport operations need to be considered. In particular, had the Kaikōura earthquake happened at a time when transport resources were already strained (as has been the case since the beginning of the COVID-19 pandemic), the impact of the event on the domestic movements of goods would have been significantly more severe.

The modularity/synchromodality principles discussed in this paper align with current freight strategies and policy developments that aim to both increase disaster resilience and reduce carbon emissions in NZ (Ministry of Transport, 2022). In the same vein, the academic literature takes a growing interest in the development of environmental considerations in disaster response and recovery operations (Jilani *et al.*, 2018). However, in practice, the reduction of carbon emissions is not a dominant concern in crisis situations where businesses prioritise recovery and the continuity of their operations (Chowdhury *et al.*, 2021).

6. Contribution

With sudden and unforeseen freight disruptions expected to be increasingly frequent and severe, dealing with uncertainty has become a prevalent topic in industry, policy-making, and academic discussions. This study adds to this growing body of knowledge by contributing a better understanding of modular and flexible freight operations across modes. To date, little qualitative research had focused on the ability of freight transport systems to adapt and recover from a disaster by using and integrating multiple transport modes. Rather than focusing on mathematical modelling and the optimisation of freight operations, this qualitative study identifies nine factors enabling modular transport operations across modes and presents a rich and detailed description of the mechanisms underlying the continuity of freight operations in the wake of a disaster. It contributes a better understanding of transport capacity building and the ability of transport systems to keep goods moving when natural hazards cause sudden freight disruptions.

By applying the theoretical concept of modularity, this study also contributes a more structured overview of the architecture and interfaces making up a modular freight system. It shows that the recombination of transport operations in the aftermath of a disaster goes beyond the physical design of a network. Digital, operational, and inter-organisational interfaces are needed to support smooth interconnections between transport modes. Ultimately, this paper argues that developing interfaces and building a modular system requires a holistic and integrated approach involving all stakeholders, including governmental actors, seaports, and transport operators.

7. Limitations and future research

Although this study recognises that redundancy incurs a high level of capital investment, it does not address the question of who should bear the cost of resources that remain idle or underused in normal circumstances. Therefore, future investigations should understand and quantify the costs, benefits, and net impacts of building redundancy in a freight system in order to ensure supply chain continuity in the aftermath of a disaster.

This research is grounded in one particular event (the 2016 Kaikōura earthquake) and, therefore, produces context-dependent knowledge. In other words, the mechanisms underlying modal shifts identified in this study might not all be fully applicable to another context. However, the Kaikōura event provides information that has general relevance and is of interest beyond the NZ context. More specifically, many of the topics covered are relevant to other disaster-prone countries vulnerable to sudden transport disruptions. Therefore, despite being situationally grounded, this research achieves a sense of generality. Similar studies should, nevertheless, be conducted in the context of different disaster types and countries.

This paper focuses on modularity and post-disaster transport adjustments. It does not investigate the additional benefits of intermodal/synchromodal transport, such as the reduction of transport costs and of carbon emissions. As previously mentioned, these are not dominant concerns in crisis situations. However, additional research should take a more comprehensive approach and simultaneously investigate the multiple benefits of intermodal/synchromodal transport in post-disaster contexts.

8. Conclusion

This study adds to the limited body of qualitative research investigating the post-disaster reconfiguration of freight operations across modes. As illustrated by the 2016 Kaikōura earthquake, natural hazards place a significant strain on transport operations, make some of the established transport practices immediately inadequate, and require new routes to be arranged rapidly, often across modes. In other words, businesses need to shift from well-established transport practices to ad hoc solutions, increasing delivery lead times and causing significant supply chain disruptions.

This research extends the theoretical concept of modularity to post-disaster freight operations, provides insight into the development of interfaces between modes and, ultimately, informs the building of a more integrated and adaptable freight system that is no longer dependent on one mode. It also shows that creating modular and flexible movements of goods requires four forms of interfaces built into the freight system and a holistic approach to transport capacity building.

