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# **Mitigating FMCG transport bottlenecks following an extended Cook Strait ferry outage in Aotearoa New Zealand**

A thesis  
submitted in partial fulfilment  
of the requirements for the degree  
of  
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THE UNIVERSITY OF  
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## i. Abstract

This research aims to understand how an extended Cook Strait ferry outage would impact the movement of fast-moving consumer goods (FMCGs) in New Zealand (NZ). The Cook Strait ferries are critical to the country's freight system, serving as an extension of the main state highway and rail line connecting the North and South Islands. Despite the significance of the ferries, the ferry terminals are aged and lack redundancy, and they could fail in an earthquake. To understand how an extended terminal outage would impact the movement of FMCGs, data was collected through interviews with 30 industry experts in the transport and FMCG sectors, which was thematically analysed and supplemented with quantitative details to further understand the impact. The findings revealed numerous transport bottlenecks would surface in an extended terminal outage and a lack of preparedness in NZ's freight system. To guide this research, a set of management tools known as the Theory of Constraints Thinking Process were used, enabling sense to be made of NZ's domestic freight system following a Cook Strait ferry outage. Using these tools to generate visual diagrams, the cause-and-effect relationships between bottlenecks were identified, root causes were uncovered, and potential solutions were explored. Given that it is not a case of if a major disaster will occur, but when, it is important that progress is made towards addressing the identified root causes so that the impact from future disruptions is minimised and goods can continue moving.

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## vi. List of acronyms

5FS	Five Focusing Steps
AMDS	Asset Management Data Standard
ANL	Australian National Line
CES	Canterbury Earthquake Sequence
CRT	Current Reality Tree
CT	Container terminal
EC	Evaporating Cloud
EFTPOS	Electronic Funds Transfer at Point of Sale
ER	Emergency responders
FIGS	Freight Information Gathering System
FMCG	Fast-Moving Consumer Goods
FO	Ferry operators
FRT	Future Reality Tree
FY19	Fiscal Year 2019
GNS	Geological and Nuclear Sciences Limited
GO	Government officials
GPS	Governments Priorities for Expenditure
IR	Industry representatives
iReX	Inter-island Resilient Connection
JIT	Just-in-time
MBIE	Ministry of Business, Innovation and Employment
MNL	Main North Line
MOT	Ministry of Transport
NFDS	National Freight Demand Study
NIWA	National Institute of Water and Atmospheric Research Ltd
NLTP	National Land Transport Programme
NZ	New Zealand
NZTA	NZ Transport Agency
Palmy	Palmerston North
PBC	Project Business Case
PO	Port operators
RoRo	Roll-on Roll-off
PRT	Prerequisite Tree
SH	State Highway
TEU	Twenty-foot Equivalent Unit
TOC	Theory of Constraints
TO	Transport operators
TP	Thinking Process
TT	Transition Tree
TU	Transport users
WENIRP	Wellington Earthquake National Initial Response Plan
WREMO	Wellington Regional Emergency Management Office

## Chapter 1: Introduction

*This chapter provides an overview of the key topics discussed in the thesis.*

The Cook Strait ferries are a critical component of New Zealand's (NZ) freight system, forming an extension of the country's main state highway and rail line, connecting the North and South Islands. Combined, the ferries enable the movement of thousands of trucks and rail wagons between the two islands each year (The Treasury, 2024), carrying a range of freight, including Fast-Moving Consumer Goods (FMCGs), such as food products, beverages, and over-the-counter medicines (Liczmańska-Kopcewicz et al., 2019). Because FMCGs often have a quick turnover, are sold at a relatively low price (Mohan & Sequeira, 2016), and are ordered as they are needed when they are needed (Webster et al., 2006). In NZ, these goods are primarily sold through supermarkets, which are replenished from a small number of centralised distribution centres in the North and South Islands (Hamilton & L'Hermitte, 2022; Renwick, 2023).

To ensure these goods are replenished as they are needed when they are needed and to avoid spoilage, road transport is generally used (Dekker et al., 2009) in combination with the Cook Strait ferries (Kim et al., 2014). In other words, the movement of FMCGs relies on the freight transport system, comprising the road network, the Cook Strait ferries and several other critical infrastructures. Consequently, a critical infrastructure outage can cascade and disrupt others (Ouyang, 2014), impacting the movement of FMCGs. However, it is unclear exactly how critical infrastructure interdependencies would impact the movement of FMCGs following a disaster.

At the same time, the ferry terminals are aged, lack redundancy, and are exposed and vulnerable to natural hazards, such as earthquakes and tsunamis (Boffa Miskell Limited, 2022). Of all the natural hazards NZ is exposed to, a Hikurangi Subduction Zone event could be the largest source of earthquake and tsunami hazards in the country (GNS Science, n.d.a) and is capable of taking out the two ferry terminals. If this were to happen, the movement of FMCGs between the North and South Islands would almost completely stop. Despite this, no research exists on how the disruptions stemming from an extended Cook Strait ferry outage would cascade through the NZ freight system. Because of these uncertainties, the potential bottlenecks that may surface are not well understood, and equally, potential solutions to mitigate these bottlenecks and keep goods moving are unknown. In other words, there is limited insight into how the transport network would be able to adjust in a Cook Strait ferry terminal outage.

To make sense of the bottlenecks that would surface following an extended Cook Strait ferry outage, the study adopted a qualitative focus, where data was collected through interviews with a wide range of stakeholders in the transport and FMCG sectors. Quantitative details were then used to complement the interview data and to understand the severity better. To guide this research, a management tool known as the Theory of Constraints (TOC) was adopted, which was initially used to address bottlenecks in a manufacturing environment (Rahman, 1998). The underlying concept of TOC is that every system (or organisation) has one or more dominating constraint (Mabin & Balderstone, 2000). Because of its value in addressing constraints, TOC

has evolved beyond a manufacturing method and is seen as a general theory of management (Tulasi & Rao, 2012) that can be applied to almost any sector (Şimşit et al., 2014).

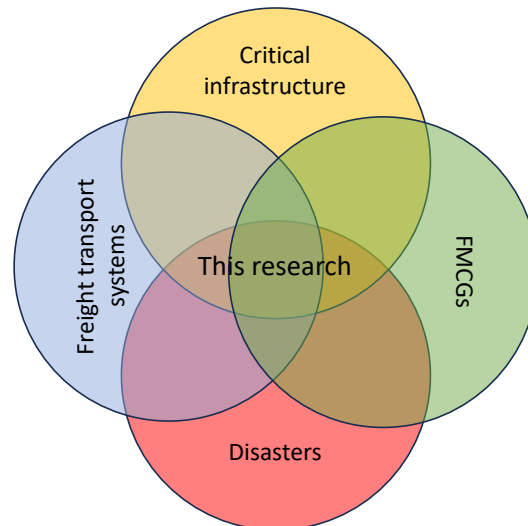
In the context of this research, one of the major components of TOC, known as the Thinking Process (TP), was used, which provides a set of problem-solving tools to develop cause-and-effect diagrams (Rahman, 1998). The TOC TP tools were used to address the research gaps by following three steps sequentially. The first step was to identify the constraints in NZ's FMCG transport system that would result from an extended Cook Strait ferry outage. The second was to establish and visualise the cause-and-effect relationships between the identified constraints. The third was to identify possible solutions to mitigate FMCG transport disruptions and support timely deliveries between the North and South Islands. In other words, these three tools were used to make sense of the complexities that surface in a post-disaster environment. Through the application of the three TOC TP tools, the three research questions were addressed:

- Research question 1: How would disruptions cascade through the NZ freight system during an extended Cook Strait ferry outage?
- Research question 2: How would critical infrastructure dependencies and interdependencies impact the movement of FMCGs in NZ following a disaster?
- Research question 3: How could freight bottlenecks be mitigated to keep goods moving between the North and South Islands following an extended Cook Strait ferry outage?

This thesis comprises ten chapters. Chapter 1 provided an introduction to the study. Chapter 2 reviews the existing academic and grey literature on critical infrastructure, freight transport systems, FMCGs and disasters, and the identified gaps. Chapter 3 looks at the theoretical framework, TOC TP, and how it can be used to make sense of complex systems through visual diagrams. Chapter 4 outlines the assumptions and reasoning behind the proposed scenario. Chapter 5 provides insight into the methodology and the framework used in this research. Chapter 6 provides insight from key stakeholders, and Chapter 7 analyses and discusses these insights. Chapter 8 then highlights the contributions to practitioners, policymakers and the expansion of knowledge. Chapter 9 outlines this study's limitations and areas for future research, while Chapter 10 concludes this research with some final remarks.

## Chapter 2: Literature review

*The purpose of this chapter is to review the academic and grey literature on the four main topics of this research, which include critical infrastructure, freight transport systems, FMCGs and disasters, as shown in Figure 1. The chapter is then concluded by a section reiterating the identified research gaps and the research questions.*



*Figure 1: Primary topics in this research*

### 2.1 Critical infrastructure

Critical infrastructure, also known as lifeline utilities, can be defined as the elements of infrastructure that, if disrupted or taken out, could pose a significant threat to essential supplies (such as food, energy and medicines), services (such as police, fire, and ambulance services), and communication (Church et al., 2004). Therefore, critical infrastructures are crucial to the performance of the economy and society (Moteff et al., 2004), as they enable the production and distribution of essential goods and services, including electricity, fuel, water, telecommunications, finance, and transport systems (Brown et al., 2017; Rinaldi et al., 2001). Although what constitutes critical infrastructure is not defined in NZ law, numerous entities throughout NZ offer essential services (Department of the Prime Minister and Cabinet, 2023). These include, but are not limited to, energy, telecommunications, water services (freshwater, wastewater, and stormwater), government services (emergency management, defence, intelligence, and government data), food and grocery providers, financial services and payments, cloud service and data storage providers, transport, and the health system (Department of the Prime Minister and Cabinet, 2023, p. 11).

### 2.1.1 Critical infrastructure dependencies and interdependencies

Critical infrastructure networks are complex systems spanning multiple geographical areas, such as across entire countries, and have become increasingly dependent and interdependent on one another for their everyday operations (Pederson et al., 2006; Zorn et al., 2020). Dependencies occur when there is a connection between two infrastructures through which the state of one infrastructure influences or is correlated with the state of the other. On the other hand, interdependencies occur when a relationship exists between two elements of critical infrastructure, referred to as a bidirectional relationship, where the output of one infrastructure is essential for the other to function (Rinaldi et al., 2001). As a result of these interdependencies, infrastructure networks are complex systems, and a holistic ‘systems of systems’ approach is required to improve resilience (Croope, 2010).

According to Peerenboom et al. (2002), there are four types of interdependencies. The first is physical, where the material produced by one infrastructure is used by another. Second, cyber, where data is transmitted over information and communications infrastructure. Third is geographic, where two or more infrastructures are located in the same area and susceptible to a local event. Lastly, logical, where the state or condition is dependent on the state and condition of another infrastructure in a way that is neither physical, cyber, nor geographical, such as connections through financial markets. Due to these interdependencies, damage to one critical infrastructure can cascade and affect others at regional or national scales (Ouyang, 2014; Rinaldi et al., 2001). In other words, disruptions to critical infrastructure can go beyond physical damage, causing economic, social and environmental impacts (Cassottana et al., 2019; Forzieri et al., 2018; Wilson et al., 2017), while these impacts can still be felt even when the disruption is minor (Brown et al., 2006).

Figure 2 provides a simplified example of just how interconnected critical infrastructures are. The solid grey lines represent dependencies, while grey dashed lines represent infrastructure interdependencies. For example, a disruption to the electricity sector could result in an electrical substation failing, preventing a sewer pumping station from operating, which results in inaccessible roads. At the same time, failure of the electrical substation can result in cellular networks failing, affecting communication between transport users. Because of these interdependencies, protecting critical infrastructure (i.e., transport) from a specific hazard may not be sufficient if the systems they depend on (i.e., power, water and communication) are left unprotected (Markolf et al., 2019; Pederson et al., 2006).

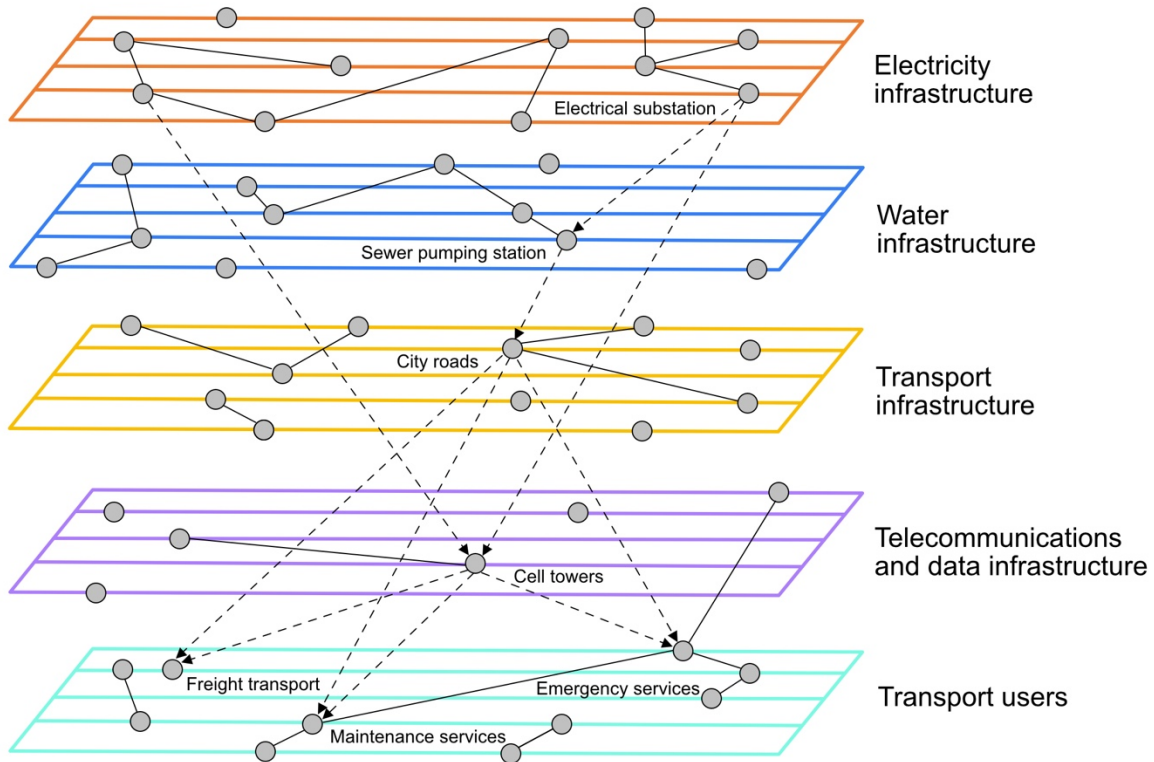


Figure 2: Dependencies and interdependencies between critical infrastructures (adapted from Pederson et al., 2006)

Because infrastructures are often thought of independently, the interdependencies between critical infrastructures can be overlooked or misunderstood until a disruption occurs and the relationship becomes apparent (Ouyang, 2014). Therefore, a holistic approach must be undertaken to understand the interdependencies that exist and their causal relationships, as opposed to viewing critical infrastructure independently (Seager et al., 2017). Doing so is vital to capturing and understanding all the associated risks (Moini, 2016), enabling greater preparation, response, and recovery from disasters and aiding in better-informed decision-making around business continuity, security, and risk management (Petit et al., 2018).

In NZ, a number of publications discuss the critical infrastructure dependencies and interdependencies. For example, the electricity network provides the foundation for many other critical infrastructures, as shown in Figure 3. Therefore, in an electricity outage, there is a chance for cascading failures to occur, as without electricity, telecommunications networks cease to operate, upon which many utility businesses depend. Without the water supply, many operations dependent on water for cooling and emergency management would be impacted, such as fuel terminals, airports, telecommunications, and natural gas-run electricity generators (Department of the Prime Minister and Cabinet, 2023).

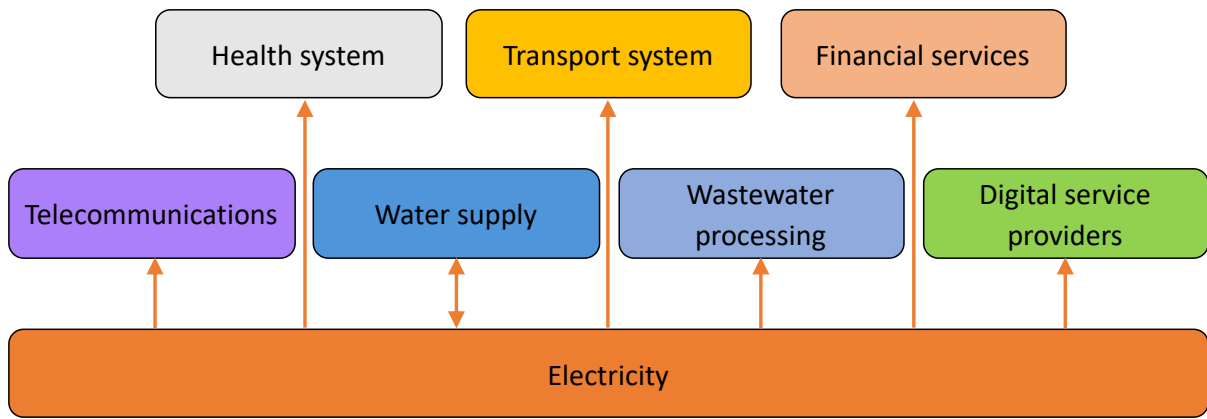


Figure 3: Dependencies and interdependencies from electricity infrastructure in NZ

To understand the impact and significance of critical infrastructure outages in NZ, Brown et al. (2017) surveyed 30 senior managers and 189 staff across four organisation types. These included those responsible for the generation and retail of electricity, telecommunications, gas and fuel. Those responsible for the electricity, telecommunications and gas networks. Road, rail and port organisations. Water, wastewater and stormwater organisations. Across all four organisation types, 30% noted that they could not function without data networks, 30% could not function without electricity, and 24% could not function without phone networks. Therefore, an outage to any of these infrastructures can cascade and impact other sectors, such as the freight transport system. Furthermore, the findings showed that the road, rail and port sectors depend most on electricity and phones, while the electricity, telecommunications and gas network providers are most affected by road, phone and data network outages (Brown et al., 2017).

In addition to the road network being essential for the operation of utilities (i.e., the electricity, telecommunications and gas networks), it is also crucial for accessing the wider transport system, such as sea, air and rail networks (New Zealand Lifelines Council, 2023). At the same time, the road and rail networks depend on the Cook Strait ferries, which are seen as a nationally significant critical infrastructure (Boffa Miskell Limited, 2022).

At the same time, the transport system depends on the fuel network, which again has several dependencies and interdependencies. For instance, fuel is initially brought in by ship to one of 11 seaports in the North and South Islands, where fuel is then pumped into the fuel terminals, as shown in Figure 4. From there, the terminals deliver fuel to nearby users, including service stations, airports and industries (Civil Defence, 2020). However, because of the limited number of fuel terminals, the distribution of fuel throughout the country depends on the road network and trucks. At the same time, trucks depend on fuel from retailers, who require the electricity network to pump fuel and the Internet to process payments (New Zealand Lifelines Council, 2023). Therefore, in the absence of electricity or internet, trucks would be unable to refuel, impacting the movement of fuel, FMCGs and other freight. Although past research provides some insight into the relationships between critical infrastructures, it is unclear how these dependencies and interdependencies would impact the movement of FMCGs following a disaster.

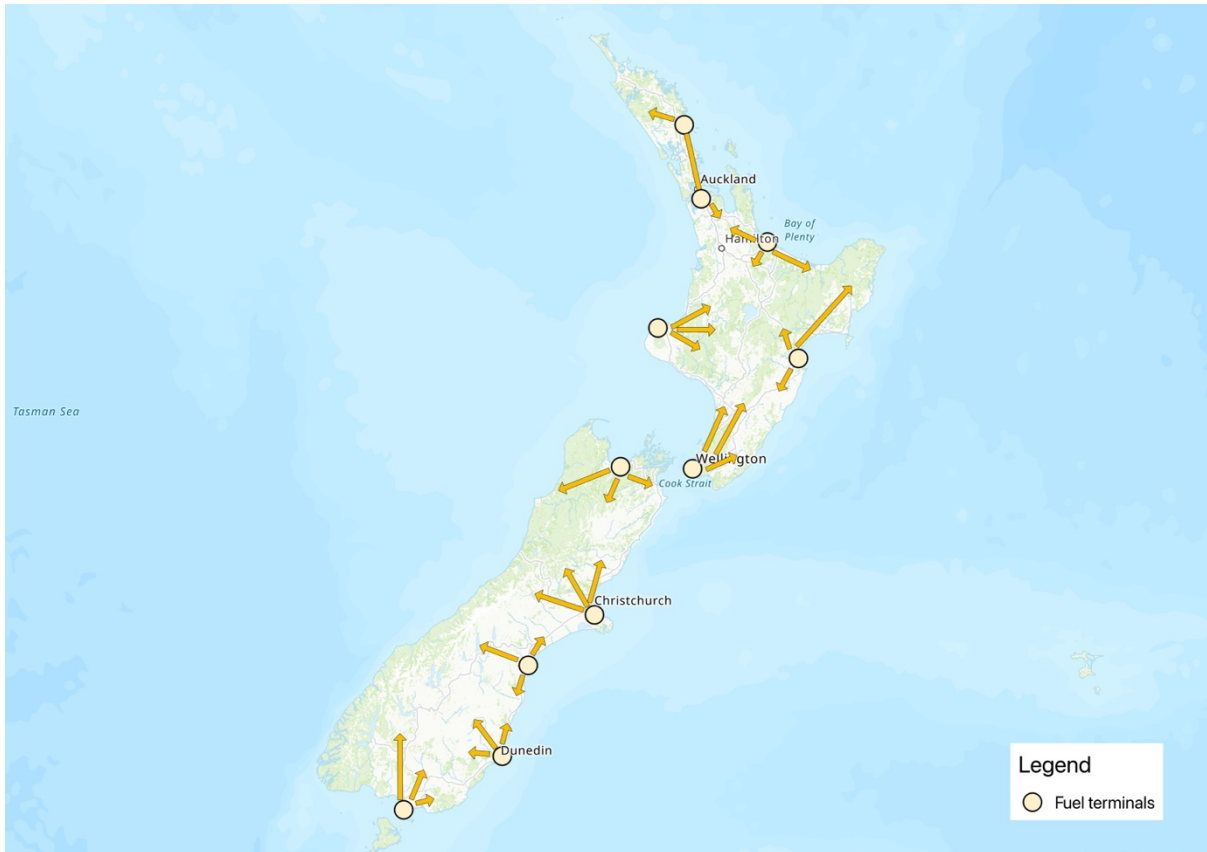


Figure 4: Map of NZ's fuel terminal network (adapted from Civil Defence, 2020)

## 2.2 Freight transport systems

Transport systems are considered the backbone of modern communities and economies (Blake et al., 2019) and have become increasingly complex and interdependent (Mattsson & Jenelius, 2015). These systems comprise a range of nodes, such as terminals, airports, and seaports, connected through several links, such as railway lines, roads, and waterways (Lordieck & Corman, 2021). Together, these nodes and links facilitate the movement of freight by road, rail, air, and sea (Janić & Janić, 2014). These systems are especially crucial for the movement of people and freight following a disaster (Kunaka et al., 2014), in which they act as lifelines (Zhou et al., 2019), as they can operate to and from impacted areas, supporting emergency response and long-term recovery options and thereby playing a critical role in the economy and individual well-being (Kunaka et al., 2014; Zhou et al., 2019).

However, like all critical infrastructure, freight transport systems are vulnerable to disruptions (Ahmady & Eftekhari Yeghaneh, 2022), with each node and link representing a potential point of failure (Rogers et al., 2012), which can lead to freight bottlenecks. For example, freight bottlenecks can occur if the capacity in a link, such as a highway, is reduced and the traffic volume exceeds the available capacity (White & Grenzeback, 2007). In order to mitigate such constraints, freight transport systems need to be resilient. In the context of freight systems, Ta et al. (2009) define resilience as “the ability of the system to absorb the consequences of disruptions to reduce the impacts of disruptions and maintain freight mobility” (p.21). Breaking

this down further, Rice and Caniato (2003) argue that resilience can be achieved either by building in redundancy or through flexibility.

Redundancy is about having a certain amount of resources in reserve that can be used when a disruption occurs. Some of the most common forms of redundancy include safety stock and the use of multiple suppliers, which act as an insurance premium (Sheffi & Rice Jr., 2005). In transport operations, redundancy can include having multiple alternate routes and modes to move between two points, reducing the degree of consequence in the event of a disturbance to a part of the transport system (Berdica, 2002; Xu et al., 2018). Redundancy can also be achieved by strengthening the existing infrastructure to withstand disruptions (also referred to as robustness) (Xu et al., 2018). In any case, the drawback to implementing redundancy is that it incurs a cost, regardless of whether a disruption occurs, and therefore provides little benefit in day-to-day operations (Kamalahmadi et al., 2022; Sheffi & Rice Jr., 2005).

On the other hand, flexibility is the ability to swiftly adjust processes and structures according to the disruption (Huo et al., 2018; Sheffi, 2019). For instance, flexibility can be achieved through establishing a flexible supply base, which can enable fluctuations in demand to be met, as well as ensuring continuity of supply when a disruption occurs (Tang, 2006). From a transport perspective, flexibility can be seen as the ability of the transport system to accommodate changes in traffic demand while continuing to provide a satisfactory level of performance (Morlok & Chang, 2004). In practice, this could be achieved by having contracts with multiple third-party logistics providers (Agigi et al., 2016) and using various transport modes and routes to ensure a smooth flow of goods (Tang, 2006).

### 2.2.1 Intermodal transport systems

One way to achieve flexibility and redundancy is through intermodal freight transport (Suzuki & Li, 2012), which is the movement of freight in a single loading unit or vehicle that is moved across more than one mode of transport and where the freight is not handled when transport modes are switched (European Conference of Ministers of Transport, 2001). Intermodality is commonly achieved with shipping containers, where the freight is only handled at its origin and destination (Crainic & Kim, 2007). A key component of intermodality is intermodal terminals, which can be defined as a location where containers are picked up, dropped off, maintained, stored, loaded or unloaded from one mode of transport to another, such as from rail to road. These systems comprise entities, such as trains and trucks, resources, such as workers, and equipment, such as reach stackers (Silva et al., 2015). Although single-mode networks are more risk-averse than intermodal networks, intermodal networks have become a more favourable option post-disaster, as they provide a greater opportunity for recovery through alternate transport modes (Chen & Miller-Hooks, 2012).

### 2.2.2 Mode choice

In any case, the suitability of intermodal transport depends on the specific requirements of freight, such as distance, speed, reliability, capacity (Tuzkaya & Önüt, 2008), cost, flexibility and infrastructure availability (Cullinane & Toy, 2000). For instance, truck transport is typically the primary mode for goods that need to be moved in a relatively short timeframe

(such as perishables) while also offering door-to-door service, flexibility, access to rugged terrains, straightforward loading and unloading of freight, and the ability to utilise widespread road networks (Tuzkaya & Önüt, 2008). In contrast, rail and sea transport is often used for the transport of heavy, bulk freight over long distances and usually follows inflexible routes, while due to high costs, air transport is typically reserved for the movement of high-value, low-weight, low-volume goods, and those that are not suitable for long transit times, such as high-tech components and pharmaceuticals (Elliott & Bonsignori, 2019). Therefore, as shown in Table 1, depending on the type of freight being moved and its requirements, intermodality has the potential to benefit from using multiple modes of transport (Suzuki & Li, 2012). For instance, a combination of truck and sea keeps costs down while enabling the collection and delivery of goods between their origin and final destination (Tuzkaya & Önüt, 2008).

Road	Rail	Sea	Air
Limited capacity	Large capacity	Large capacity	Limited capacity
Flexible	Inflexible	Inflexible	Inflexible
Fast	Slow	Slow	Fast
Higher operating costs	Lower operating costs	Lower operating costs	Higher operating costs

Table 1: Advantages and disadvantages of the four major transport modes (adapted from Suzuki & Li, 2012)

Although each transport mode provides different advantages and disadvantages, road transport is by far the most commonly used in NZ. Data from 2017/18 shows that road transport accounted for 92.8% of total tonnage transported, followed by rail at 5.6%, coastal shipping at 1.6%, and air at less than 1% (Paling & King, 2019). As shown in Figure 5, road transport accounted for 83% in 2002, and over the subsequent years, there has been a shift away from rail and coastal shipping and towards road transport (Bolland et al., 2005; Ministry of Transport, 2014a; Paling & King, 2008, 2019).

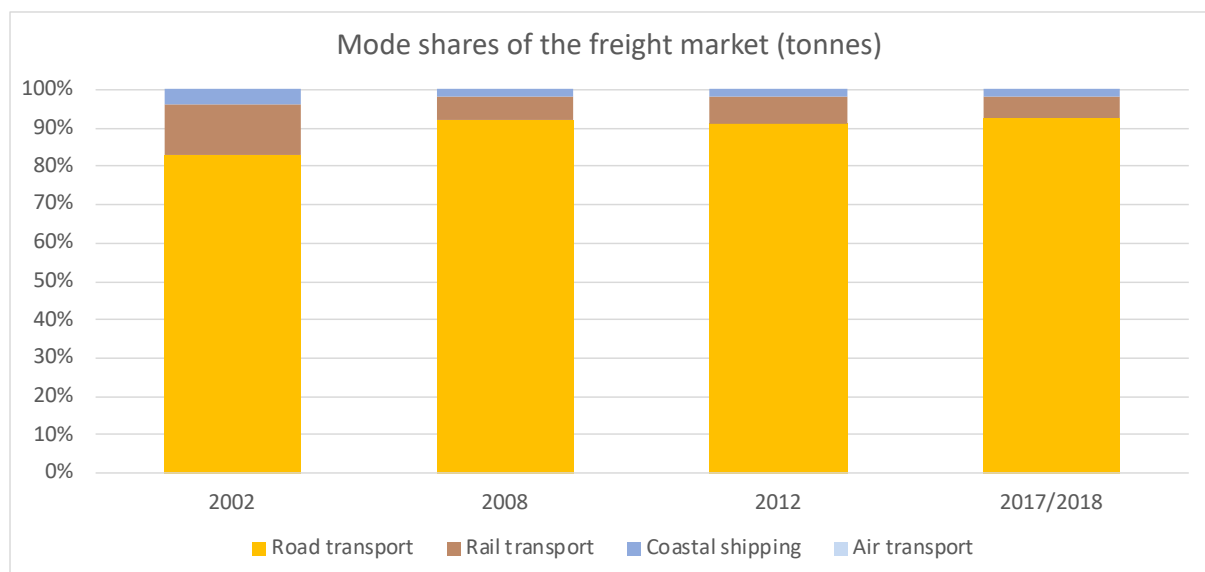


Figure 5: Mode shares of the freight market (tonnes) (adapted from Bolland et al., 2005; Ministry of Transport, 2014a; Paling & King, 2008, 2019)

One reason for the high dependence on road transport is that road (and rail) can move between the North and South Islands through five Roll-on, Roll-off (RoRo) ferries, forming a “bridge” across the Cook Strait (L’Hermitte et al., 2023). Because of this link, the Cook Strait ferries enable freight to be moved from Auckland to Christchurch in 24-48 hours, as seen in Table 2. Consequently, rail and ferry or road and ferry are the most common combination of transport modes for domestic freight movement (Kim et al., 2014). Looking ahead, the annual freight movement in NZ is expected to increase from around 280 million tonnes of freight to 366 million tonnes by 2042/43 (Ministry of Transport, 2022a), which, based on current trends, will put further pressure on the road network and, in turn, the ongoing criticality of the Cook Strait ferries for domestic freight movement.

	Rail	Road	Sea (Coastal shipping)
Days to deliver freight between Auckland and Christchurch	2 - 3	1 - 2	4
Costs per tonne of freight (in New Zealand Dollars (NZD))	\$150	\$233	\$100
Costs per hour (in NZD)	\$30	\$78	\$12
Number of times that freight is handled	4	2	6

*Table 2: Cost information ratios across the three transport modes (adapted from Hyder Consulting, 2008)*

### 2.2.3 Road transport

As previously indicated, NZ has a high reliance on road transport (Connelly et al., 2019), accounting for 92.8% of the total tonnage transported (Paling & King, 2019). It is projected that road transport will continue to account for 92.8% of freight tonnage by the year 2042/2043 (Ministry of Transport, 2017a). The projected dependence can be attributed to rail and coastal lacking the efficiency, resilience, and convenience of road transport (Transporting New Zealand, 2023). Moreover, because of the convenience road transport offers, such as speed and flexibility, it is ideal for moving freight that is replenished just-in-time (JIT) (as it is needed when it is needed) (Gallardo, 2023), such as FMCGs, which can be moved between Auckland and Christchurch in just 1 to 2 days (Hyder Consulting, 2008).

As a result of the high dependence on road transport, NZ has a heavy vehicle fleet of about 30,000 trucks moving commercial freight, and almost all those travelling long distances will tow heavy trailers (Transporting New Zealand, n.d.), travelling at speeds of up to 90km (kilometres) an hour (New Zealand Transport Agency, n.d.). It is estimated that around 80% of high-productivity motor vehicles (heavy trucks) operating non-rural routes will ‘cube out’ (NZTA, 2010). This means that low-density products fill the available space before the maximum weight is reached (McKinnon, 2010). In other words, many trucks operating on key routes, such as state highways, carry lightweight freight, such as FMCGs.

The state highway network runs for 11,000km and is government-owned and funded through the NZ Transport Agency (NZTA) (Rockpoint, 2009). Although state highways account for just 11.6% of NZ’s roading network, they carry almost half of all the country’s traffic (MBIE, 2016). The longest of the state highways is State Highway 1 (SH1), spanning the North and

South Islands, with the Cook Strait ferries acting as an extension, linking the two islands together (KiwiRail, 2021a). Unsurprisingly, SH1 is referred to as the backbone of the transport system (Aghababaei et al., 2020; Ministry of Transport, 2017). The remaining roading network comprises around 83,000km of local roads, owned and managed by individual territorial authorities and partly funded by the central government (Rockpoint, 2009). As shown in Figure 6, there are a limited number of State Highways, and thus, limited redundancy in the state highway network (Davies et al., 2017).

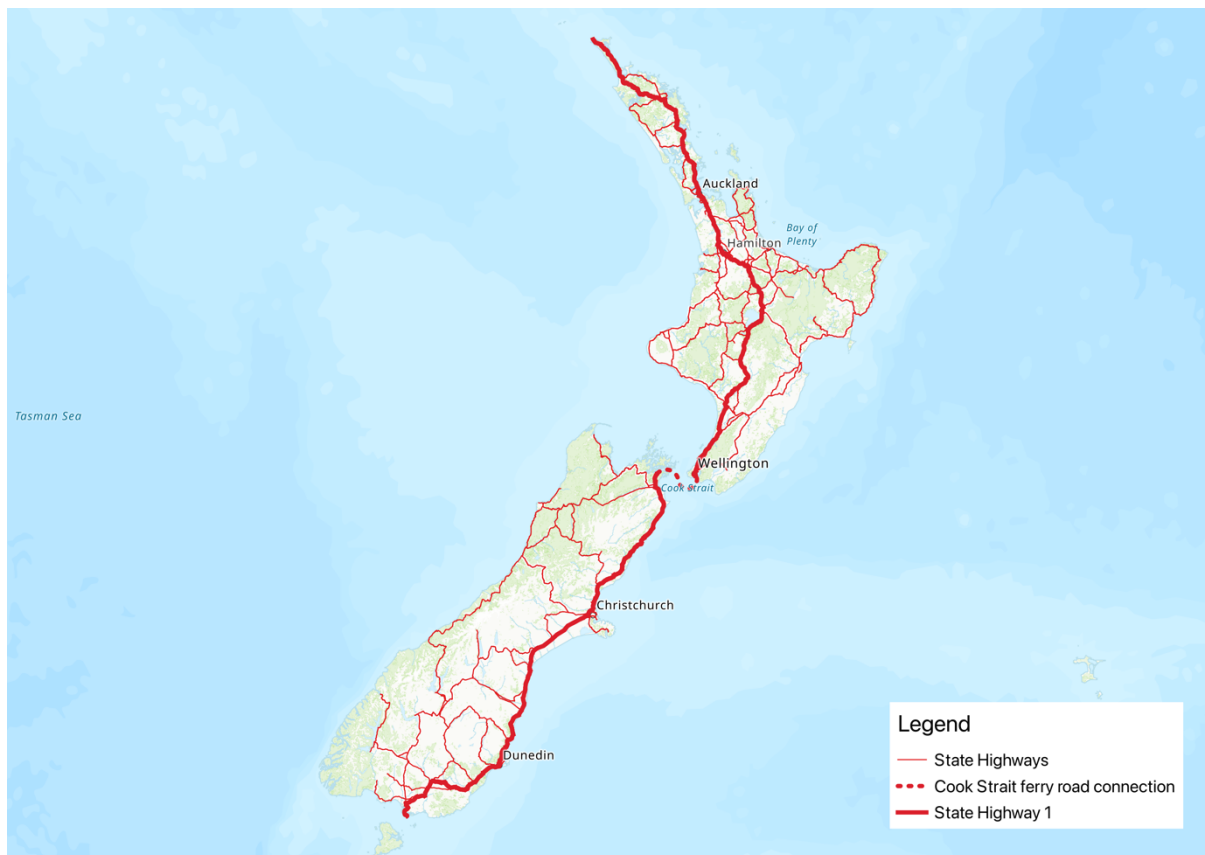


Figure 6: Map of NZ's state highway network

#### 2.2.4 Rail transport and CT sites

As mentioned earlier, NZ's rail sector accounts for just 5.6% of freight volumes by tonnes (Paling & King, 2019). State-owned enterprise KiwiRail operates the rail network (KiwiRail, n.d.) and moves a range of goods, including bulk, such as milk, dairy products and steel, timber and forestry products, domestic freight between cities, and import and export freight between seaports (KiwiRail, n.d.b). Unlike trucks, which can travel 90km, trains are slower, as they are limited to a maximum speed of 80 km per hour, partly due to poor track geometry, which can cause wagons to roll and derail (New Zealand Productivity Commission, n.d.). Limited schedules also constrain rail, the need for freight aggregation, and additional handling when freight is moving to and from rail at intermodal sites. Therefore, rail is not well suited for JIT freight operations (Rockpoint, 2009), making it a less attractive option when moving FMCGs.

Historically, the rail network has faced decades of underinvestment, with maintenance typically being reactive rather than proactive, resulting in many parts of the network being neglected

(KiwiRail, 2021b). In 1953, NZ's national rail network ran 5,689km and was the primary mode of transport for interregional freight (Rockpoint, 2009). In contrast, the rail network now spans around 3,700km (KiwiRail, 2023). Moreover, the network is primarily single-track, except for a few metropolitan areas (KiwiRail, 2021b), and the main highways and rail lines often run in parallel, meaning they are exposed to the same hazards, which can lead to long detours if they become unavailable (New Zealand Lifelines Council, 2023a). For example, in the South Island, SH1 runs parallel to the MNL along the East Coast, which is exposed to tsunamis (Nelson Tasman Emergency Management Group, n.d.).

As seen in Figure 7, the rail network is designed to run through the centre of the North Island, with the North Island Main Trunk line connecting Wellington and Auckland (KiwiRail, 2021b). This line is then connected to the North Island through the Cook Strait ferry connection, referred to as the Main Trunk Rail Line, which serves as an extension of the rail network, connecting Wellington and Picton, primarily through the rail-enabled RoRo ferry, the Aratere (KiwiRail, n.d.c). As for the South Island, the rail network primarily runs along the East Coast, with the Main North Line connecting Picton to Christchurch and the Main South Line connecting Christchurch to Invercargill at the bottom of the South Island (KiwiRail, 2021b). In other words, the rail network has little to no redundancy (New Zealand Lifelines Council, 2020).

To accommodate the limited redundancy, the rail network achieves resilience through 16 CT (container terminals) sites throughout the rail network, which provide facilities to transfer freight between trains and trucks (KiwiRail, n.d.a; Ministry of Transport, 2022), as seen in Figure 7. In other words, these CT sites act as intermodal terminals as they enable containerised freight to be moved between rail and road (Silva et al., 2015). At the same time, these sites are often accessed through or are located near seaports (KiwiRail, n.d.a). In line with KiwiRail's focus on intermodality, 59% of its wagon fleet is intermodal, making it easier to shift freight between ships, trains and trucks (KiwiRail, 2018).



Figure 7: Map of NZ's key rail lines and CT sites

### 2.2.5 The Cook Strait ferries

As mentioned in the subsequent sections, the five Cook Strait ferries serve as an extension of the road and rail lines and are the only means of moving rolling stock (trucks and rail wagons) between the North and South Islands (Moffiet, 2022). Annually, the ferries perform around 6,300 one-way sailings (Stone et al., 2023), moving almost 5 million tonnes of freight (Maritime NZ, 2023) at a value of around \$20 billion (CentrePort, n.d.). Put simply, the ferries move thousands of trucks and rail wagons each year (The Treasury, 2024). Of the total tonnage moved by ferries in 2019, around 0.7 million tonnes was rail freight, and 3.3 million tonnes was road freight, meaning the vast majority (around 80%) of the freight moved inter-island is by trucks. Breaking this down further, of the road freight moved, around 60% was southbound, and 40% was northbound. To provide perspective, the freight moved by ferries equates to around twice as much as that which is moved by coastal shipping (Pacific Marine Management Ltd, 2021). In other words, the Cook Strait ferries are a critical strategic corridor in the NZ transport system, with the potential to become a bottleneck for inter-island freight movement in the event of a disruption (Transport Knowledge Hub, 2016).

The five Cook Strait ferries are operated by Interislander and Bluebridge. Interislander, which is owned and operated by State Owned Enterprise KiwiRail, operates three ferries: the Kaiarahi, the Kaitaki, and the rail-enabled Aratere, which are between 26 and 29 years old (Interislander, n.d.). Bluebridge, on the other hand, is owned and operated by StraitNZ and runs two ferries, the Strait Feronia, built in 1997 and the Strait Connemara, built in 2007

(Bluebridge, n.d.). Because the ferries are aged and nearing the typical 30-year working life (KiwiRail, 2021a), there have been a number of ongoing issues.

For example, in January 2021, one of the Bluebridge ferries faced technical issues resulting in cancellations (Hunt, 2021). In August 2021, the Kaiarahi was put out of service for a year due to a gearbox failure (Scoop, 2022), while the Feronia experienced a propeller fault the same month (Pearse, 2022). The Aratere was unavailable for around two weeks during the outage due to dry dock work in Sydney, leaving Kaitaki as the only Interislander ferry sailing (Hickman, 2021). To meet demand while these vessels were unavailable, a freight-only vessel, the Valentine, was chartered to improve resilience by offering additional capacity during one of the year's busiest periods (Moffiet, 2021). The Valentine was purchased in 2021 and then announced for sale six months later once the remaining fleet was back operating at full strength (Stuff, 2023).

More recently, a series of disruptions occurred at the start of 2023, again highlighting the vulnerability of the ferries when four out of the Cook Strait ferries were not operating. Of StraitNZ's fleet, the MV Straitsman (since sold) had to stop for urgent operational requirements, the newer Connemara was unavailable due to an engine problem, and the Feronia was in Sydney for a routine dry dock. At the same time, Interislander's Kaiarahi stopped sailing due to an engineering fault, and the Kaitaki was only transporting freight due to recent engine issues, leaving the Aratere as the only other ferry operating (Knell, 2023).

Bluebridge and Interislander have ferry infrastructure (terminals) at Wellington's CentrePort and Picton's Port Marlborough, as shown in Figure 8. For the North Island, CentrePort provides the land and marine infrastructure necessary to support the ferry services, including the wharves, linkspans (used to connect the ferries to the terminal), and marshalling areas (CentrePort, n.d.). Conversely, Port Marlborough provides the terminal for the Cook Strait ferries for the South Island (Herbert et al., 2018; Port Marlborough, n.d.). Because Interislander caters to rail, its Picton and Wellington ferry terminals have undergone specific changes to support intermodal road-bridging operations, where rail containers and wagons are lifted onto road trailers, which are then towed on the ferries for loading and towed off again for unloading (KiwiRail, 2016, 2017a). Therefore, rail freight can continue to move between the islands in the event the rail-enabled Aratere is unavailable.

Despite the significance of the Cook Strait ferry service, the existing terminal assets are life-expired and sub-optimally configured as a result of a historical trend of incremental, short-term changes. Consequently, there is no viable alternative to the CentrePort and Port Marlborough terminals for operating a ferry service between the North and South Islands (Boffa Miskell Limited, 2022). In other words, there is no redundancy in the event the linkspan or berth were to fail (Herbert et al., 2018; KiwiRail, 2021a). At the same time, infrastructure is vulnerable to multiple natural hazard events, and Interislander's infrastructure knowingly has poor resilience overall (Boffa Miskell Limited, 2022).

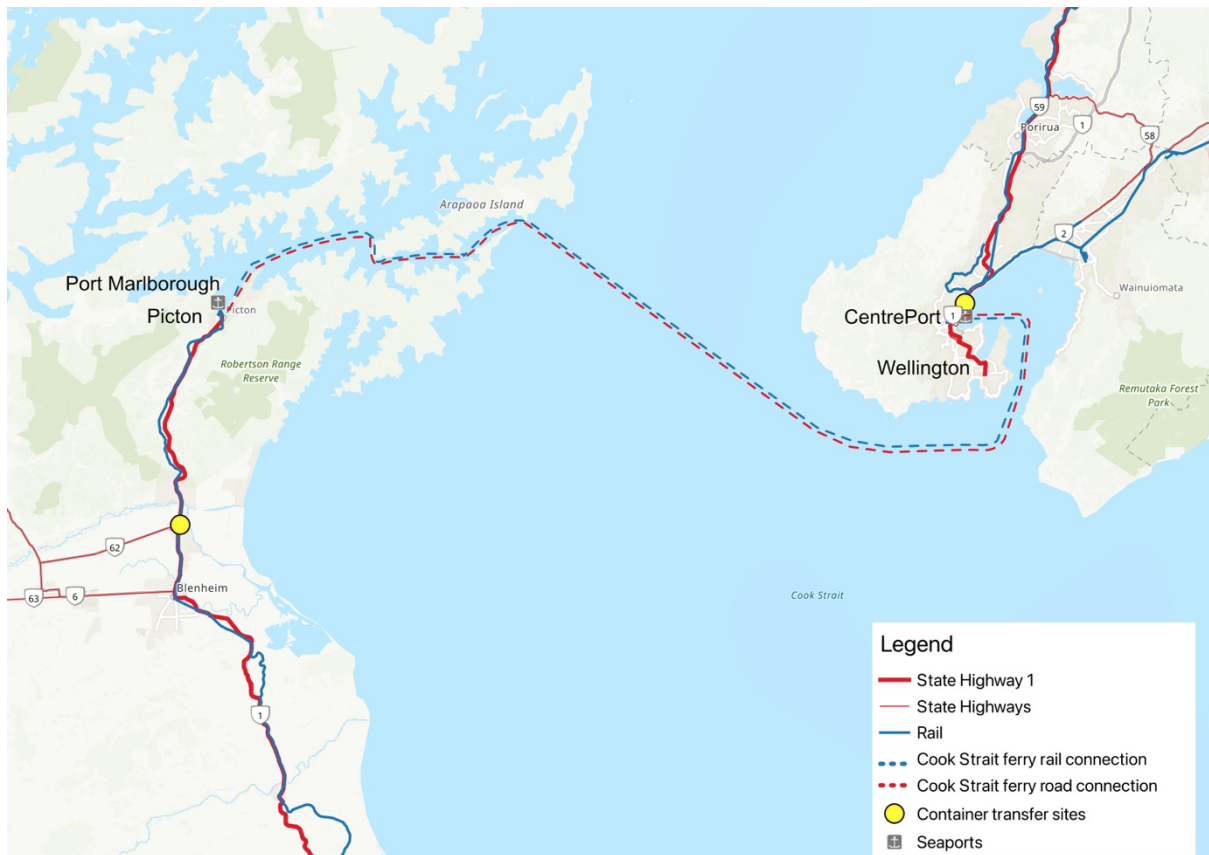


Figure 8: Map of the Cook Strait ferry terminal locations and the ferry connection

The combination of aged ferries and poor-quality infrastructure means there is a significant and increasing risk that the inter-island link could be compromised, which would significantly disrupt the movement of freight and result in major economic and social consequences (Boffa Miskell Limited, 2022). To improve the resilience of SH1 and the Main Trunk Rail Line across the Cook Strait, Interislander announced the Inter-island Resilience Connection (iReX) project in 2020 at an estimated cost of just under \$1 billion NZD (KiwiRail, 2021a) (Hart, 2023). The project included replacing Interislander’s existing three vessels with two new hybrid-electric ferries, which were expected to arrive in 2025 and 2026 (Boffa Miskell Limited, 2022).

The new vessels were future-proofed to cater to 30 years of freight and passenger growth due to the ability to carry 300% more rail wagons and almost twice the number of trucks and other vehicles. As KiwiRail is a lifeline utility in NZ, the new vessels were specifically designed to have the capability to berth at alternate berths and seaports by using attachable stern ramps (Boffa Miskell Limited, 2022), thereby overcoming the lack of redundancy mentioned earlier. However, despite initial cost projections, the iReX project grew to an estimated \$3 billion NZD (Hart, 2023). Consequently, KiwiRail was dependent on government funding to complete the project, which, as of December 2023, was stopped, resulting in the wind-down of the project (iReX, n.d.).

### 2.2.6 Coastal shipping

Like rail, NZ's coastal shipping sector has experienced a historic decline (Ministry of Transport, 2022a), accounting for just 1.6% of freight volumes by tonnage (Paling & King, 2019). Excluding the Cook Strait ferries, the domestic coastal shipping fleet comprises eight vessels, two of which are container ships, and the rest include petroleum, cement and general bulk vessels (Castalia, 2018; Ministry of Transport, 2023a; Pacific Marine Management Ltd, 2021a). In 2019, NZ operated just one container ship, which carried 22% of the country's containerised freight (domestic and transshipment), while the remaining 78% was carried by international ships (Pacific Marine Management Ltd, 2021).

The risk of having such a high dependence on international ships was highlighted at the Ports of Auckland in 2021, which experienced significant congestion due to the COVID-19 pandemic and labour shortages. As a result, the international shipping line Maersk halved its weekly port calls from 3 to 1.5 (Fox, 2021). With disruptions continuing into the following year, Maersk introduced a dedicated coastal shipping service for NZ halfway into the year. The service comprised two 2,500 TEU vessels, the Maersk Nadi and Maersk Nansha, which called between Timaru, Nelson, and Tauranga weekly and Auckland and Nelson fortnightly (Transport Talk, 2022). However, less than one year later, the dedicated service was withdrawn (Barry, 2023), highlighting the vulnerability of relying on international lines. Therefore, to improve resilience, NZ's domestic shipping network must shift away from this dependence on international shipping lines and the terminals that serve them (Pacific Marine Management Ltd, 2021).

Fortunately, there has been recent investment in coastal shipping by way of new ships through the 2021 Government's Priorities for Expenditure (GPS), which is part of the National Land Transport Programme (NLTP) and is reviewed every three years to provide a 10-year view of investment prioritisation into the transport sector (Ministry of Transport, 2021). As part of the 2021 GPS, \$30 million NZD was committed for coastal shipping. As a result of this funding, domestic provider Coastal Bulk Shipping acquired a second bulk vessel, the Rangitata. Swire Shipping (Pacifica), NZ's only flagged and crewed container vessel, acquired a second vessel, the M.V. Takutai Chief, which started sailing in 2022 (Pacific Marine Management Ltd, 2021a). Domestic company MOVE Logistics received \$10 million to acquire and operate a RoRo vessel, with three sailings per week between New Plymouth and Nelson, so that rolling stock (trucks and rail wagons) was not solely dependent on the ferries when moving between the North and South Islands. However, this proposal was later scrapped due to tidal issues at the seaports (McLean, 2023).

### 2.2.7 Seaports and inland ports

NZ has 13 international seaports, which handle 99% of the country's exports (New Zealand Port Company CEO Group, 2023). At the same time, several smaller ports serve local economies, such as Whanganui (New Zealand Shipping Federation, n.d.). Of the international seaports, ten regularly handle containers. These include the Ports of Auckland, Port of Tauranga, Napier Port, CentrePort (Wellington), Port Nelson, PrimePort Timaru, Port Otago, Lyttelton Port Company, Northport (Marsden Point) and South Port (Bluff). The remaining three seaports, Port Taranaki (New Plymouth), Port Marlborough and Eastland Port, cater to bulk trade (Deloitte, 2022). The largest port in NZ is the Port of Tauranga, which accounts for approximately 48% of all containers exported from NZ by volume, followed by Lyttelton Port at 14% and the Ports of Auckland at 13% (Deloitte, 2022). As for imports, the Port of Tauranga accounts for 34%, followed by the Ports of Auckland at 33%, and Lyttelton Port at 10%. The location of the 13 international ports, as well as Port Whanganui, are shown in Figure 9.