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Figure 1

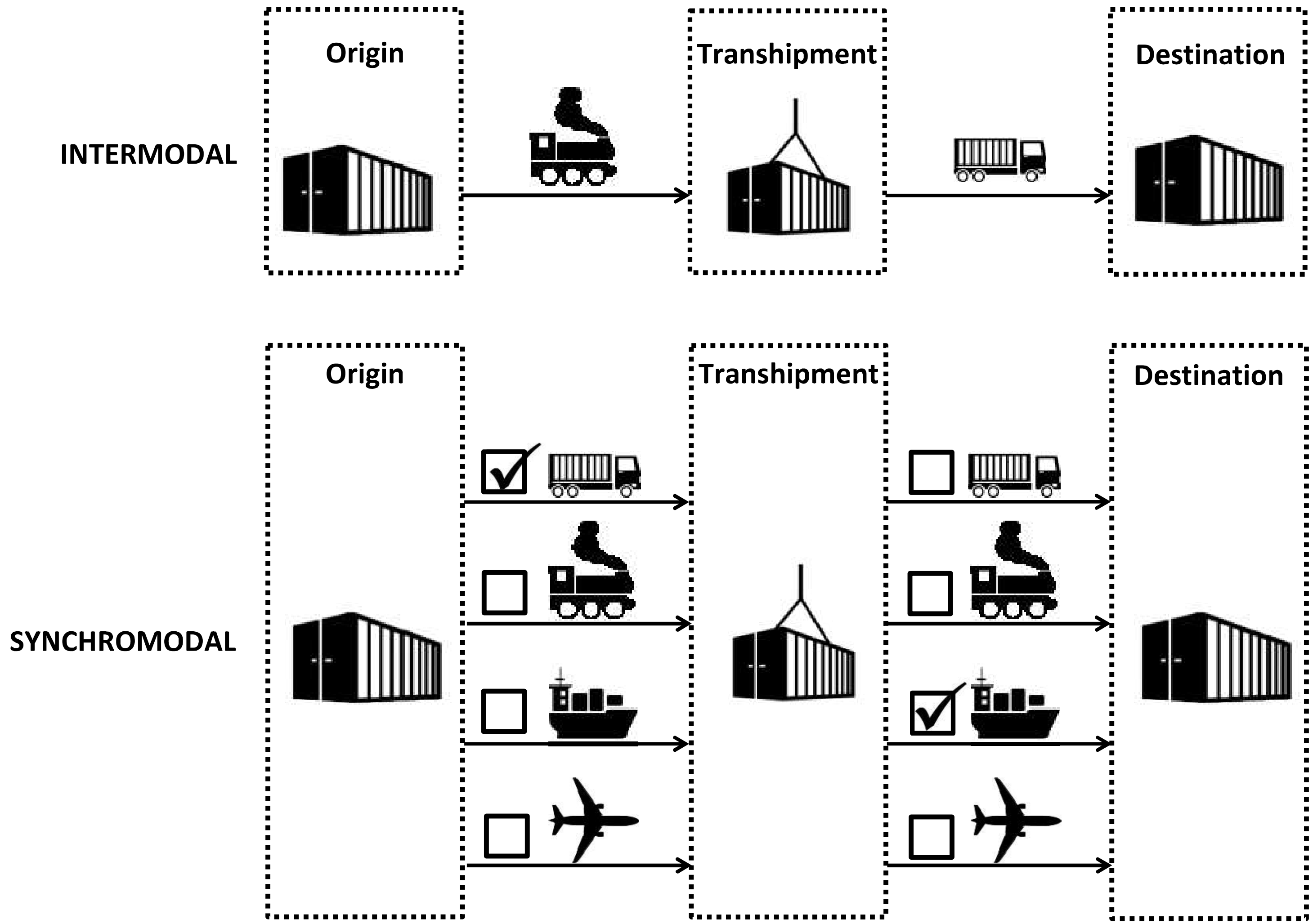

INTERMODAL
Origin
Transhipment
Destination
SYNCHROMODAL
Origin
Transhipment
Destination