NZ also has several inland ports, which are defined as inland facilities with or without intermodal terminals and logistics companies, that are directly connected to one or more seaports through either rail, road or sea, enabling customers to deliver and collect standard units (such as containers) as if directly to and from a seaport (Witte et al., 2019). In NZ, inland ports often utilise road and rail networks to provide linkages between inland regions, seaports and airports (Central Economic Development Agency, 2021). In Auckland, these inland ports include the Port of Tauranga's MetroPort and the Ports of Auckland's Wiri Inland Port (Ministry of Transport, 2014). South of Auckland, in the Waikato, are The Ports of Auckland's Waikato Freight Hub (Central Economic Development Agency, 2021; Port of Tauranga Limited, n.d.) and the Ruakura Superhub, which connects the Waikato to the Ports of Auckland and the Port of Tauranga (Ruakura, n.d.). In the lower North Island, there is the Manawatu Inland Port, which is located in Palmerston North (Central Economic Development Agency, 2021). As for the South Island, the Port of Tauranga operates MetroPort Christchurch, and Lyttelton Port Company operates Midland Port (Central Economic Development Agency, 2021; Port of Tauranga Limited, n.d.). Figure 9 provides an overview of the location of these inland ports in relation to seaports.

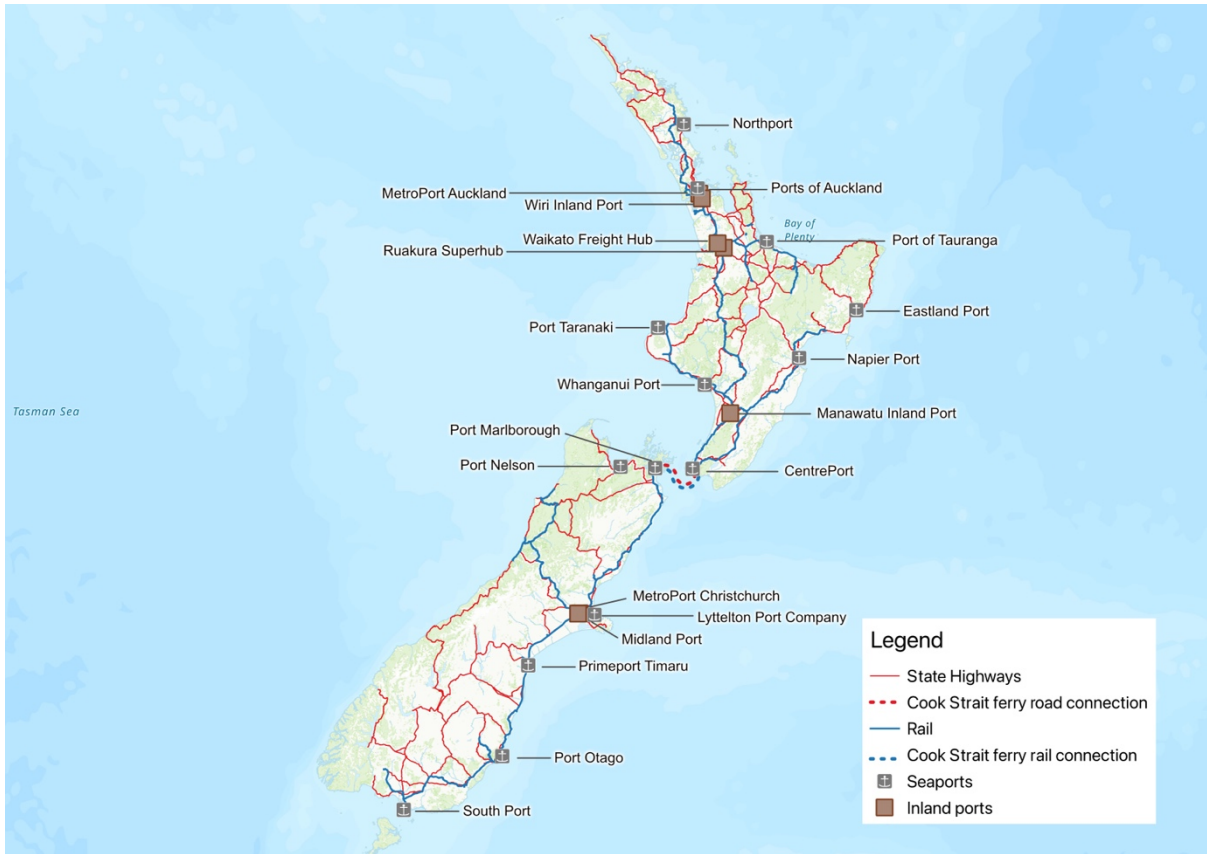


Figure 9: Map of NZ's inland ports and seaports

### 2.2.8 Air transport

The remaining mode share of the freight market comprises air freight, which is minimal by volume, representing less than 1% of tonnes transported, yet valuable as it represents 16% of NZ's exports and 22% of imports by dollar value (Ministry of Transport, 2022a). Therefore, air freight is primarily used to move high-value, time-sensitive, or critical goods, often transported in the belly of passenger aeroplanes (Ministry of Transport, 2022a). NZ's national carrier, Air NZ, operates over 100 aircraft (Pacific Marine Management Ltd, 2021), while the carrier's subsidiary, Air NZ Cargo, moves freight domestically and internationally, with connections to 20 NZ airports, as shown in Figure 10. Of NZ airports, the busiest freight-handling airports are Auckland, Christchurch and Palmerston North (Palmerston North City Council, 2022). In addition to Air NZ, Freightways and NZ Post have national air freight operations. Airwork, a joint venture with Freightways' subsidiary Fieldair, operates four Boeing 737-400 freighter aircraft, with the fleet catering to the Freightways' express package business and NZ Post's Express Couriers Limited business, operating daily between Christchurch, Palmerston North, and Auckland, carrying around 17,000kg (Freightways, n.d.).

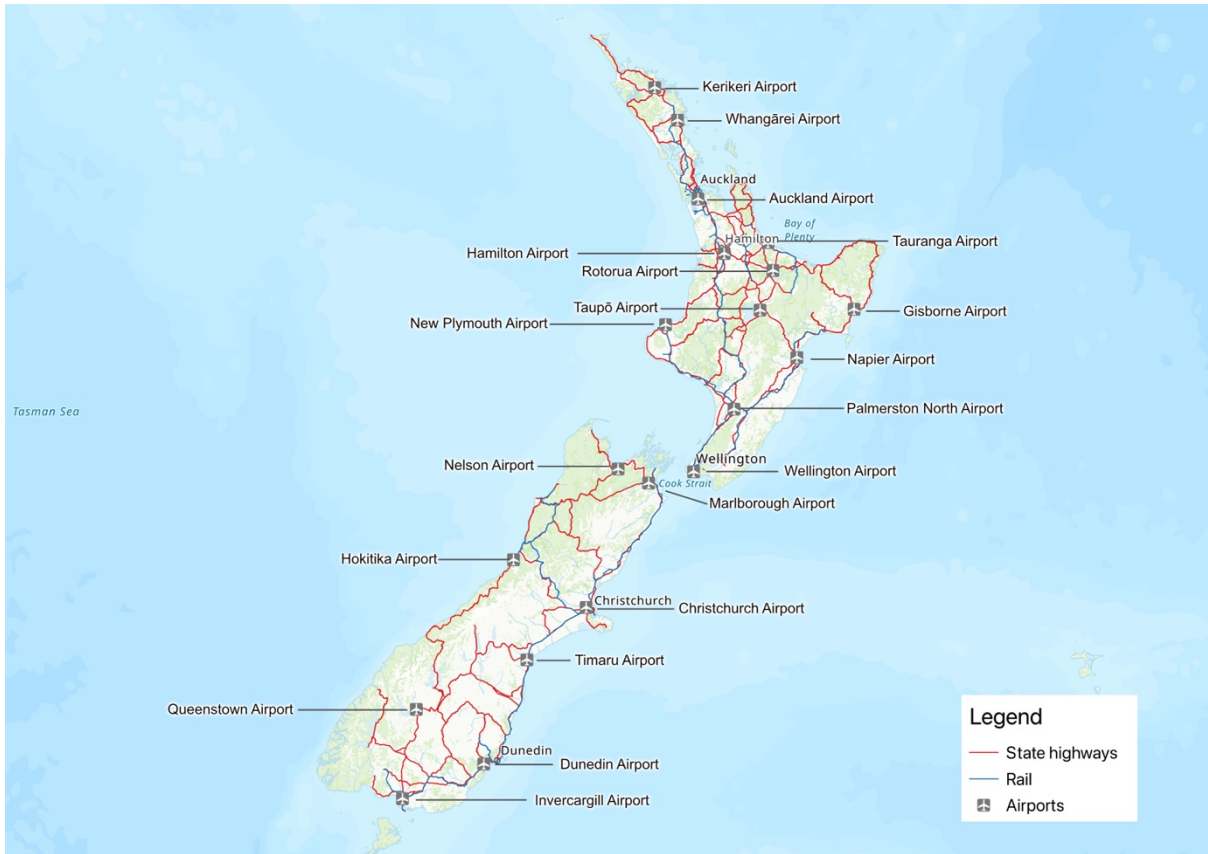


Figure 10: Map of NZ's airports

NZ also saw the introduction of a new cargo airline, Texel Air, which started its NZ operations by adding a Boeing 737-800BCF freighter to Freightways aircraft fleet, providing cargo services to NZ Post and Freightways and flying between Auckland and Christchurch multiple times each week (Hamilton Airport, 2023). The addition of the 737-800 enables more significant quantities of freight to be moved, with reduced emissions and greater reliability. The remainder of Freightways' fleet will be steadily upgraded in line with Freightways' goal of moving more freight in fewer cycles (Freightways, 2023). Although air freight transport in NZ is only a fraction of the freight volumes moved, having sufficient capacity can be crucial in times of disruption, as was observed during COVID-19 and recent extreme weather events (Radio New Zealand, 2023a).

## 2.3 FMCG operations

FMCGs, also called consumer packaged goods, have a quick turnover and relatively low cost (Mohan & Sequeira, 2016; Raman et al., 2021) while being essential to society and the economy (Moteff et al., 2004). FMCGs comprise a broad group, including food products, such as fruit, vegetables, meat, beverages, alcohol, cosmetics, household chemical products, and over-the-counter medicines (Liczmańska-Kopcewicz et al., 2019; Tarallo et al., 2019). In NZ, the FMCG sector primarily comprises dairies (corner stores), service stations, food producers, supermarkets (Whitman et al., 2014), and certain retailers, including The Warehouse Group, which sells a range of FMCGs and Chemist Warehouse, which sells a range of pharmaceuticals. In NZ, the FMCG sector is seen as an essential service due to its role in the functioning of communities (New Zealand Lifelines Council, 2023). Additionally, the sector provides significant economic value to the country. For FY19, NZ's food and beverage industry had a combined revenue of \$71.7 billion, accounting for 46% of all goods and services exports (Coriolis Research, 2019). Therefore, a disruption to the NZ FMCG sector would significantly impact society and the economy.

### 2.3.1 Inventory management (distribution practices)

To reduce costs in the FMCG sector, a JIT approach is often followed, which aims to continuously find ways to make processes more efficient through the elimination of waste (Canel et al., 2000), which is seen as anything that does not add value to the product and is most commonly inventory (Aradhye & Kallurkar, 2014). By reducing inventory (waste), goods are only received as needed, when needed (Webster et al., 2006). In other words, goods are available at the right place at the right time, also referred to as place utility and time utility. Place utility is achieved when goods are moved from one location to another where there is demand, while time utility is achieved when goods are available when they are needed (Coyle, 2017). At the same time, other authors argue that a further key component is ensuring that goods are available for the right price (Teoman, 2020). As a result, FMCGs are often replenished at regular intervals, such as multiple times a week (Hamilton & L'Hermitte, 2022). Moreover, frequent replenishment is essential for perishable goods, such as fresh produce, which spoil quickly (Ahumada & Villalobos, 2009). Therefore, value is largely generated in the FMCG sector through place and time utility.

The replenishment of FMCGs is often achieved through road transport, as opposed to other modes, as road transport is faster and more reliable than rail and sea and cannot justify the high costs associated with air freight (Kellner, 2016; Rossi et al., 2021; Tuzkaya & Önüt, 2008). Because these goods largely depend on road transport, they can be substantially affected by various disruptions to road networks (Kellner, 2016), such as congestion at port entrances, road accidents, vehicle issues and adverse weather conditions (Scholz et al., 2020). Regardless of the disruption type, because FMCGs are replenished at regular intervals and run lean, a disruption to road transport would soon result in FMCGs selling out at the point of sale, such as at retail stores (McKinnon, 2006). Additionally, depending on the extent and duration of the disruption, there may be concerns about running out of inventory due to panic buying (Arafat et al., 2022). For example, during COVID-19, consumers made impulsive and obsessive

purchases to stock up on essential items, including FMCGs, such as frozen foods, toiletries, rice, bread, eggs and beans, resulting in empty store shelves (Islam et al., 2021).

Although there is no data on FMCG movement in NZ, the National Freight Demand Study for 2017/18 provides an overview of the inter-island freight movement of other manufactured and retail products (i.e., non-perishable goods) and horticultural products (i.e., perishable goods), as shown in Figure 11 and Figure 12. For other manufactured and retail goods, around 64% are southbound, and for horticultural, around 74% are northbound (Paling & King, 2019). One reason for the imbalance of retail goods is that most imports arrive into the North Island through the Ports of Auckland and the Port of Tauranga, destined for the leading centres within the upper North Island (Ministry of Transport, 2022a). At the same time, over 50% of national goods originate or end up in the upper North Island (NZTA, 2015).

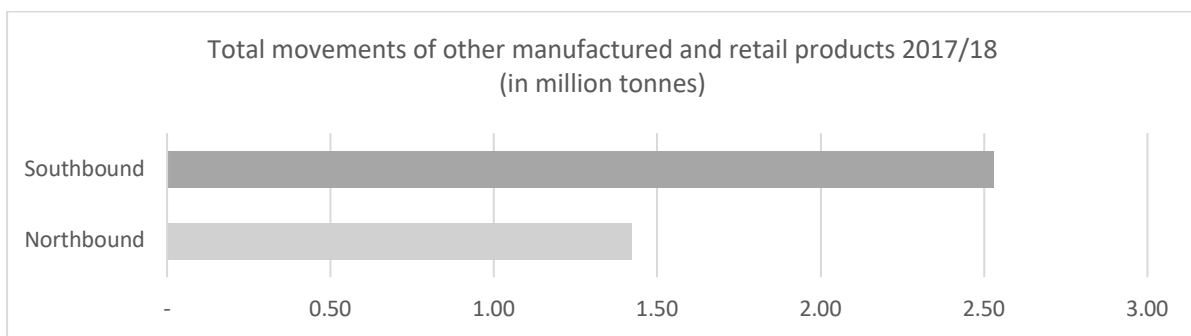


Figure 11: Total movements of other manufactured and retail products 2017/2018 (million tonnes) (adapted from Paling & King, 2019)

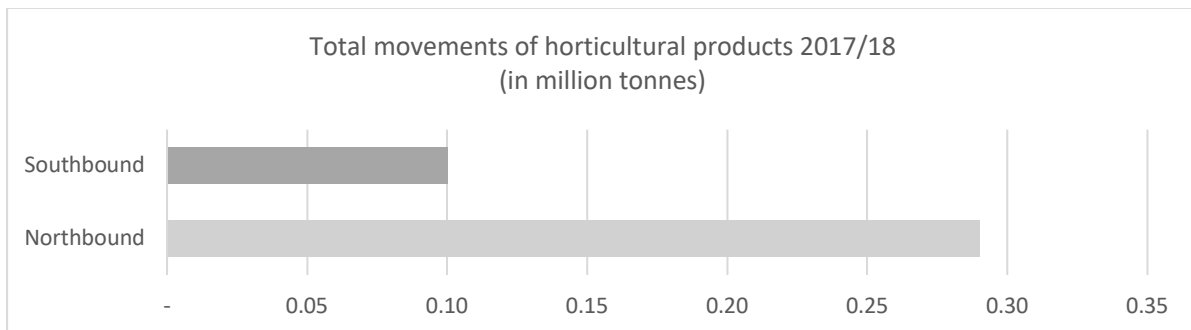


Figure 12: Total movements of horticultural products 2017/2018 (million tonnes) (adapted from Paling & King, 2019)

The two major FMCG organisations in NZ are the supermarket retailers Foodstuffs (Foodstuffs North Island and Foodstuffs South Island) and the Woolworths Group. Combined, the two control up to 90% of the retail grocery market share and are referred to as major grocery retailers. Because of this duopoly, the remaining 10% of the retail grocery market share is described as a fringe of competitors, such as international food stores, convenience stores and online-only supermarkets, referred to as other grocery retailers. As shown in Figure 13, the FMCG sector depends on several actors, from producers and growers to retail consumers (Commerce Commission New Zealand, 2022). When moving perishable goods that are time-sensitive, such as milk and bread, they are sometimes delivered directly from the supplier to the retailer rather than through a distribution centre. In contrast, non-perishable goods often go from the supplier to the distribution centre and then to the retailer (Kemp et al., 2012).

For certain perishable goods that are highly time-sensitive and cannot justify the cost of air (Kemp et al., 2012), firms tend to have a warehouse (or distribution centre) in Auckland to serve the North Island market and a second warehouse in Christchurch to serve the South Island market (Sankaran, 2000).

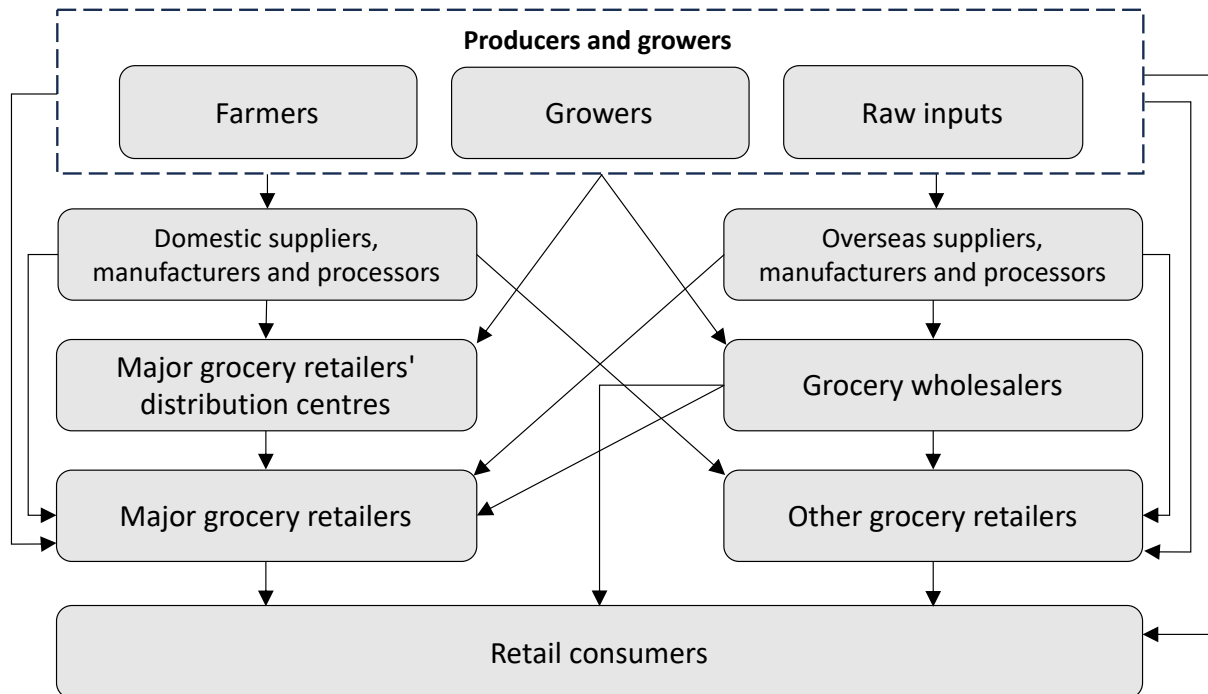


Figure 13: Overview of NZ's Fast-Moving Consumer Goods sector (adapted from Commerce Commission New Zealand, 2022)

As for NZ's grocery retailers, the sector follows a centralised approach across the two islands (Renwick, 2023). For example, as shown in Figure 14, Foodstuffs North Island operates five distribution centres in the North Island, three in Auckland, and two in Palmerston North (Foodstuffs, n.d.), while Foodstuffs South Island operates one distribution centre in Christchurch and another in Dunedin (Foodstuffs, n.d.). Conversely, in the North Island, Woolworths operates three distribution centres in Auckland, two in Palmerston North, and two in the South Island, which are located in Christchurch (Woolworths Group, 2023). The seven Woolworths distribution centres nationwide supply over 180 retail stores, while Foodstuff's seven supply over 400 retail stores (Commerce Commission New Zealand, 2022). Importantly, around 80% of NZ's grocery supplies are estimated to be sourced from Auckland (Kemp et al., 2012).

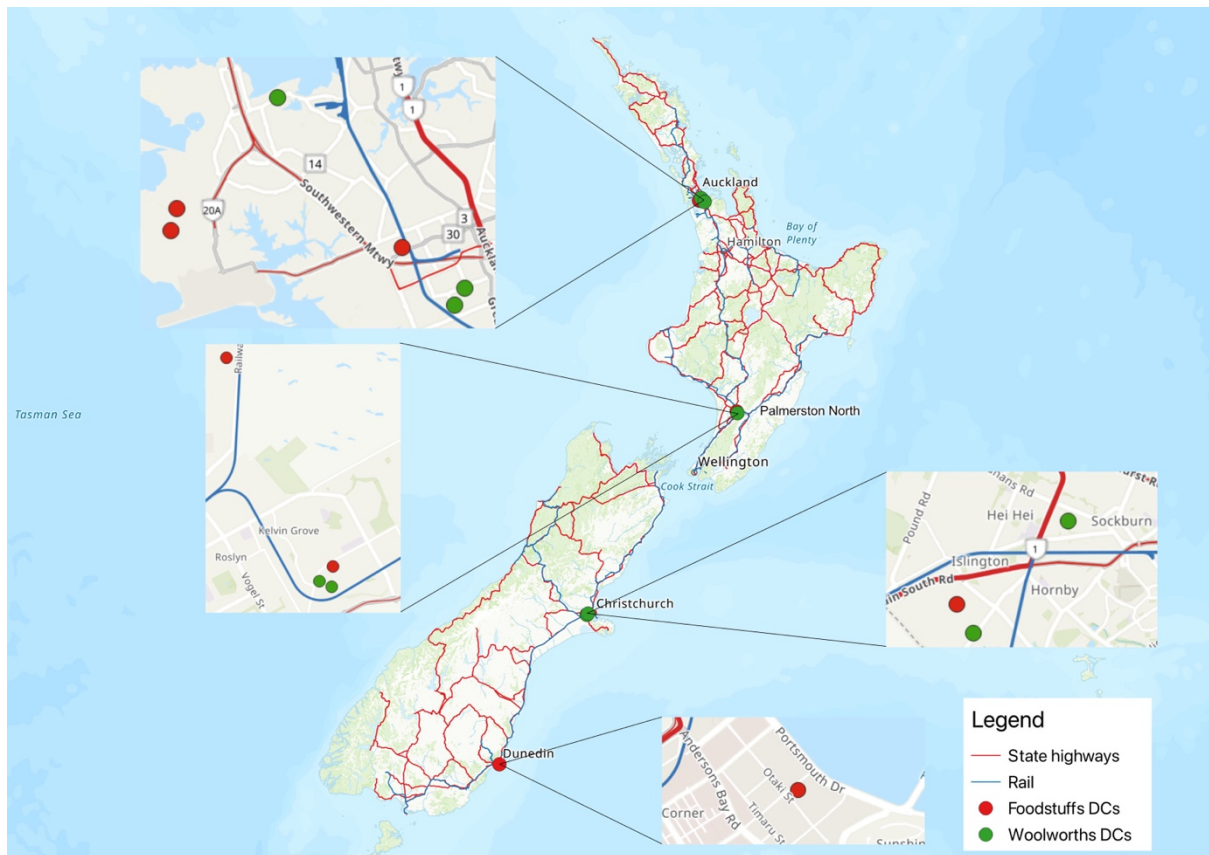


Figure 14: Map of NZ's major grocery retailers' distribution centres

When goods are moved between distribution centres or from the suppliers to the distribution centres, coastal and rail transport is occasionally used. However, as discussed earlier, the viability of these modes depends on the products' perishability, such as whether refrigeration is needed, the economic feasibility, and the speed of the transport mode. Therefore, road transport is generally the only practical delivery option when moving FMCGs (Kemp et al., 2012). Because of the dependence on road and rail, and by extension, the Cook Strait ferries, if there were a significant disruption to the transport system, coastal shipping capacity would be critical to ensure FMCGs can continue moving. However, despite government investment into improving coastal shipping, as discussed earlier, it is unclear if it would be effective in delivering the core service needs of Auckland, Tauranga and Christchurch (Woolworths Group, 2023a).

Surveys conducted with 14 NZ supermarket retailers revealed that 86% of participants replenish their inventory every three days or less, with 50% replenishing daily, 36% every 2-3 days, and none restocking more than every eight days. As a result of these regular replenishment intervals, an individual supermarket can receive up to 10 trucks delivering stock daily from distribution centres, producers and growers, domestic and overseas suppliers and grocery wholesales (Commerce Commission New Zealand, 2022; Kemp et al., 2012). As for buffer inventory among the 14 supermarkets surveyed, at least 79% of respondents maintained a buffer of seven days or less for perishable goods (fruit and vegetables, meat and fish), and 71% of respondents carried eight or more days of buffer stock for non-perishable items (Hamilton & L'Hermitte, 2022).

### 2.3.2 Dependence on critical infrastructures in FMCG organisations

Because the transport and FMCG sectors are highly interdependent, a disruption to the transport network would impact the availability of FMCGs (Department of the Prime Minister and Cabinet, 2023; Kachali et al., 2012; New Zealand Lifelines Council, 2023a). For example, the road network is particularly exposed to congestion stemming from high traffic volumes, road works, and road closures (Kemp et al., 2012), which can prevent the movement of goods and cause freight bottlenecks (Short et al., 2010). Furthermore, because of the centralisation of distribution centres, a disruption in one region can be felt nationwide (Renwick, 2023).

In addition to the dependence on the transport network, the FMCG sector relies upon several other critical infrastructures, such as the supply and distribution of fuel, which requires road and port networks. The water, electricity, and gas network is used for everyday operations at stores and distribution centres, and the telecommunications network for communicating across stores and the wider supply chain (New Zealand Lifelines Council, 2023). As a result, there are multiple potential failure points and the opportunity for these failures to cascade through the wider freight system. For instance, without access to fuel, the distribution of food, which is primarily achieved by trucks, would be constrained and could lead to shortages of goods on supermarket shelves (Foodstuffs, 2022). Figure 15 provides a simplified overview of these dependencies and interdependencies between infrastructures, where the head of the arrow signifies a dependent (unidirectional) or interdependent relationship (bidirectional).

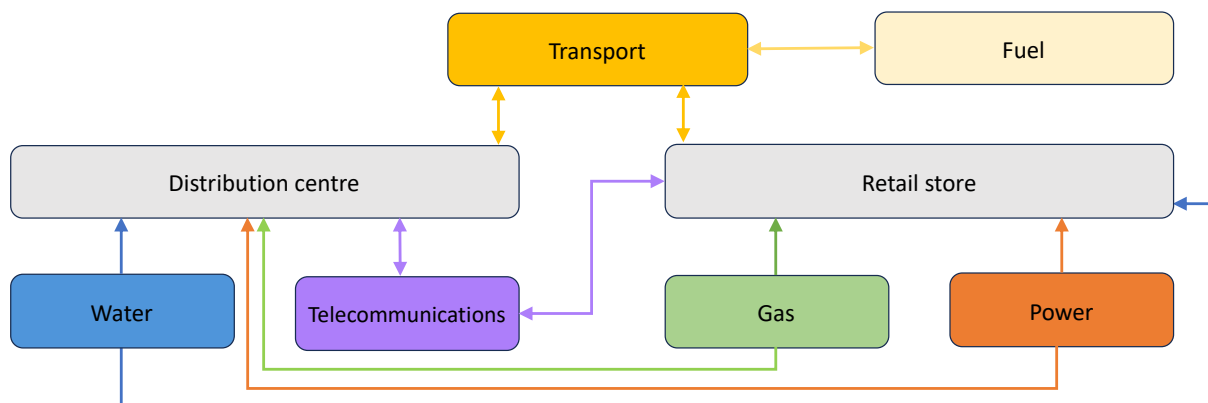


Figure 15: Critical infrastructure dependencies and interdependencies in the FMCG sector

## 2.4 Impact of disasters on freight transport systems

The frequency of natural hazard events has increased in recent years, impacting critical infrastructure and disrupting freight transport systems (Lu et al., 2020), and as the frequency of these natural hazard events increases, so does the need for resilient transport systems (Bešinović, 2020). The environment and geography of NZ mean that the country's critical infrastructure is exposed to a wide and more consequential range of potential hazards when compared to other highly developed countries (Department of the Prime Minister and Cabinet, 2023). Because of this exposure, NZ has the second-highest disaster loss risk globally (Lloyd's, n.d.).

### 2.4.1 Disruptions to the NZ freight transport system (reduced capacity)

Depending on the type and severity of the disruption, nodes and links can be damaged, resulting in reduced capacity (Lordieck & Corman, 2021). For example, the 2016 Kaikōura earthquake damaged Wellington's CentrePort's container-dedicated gantry cranes, reducing container handling capacity and resulting in an almost complete stop to container shipping for just under two months (Juno et al., 2022; Stevenson et al., 2017). In instances of reduced capacity at seaports, flexible transport systems are essential, where capacity can be absorbed elsewhere in the network, such as through alternative seaports (Rogerson et al., 2022). Fortunately, because of NZ's many seaports, the freight transport system successfully absorbed the disruption, as there was sufficient capacity at alternate seaports to cater to CentrePort's container volumes (Stevenson et al., 2017). Additionally, a weekly service was set up three months after the earthquake with the shipping company Australian National Line (ANL), which enabled CentrePort to continue moving containers through the use of a geared (craned) container ship, bypassing the need for the container dedicated gantry cranes that were still disabled (Frykberg, 2017).

The earthquake also saw damage to one of the ferry linkspans at CentrePort, which resulted in the rail-enabled Aratere not sailing until 15 days after the earthquake. As the linkspan was still damaged, rail freight had to be road-bridged (Cubrinovski et al., 2020), and ferry crossings were reduced (Davies et al., 2017). As a consequence of the Cook Strait ferries operating on reduced timetables, Foodstuffs distribution centres in Auckland and Palmerston North struggled to get sufficient FMCGs across the Cook Strait, leading to purchasing limits on certain goods in the upper South Island (Chamerlain, 2016). Fortunately, the rail-enabled functionality of the linkspan was restored 22 days after the earthquake (Davies et al., 2017).

The damage to the ferry infrastructure highlights the lack of redundancy in available linkspans at alternate ports and the need for an alternate RoRo linkspan solution (Herbert et al., 2018; Marico Marine, 2018). Following the earthquake, new linkspan facilities in Napier were proposed, which would have provided network redundancy for the ferries. However, a decision was later made not to go ahead with this suggestion (Herbert et al., 2018). At the same time, although the disruption to the Cook Strait ferries was minor, the event highlights just how critical the service is for the movement of FMCGs between the North and South Islands, and it is unclear just how severe a complete outage would be on FMCG operations.

#### 2.4.2 Disruptions to the NZ freight transport system (outages)

In other instances, links and nodes can be completely destroyed (Xu et al., 2020). For example, shaking from earthquakes can damage infrastructure, taking out multiple modes of transport (Chang, 2016), as was observed in the 2016 Kaikōura earthquake that took out a section of SH1 along the East Coast for 13 months. The impact of this closure was significant, as the corridor is the primary freight route in the South Island, providing a critical link between Christchurch and Picton (Mason & Brabhaharan, 2020). Because of the limited redundancies in the road network, the only alternate route was through State Highway 7 (SH7), which increased the journey between Christchurch and Picton from 4 hours to 6 and a half hours (Davies et al., 2017; Stevenson et al., 2017).

As a result of the longer journey and the fact truck drivers cannot work for more than 13 hours a day, additional trucks and drivers were sourced, putting pressure on a limited pool of drivers and increasing the wear to alternate roads, which were dangerous and hardly fit for purpose (Freightways, 2022; Herbert et al., 2018). Consequently, the alternate route soon became congested with heavy traffic (Stevenson et al., 2017), significantly disrupting the national transport system and causing substantial fuel and FMCG distribution issues (Cubrinovski et al., 2020; Environment Canterbury Region Council, 2017). From a roading perspective, the earthquake emphasised the roading network's lack of capacity and the need for upgrades so that alternate routes could be viable alternatives (Davies et al., 2017; NZTA, 2014).

The disruption was further exacerbated by the fact the road and rail lines run parallel along the East Coast, which meant that the primary rail line for the South Island, the MNL, was also severely damaged and unusable for nine months (Mason & Brabhaharan, 2020). Like SH1, the MNL is a critical rail route for the South Island, moving around 1 million tonnes of freight annually (KiwiRail, 2017). However, unlike the roading network, there are no alternate rail lines between Picton and Christchurch, meaning rail freight had to be shifted to alternate transport modes. To facilitate this shift, KiwiRail's Spring Creek, CT site played a pivotal role, serving as an intermodal terminal, which enabled rail freight to be moved off trains and onto trucks (L'Hermitte et al., 2023). During the outage of the MNL, Interislander reported an 11% increase in commercial vehicle activity (trucks) (KiwiRail, 2018). The disruption to the road and network demonstrated the significance of the inter-island link between the North and South Islands (Cubrinovski et al., 2020).

However, in order to minimise the impact of shifting the total rail freight task to trucks travelling through SH7, KiwiRail set up a coastal shipping service for the impacted rail freight called "NZ Connect", which was made possible with the support of the Ports of Auckland, Lyttelton Port and shipping line ANL. The coastal service provided an alternate way of moving inter-island freight between the North and South Island through Christchurch and Auckland (Davies et al., 2017). As a result of the NZ Connect service and the damage to CentrePort, freight volumes between the Ports of Auckland and Lyttelton Port doubled to more than 1,000 additional TEU each week (Ports of Auckland, 2016). The consequence of diverting vessels to

other seaports is that there were soon knock-on implications for road transport to and from certain seaports (Herbert et al., 2018).

As for shifting rail freight to coastal shipping, the event revealed the country's limited containerisation availability (Herbert et al., 2018). For instance, container shortages resulted in firms sourcing as many containers as they could within the country and purchasing new containers from overseas (L'Hermitte et al., 2023). In short, the Kaikōura earthquake highlighted that there has never been a greater need for resilient transport, particularly when we have a growing reliance on transport networks to provide vital services (Davies et al., 2017), such as the movement of FMCGs. As disruptive as the Kaikōura earthquake was, a Cook Strait ferry terminal outage would be far greater, as unlike rail freight, which was easily shifted to coastal shipping, trucks would be more challenging, as FMCGs use curtain-side containers, as opposed to containers (L'Hermitte et al., 2023). In any case, it remains unclear how severe a Cook Strait ferry outage would be and how the subsequent disruptions would cascade through the freight system.

The fragility of the freight transport system was again demonstrated by Cyclone Gabrielle in 2023, which saw similar outages to the road and rail network. For instance, State Highway 2 (SH2) was taken out for three months, cutting off Hawkes Bay's Napier from Gisborne (Dunseath & Knell, 2023) and impacting the movement of goods in the Hawke's Bay and Gisborne regions (New Zealand Foreign Affairs & Trade, n.d.). At the same time, a section of the Palmerston North – Gisborne rail line connecting Hawkes Bay's Hastings to Napier was taken out, preventing rail access to the region's CT site, located near Napier Port (KiwiRail, 2023a). To overcome this outage, temporary CT sites were established with transport company Team Global Express and food producer Heinz Wattie's, who had facilities in Hastings with road and rail access. These sites enabled rail freight to be shifted to trucks, which could then access Napier Port by road (King, 2023; KiwiRail, 2023a).

As there is no rail line between Napier and Gisborne, and in the absence of SH2, a coastal shipping service was established to keep containers moving between Gisborne's Eastland Port and Napier Port during the three-month period. In total, the service moved 294 containers containing meat and produce (Gisborne Herald, 2023). The ability to utilise coastal shipping was made possible by domestic carrier Coastal Bulk Shipping's vessel, the Rangitata, which had been acquired under the NLTP funding in 2021 (Moffiet, 2022a). With the exception of the SH2 link between Gisborne and Napier being taken out, the impact on FMCGs was not severe, as trucks were able to continue to deliver goods by road into Napier and Hastings from supermarket distribution centres. For instance, on the first day, Woolworths moved 150 tonnes of FMCGs and 250 tonnes over the next two days (Woolworths Group, 2023a).

Both the Kaikōura earthquake and Cyclone Gabrielle demonstrated the vulnerability of the road and rail networks and the value of coastal shipping, which is increasingly viewed as an alternative emergency supply chain in the absence of road and rail networks (New Zealand Lifelines Council, 2023a). The events have also highlighted the value of a modular transport

system, where intermodal terminals provide flexibility by integrating transport modes (L'Hermitte et al., 2023).

In addition to transport infrastructure outages, distribution centres can also be taken out which puts further pressure on the transport network. For instance, the Kaikōura earthquake took out Woolworth's distribution centre in Palmerston North, impacting freight movement in the North Island as goods had to be stored elsewhere in Auckland (Herbert et al., 2018). Similarly, the 2010 Canterbury Earthquake caused extensive damage to Foodstuffs' two distribution centres (one of which has since been sold) in Christchurch and a 40% loss of goods at the Woolworths Group's distribution centres. Consequently, these damaged stores had to be replenished from the North Island (Heather & Schouten, 2010) and, by extension, through the Cook Strait ferries. Fortunately, because Foodstuffs operates a second distribution centre in Dunedin, major operations were shifted over from the Christchurch site to the alternate distribution centre in a matter of hours, followed by 24/7 operations to supply the entire South Island (Forbes & Wilson, 2018). Although this example demonstrates the value of redundancy and flexibility in the FMCG sector, it is unclear how distribution centres would replenish goods in the absence of the Cook Strait ferries, given most FMCGs originate in Auckland (Kemp et al., 2012).

#### 2.4.3 Critical infrastructure interdependencies (exacerbating factors)

In addition to the direct damage to the freight transport system, other critical infrastructures can be damaged, and because of dependencies and interdependencies, failures can ripple through freight systems (Ouyang, 2014), exacerbating the impact. For example, following Cyclone Gabrielle, electricity outages prevented the pumps at service stations from functioning, which resulted in trucks being unable to load fuel (Webb-Liddall, 2023). Electricity outages cut off access to payment systems, forcing supermarkets and service stations to close (Department of the Prime Minister and Cabinet, 2023; Gisborne District Council, 2023). At the same time, telecommunications outages made it unclear what roads were accessible, what fuel terminals were functioning, and what quantities of fuel capacity were available at the fuel terminals. Furthermore, restoring telecommunications without electricity required fuel-dependent generators (Webb-Liddall, 2023). Even when sufficient fuel was available, road outages prevented tanker trucks from accessing it (Radio New Zealand, 2023).

In other words, Cyclone Gabrielle demonstrated the interdependencies of critical infrastructure, the impact of cascading outages (Department of the Prime Minister and Cabinet, 2023), and the need for investment in resilience and infrastructure to withstand future disruptive events (Morton, 2023). Although Cyclone Gabrielle provided insight into the dependencies and interdependencies between critical infrastructure, the disaster had little impact on the movement of FMCGs.

## 2.5 Identifying the research gaps

As this chapter has shown, NZ's freight system is complex and vulnerable. Numerous dependencies and interdependencies exist between critical infrastructures, and through a combination of nodes and links, freight can be moved between the North and South Islands by the Cook Strait ferries. This overcomes imbalances between perishable and non-perishable goods in the North and South Islands and ultimately ensures goods are available in the right place, at the right time and in the right condition. At the same time, the frequency of the ferry services enables the FMCG sector to run JIT, where inventory is replenished at regular intervals from a small number of centralised distribution centres in each island. Despite the criticality of the Cook Strait ferries, there is no insight into how disruptions would cascade through the NZ freight system during an extended Cook Strait ferry outage. Moreover, it is unclear how the causal relationships between critical infrastructures would impact the movement of FMCGs following a disaster. In the absence of this information, it is unclear what freight bottlenecks may surface and how these bottlenecks could be mitigated to keep goods moving between the North and South Islands.

Therefore, this research focuses on addressing these gaps and enhancing the understanding of the impact an extended Cook Strait ferry outage would have on NZ's domestic freight system. The following research questions will be addressed in this research:

- Research question 1: How would disruptions cascade through the NZ freight system during an extended Cook Strait ferry outage?
- Research question 2: How would critical infrastructure dependencies and interdependencies impact the movement of FMCGs in NZ following a disaster?
- Research question 3: How could freight bottlenecks be mitigated to keep goods moving between the North and South Islands following an extended Cook Strait ferry outage?

Figure 16 provides an overview of the three gaps identified and how these gaps lead to the three related research questions.

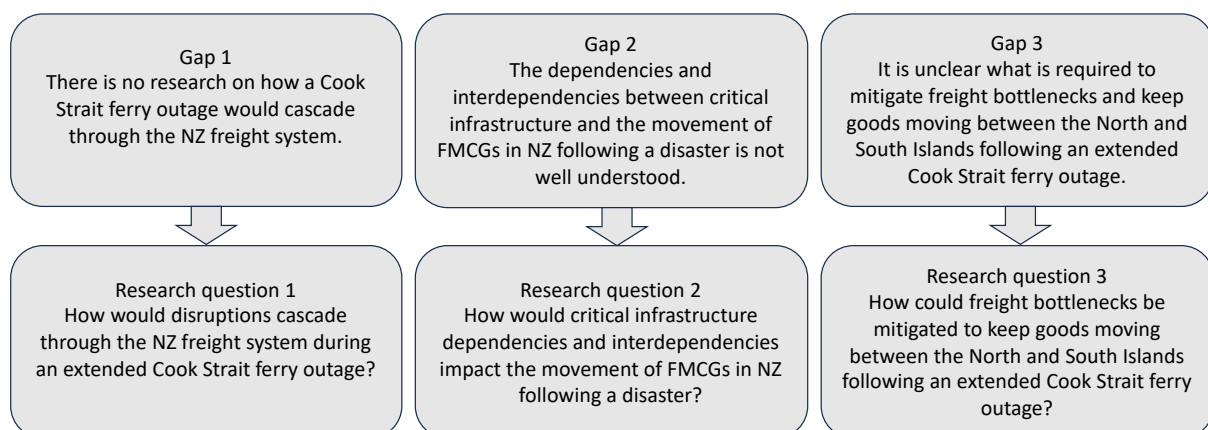


Figure 16: Research questions and gaps

## Chapter 3: Theoretical framework

*This chapter presents the set of problem-solving tools which were used to guide this research and address the three research questions by understanding what to change in the current domestic freight system and what to change to.*

### 3.1 The Theory of Constraints

The Theory of Constraints (TOC) is a multifaceted management tool introduced by Israeli physicist Dr. Eliyahu Goldratt (Mabin & Balderstone, 2000). TOC initially evolved from a software package called Optimised Production Timetables (OPT), which first emerged in the late 1970s (Goldratt, 1988; Spencer & Cox, 1995). The OPT software was developed to optimise production timetables in a manufacturing context (Goldratt, 1988). To market OPT, Goldratt illustrated the concepts in his first novel in 1984, titled "The Goal: A Process of Ongoing Improvement" (Goldratt & Cox, 1986). A second book titled "The Race" was subsequently released in 1986 to address challenges to implementing the OPT concepts, which revealed that the general concepts could be applied beyond the production floor to encompass all aspects of business (Rahman, 1998). As a result, this led to the creation of TOC, which Goldratt (1988, p. 453) defines as "an overall theory for running an organisation". The underlying concept of TOC is that every system (or organisation) has one or more dominating constraints (Mabin & Balderstone, 2000). Therefore, TOC can be applied to almost any sector and size (Şimşit et al., 2014) and is considered a general management theory (Tulasi & Rao, 2012).

#### 3.1.1 Types of constraints

According to Goldratt, a constraint is anything that prevents a system from achieving improved performance and moving towards its goal (Goldratt, 1988; Goldratt, 1990). In other words, it is the entity that will prevent a system's throughput, regardless of improvements made to any other aspect of the system (Dettmer, 2007). For example, a firm's goal may be to make more money now and in the future (Goldratt, 1990), yet unless the physical and policy constraints are addressed, the system cannot reach its goal (Dettmer, 2007). Physical constraints can comprise shortages of people, facilities and tangible resources (Dettmer, 1995), such as material and distribution capacity (Simatupang et al., 2004).

Often, most constraints in a system stem from policies, and unlike physical constraints, which are easy to identify and break, policy constraints are much more challenging to identify and break. Often, when policy constraints are removed, they result in a greater degree of system improvement, as opposed to eliminating a physical constraint. Policy constraints can result from laws, government regulations, and an organisation's rules. Although policies are initially implemented to produce a desired outcome, they can become constraints in another respect and could degrade or reduce system performance if not addressed. In this light, although physical constraints are easier to identify, removing them may not improve the system if the underlying policy constraints have not been addressed (Dettmer, 2007).

One example of this can be observed in highways, where a substantial portion is frequently under repair. Despite the issue appearing to be a physical constraint on traffic flow, the underlying issue is policy-related as government acquisition policy awards contracts to the lowest bidder, incentivising contractors to compromise on quality to remain competitive. In other words, the policy's initial intention to save costs indirectly leads to faster deterioration of the highway network. Figure 17 shows how both constraint types can be present in a system at a given time and can be interrelated. Therefore, policies must be reviewed over time and replaced or revised to support increased throughput (Dettmer, 1995).

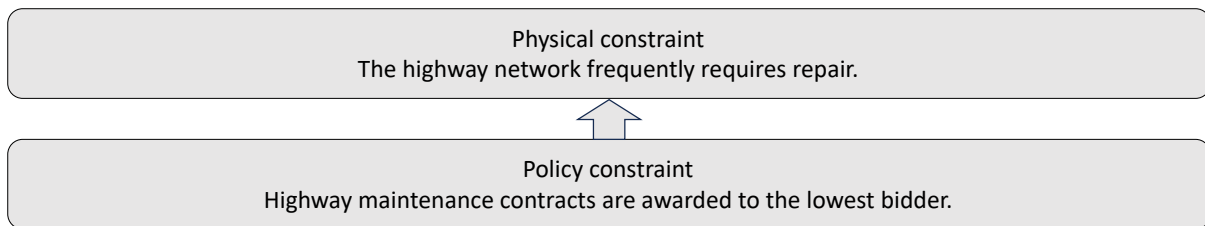


Figure 17: Example of the types of constraints

### 3.2 The Five Focusing Steps

TOC comprises two major components (Rahman, 1998). The first component is a series of five steps known as the Five Focusing Steps (5FS), which originate from Goldratt's first novel, *The Goal* (Goldratt, 1990). The 5FS can also be framed as a set of three questions expressed in the improvement process's terminology (Goldratt, 1990). Figure 18 provides an overview of the five steps, which are further explained below.

Step 1 involves identifying the system's constraint, which could be physical, policy, or both.

Step 2 explores what can be done with a physical constraint to get the most out of them without undergoing costly changes or upgrades. If the constraint is policy, it must be replaced with a revised policy to increase throughput.

Step 3 is achieved by adjusting the system to enable the maximum effectiveness of the constraint. In other words, the non-constraints are subordinated to eliminate the identified constraint. To achieve this, some non-constraints may be decreased, and others may be increased. The next step is followed if the initial constraint has yet to be eliminated. If the constraint has been eliminated instead, step 4 is skipped.

Step 4 is followed when Steps 2 and 3 were insufficient to remove the identified constraint. Elevating the constraint means beginning to take any action necessary to eliminate it. This requires exploring significant changes to the system, which can entail costly changes.

Step 5 is to return to Step 1 when the constraint has been broken in Step 3 or 4. This last step looks for the next constraint impacting the system's performance. It is important at this point not to become complacent, as there will always be more constraints to address. In other words, addressing constraints in a system is an endless cycle (Dettmer, 2007).

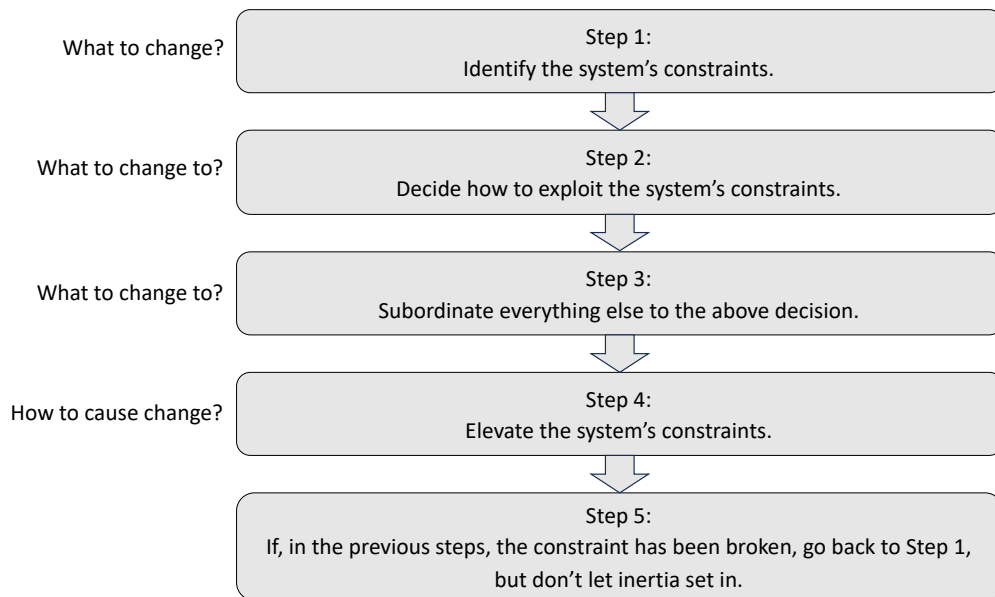


Figure 18: Diagram of the Five Focusing Steps (adapted from Goldratt, 1990)

The 5FS are best suited for dealing with physical constraints (Rahman, 1998) and can be insufficient when dealing with complex processes and the need to identify potential solutions (Şimşit et al., 2014). A second component, the Thinking Process (TP), is used in such situations.

### 3.3 The Thinking Process

The second component of TOC, the TP, is a set of problem-structuring approaches that uses five logic tools to address the questions: what to change, what to change to, and how to cause change (Mabin & Balderstone, 2000). These tools are used to identify, verbalise, challenge, or change assumptions, providing a systematic approach to finding information in situations where the data might be overwhelming or complex (Scheinkopf, 1999). The introduction of the TP broadened the scope of TOC to an organisation-wide perspective, providing a way to address behavioural and policy constraints by developing practical solutions (Dettmer, 1998; Mabin & Balderstone, 2003). The five TP tools include the Current Reality Tree (CRT), Evaporating Cloud (EC), Future Reality Tree (FRT), Transition Tree (TT) and Prerequisite Tree (PRT) (Dettmer, 1997). Although each of the five tools can be used independently, when combined, they enable a complex set of questions to be answered (Dettmer, 1997; Scheinkopf, 1999). Figure 19 provides an overview of the five TP application tools, which are elaborated on in the following subsections.