Table 1

Interview number	Participant	Date	Length (minutes)
1	Transport user	12-May	49
2	Industry representative	14-May	40
3	Transport operator	18-May	75
4	Industry representative (x1) + Transport users (x6)	19-May	70
5	Transport operator	20-May	60
6	Transport operator	21-May	50
7	Industry representative	21-May	20
8	Seaport managers (x2)	26-May	70
9	Transport operator	28-May	55
10	Transport user	5-Jun	45
11	Industry representative	8-Jun	35
12	Seaport manager	10-Jun	40
13	Seaport manager	11-Jun	45
14	Transport operator	11-Jun	35
15	Transport user	12-Jun	35
16	Transport operator	19-Jun	45
17	Government official	23-Jun	50
18	Government officials (x2)	24-Jun	60
19	Government official	27-Jul	45

Table 2

Question 1	What transport disruptions were encountered after the Kaikōura earthquake?
Question 2	What transport adjustments were needed to keep goods moving after the Kaikōura earthquake?
Question 3	What enabled the rapid reconfiguration of transport operations across modes?
Question 4	What were the obstacles to the rapid reconfiguration of transport operations across modes?
Question 5	What did you learn from this experience?

Figure 2


NEW ZEALAND
State Highways
Rail
Ports
Spring Creek
168°E
170°E
172°E
174°E
176°E
178°E
34°S
36°S
38°S
40°S
42°S
44°S
46°S
AUCKLAND
TAURANGA
NAPIER
WELLINGTON
PICTON
Spring Creek
Cook Strait
State Highway 1
Main North Line
CHRISTCHURCH
TIMARU
DUNEDIN
Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors.