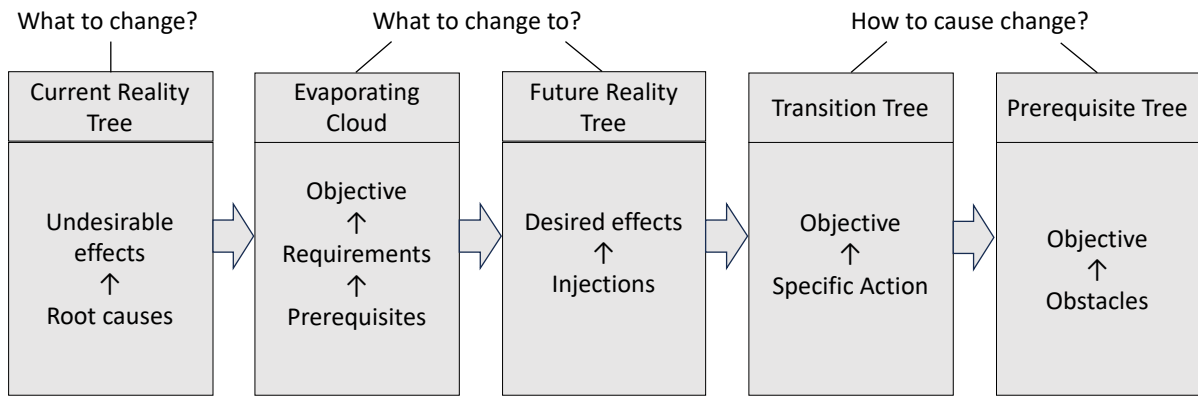


Figure 19: Diagram of the Thinking Process (adapted from Dettmer, 1997)

### 3.3.1 Current Reality Tree

The first of the five tools is the CRT, which is a logical diagram designed to make sense of complex systems. It depicts the current reality in a system and determines why the current reality differs from the ideal reality. The CRT addresses the question of *what to change?* by examining and documenting the cause-and-effect relationships logically (Dettmer, 2007; Rahman, 2002). The CRT aims to identify undesirable effects (UDEs), which are visible symptoms of an underlying issue or issues referred to as root causes. In other words, the root causes are the invisible constraints responsible for many of the system’s problems (Scheinkopf, 1999). Hence, the objective of the CRT is to identify UDEs and the causal relationships between them and to isolate what needs changing in the current system (Dettmer, 2007).

The CRT is constructed in a step-by-step manner, starting from the top-down (effect-cause), identifying the UDEs in the current system and the probable causes for those effects. Once completed, the diagram is read bottom-up (effect-cause) as “if this, then that” (Dettmer, 2007; Rahman, 2002). Figure 20 provides a simplified CRT diagram where root cause 1 is responsible for UDE1, which is causing UDE2, and both UDE1 and UDE2 are preventing the system from achieving its goal. In the context of this research, the CRT is used to create clear, detailed diagrams of the UDEs in the post-disaster domestic freight transport system, which aids in understanding the cause-and-effect relationships between entities and ultimately identifies the underlying root causes that need to be addressed.

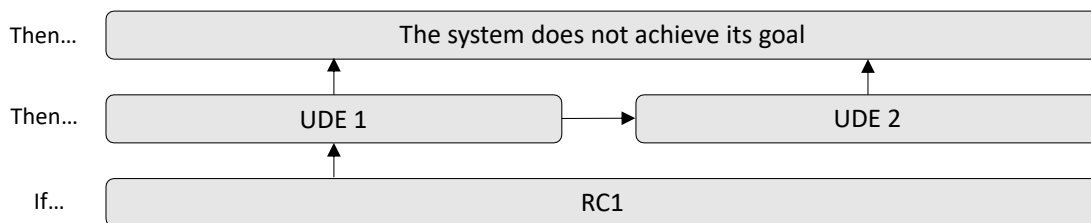


Figure 20: A simplified CRT diagram

### 3.3.2 Evaporating Clouds

Once the CRT is built, ECs are created, which are conflict resolution diagrams designed to identify and display the essential components in a conflict situation and find and explore ways to resolve it. The logic of the tool is that root causes exist due to underlying conflicts between solutions, and without these conflicts, the issue would have been resolved long ago. Therefore, as shown in Figure 21, the EC starts with the articulation of two conflicting prerequisites, one of which is the root cause, and the other is the opposite of the root cause. The prerequisites are then followed by listing the requirements each side must satisfy, and lastly, the common objective both requirements support. Once the diagram has been constructed, injections (ideas for solutions) are introduced to break the conflict between the prerequisites. Therefore, the aim of the EC is to achieve a conflict resolution where a win-win solution is identified (Dettmer, 2007; Scheinkopf, 1999). For this research, ECs are used to understand the conflict between identified root causes as they exist in the freight system and what is needed to address them. The injections proposed either come from the existing literature or from engaging with key stakeholders.

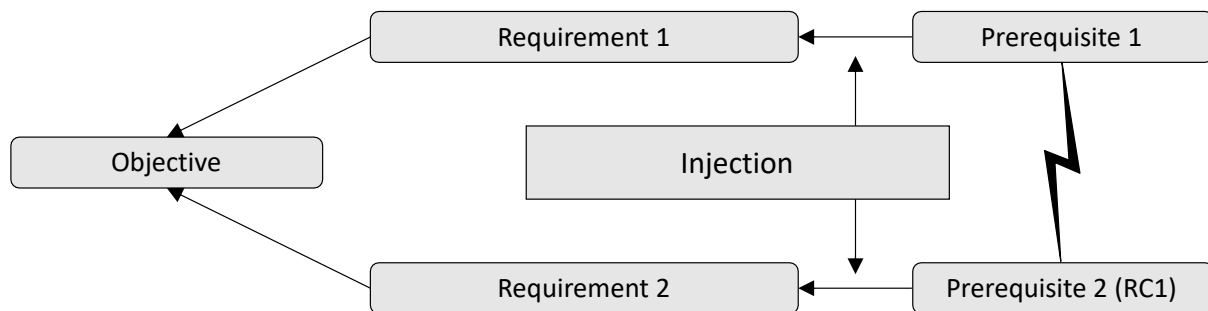


Figure 21: A simplified EC diagram

### 3.3.3 Future Reality Tree

The next step is to construct the FRT, which expresses a reality that does not yet exist. The FRT consists of creating a diagram of future cause-and-effect relationships, depicting how changes made to the current system would affect the future. The FRT enables the efficacy and validity of proposed injections to be explored before they are implemented in the real world. In other words, the FRT allows proposed courses of action to be tested before investing time, energy or resources and preventing the situation from worsening (Dettmer, 2007). Therefore, the FRT can identify any unfavourable consequences the considered injection may have and allows the opportunity to address them before moving forward.

The proposed injections come from either a preceding EC, as discussed earlier, or from elsewhere, such as the opinions of others (Scheinkopf, 1999). Because FRTs are used in complex situations, there is generally no easy fix, and multiple injections are required. In any case, the aim of introducing injections is to turn UDEs into desired effects (DEs) and ultimately to enable the system to achieve its goal (Dettmer, 2007). Figure 22 provides a simplified depiction of an FRT, where an injection identified in the earlier EC is used to address (replace) root cause 1, which changes UDE1 and UDE2 into DEs and results in the system achieving its goal.

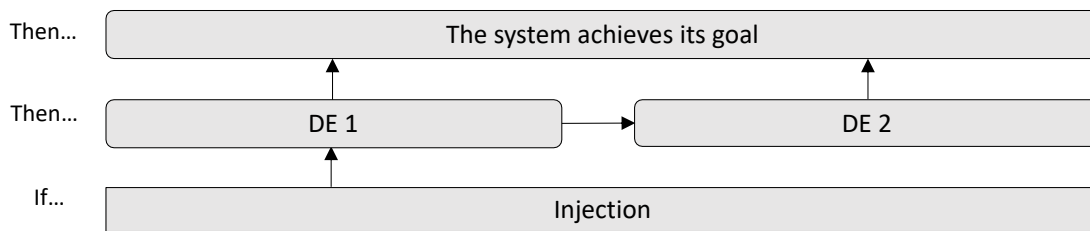


Figure 22: A simplified FRT diagram

### 3.3.4 Prerequisite Tree

Once the FRT has been completed, the PRT is constructed, which is a logical diagram designed to identify all obstacles and the responses necessary to overcome them in order to reach an objective, which is usually an injection from an FRT. Linking with the FRT, the PRT seeks to implement the decided course of action by clarifying the necessary sequence to complete the activities in implementing the decision. At the same time, it identifies implementation obstacles and alternate ways to overcome them in order to reach the objective. In short, the process consists of defining the PRT's purpose, listing the obstacles preventing the objectives from being reached, and then implementing the PRT (Dettmer, 2007).

### 3.3.5 Transition Tree

The last of the five tools, the Transition Tree (TT), provides detailed step-by-step instructions for implementing a course of action through a sequence of steps and the rationale for each step. In other words, the TT serves as a detailed road map outlining what is necessary to achieve the objective of the system (Dettmer, 2007). In short, the TT is concerned with transitioning from the current state to the future state. Therefore, the PRT and TT address the final question of *how to cause change?* through the implementation of solutions (Dettmer, 1998). Both the PRT and the TT are beyond the scope of this research, given their focus on the practical implementation of identified solutions.

## 3.4 The application of TOC in freight transport systems

Despite most research on TOC initially addressing production problems in the manufacturing sector (Rahman, 1998), the tool has been applied to other areas of business, including distribution, marketing, project management, accounting and supply chain management (Mabin & Balderstone, 2003). TOC has also been applied outside the business context, such as medical (Ronen et al., 2006), government (Scoggin et al., 2003), education (Goldratt & Weiss, 2005), military (Kohli et al., 2009) and transport (Zivaljevic, 2015). However, the application of TOC to transport systems is limited. For instance, Hranický et al. (2021) used the general theory of TOC to address railway personnel acting as a transport bottleneck. Zivaljevic (2015) used the 5FS of TOC to address the bottleneck of traffic congestion on motorways. More and Sharma (2014) also used the 5FS to improve aircraft turnaround time.

The literature on the application of TOC TP to transport is even more scarce. Patriciu et al. (2018) used all five of the TP tools to explore the benefit of using different modes of passenger transport to solve urban population challenges on transport systems. Stopka et al. (2023) used the CRT, ECs, and FRT to understand the interdependencies in manufacturing firms, optimise

the distribution route, and reduce transport costs. The only literature that uses TOC TP to make sense of post-disaster freight systems is the work of L'Hermitte et al. (forthcoming) who focus on a disruption to NZ's fresh produce sector. The research applies the CRT to make sense of the complexities involved in post-disaster freight systems (L'Hermitte et al., forthcoming). In other words, the remaining TOC TP tools have yet to be applied in post-disaster freight transport systems. Therefore, this research extends the work of L'Hermitte et al. (forthcoming) through the application of the first three TOC TP tools, the CRT, ECs and FRT.

In the context of this research, three steps were developed to address each of the research questions, which relate to the first three TOC TP tools, the CRT, ECs and FRT. By following the three steps, this research answers the TOC questions of *what to change?*, *what to change to?*, and *how to cause change?*, as shown in Figure 23. The application of each of the tools is discussed in the subsequent sections.

- Step 1: Identify the constraints in NZ's FMCG transport system resulting from an extended Cook Strait ferry outage.
- Step 2: Establish and visualise the cause-and-effect relationships between the identified constraints.
- Step 3: Identify possible solutions to mitigate FMCG transport disruptions and support timely deliveries.

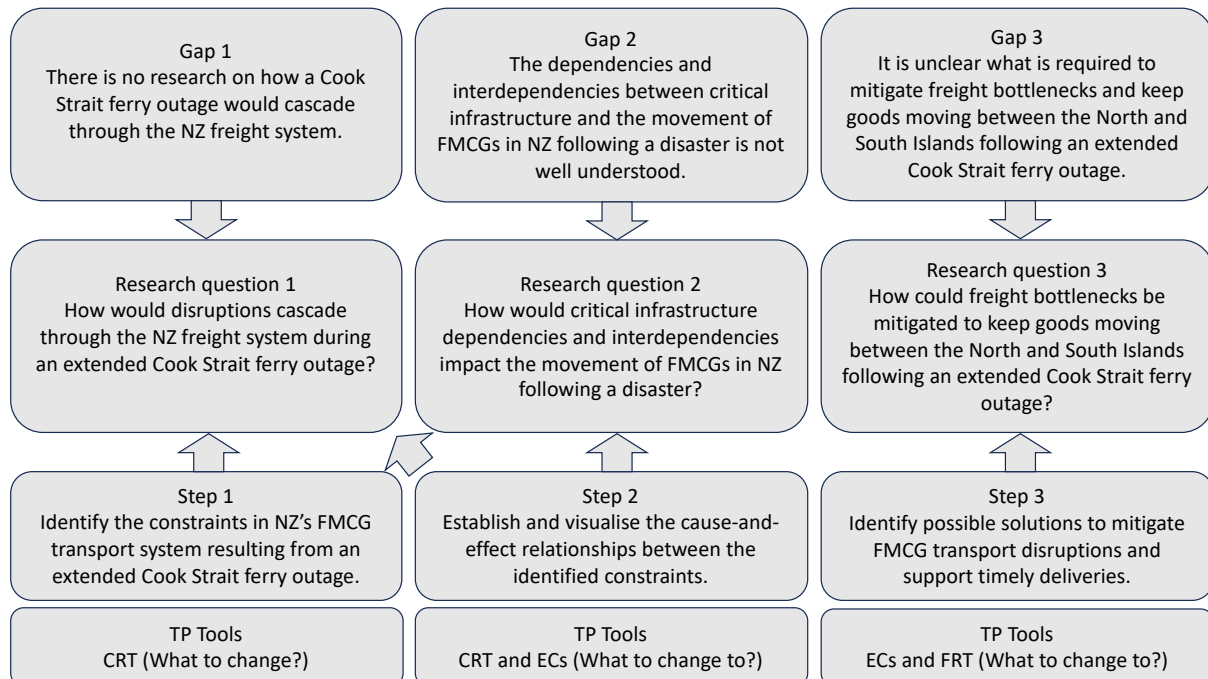


Figure 23: Steps and Thinking Process tools used to address the research questions

## Chapter 4: Research scenario

*This chapter provides an overview of the impact a Hikurangi Subduction Zone event could have on NZ's freight transport system.*

The study proposes that a Hikurangi Subduction Zone earthquake and tsunami occur, severely damaging critical infrastructure, including state highways, rail lines, seaports and the Cook Strait ferry terminals in Wellington and Picton. Research shows that a Hikurangi Subduction Zone event could be responsible for NZ's largest earthquake and tsunami (GNS Science, n.d.a). It is estimated that the earthquake would release around 45 times more energy than the 2016 Kaikōura earthquake, which took out critical road, rail and seaport infrastructure for several months (Mason & Brabhakaran, 2017). In addition to damage from the earthquake, a Hikurangi Subduction Zone event could also cause liquefaction, landslides, and fires, while waves could reach up to 20 metres in height in certain areas (GNS Science, n.d.a). Consequently, there is a high likelihood that a tsunami will occur across the Cook Strait region (Pizer et al., 2021), where the Cook Strait ferry terminals are situated. There is a 26% chance this event will take place in the next 50 years.

To better understand the impact on critical infrastructures, the scenario was based on the GNS (Geological and Nuclear Sciences Limited) Science Hikurangi Response Plan, which developed a scenario for an Mw 8.9 Hikurangi earthquake, with tsunami modelling and potential impacts (GNS Science, 2018), and work by Popovich et al. (2021) who looked at the impact on seaports. Using these publications, it was assumed that Gisborne's Eastland Port, Napier Port, and Wellingtons CentrePort would be badly impacted and unusable. The scenario proposes that Port Marlborough is also damaged and unavailable, and the outage time for all four seaports is at least three months while all other seaports remain operational. Given the proximity of CT sites to the East Coast, it is assumed that KiwiRails CT sites in Napier, Blenheim and Wellington are unavailable for at least three months. It is also likely that fuel terminals located in Napier and Wellington (elaborated on below) would fail in a Hikurangi Subduction Zone event (New Zealand Lifelines Council, 2020), which is why they are also proposed to be unavailable for the same period. Figures 24, 25 and 26 provide an overview of the available and unavailable seaports, CT sites, and fuel terminals, respectively.

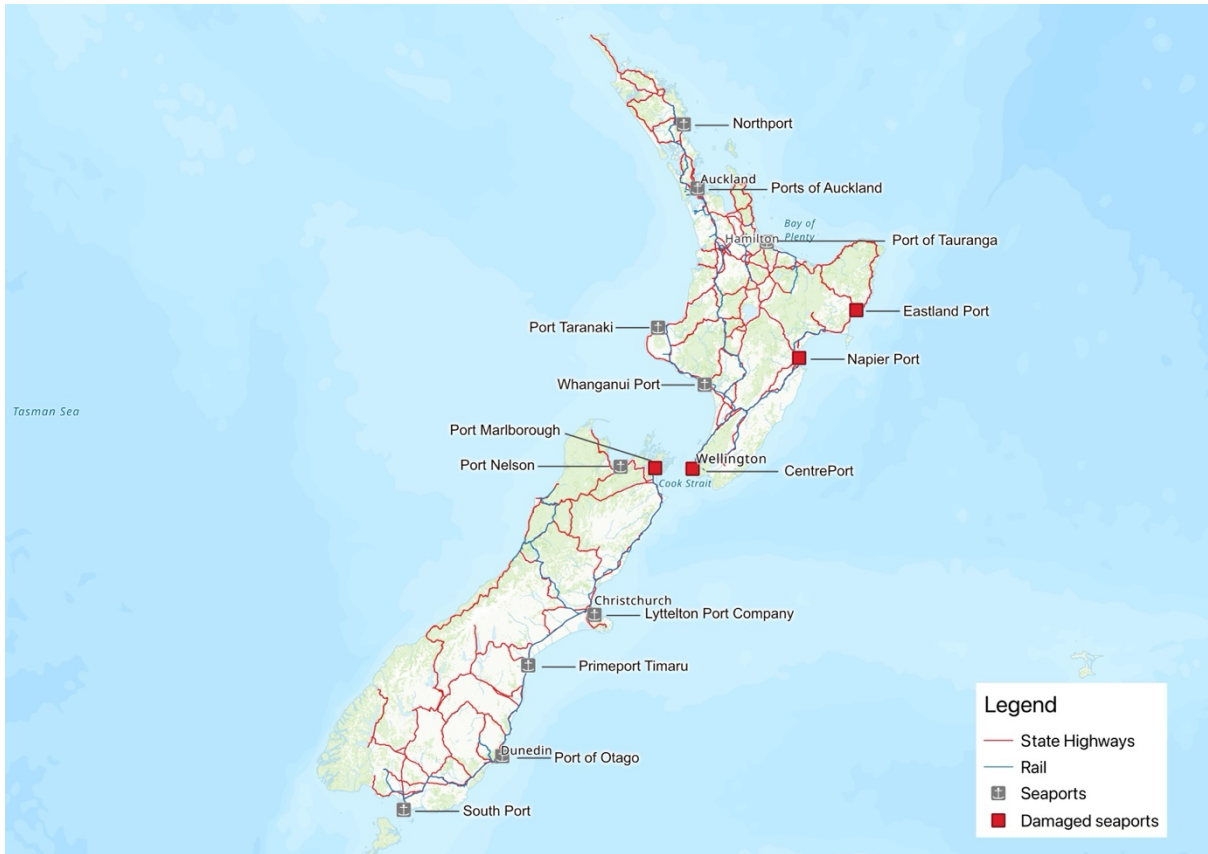


Figure 24: Map of the available and unavailable seaports



Figure 25: Map of the available and unavailable CT sites

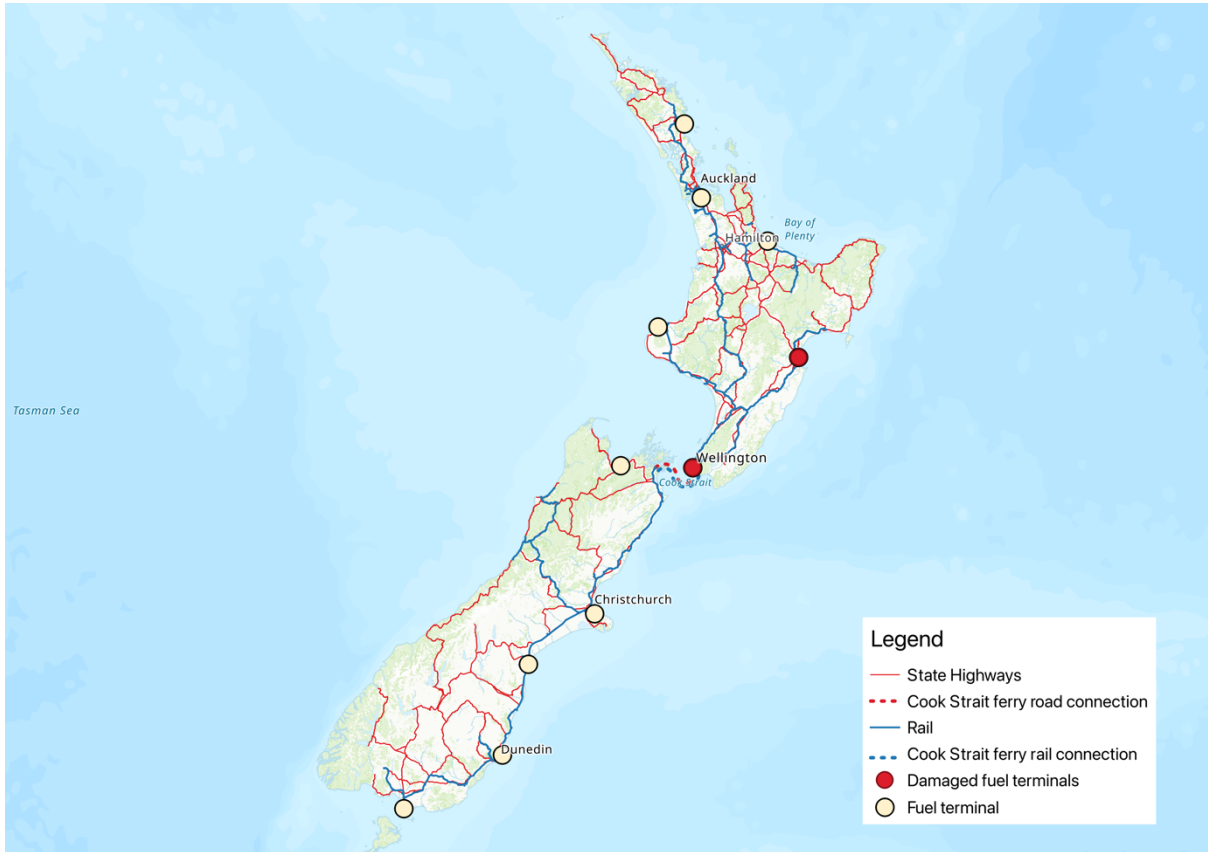


Figure 26: Map of the available and unavailable fuel terminals

The Wellington Region Emergency Management Office’s (WREMO) Project Business Case was used to understand the impact on the Wellington region better. The ferry terminals in Wellington are expected to be damaged and unavailable for three months (WREMO, 2019), and fuel terminal storage facilities are located in Seaview and Kaiwharawhara. Critical transport infrastructure around the ferry terminals, including sections of local roads, state highways, rail lines, and bridges are severely damaged and unavailable. Electricity in Wellington and Picton is unavailable for the initial two days, while communication infrastructure, including fibre, copper (internet) and cellular (phone), are unavailable for the initial five days. Throughout this scenario, it is assumed that the Cook Strait ferries will remain operational. Figure 27 provides an overview of infrastructure availability in the Wellington region, depicting the positioning of the Wellington Fault line, state highways, rail lines, fuel sites, Wellington’s CentrePort, airport, and ferry terminals. The scenario for Picton is depicted in Figure 28, which shows the status of critical infrastructure, including rail lines, state highways, and the aerodrome in Picton.



Figure 27: Map of the Wellington region in the proposed scenario



Figure 28: Map of the Picton region in the proposed scenario

The exposure to earthquakes and tsunamis results from the country's positioning to the southwest end of the Pacific Ring of Fire (Organisation for Economic Co-operation and Development & World Bank, 2019). The North Island of NZ is on the Australian plate, while the South Island is between the Australian and Pacific Plate (Campbell et al., 2012). The boundary between these plates, which runs down the east side of the North Island, is referred to as the Tonga-Kermadec Trench and Hikurangi Trough and continues through the South Island along the Hope Fault, which connects to the Alpine Fault and eventually the Puysegur Trench (Campbell et al., 2012). Of NZ's faults, the most major include the Kermadec/Taupō Volcanic Zone (which consists of the Wellington Fault), the Hikurangi Subduction Zone, the Alpine Fault and the Marlborough Fault System (which consists of the Wairau and Hope Faults) (GNS Science, n.d.b). These faults can be seen below in Figure 29.

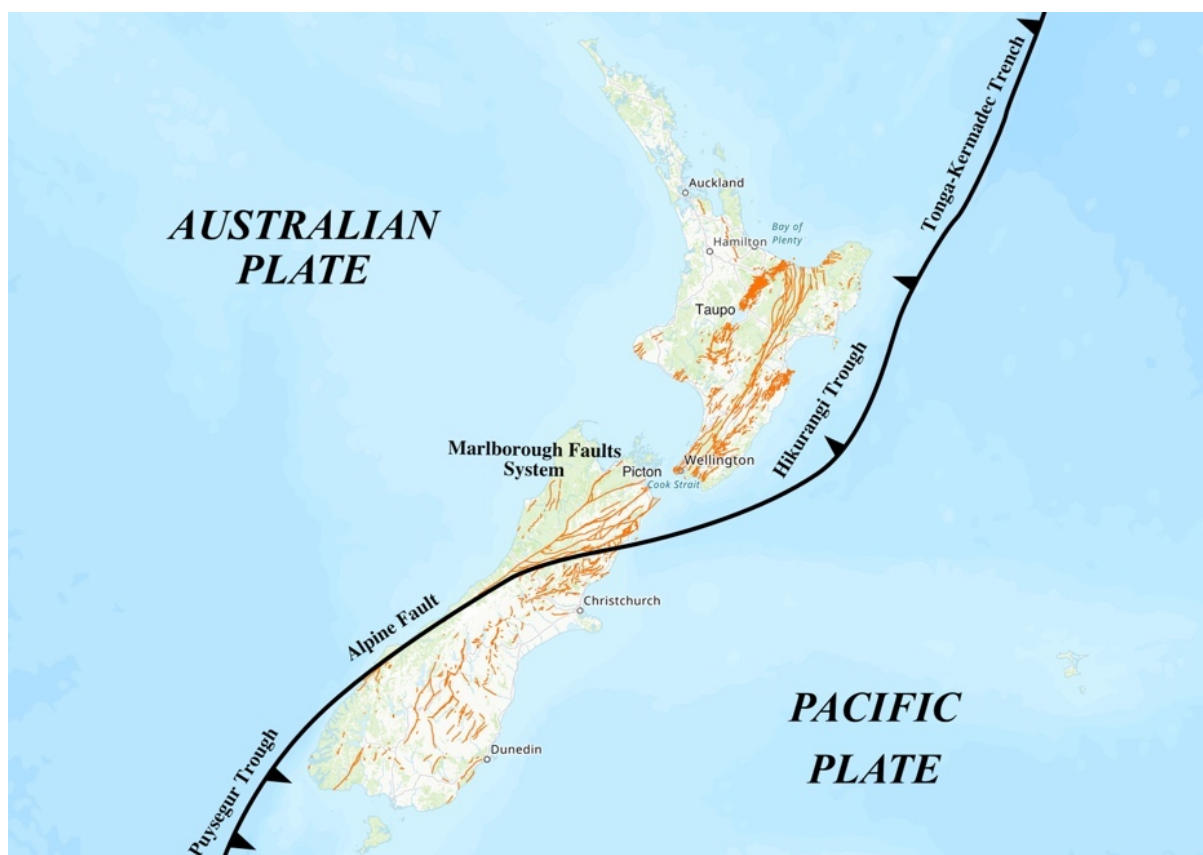


Figure 29: Map of NZ fault lines (in orange) and the plate boundary (in black). Metadata was sourced from GNS Science (n.d.)

Among the known active faults, a Hikurangi Subduction Zone event has the potential to be the largest source of earthquake and tsunami hazards in the country. Such an earthquake is expected to release about 45 times more energy than the 2016 Kaikōura earthquake. In addition to the shaking, the earthquake could cause liquefaction, landslides, and fires in some areas. It could also see the East Coast waves reaching about 10 metres above normal sea level and 20 metres in other areas (GNS Science, n.d.a). The probability of a large subduction earthquake occurring in the Hikurangi Subduction Zone within the next 50 years is 26%, with a high likelihood of a tsunami across the Cook Strait region (Pizer et al., 2021).

A rupture along the Hikurangi Subduction Zone poses the biggest threat to the Picton Area (Environmental Protection Authority, 2020). At the same time, the Marlborough region is expected to experience slips, cutting off state highway access. Like Picton, Wellington would also be impacted by a Hikurangi Subduction Zone event. It is possible that landslides following the event could block key state highways, including SH1. It is also expected that CentrePort will sustain damage and the Cook Strait ferry service will cease to operate (East Coast Lab, 2020). On a national level, modelling of an Mw 8.9 event has shown that the seaports of Eastland, Napier and Lyttelton will be among those most strongly affected, with less severe effects felt at Northport, Tauranga and Marlborough (Popovich et al., 2021).

## Chapter 5: Methodology

*This chapter discusses the research methods used to address the research questions.*

This chapter follows the structure of Saunders' research onion, which comprises six stages, starting with the philosophy and ending with the data collection and analysis (Saunders et al., 2019). Table 3 provides an overview of the subsequent subsections and the approach adopted for this research.

<b>Subsection</b>	<b>Adopted approach</b>
Research philosophy	Pragmatic constructivism
Research approach	Inductive
Research methods	Sequential exploratory
Research strategy	Applied research and scenario planning
Time horizon	Cross-sectional
Data collection	Semi-structured interviews
Data analysis	Thematic analysis

*Table 3: List of the chapters' subsections and adopted approaches*

### 5.1 Research philosophy

As the literature review highlights, post-disaster freight transport systems are complex and comprise many interdependencies, and when critical infrastructure is taken out, they become even more complicated. Because of the complexity of the research topic and its practical nature, a pragmatic constructivism philosophy was followed.

The idea of constructivism, founded by Piaget, is that humans cannot immediately understand the information they receive and instead must construct their own knowledge (Piaget & Cook, 1952). In other words, constructivism is the idea that individuals develop new understandings from their encounters in the real world (Andika et al., 2023). Expanding on this, constructivism allows for problem-based learning, inquiry and dialogues, which can help with sense-making and exposure to various information sources and opportunities that enable learners to benefit from diverse ways of understanding (Windschitl, 1999). Thus, constructivism refers to theories of knowledge and learning (Lowenthal & Muth, 2008) and is a common philosophy in qualitative research (Creswell, 1998).

On the other hand, pragmatism is the underpinning that allows and guides mixed methods researchers to adopt various approaches when answering research questions that cannot be addressed using either a qualitative or quantitative method (Doyle et al., 2016). It has been said that early pragmatists argued that pragmatic behaviour stemmed from a need to solve problems promptly with a limited understanding of the situation (Ormerod, 2021). This approach allows the collection of credible, reliable, and relevant data to address the research problem (Saunders et al., 2019). Thus, pragmatism focuses on the practical outcomes concerning what one thinks and does (Korte & Mercurio, 2017) and is commonly used to solve real-world problems (Creswell, 1998).

Gordon (2009) notes that a combination of pragmatism and constructivism, called pragmatic constructivism, can allow each philosophy to inform and influence one another, as constructivism's educational aspect can connect with pragmatism's practicality. In the context of this research, a pragmatic constructivism approach was undertaken, where the constructivist component was used to leverage participants' unique knowledge, which has been built from their experience as practitioners in the industry. This is then complimented by the constructivist component, which starts with a real-world problem (a Cook Strait ferry outage) and then explores practical solutions to inform future decision-making (minimising the disruption to FMCGs).

## 5.2 Research approach

An inductive approach was followed as it seeks to establish a theory based on observations and findings, as opposed to deductive, which starts with existing theory to shape the approach to the data analysis. The purpose of an inductive approach is to allow meanings to emerge from the data as they are collected, uncovering patterns and relationships, which are then used to build a theory (Saunders et al., 2019). For this research, an inductive approach was deemed most appropriate as the data from key stakeholders were leveraged to understand better the impact of an extended Cook Strait ferry outage on FMCG movement. Further details on the research approach are discussed in the data analysis section.

## 5.3 Research methods

For this research, an exploratory approach was undertaken, which can be defined as a way to find out what is happening and seek new insights, especially in situations that are little understood (Robson, 2002). Undertaking this approach made the most sense, given the research gaps and the limited understanding of an extended Cook Strait ferry outage. In particular, a sequential exploratory approach was undertaken, as shown in Figure 30, which is commonly associated with pragmatism (Nastasi et al., 2010), as it provides pragmatic advantages when exploring complex research questions (Driscoll et al., 2007). The approach generally starts with a qualitative data collection phase, followed by a quantitative phase (Creswell & Plano Clark, 2017). The qualitative component aims to examine rich, complex data and explore the interconnections of the data (Meyer & Avery, 2009), while the quantitative component offers complementary insight (Driscoll et al., 2007; Rahman, 2020). In other words, this approach enables qualitative findings to be expanded on using quantitative details (John & Creswell, 2017).

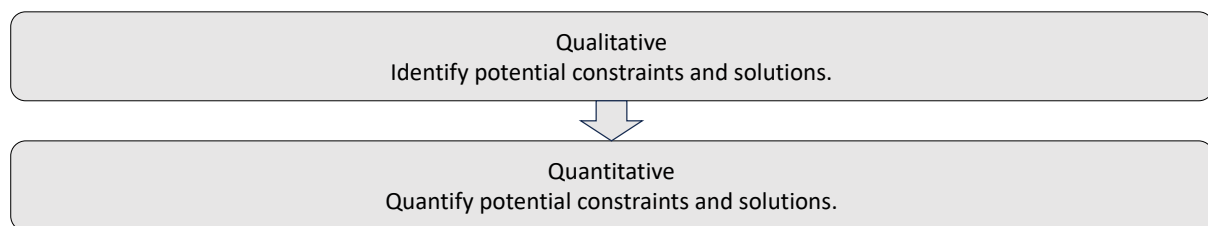


Figure 30: Diagram of the sequential exploratory approach

In the context of this research, semi-structured interviews were used to collect qualitative data and to identify potential constraints and solutions following an extended Cook Strait ferry outage. To complement these insights, quantitative details were subsequently collected and applied to quantify these constraints and solutions, such as the demand and capacity available, thereby addressing questions around how many, how much, and to what extent (Rasinger, 2013). Combining the two methods results in greater breadth and depth (Leydens et al., 2004), enabling the generation of rich, nuanced knowledge, which can provide opportunities to achieve greater insight and understanding than would otherwise be possible had a qualitative or quantitative approach been taken on its own (Krivokapic-Skoko & O'Neill, 2011). Moreover, this approach allows researchers to comprehensively understand a complex phenomenon (Taguchi, 2018), which, in the research context, offers an enhanced understanding of the impact on freight movement and post-disaster transport systems.

## 5.4 Research strategy

### 5.4.1 Applied research

An applied approach was deemed the best strategy to guide the research systematically. Unlike basic research, which seeks to generate universal knowledge that anyone can use, applied research often provides a complementary approach by applying existing basic knowledge to solve complex real-world problems through evidence and thinking (Baimyrzaeva, 2018). Although the primary outcome of applied research is to solve problems through evidence, new knowledge can be generated from the process (Dolnicar, 2020). Applied research starts with the practical need for an informed decision to be made in the real world, which requires action (Lens, 1987). From this need, the strategy seeks to improve the understanding of a specific problem and contribute to the solution of that problem (Hedrick et al., 1993). In other words, applied research can help holistically make sense of an area (Oxburgh et al., 2011). Given the complex nature of post-disaster systems and the need to make sense of a real-world problem (an extended Cook Strait ferry outage), an applied research approach was adopted.

### 5.4.2 Scenario planning

One way to explore the usefulness of applied research further is through scenario planning (Enfors et al., 2008), which has been defined as “a process of positing several informed, plausible and imagined alternative future environments in which decisions about the future may be played out, changing current thinking, improving decision making, enhancing individual and organisational learning and improving performance” (Chermack & Lynham, 2002, p. 16). Put simply, scenario planning can help ‘make sense’ of complex future uncertainties (Van Reedt Dortland et al., 2014) by capturing the richness and range of possibilities, enabling decision-makers to explore changes they otherwise may have ignored (Schoemaker, 1995).

The primary advantage of scenario planning is that it enables potential future states to be explored so that organisations can generate strategies to reduce risk, capitalise on opportunities or avoid risk (Cordova-Pozo & Rouwette, 2023; Varum & Melo, 2010). Further, it creates narratives for different possibilities that are easy to grasp and aims to challenge existing

assumptions (Schoemaker, 1995). Therefore, in the context of this research, scenario planning was undertaken to make sense of the constraints in NZ's freight system following an extended Cook Strait ferry outage and to explore potential solutions to these challenges.

## 5.5 Time horizon

Considering time constraints, a cross-sectional time horizon was selected, which provides a snapshot of a particular phenomenon or phenomena at a given time (Saunders et al., 2019). In the context of this research, the snapshot relates to the sequence of events following a Hikurangi subduction Zone earthquake and tsunami that takes out the Cook Strait ferry terminals.

## 5.6 Data collection

Purposive sampling was used for the data collection, which is defined as a non-probability sampling technique commonly used in qualitative research as it seeks to deliberately include participants based on specific characteristics deemed appropriate for the research focus (Etikan et al., 2016). Moreover, purposive sampling enables an in-depth study of information-rich cases by focusing on relatively small sample sizes rather than empirical generalisations (Patton, 2002). Additionally, snowball sampling was used where additional participants were obtained from information provided by the initial participants (Saunders et al., 2019). Heckathorn (2011) describes the initial subjects in the snowball sampling method as "seeds" that can produce waves. For example, wave one participants are recruited through the seed, which then recruits wave two subjects, growing in size each time.

Generally speaking, there is an optimal sample size for qualitative research, as having a sample that is too small can result in the inability to detect crucial effects, while having a sample that is too large can be a waste of resources. Thus, determining an optimum sample size is essential in any type of research (Noordzij et al., 2011). When collecting qualitative data from participants, the intent is to reach the point of saturation (Guest et al., 2006). Saturation is reached when no new or appropriate insight comes from a category, the category is well developed, and the categories' relationships are established and validated (Strauss & Corbin, 1998). In qualitative research, saturation is typically reached when between 20 and 30 interviews occur (Marshall et al., 2013). As mentioned earlier, this research follows an exploratory approach, where qualitative data was collected through interviews. More specifically, the interviews were semi-structured, starting with several predefined themes and key questions relating to those themes to help guide the interviews, enabling each theme to be systematically explored with each interview (Saunders et al., 2019). Using semi-structured interviews, the complexity could be captured conversationally while allowing for follow-up questions and clarification.

In the context of this research, 60 potential participants were identified using publicly available information and suggestions from supervisors. These potential participants fell into seven sectors: seaports, emergency responders, transport operators, transport users, ferry operators, government officials and industry representatives. The questions developed for the interviews were open-ended, enabling participants to provide answers in their own words (Fink, 2015),

meaning that new ideas and questions could surface during the interview (Harding, 2019) and ultimately provide insight into what would happen (Saunders et al., 2019). The open-ended questions ranged from 14 to 15 and were tailored for each of the seven sectors. At times, these questions were further refined for the specific interview participant. As shown in Figure 31, a systematic approach was taken when developing the interview questions, which aided in addressing the TOC questions, *what to change?*, and *what to change to?* First, participants were asked about the present environment, which relates to their responsibilities and the movement of goods during business as usual. Next, they were asked about the impact of past disruptions and how these disruptions were overcome. The remaining questions were around the future, which sought to understand the impact of an extended Cook Strait ferry outage, what is necessary to overcome the outage, and how the resilience of NZ’s wider transport network can be improved. Table 4 provides an overview of the questions presented to transport users.

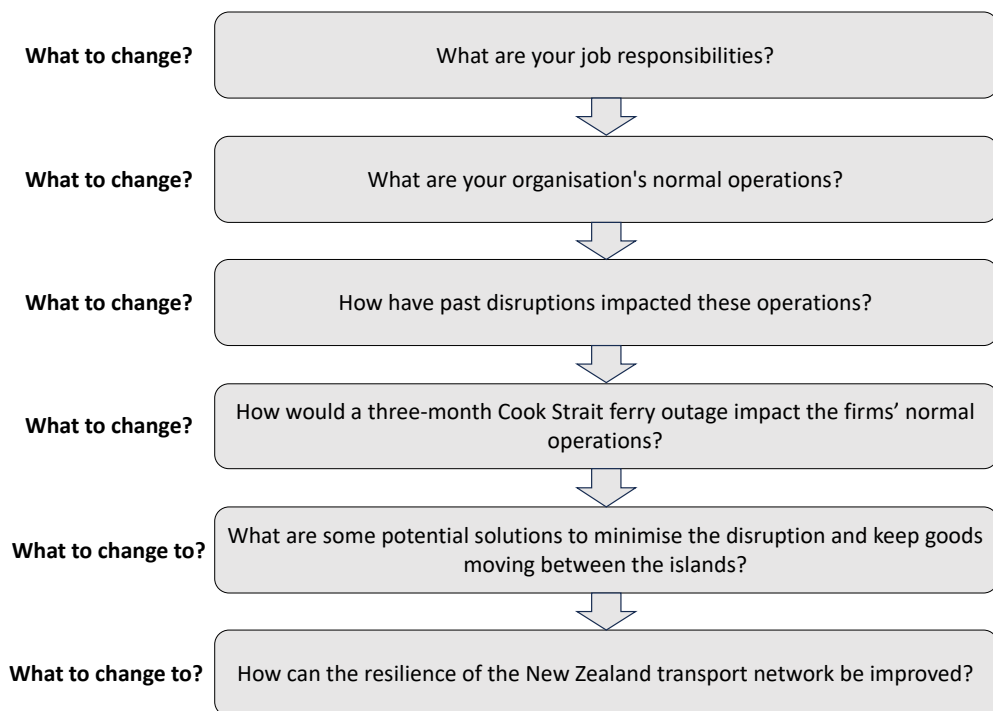


Figure 31: Structure used to develop the interview questions

<b>Transport users' questions.</b>	
1. Respondent	
a.	What are your job responsibilities?
2. Normal operations	
a.	Can you describe your normal FMCG transport operations between the North and South Islands?
3. Past disruptions	
a.	How did past natural events disrupt your transport operations, and how were these disruptions addressed?
b.	What was your role in these events?
c.	How did this impact FMCG distribution?
d.	What did you and your team learn from these events?
4. Cook Strait ferry outage	
a.	How would a three-month Cook Strait ferry outage impact your operations?
b.	What transport-related consequences would a two-day power outage and five-day phone and internet outage in Wellington and Picton have?
c.	What transport-related shortages would surface during an extended Cook Strait ferry outage?
d.	What would be the weakest point(s) in NZ's freight system during an extended Cook Strait ferry outage, and why?
5. Potential solutions to keep goods moving between the North and South Islands.	
a.	How would freight transport operations need to be adjusted to keep goods moving during the three-month ferry outage?
b.	What alternative transport modes would be used to continue moving goods between the North and South Islands?
c.	What information would you need to quickly adjust your freight transport operations?
d.	What support would you need to minimise the impact of an extended Cook Strait ferry outage?
6. Resilience	
a.	Do you think the resilience of NZ's transport network should be improved, and if so, how?

*Table 4: Transport users' questions*

Once the interview questions had been finalised, an information sheet (see Appendix 1) and consent form were made to outline the research and inform participants of what was required of them and their rights. An email template was also created to invite participants to participate in the research. These documents were then submitted to the Research Ethics Committee of the Waikato Management School for ethics approval in August 2023, and ethics approval was granted one week later.

The 60 potential participants were contacted by email or phone upon receiving ethics approval between October 2023 and December 2023. Among those contacted, 30 participants agreed to be interviewed, spanning 26 interviews, reaching a point of saturation. Out of the 30 interviewees, 12 were identified through established contacts with supervisors, 10 through publicly available information, four through snowball sampling, and the remaining four were colleagues of interviewees. Moreover, 23 of these interviews were conducted with one participant, two with two participants, and one with three participants.

As shown in Figure 32, the participants interviewed comprised five transport users (consumer goods organisations), seven transport operators (road, rail, sea and air), two ferry operators, three government officials (central government), four industry representatives (road, sea and air), four seaport operators, and one emergency agency. Participants' roles included managers (i.e., supply chain managers, general managers, operations managers), directors, and executives. Five of these interviews were conducted face-to-face in Wellington, and the remaining 21 were conducted online through conferencing software, Teams or Zoom. The interviews ranged from 35 to 67 minutes, with an average of 50 minutes. All interviews were audio recorded with the participant’s consent and professionally transcribed afterwards to ensure accuracy. Each interview was then assigned a code according to the industry they represent and the interview sequence, as shown in Table 5.

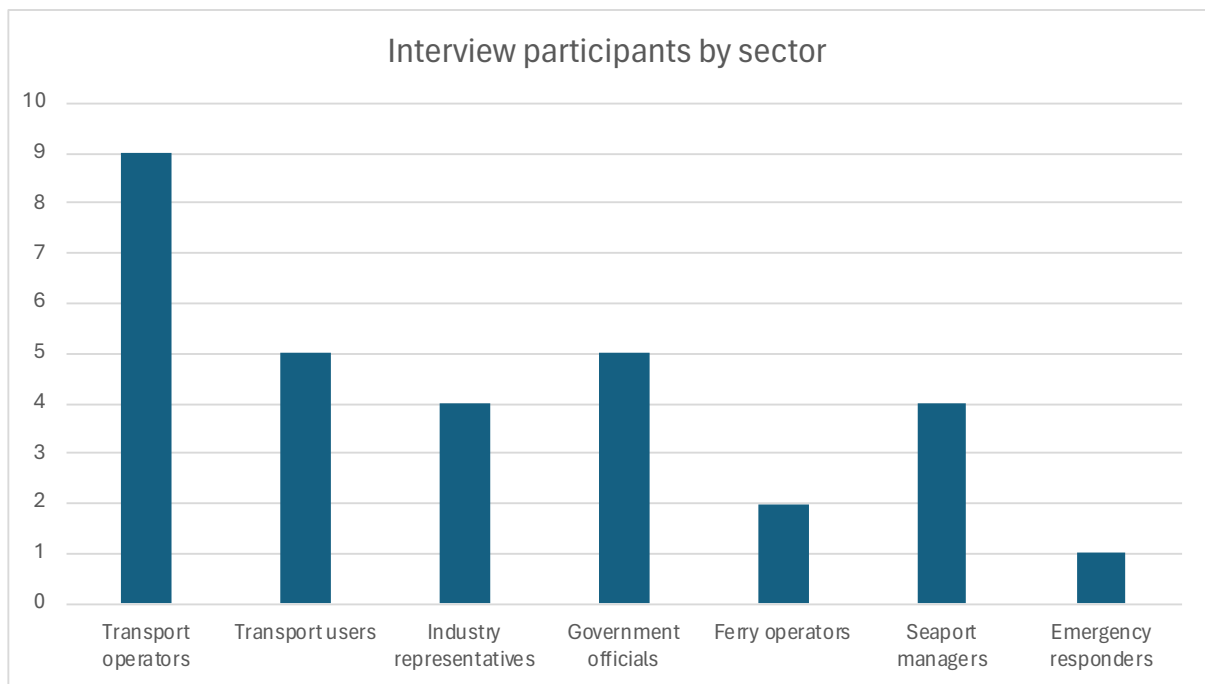


Figure 32: Interview participants by sector

<b>Code</b>	<b>Participant</b>	<b>Position</b>	<b>Date</b>	<b>Duration (minutes)</b>
TO1	Transport operator	Branch manager	13/10/2023	52
TO2	Transport operator	Chief executive officer	16/10/2023	59
TO3	Transport operators (x3)	General manager, National operations manager, South Island manager	16/10/2023	53
TO4	Transport operator	Executive general manager	17/10/2023	46
TU1	Transport user	Supply chain development manager	17/10/2023	50
IR1	Industry representative	Chief executive officer	18/10/2023	64
IR2	Industry representative	Transport consultant	18/10/2023	50
GO1	Government officials (x2)	Supply chain team, Resilience and security team	19/10/2023	54
FO1	Ferry operator	Executive general manager	19/10/2023	57
FO2	Ferry operator	Marine projects	19/10/2023	50
TU2	Transport user	Regional supply chain manager	17/10/2023	35
GO2	Government officials (x2)	Team lead, Systems resilience	01/11/2023	53
TU3	Transport user	Head of transport	02/11/2023	54
GO3	Government official	Lead advisor for resilience	03/11/2023	47
TO5	Transport operator	Line manager	06/11/2023	44
IR3	Industry representative	Policy director	06/11/2023	60
TU4	Transport user	General manager supply chain	08/11/2023	52
TU5	Transport user	General manager logistics	09/11/2023	37
PO1	Seaport manager	Chief executive officer	15/11/2023	55
TO6	Transport operator	Global head of cargo strategy	15/11/2023	57
TO7	Transport operator	General manager	22/11/2023	38
PO2	Seaport manager	Port operations manager	22/11/2023	45
IR4	Industry representative	Executive director	23/11/2023	67
ER1	Emergency agency	Team leader infrastructure resilience	29/11/2023	36
PO3	Seaport manager	Head of operational capability	5/12/2023	56
PO4	Seaport manager	Head of commercial	11/12/2023	35

Table 5: Interviewee details

## 5.7 Data analysis

Once the qualitative data had been collected and transcribed, it was thematically analysed, which, as Braun & Clarke (2006) note, is an analysis method used to identify, analyse and report patterns (themes) in the data. As mentioned earlier, an inductive approach allowed the themes to emerge from the data. These themes are seen as analytic outputs constructed from the coding process (Braun & Clarke, 2019). The thematic analysis approach is seen as interpretive. It should result in not just a description of the data but also arguments about how the data addresses the research question(s) (Byrne, 2022). In the context of this research, a reflexive thematic analysis approach was taken, which comprises six phases (Braun et al., 2023):

1. Familiarisation (with the data)
2. Coding
3. Initial theme generation
4. Reviewing and developing themes
5. Refining, defining and naming themes
6. Producing the report

This approach provides a valuable way of examining the differing perspectives of participants, highlighting similarities and differences and generating unanticipated insights. Moreover, the approach enables key features in the data to be summarised and, due to the structure of the steps, ensures the results are clear and organised (King, 2004). Therefore, the approach goes beyond describing the data to interpreting it, requiring more involvement and contribution from the researcher (Staller, 2015). In this research, data analysis software NVivo 14 was used for the thematic analysis process and to generate a codebook showing the key themes identified from the qualitative data. The themes identified comprise the data required to respond effectively and the impact on FMCG operations, critical infrastructures, and transport modes. A colour scheme was also chosen to differentiate each category and aid in visualising the TP tools. Table 6 provides an overview of the code book, including the categories, their definition and colours. These colours are used to differentiate each of the nine themes and are used throughout the remainder of the thesis when depicting the different types of constraints and events that may surface following a Hikurangi Subduction Zone earthquake and tsunami.

Themes and codes	Definition
<b>Electricity</b>	
Electricity dependent services	Services that require electricity to function.
<b>Telecommunications</b>	
Telecommunications dependent services	Services that require telecommunications networks to operate.
<b>Fuel</b>	
Fuel infrastructure	The storage and distribution of fuel.
<b>Data</b>	
Required information	The insight and systems needed following a major disruption.
Compatibility	The ability for systems to work together, particularly between different users and organisations.
<b>FMCG operations</b>	
Characteristics	Properties and requirements unique to the type of freight.
Prioritisation and restrictions	The management of critical freight.
Seasonal variations	Changes in the demand for freight throughout the year.
<b>Road</b>	
Road infrastructure	The current state and availability of roading infrastructure.
Road carrying capacity	The amount of freight that can be carried by road transport.
Road capacity	The number of vehicles that can operate on roads.
Road resources	The equipment and labour required for road transport.
<b>Rail</b>	
Rail infrastructure	The current state and availability of rail infrastructure.
Rail resources	The equipment and labour required for rail transport.
<b>Air</b>	
Airport handling and storage capacity	The available capacity of airport aprons and runways.
Aircraft carrying capacity	The amount of freight that can be carried on an aircraft.
Airfreight resources	The equipment and labour required in air transport.
Rail and road to air shift.	The ability of aircraft to absorb rail and road freight.
<b>Sea</b>	
Seaport infrastructure	The current state and availability of seaport infrastructure.
Seaport handling and storage capacity	The available capacity of yard and berth capacity at seaports.
Vessel carrying capacity	The available capacity of vessels and the amount of freight which can be carried.
Maritime resources	The equipment and labour required for sea transport.
Rail and road to sea shift	The ability for coastal shipping to absorb rail and road freight.

Table 6: Codebook from the qualitative data

Quantitative details were incorporated by using a study on the Cook Strait ferries, which estimated the lane-metres (lane-m) (a measure of vehicle deck space capable of accommodating wheeled vehicles, with one lane-m being 1m long and 2m wide) sold for FY19 (Fiscal year 2019) (Stone et al., 2023). Using this as a baseline, participants provided additional quantitative details, which were used to understand how many trucks and TEU worth of rail wagons were moved during FY19. By using the estimated lane-m sold in conjunction with the number of units moved for the same period, a nominal vehicle length of 16 metres was obtained. In addition, stakeholder engagement with an FMCG company provided insight into the estimated number of TEUs required to absorb the freight typically moved by two types of trucks.

### 5.7.1 Theory of Constraints Thinking Process design conventions

The CRT and FRT diagrams were constructed using the typical conventions, as shown in Figure 33 and further explained below (Scheinkopf, 1999). In addition to the typical conventions, the colour schemes from the code book were used to differentiate the types of entities in the system (i.e., orange relates to electricity, and light green relates to FMCG operations).