Figure 3

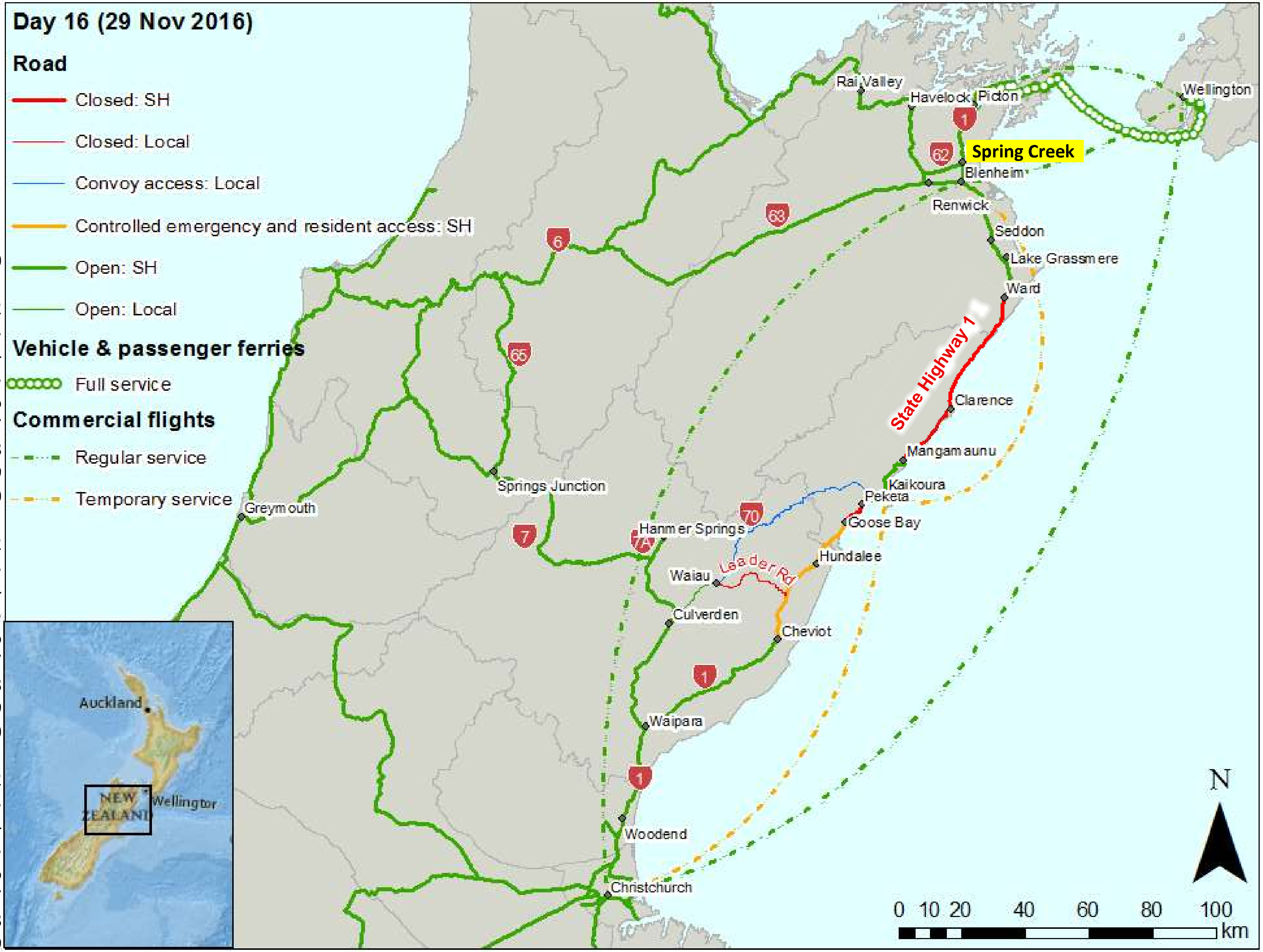

Day 16 (29 Nov 2016)
Road
Closed: SH
Closed: Local
Convoy access: Local
Controlled emergency and resident access: SH
Open: SH
Open: Local
Vehicle & passenger ferries
Full service
Commercial flights
Regular service
Temporary service
Spring Creek
State Highway 1
Leader Rd
Rai Valley
Havelock
Picton
Wellington
Blenheim
Renwick
Seddon
Lake Grassmere
Ward
Clarence
Mangamaunu
Kaikoura
Peketa
Goose Bay
Hundalee
Cheviot
Waiau
Culverden
Hanmer Springs
Waipara
Woodend
Christchurch
Springs Junction
Greymouth
Auckland
NEW ZEALAND
N
0 10 20 40 60 80 100 km