- Round-edged boxes depict entities that exist in the system, which can be a cause, an effect, or both.
- Arrows depict a relationship between two entities, where the arrow's tail represents the cause and the head the effect.
- Square-edged boxes depict entities that do not yet exist in the system referred to as injections (solutions).
- Ellipses represent the “and-connector”, which depicts an effect that can only exist when two or more causes (entities) are combined.
- Entry points occur when there is no arrow pointing to the entity.
  - Entry points depicted with round-cornered boxes represent entities that are assumed to exist in the current reality. As these entities are entry points, they are root causes, and to help with visualisation, they are outlined with a red border.
  - Entry points depicted with square corners represent entities that do not yet exist in the current reality, referred to as injections. These are outlined in green for short-term solutions, blue for work underway, and purple for long-term solutions.

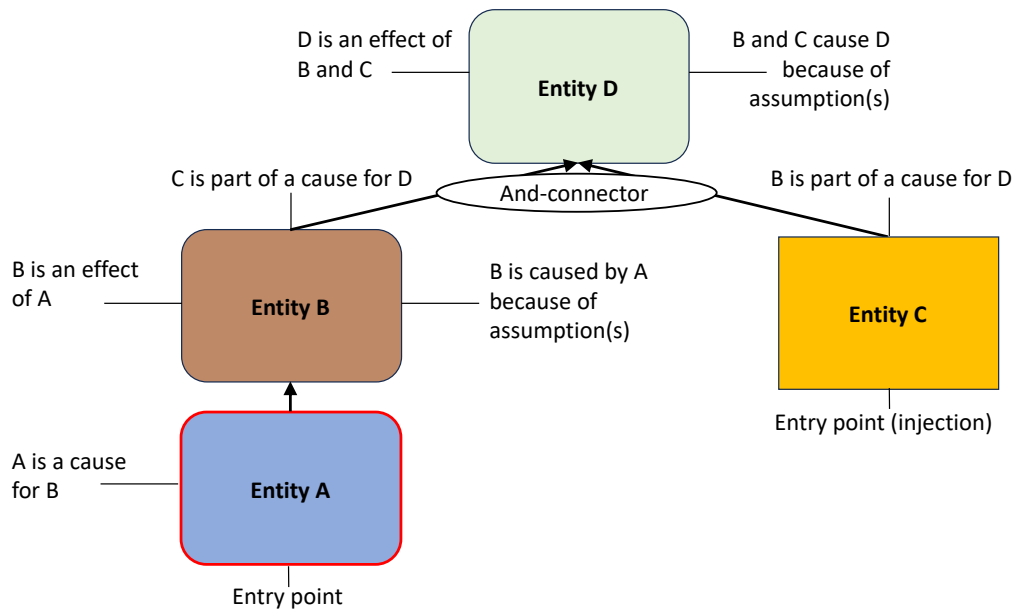


Figure 33: Theory of Constraints Thinking process design convention (adapted from Scheinkopf, 1999)

### 5.7.2 Building the Current Reality Tree

As mentioned earlier, the CRT is used to make sense of complex systems by creating a diagram of the current reality in a system, which is then used to determine why the current reality differs from the ideal reality (Dettmer, 2007). When constructing the CRT, six major stages were followed as suggested by Scheinkopf (1999):

#### Stage 1: Determine the scope of the analysis

The first stage was achieved by defining the system, its purpose, and the system's fundamental measurements (Scheinkopf, 1999).

##### System

- NZ's inter-island domestic freight system.

##### Purpose

- Enables the movement of FMCGs between the North and South Islands.

##### Measurements

- FMCGs arriving in the right place, at the right time, and for the right price can measure the degree to which the system achieves its purpose.

#### Stage 2: List between 5 and 10 UDEs

The second stage was addressed by finding evidence in the data that the current system is misaligned with its purpose. In other words, the interview transcripts were used to understand how an extended Cook Strat ferry outage would impact FMCG movement between the North and South Islands. As the TOC literature suggests, entities were written out in full sentences in

the present tense (Dettmer, 2007). The initial five UDEs identified in the interview transcripts are as follows:

1. The ferry terminals are damaged and unavailable for three months.
2. The ferries are re-routed to other seaports.
3. Additional fuel is required.
4. The time to move FMCGs increases.
5. Deliveries are delayed.

Stage 3: Diagram the effect-cause-effect relationships that exist among the UDEs

To understand the relationships between the UDEs, the categories of legitimate reservation were followed, which are a series of tests used to validate cause-and-effect relationships in a tree (Scheinkopf, 1999). Figure 34 and Figure 35 provide an overview of these tests. The first test performed was entity existence, which is used to ensure the entity truly exists in the system. Both entities were deemed to exist in the system, as the cause comes from the proposed scenario, while the effect comes from the data. Once this test was completed, causality existence was performed to determine that there is a cause-and-effect relationship between two entities. It was deemed that there was a logical connection between the cause and effect. A clarity test was then used, where the entity was written out as a clear, unambiguous statement based on quotes from participants.

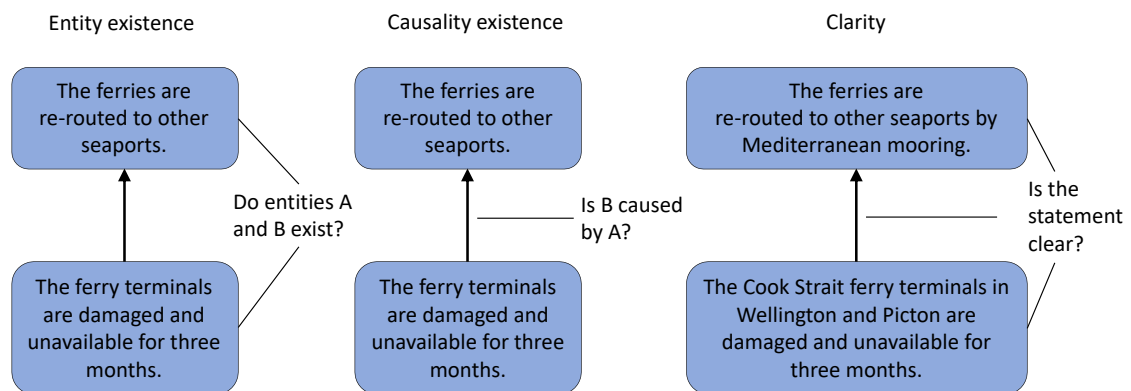


Figure 34: Categories of legitimate reservation part 1

Once these tests were completed, an additional cause test was conducted to see if there were additional causes responsible for the same effect. An insufficient cause test was used to identify where an effect could only exist when one or more causes were present, and a predicted effect test determined if there were any other effects as a result of an identified cause. As shown in Figure 35, the insufficient cause test revealed that there was a second cause responsible for the effect.

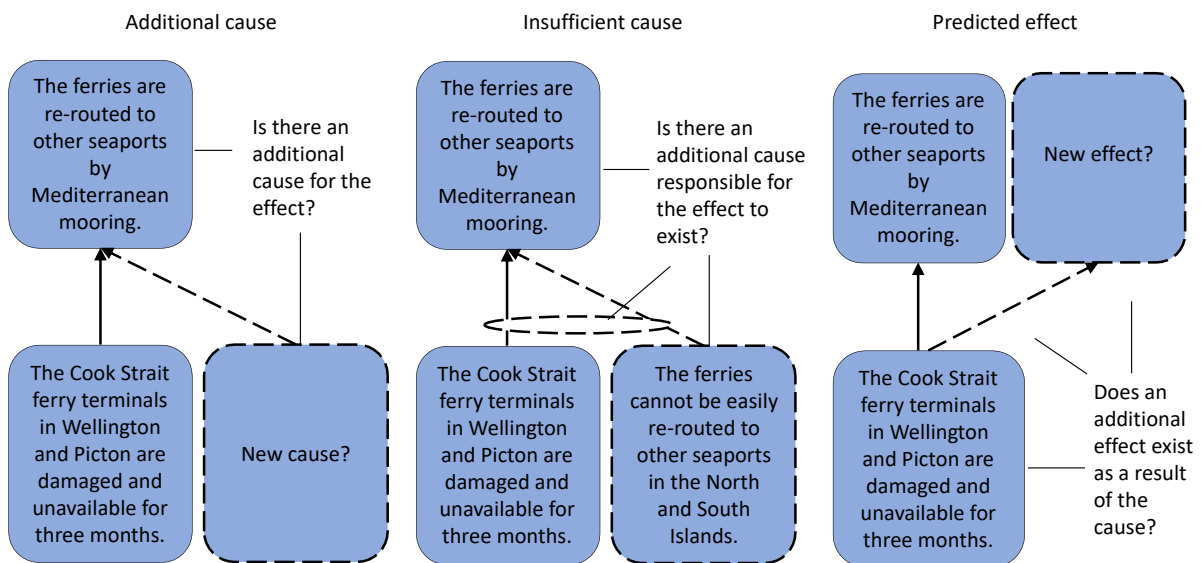


Figure 35: Categories of legitimate reservation part 2

Using the categories of legitimate reservation, all five of the initial UDEs were eventually revised and connected, as shown in Figure 36.

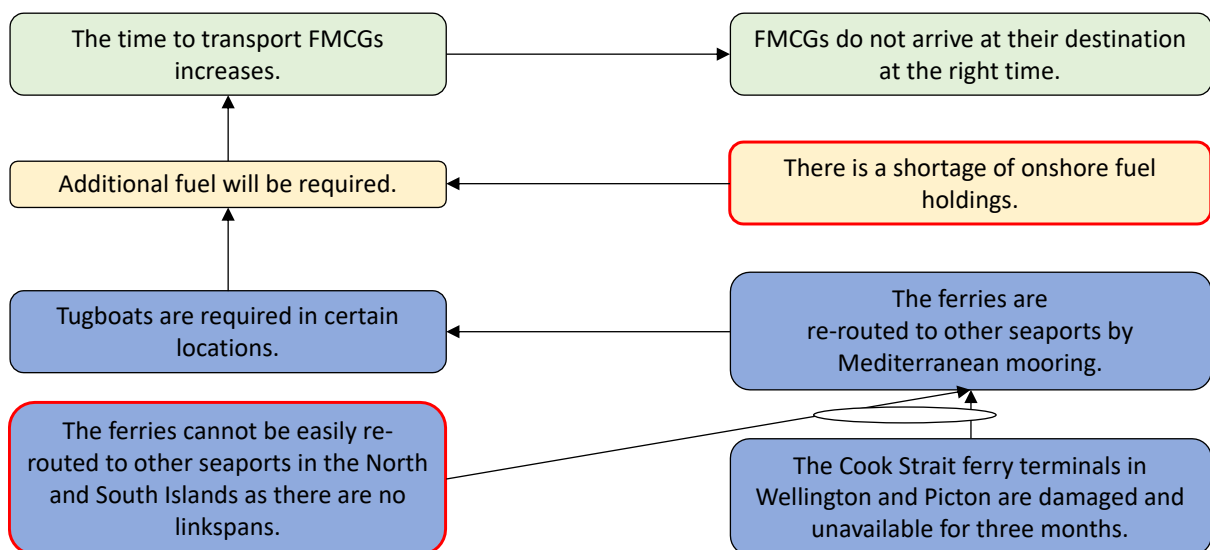


Figure 36: Applying the categories of legitimate reservation to the initial UDEs

#### Stage 4: Review and revise for clarity and completeness.

Over time, new UDEs were introduced into the CRT as the interview data was coded, and the categories of legitimate reservation were applied to understand the relationships between entities. Oftentimes, relationships between entities were not stated in the data, and instead, the connection between entities was established later using “if [cause]... then [effect]” statements (Scheinkopf, 1999). For example, tugboats and fuel shortages were mentioned as constraints by different participants. When applying cause and effect logic, the relationships were added. For example, if *tugboats are required*, then *additional fuel will be needed in certain locations*.

In other instances, as shown in Figure 36, an ellipse was added to represent when an entity can only exist when two entities are combined. In this case, the ferries are re-routed to other seaports by Mediterranean mooring because there are no linkspans at other seaports, and the existing terminals (linkspans) are damaged and unavailable.

#### Stage 5. Apply the “so what” test.

Once the CRT had been constructed, the “so what” test was applied, which requires entities to be viewed as though they relate only to the system itself and not to other entities (Scheinkopf, 1999). To apply the test, the following question was asked:

*If this entity was not caused by its purported cause(s), and if it was not causing the entities it was supposed to have caused, would I want to remove it from the system? Is it undesirable by its own merit or simply because it exists?*

Addressing this question ensures all UDEs in the CRT are relevant to the system. For example, an initial entity, “curtain-sider trucks cannot handle containers”, did not pass the test, as it is not undesirable by its own merit, as curtain-sider trucks are designed for accessible access to the goods being carried. In this instance, the entity was removed from the CRT.

#### Stage 6: Identify the root cause(s).

Scheinkopf (1999) suggests finding the root cause that is responsible for more than 80% of the UDEs in the system. In the context of this research, none of the root causes are responsible for this many UDEs. The reason for this is that although a Hikurangi Subduction Zone earthquake and tsunami is a root cause, it is beyond anyone’s control. Therefore, the CRT was used to identify the root causes responsible for the majority of the UDEs. Of which, the inability to easily re-route the Cook Strait ferries is the most significant root cause. Importantly, it is not necessary to include every underlying potential cause in the CRT but rather to ensure the most relevant ones are included for whom the tree is being built (Dettmer, 2007). Figure 37 provides an overview of the primary root cause identified.

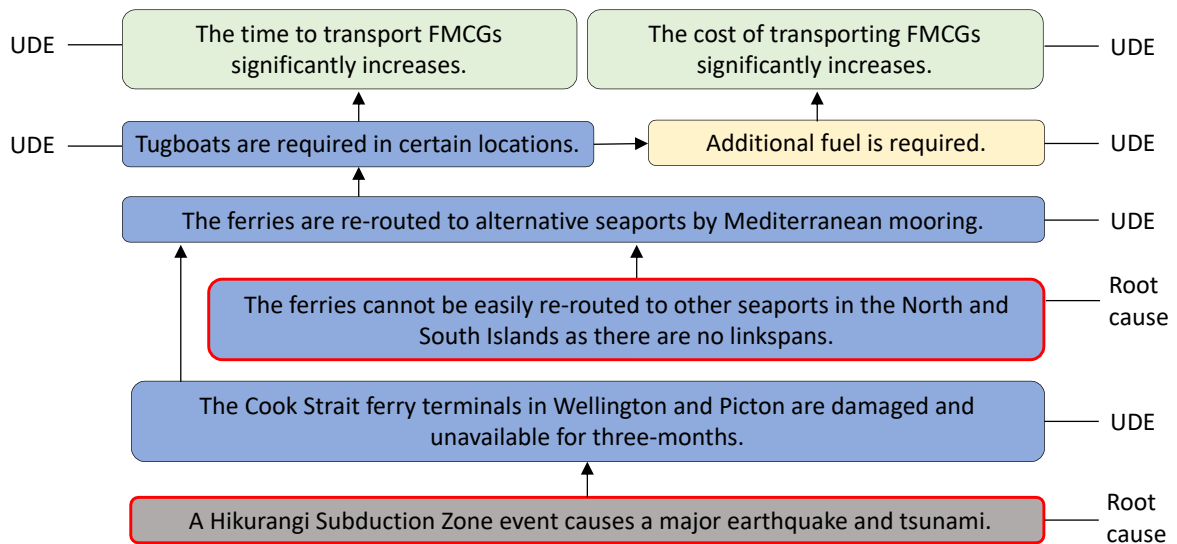


Figure 37: Applying the initial UDEs to a simplified CRT diagram

### 5.7.3 Building the Evaporating Clouds

Once the CRT was built, ECs were constructed according to Scheinkopf (1999) three steps. First, the problem was articulated, often originating from the interview data. Then, the problem was diagrammed as the five entities shown in Figure 38 below. In the example, the root cause and the injection both come from the interview data. As the example shows, (A) requires (B) and (C) to exist, which require (D) and (D') to exist. However, (D) and (D') are conflicting and cannot coexist.

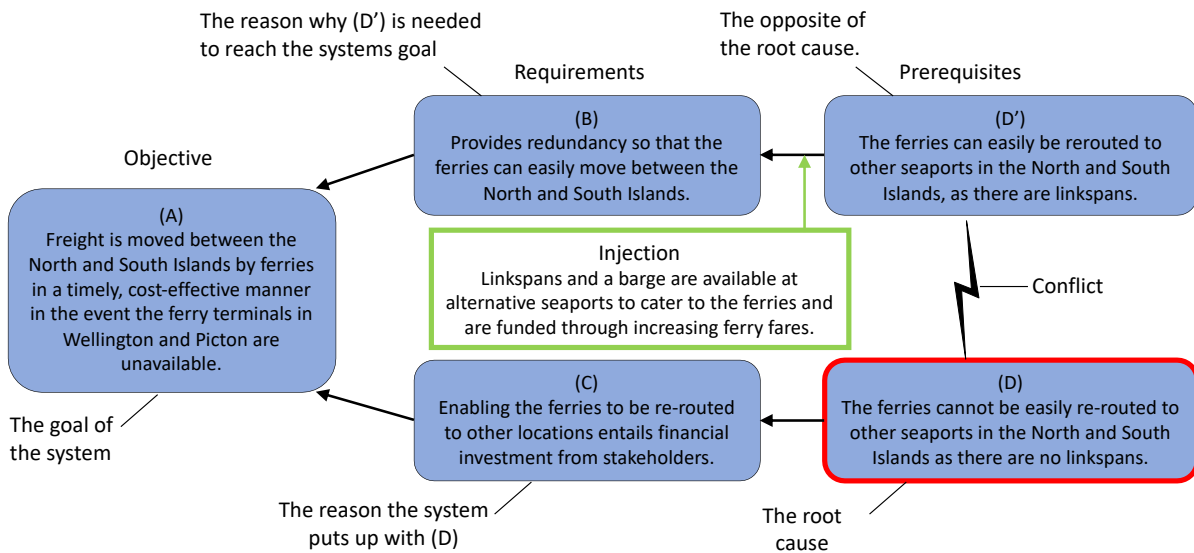


Figure 38: Applying the initial UDEs to a simplified EC diagram

Second, the assumptions for each arrow in the EC were uncovered. For the creation of the EC in Figure 38, these assumptions were as follows: It is assumed that the ferries cannot be both easily re-routed to other seaports (D') and easily re-routed to other seaports (D). If the ferries can be easily re-routed (D'), it is assumed that this would provide redundancy so that the ferries can move easily between the North and South Islands (B). The reason the ferries cannot be easily re-routed (D) is assumed to be the result of an unwillingness from stakeholders to invest

in the necessary infrastructure, as it entails a financial burden (C). Conversely, it is assumed that if the ferries can be easily re-routed (D), it provides a level of redundancy when moving between the North and South Islands (B). In order for freight to be moved between the North and South Islands by ferries in a timely, cost-effective manner (A), it is assumed the ferries would need to be easily re-routed (B) while also not causing a financial burden to stakeholders (C).

Lastly, an injection was selected to eliminate the conflict (evaporate the cloud) and replace the root cause. To achieve this, both requirements need to be met in order to reach the objective. As interviewees noted, a backup linkspan is required to easily re-route the ferries and to overcome the reluctance from an individual stakeholder to take on the financial burden. It was suggested that a ferry company purchase the asset and increase the cost of moving freight to recoup the investment. All ECs used in this research can be found in the discussion section.

### 5.7.4 Building the Future Reality Tree

The third and final tool in this research, the FRT, starts from either the injections developed in ECs or from suggestions from others (Scheinkopf, 1999), which in the case of this research were suggestions from key stakeholders. Typically, the injection is used to address the primary root cause, thus forming the basis of the tree (Dettmer, 2007). However, as there is no solution to preventing a Hikurangi Subduction Zone earthquake and tsunami, the basis of the tree stems from the subsequent root causes. When first developing the FRT, the basis of the tree started with the fact that alternative seaports do not have linkspans and a barge to cater for the ferries. Once the injections were identified, the categories of legitimate reservation were applied to test the injection for validity (Scheinkopf, 1999) before it was added to the FRT. Injections were only added to the tree when they would address the root cause and turn the UDE into a DE so that the objective could be reached (Dettmer, 2007).

For instance, as shown in Figure 39, the injection passed the categories of legitimate reservation and was then added as it addresses the root cause (Alternative seaports do not have linkspans and a barge to cater for the ferries). As a consequence of addressing the root cause, the preceding UDE becomes a DE, as the ferries are now able to be re-routed to alternate seaports without the need for Mediterranean mooring (as had been the case before).

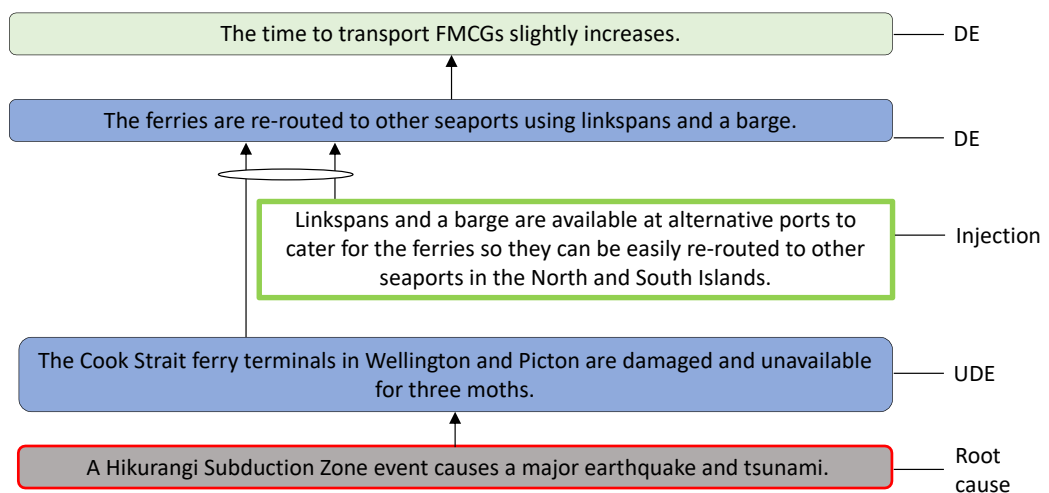


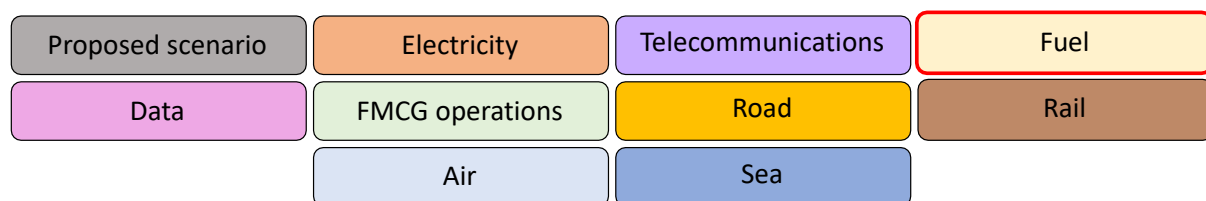
Figure 39: Applying the initial UDEs to a simplified FRT diagram

## Chapter 6: Findings

*This chapter presents the key findings from the qualitative data, supplemented with quantitative details, which resulted in the construction of CRT and suggestions for the future, thereby addressing the questions of what to change? and what to change to?*

### 6.1 Structure of findings chapter

As shown in Figure 40, the colour schemes from the code book were used to categorise entities. The entities (categories) include the proposed scenario (the Hikurangi Subduction Zone earthquake and tsunami), the data required to respond to the disruption, the impact on FMCG operations, critical infrastructures, and transport modes. In instances where one of the entities was deemed to be a root cause, it is outlined in a red border (as shown with fuel in the below example). As mentioned earlier, each interviewee was assigned a code to represent the industry. The industry groups include transport users (TU), transport operators (TO), ferry operators (FO), port operators (PO), industry representatives (IR), government officials (GO) and an emergency responder (ER). These codes are then followed by the sequence of the interview, such as TO1, which represents the first interview conducted with an interviewee or interviewees from the transport operator.



*Figure 40: Types of categories identified in the qualitative data and the identification of root causes*

The subsequent sections are structured around the narrative provided by interviewees. Direct quotations were used to make the findings easier to understand and more credible (Côté & Turgeon, 2005) and are commonly used in qualitative research (Arnold & Lane, 2011). At the end of each subsection, a snippet of the CRT is included, representing the UDEs and causal relationships mentioned by interviewees. This is then followed by the proposed solution(s) (injections), which are used to create the ECs used in the FRT in Chapter 7. As shown in Figure 41, this chapter addresses the first research question through the development of the CRT and begins to address the second question through the suggestions for injections. At the end of this chapter, the final CRT, a primary research output, is provided, detailing the cause-and-effect relationships of each constraint. In other words, the snippets only display a section of the current reality.

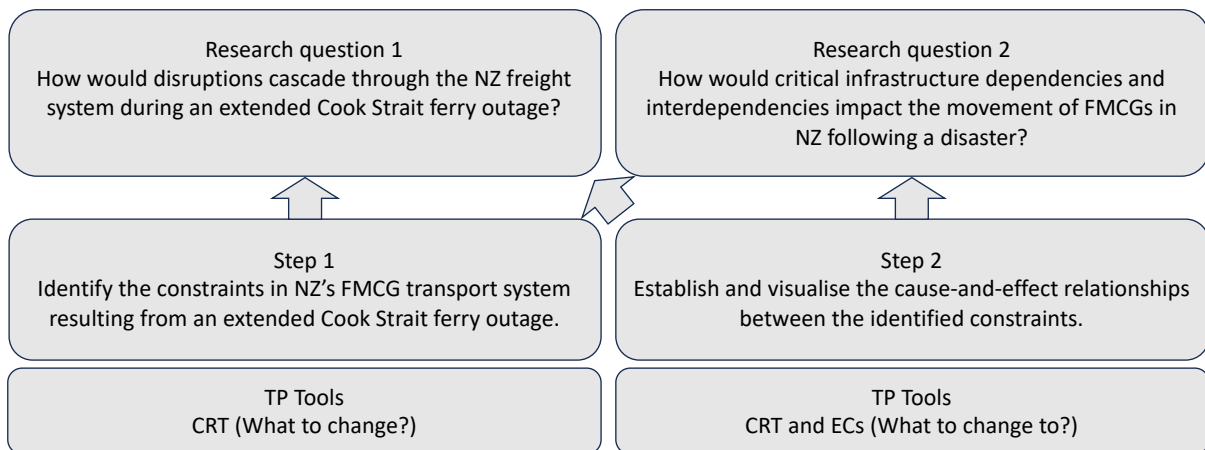


Figure 41: Addressing research questions 1 and 2

## 6.2 Proposed scenario

As mentioned earlier, the proposed scenario is that a Hikurangi Subduction Zone earthquake and tsunami occurs, and critical infrastructure is badly damaged and unavailable in and around Wellington and Picton. As shown in Figure 42, six initial UDEs were proposed to surface in the scenario, which include outages to infrastructures including electricity and telecommunications, fuel, roads and rail lines and the Cook Strait ferry terminals. The subsequent sections stem from these six critical infrastructure failures. Although the Hikurangi event is a root cause responsible for many constraints, it is a natural hazard that cannot be controlled. Therefore, this section focuses on the impacts stemming from each of the six UDEs.