Figure 4

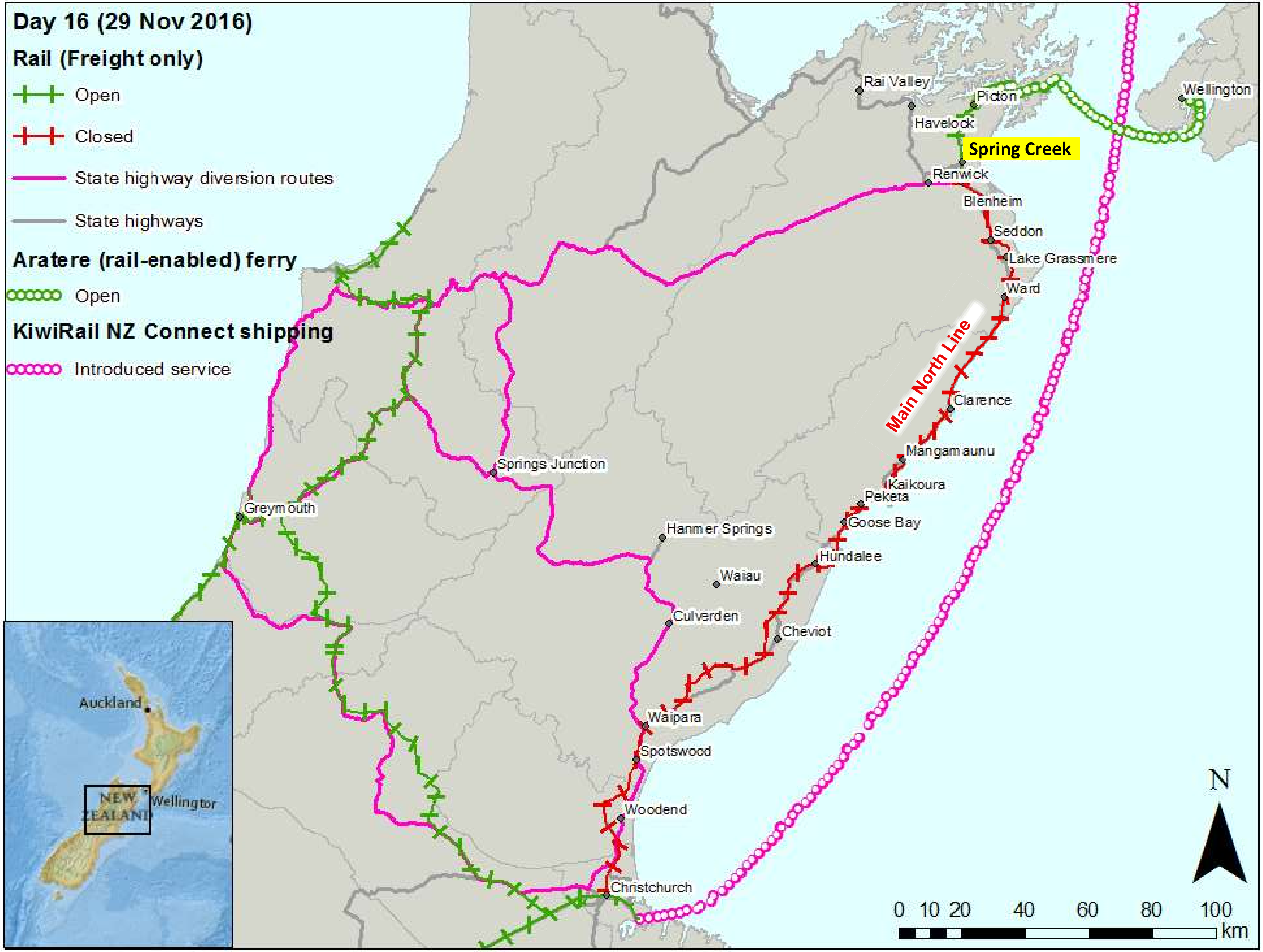

Day 16 (29 Nov 2016)
Rail (Freight only)
Open
Closed
State highway diversion routes
State highways
Aratere (rail-enabled) ferry
Open
KiwiRail NZ Connect shipping
Introduced service
Rai Valley
Picton
Havelock
Wellington
Spring Creek
Renwick
Blenheim
Seddon
Lake Grassmere
Ward
Main North Line
Clarence
Mangamaunu
Kaikoura
Peketa
Goose Bay
Hundalee
Springs Junction
Greymouth
Hanmer Springs
Waiau
Culverden
Cheviot
Waipara
Spotswood
Woodend
Christchurch
Auckland
NEW ZEALAND
Wellington
N
0 10 20 40 60 80 100
km

Table 3

<table>
<tr><th>Interfaces</th><th colspan="2">Factors enabling modular transport operations and rapid modal shifts</th></tr>
<tr><td rowspan="8">PHYSICAL</td><td rowspan="2">1. Transport linkages</td><td>Adequate secondary road network with sufficient traffic capacity</td></tr>
<tr><td>Alternative modes of transport available with sufficient traffic capacity and regular/reliable schedules</td></tr>
<tr><td rowspan="2">2. Nodal points</td><td>Redundant transhipment capacity (including at seaports and inland ports)</td></tr>
<tr><td>Ability to swiftly set up/upgrade ad hoc terminals for the transhipment of freight between modes</td></tr>
<tr><td rowspan="2">3. Vehicles</td><td>Fleets of vehicles allowing for the transport of shipping containers</td></tr>
<tr><td>Redundant carrying capacity</td></tr>
<tr><td rowspan="2">4. Standard load units</td><td>Consolidated loads and use of shipping containers</td></tr>
<tr><td>Redundant shipping container capacity</td></tr>
<tr><td rowspan="2">DIGITAL</td><td>5. Information availability</td><td>Rapidly available information about network accessibility and incoming freight</td></tr>
<tr><td>6. Interoperable technologies</td><td>Integrated information systems across actors and modes</td></tr>
<tr><td>OPERATIONAL</td><td>7. Operational alignment</td><td>Reconciliation of operational requirements and constraints across modes (e.g. schedules, pallet loading)</td></tr>
<tr><td rowspan="2">INTER-ORGANISATIONAL</td><td>8. Collaborative network</td><td>Well-established networks of industry contacts across the whole transport industry, including competitors</td></tr>
<tr><td>9. Trust</td><td>Trust between actors (and sometimes competitors) involved in transport operations</td></tr>
</table>

Figure 5

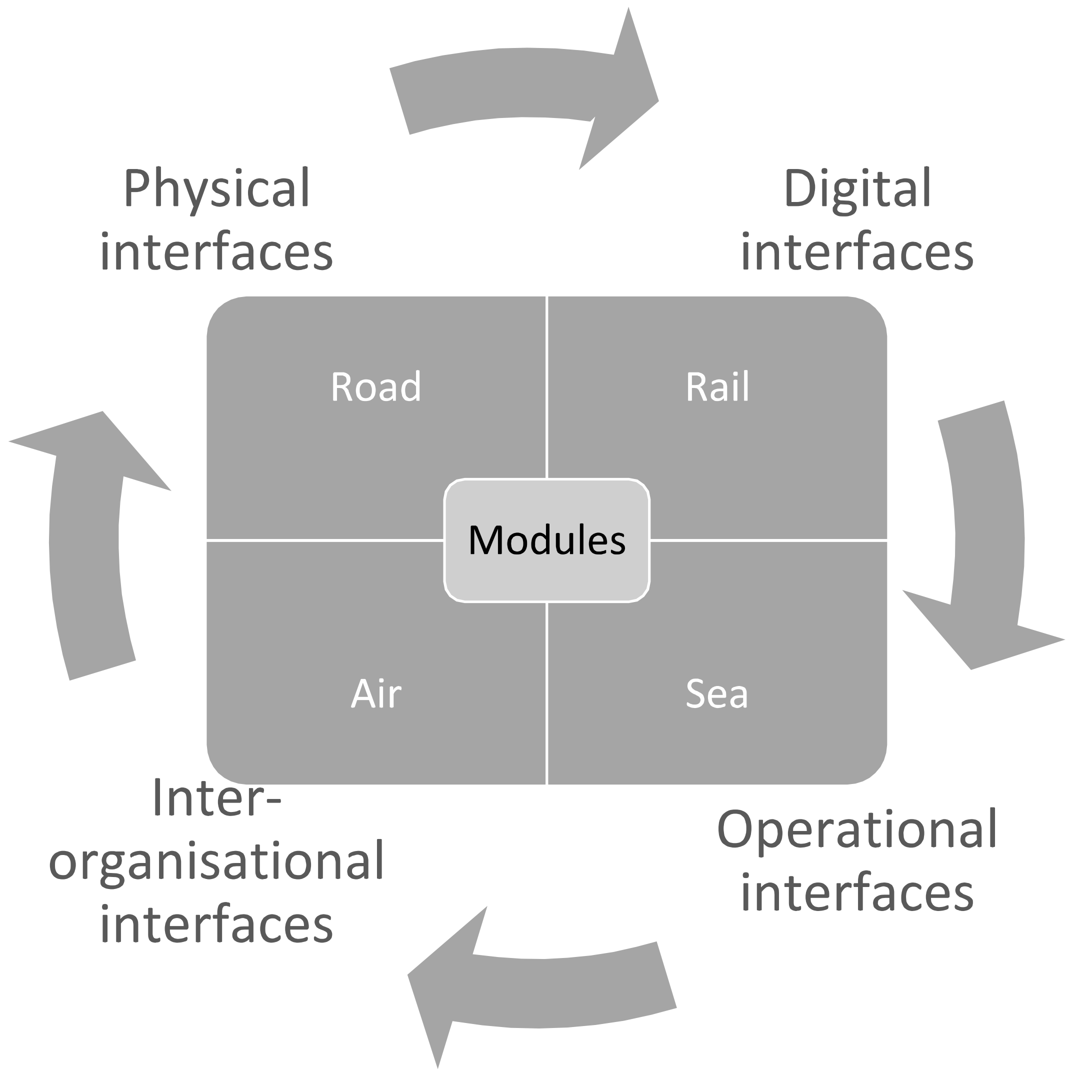
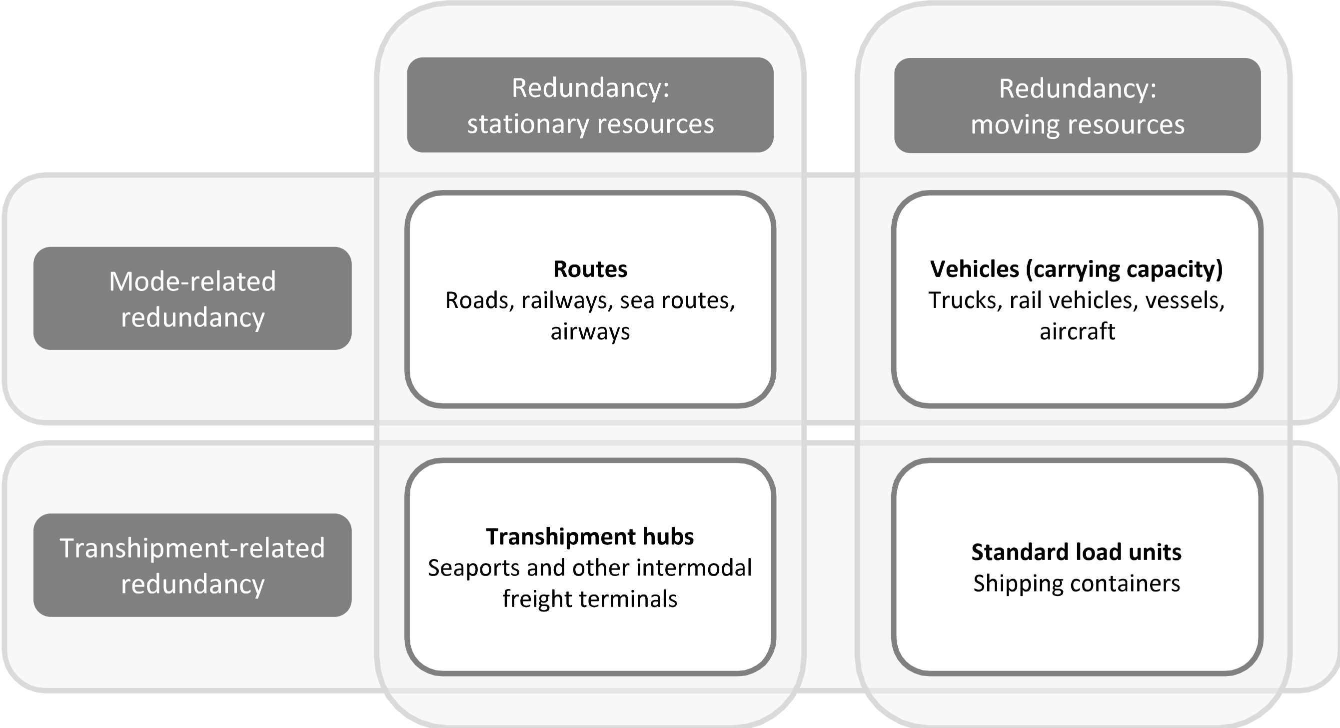

Physical interfaces
Digital interfaces
Road
Rail
Modules
Air
Sea
Inter-organisational interfaces
Operational interfaces

Figure 6


Redundancy:
stationary resources
Redundancy:
moving resources
Mode-related
redundancy
Routes
Roads, railways, sea routes, airways
Vehicles (carrying capacity)
Trucks, rail vehicles, vessels, aircraft
Transhipment-related
redundancy
Transhipment hubs
Seaports and other intermodal freight terminals
Standard load units
Shipping containers