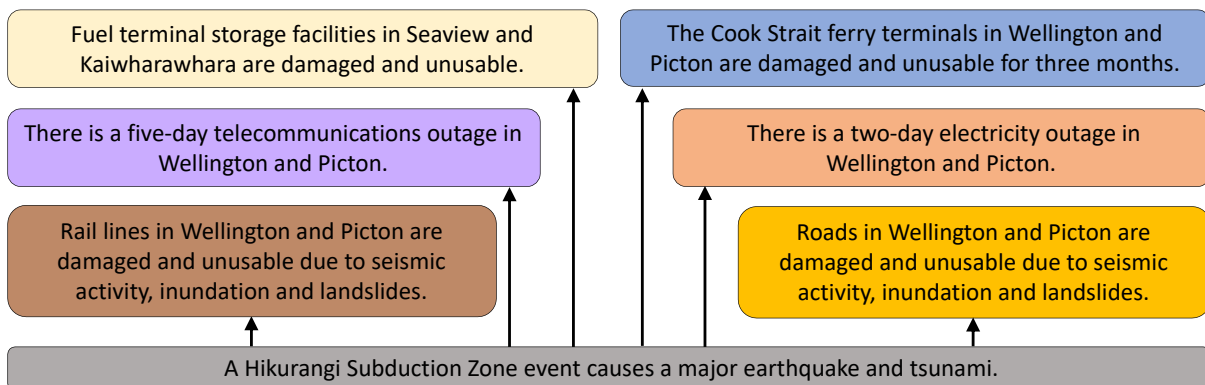


Figure 42: CRT snippet of the proposed scenario constraints

## 6.3 Electricity

### 6.3.1 Electricity outage

Without electricity in Wellington and Picton, electronic booking and logistics systems would be unusable, reducing the frequency of the ferry services and disrupting FMCG movement. “We would maybe only be able to do one return sailing per day because everything would be manually processed [...]. Or we would go twice a day, but we may not be as full as we could be because customers did not know whether [we are operating] or not. So [...] people would turn up, and we would truck them on and off” (FO2). As a result, goods would not arrive at their destination at the right place: “The consequences would be hesitation, loss of value of

perishables, and a bit of chaos on the network as people were trying to make best guesses as to what the alternate solutions should be. So, you would probably see quite long queues [...] at both ends” (GO3). Adding to the disruption is that electricity outages would cause outages to other critical infrastructure, as evidenced by recent natural hazards: “Power and all that was out and everything was cash” (TO1). “Service stations did not go [...], no EFTPOS” (IR1). In other words, without backup electricity, Eftpos systems would be offline, and trucks would only be able to load fuel with cash.

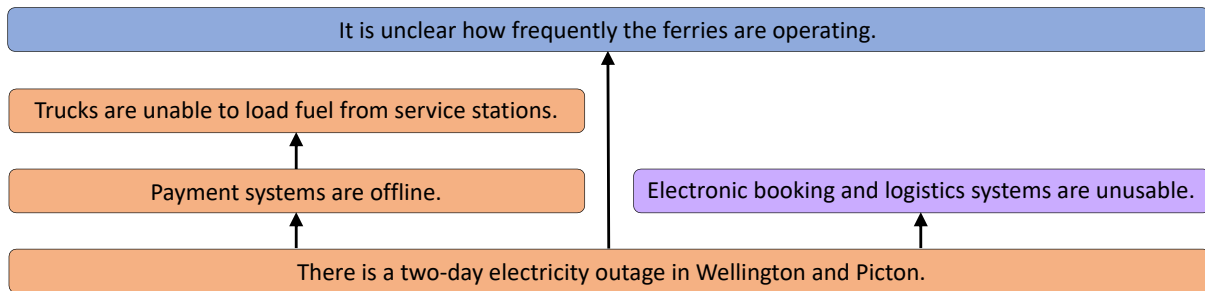


Figure 43: CRT snippet for electricity

## 6.4 Telecommunications

### 6.4.1 Telecommunications outage

With a telecommunications outage, certain organisations have backup procedures in place, enabling them to switch over to manual processes. “Communication will be more difficult, and it might be a little bit slower. But essentially most of our stuff’s paperless anyway” (TO1). “We have got a system that could enable customers still to send freight [...] albeit it would be a bit manual” (TO2). In other words, the process would be less efficient. “We are back to doing stuff with bits of paper and that those bits of paper can be produced in Christchurch and Auckland for the drivers to carry with them” (TU4). However, it is likely that not all organisations sending freight would have such manual processes in place in such an outage. “Whether customers could manage their own warehouse management systems to pump out the volume of freight they normally would, that is another question” (TO2).

For organisations that do not have backup processes, there would be a reduction in the number of goods being transported: “[If ] we could not book anything [...] five days would be as bad as three months from an impact point of view because the produce that is coming, especially from the South Island north, would just have to stay on the South Island. We would have to be literally rerouting trucks back to, probably to Christchurch, maybe Dunedin, [...] Nelson” (TU3). “The key impact for us would be lower demand. We would have a whole lot of customers in Wellington that would normally give us freight [...] would probably not have the ability to generate freight” (TO2). In other words, if fewer goods are moving, there will eventually be shortages of goods on shelves as they are not arriving at their destination at the right time. The outage would be further exacerbated by the inability to contact staff in the affected regions: “[There would be] a lot of trouble contacting staff, our Wellington-based staff” (TO3). Looking ahead, one way to reduce this disruption is through satellite internet, which would overcome terrestrial telecommunication infrastructure outages (i.e., fibre, copper

and cellular). “[One NZ] are going to establish Starlink as a matter of course. So maybe they will overcome temporary outages” (IR2).

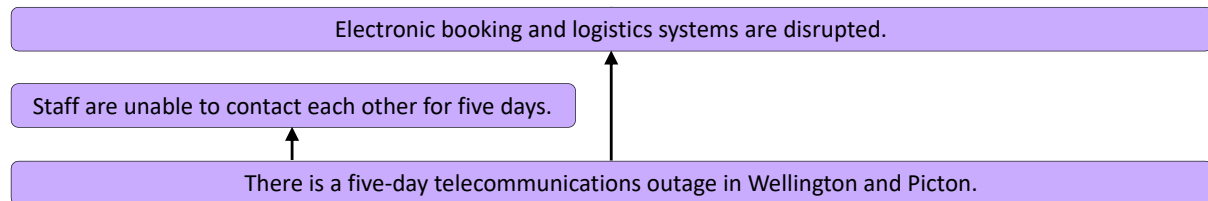


Figure 44: CRT snippet for telecommunications

### Suggestion for future reality (injection)

#### Acquire Starlink terminals:

Satellite internet, such as Starlink would overcome outages to terrestrial telecommunication infrastructure (i.e., fibre, copper and cellular) and could be a feasible backup or alternative telecommunication option for a number of organisations.

## 6.5 Fuel

### 6.5.1 Fuel outage

The interviewees acknowledged the vulnerability of fuel infrastructure in the Kaiwharawhara suburb of Wellington, which is aged and lacks resilience. “All the fuel on Aotea wharf comes from those World War II tanks sitting up Ngaio Gorge” (FO1). “[The] Cook Strait ferries [...] refuel in Wellington off some pipes and tanks, and if there was a rupture to one of those pipes and tanks, there would be no fuel for the Cook Strait ferries” (PO1). Currently, there is a bunker barge with marine fuel operating in Wellington. “It has got huge capacity, and that is good for us. We do not have to keep going round to Aotea to fuel. You just come alongside” (FO1). However, this resource would soon be depleted due to the significant amount of fuel required to operate the ferries. “When [a ferry] burns in 28 to 30 tonnes a day, that is a tanker load a day” (FO1). In other words, the bunker barge is not a practical substitute if the Kaiwharawhara site is unavailable.

Moreover, in the absence of the Kaiwharawhara site, fuel would need to be brought in from other fuel terminals. The downside to this is that fuel terminals are geographically distant from one another. “Because fuel is essentially moved between ports, [in] a hub and spoke type of approach, [...] when you have a geographical constraint [...] we push from the nearer ports in, and everyone moves up and pushes towards that. The biggest issue [...] with that is the task gets bigger, right, because trucks are having to go longer distances” (IR1). In the context of the Cook Strait ferries, fuel would have to be brought in from the next closest fuel terminals: “[Fuel] could be trucked in from north of Wellington, and similarly, Picton could be picked up by the fuel supplies through Nelson, maybe Christchurch” (GO3). At the same time, without the Cook Strait ferry terminals, it is likely there will be increased demand for fuel to keep goods moving. “You would need more aviation fuel if you were sort of... say you double the number of flights” (IR3). In other words, a significant amount of fuel will be required in specific locations. However, concern was raised around the capacity of fuel available at onshore fuel

terminals. “We have had three outages of aviation fuel in the last 12 months [...] we could do with more onshore fuel stockholders” (IR3).

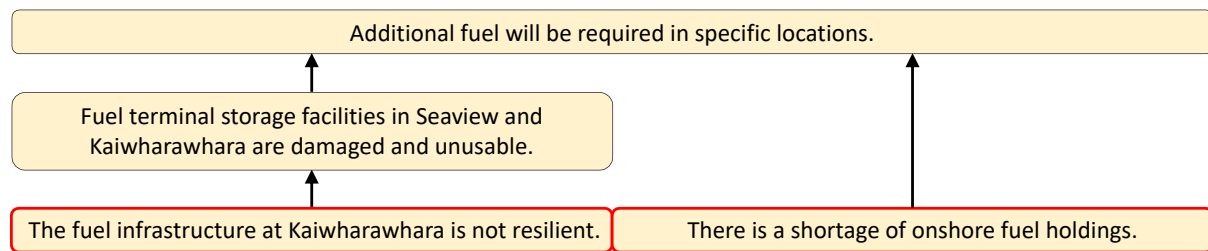


Figure 45: CRT snippet for fuel

### Suggestion for future reality (injection)

Increase the buffer of available onshore fuel holdings:  
 Having a sufficient buffer of onshore fuel holdings would help ensure there is sufficient fuel available to meet increased demand, which would be exacerbated if fuel terminals are damaged and unavailable.

## 6.6 Data

### 6.6.1 Post-disaster information

Interviewees note that in the aftermath of a Hikurangi Subduction Zone earthquake and tsunami, access to data is especially important in order to know what they are dealing with: “The information we need is good visibility” (TU1). “What is broken? Is it completely broken? Is it just down to half capacity, or is it total capacity?” (ER1). At the same time, restoration times and further insight would be needed: “Certainty [...] around when things are going to be fixed, and what is going to be available at what point in time [...] and where the new constraints would be” (GO3). Despite the need for this visibility, the current way of information disruption is fragmented: “Is it council we go to, is it civil defence? Who [...] should [we] be talking to or getting information from? [...] you have got power, you have got retailers, you have got lines companies” [...] How do I get that sort of consolidated high-level view of what is working, what is not, and what are the areas that we need to work around?” (TU4).

However, it was noted that there are potential concerns around sharing such data: “[A challenge] you run up against [...] is commercial sensitivity around private infrastructure such as electricity and fibre networks. So sometimes they are not overly willing to share that information, or certainly, there are some privacy requirements around that data” (GO2). Notably, some work has begun in sharing post-disaster information: “We are setting up to trial [a database] for the AF8 [Alpine Fault magnitude 8] event, and we are all going to share information and share URLs so we can all build that information into our own systems as well” (GO2).

### 6.6.2 Prioritisation system

Once the impact of the event is understood, a prioritisation system will need to be put in place. “After an earthquake [...] the freight that you need to move is actually equipment freight. So,

it is going to be cranes, it is going to be trucks carrying stuff [...], and people [...]. Things that will enable you to start getting your roads cleared a bit and creating some flat area to start building a laydown or unloading this or setting up a small container site to then become a staging point” (FO2). As for consumables: “you are obviously bringing some essential supplies like medicine and food and water” (FO2). Based on learnings from past events, organisations determined what goods were prioritised: “We prioritised water shipments rather than cement [...] and generally customers understand [...] that the essentials [must] get there before the other cargos” (TO5). In other instances “we would prioritise domestic cargo over international import and export tranship” (TO5).

Following a Hikurangi Subduction Zone event, interviewees acknowledged that they would prioritise certain goods. “For the pharmaceutical company, we would say, give us everything you have got because that is really urgent. But the stationary company, we might [...] [restrict] the amount of volume [...] because we have this temporary restriction within our supply chain” (TO2). In other words: “How much stuff really has to move? What is the stuff that can move in alternative ways? So absolutely urgent stuff [...] would go by air” (IR1). As for non-essential goods: “we are going to miss [...] sales because the capacity that we do have [...] needs to go for food and healthcare products” (TU4).

It was noted that government intervention may be needed: “You would have to ration stuff, and things would run out” (FO2). “Everyone would be going after containers and space, and you would need, I think, some kind of government intervention” (TO3). “The government probably would be able to prioritise which [goods] are actually necessary for the health and wellbeing of the people” (TU2). However, another interviewee advised the implications of this approach, which was trialled during COVID-19: “[Government advised] that there should be some sort of system in place to determine what freight should move and what should not, and that each company would have to register [...] essential freight, things from the supermarkets [...] were still allowed to keep moving. The problem with that is that nobody knows what is inside the box, and essential and non-essential are subjective definitions” (GO1). To address this: “police [would] stand on the side of the road [...], open the curtain[sider truck], and [...] [determine what] should be going” (GO1). In this light, government intervention may be best suited to sea transport: “Government [...] [could] direct ports to prioritise essential goods into those ports and to make the necessary capacity available for them” (TO5).

### 6.6.3 Logistics information (demand and capacity)

The key to responding to the event is having access to demand information. Such insight would include “forecasted demand from the producers, the cargo owners so we know what challenges we are dealing with [...]. The forecasted demand would then tell us how many containers we need and what container type we need, be it a dry container or a reefer container. Those are probably the key issues straight away. It is just how much and when” (TO5). As well as knowing “where they [the goods] are going, [...] the freight constraints or requirements and the volume [...]. Does it have to get somewhere in a certain amount of time?” (PO2). Having access to such demand information aids in decision-making: “If we are looking to stand up

supplementary capacity [...], then it is the demand input that becomes incredibly useful” (TO6).

With greater insight into capacity information, organisations can begin to understand the volumes of freight that can be moved: “The flow of empty containers and the slots that you can get on the various shipping lines to connect the two islands” (TO2). “So, what is the volume of containers that they would be able to take from us?” (TO2). Ultimately, having access to the right information will ensure that “every link in the supply chain knows when the goods are moving, how they are moving, who is doing it, and what needs to be in place at the other end. So then all the operators at the other end are ready to move those goods. So it is just that basic of supply logistics information” (IR4). As a result of this information, operations can be adjusted. Then “they are able to think about how to reshuffle their transport routes to fit those patterns of demand” (GO3).

However, there is currently no system in place to facilitate this information, despite the value it would provide: “Link[ing] demand and supply together a lot better [...] would make us more resilient in time [...]. So, determining what the import, export transshipment, domestic volume and everything looks like, and when those peaks and troughs are so that everyone in the supply chain can either gear up or downscale or to meet those events here to make it more economical and commercially viable” (PO4). Put simply, “the right information needs to be available to the right parties at the right time” (TO6).

#### 6.6.4 Interoperability

For data and information to be more accessible, systems need to be interoperable: “I think we do not have a great common operating picture, a great digital common operating picture to hold and display information, to analyse information” (ER1). For example: “Traditional supply chains [are] one-to-one-to-one-to-one, and [...] not very dynamic at all. Information flows slowly and often in an incomplete fashion. So [...] a more resilient system would be one that is responsive, one where information flows many-to-many where there are lead indicators coming through and as well as lag indicators and where systems are interoperable” (TO6). However, several obstacles are preventing this from being achieved: “A great portion of the industry supply chains are still so paper-based, and analogue is a hindrance to this future state” (TO6).

Even if systems were interoperable, there are still challenges: “There is very little data sharing [...] because data is king. So yeah, we have got to be careful along those tracks as to what we do share” (PO4). To overcome this, it was suggested that the government facilitates the sharing of data: “Because of the sensitivity of the information, the ownership of information [...] my opinion [...] is there is a role for government to play in this around resilience where they can be impartial, and they may have a non-commercial agenda in this, but they are playing an enabling function around the provision of information. Everyone feeds into something that they have developed which benefits everyone, but has the appropriate securities and sensitivities in place” (TO6).

Another suggestion was to share data in less detail: “So, not the granular part; it is more of a high level so that everyone can see what the freight task is from a quantity perspective and from which regions, to and from which regions or cities and everything is the demand. And then we match the demand by the supply of resource to move that volume, the ability to flex a little bit pretty much and detract as well” (PO4). In any case, “[having] a more dynamic supply chain, one where information is clearer sooner, and [...] if the modes were more interoperable, the units that you use, the formats, the shipping, the documentation, the processes, [...] it would create a more resilient system because you have got multiple pathways and nodes to move things” (TO6).

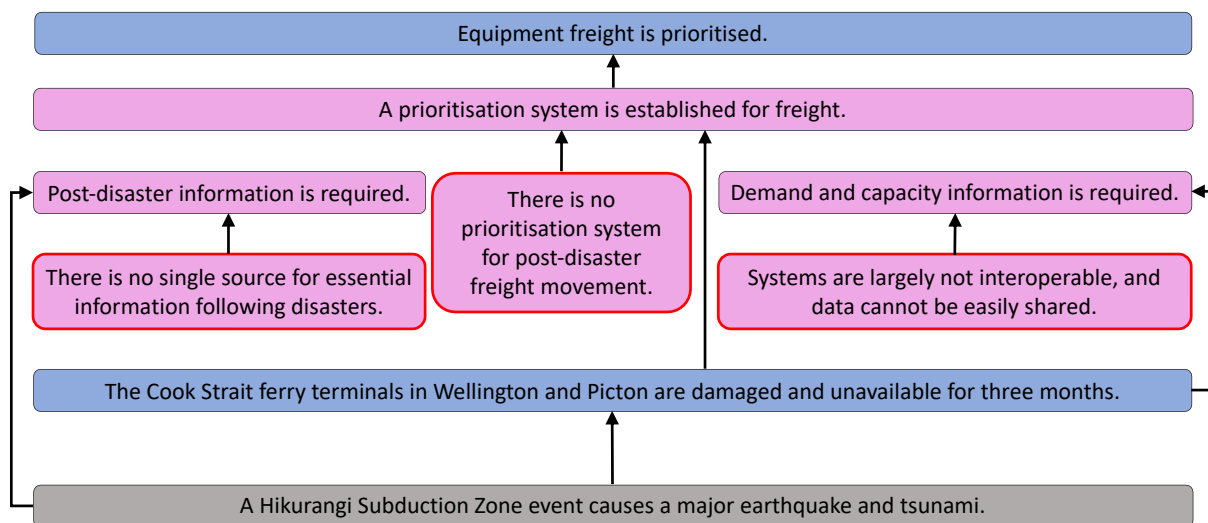


Figure 46: CRT snippet for data

### Proposed injection

Develop a freight prioritisation system:  
 A prioritisation system may need to be established to determine what freight is prioritised. To achieve this, organisations could work with the government to determine what goods are prioritised and allocate capacity to keep such goods moving.

## 6.7 FMCG operations

### 6.7.1 Freight flows and product characteristics

Because of imbalanced freight flows between the North and South Islands, most non-perishable freight travels southbound: “A lot of product in NZ is [...] imported, held at our national DC in the North Island, [and] a lot of product comes out of Auckland [...] predominantly in our ambient category, which is your grocery and [...] liquor” (TU1). On the other hand, most perishable freight is northbound. “Probably 66% of goods come north, just really roughly, just because [...] [the South Island] produces much more than it consumes” (TU3). In other words, the Cook Strait ferries enable freight to be available in the right place at the right time due to regular sailings: “You can get a container or a truck [...] of FMCGs from Auckland to Christchurch in less than 48 hours. Coastal [shipping], you cannot do that. It takes longer” (PO1).

As a result of the speed advantages the Cook Strait ferries offer, a lot of perishable goods are moved this way: “A lot of produce we move is quite temperature sensitive and obviously date sensitive. [...] It comes out of the ground and gets into your truck, and we need it at the stores. So, a lot of fruit will only last a few days at the sort of quality that is expected” (TU3). “Three days [72 hours] is [...] the tipping point for us. We could probably get away with anything less than that, but from three days on, we have got to start moving produce within the islands because they start to rot. [...]. [Therefore] most produce has to go through the ferry network” (TU3).

Because of the sensitivity of certain freight, if the Cook Strait ferries were unavailable, there would be shortages: “Growers would have to sell within their own island [...] the South Island will be absolutely flooded with its produce, it would ruin the values down there [...] that produce would end up probably going to waste, [...] [while] in the North Island, we would see a spike in costs and a huge spike in shortages coming through the market” (TU3). On the other hand, less sensitive freight can be moved by alternative transport modes. “As much as possible [we] use coastal freight because it is not as time critical. It is five days or a week. And if it is not there on the day, the DC has a little bit of safety stock” (TU5).

#### 6.7.2 Replenishment

Because the Cook Strait enables goods to be moved in under 48 hours, organisations are able to adopt a JIT inventory management, where less inventory is replenished at regular intervals to reduce operating costs: “The cost of stock holding is quite high. So it is the balance that somebody has to make about whether they would prefer to take that cost and have some security” (IR2). “In my observation [...] the freight market would rather absorb cost than pay for resilience. [...] Just-in-time is all back. Post-COVID[19], it is back big time. Why? Because if you're sitting on another \$20 million of goods of stock, just in case you need it, and your cost of capital is 6, 7, 10%, it is a lot of money that it is costing you just to sit on” (TO4).

In other words: “[Organisations] do not necessarily invest in resilience. They just pay for it if they have to” (TO4). Therefore, in the absence of the Cook Strait ferries, organisations would potentially need to increase the buffer of inventory being held at distribution centres: “I think the natural impact in our network would be increased inventory holding. So we would need more capacity, we would be holding more inventory [...]. We might say that we used to sit on a week's worth of stock [and now] we need to sit on a couple of weeks' worth of stock, and if you put that over the number of suppliers that we deal with, that would increase, and would put pressure on our capacity and inventory holding” (TU1).

### 6.7.3 Freight hubs and storage

In response to increasing inventory buffers at distribution centres, there would be a shift in where freight is primarily handled: “Christchurch and Palmy [Palmerston North] would have to be your two supplying sites. For Christchurch, big time for the South Island, and Palmy because it is the hub and spoke of the lower North Island [...] we would make Palmy the last leg” (TU3). The implication of increasing inventory is that there needs to be adequate storage facilities available: “I would be looking at who currently has capacity in their distribution network [...] to store product in highest quantities, to mitigate these delays” (TU2). “It might be the fact that we set something up in Lyttelton to make it easier instead of dragging everything into Christchurch” (TO1). This approach was used following the Kaikōura earthquake: “We took on [...] three warehouses in Christchurch. So, instead of a lot of our customers stocking in Auckland and relying on transport down [...], they were coming direct from their suppliers into Christchurch. We were warehousing it there and distributing amongst the South Island from there” (TO1).

However, it is unclear if Christchurch would have sufficient facilities: “Do we have enough [...] warehousing capacity in Christchurch if suppliers decided to establish the coastal freight network? [...] we are not just sitting around with a whole lot of empty sheds and [...] available capacity” (TU1). To reduce the reliance on Christchurch, a second hub could be established in the South Island, which also has additional storage: “Set up a much bigger hub somewhere like Timaru [...] because it is on a rail line, so you can distribute really well, and it has got really good ambient and reefer storage” (TU2).

Moreover, depending on the types of freight available, storage facilities may need to be temperature controlled, of which there are a limited number that are privately owned and operated: “If it is a really significant extended emergency, then potentially Fonterra could look to assist, and there will be other companies as well” (TU2). Another interviewee noted that they have access to their own refrigerated facilities. “We have heaps of capacity [in Hamilton, so] that would not be a big deal. We would have the capacity to be able to store it for a period of time” (TO2).

Even with sufficient cool store capacity, not all perishable freight can be stored this way: “You can only put certain produce into cool stores [...], and for most of our daily fresh type produce, that is not the case. You might get away with broccoli in a cool store for three days, and then it has got to move. You might get seven days out of, say, broccoli from start to finish from when it is harvested. So, you can see how the clock is ticking very fast” (TU3). “For those that do not have produce like that, so typically your greens, there will be other sensitive stone fruits, [...] anything like that literally just goes to rot, because if we cannot get in to move it, they cannot get it to market. It is too sensitive to throw on a boat” (TU3).

### 6.7.4 Preservation of perishables

To avoid spoilage and enable freight to travel longer distances, preservation would be needed: “Your food supply from the South Island to the North Island disappears unless it is canned or

preserved in some way” (IR4). Preserving freight can be done in a number of ways: “produce that could be put to sleep [preserved] into cool stores. You would obviously ramp that up very quickly” (TU3). “Apples are probably the interesting one because apples can be put to sleep, so, yeah, a lot of international apples and stuff can go on ships” (TU3). Another approach is to freeze perishable freight: “If we could not get pork to the North Island in a timely manner fresh, we might have to say, look, we go to the supplier would say, "Look, we cannot get it there. We are going to do it frozen instead” (TU5). Again, this would require adequate facilities and capacity: “We would have to obviously then look at the capacity for frozen ability [...] I know that Heinz and McCain would try and do their best to take the produce to at least put it into a frozen configuration” (TU3).

### 6.7.5 Seasonal fluctuations

The extent of the disruption would be further exacerbated if it occurred during seasonal peaks: “October through till Christmas, the freight really [...] builds [then] another mini peak but not as big just after Christmas. [...]” (FO2). “Between October and March, we see a marked seasonal pattern coming through with spring and things like lamb coming on and then over Christmas into stone fruit, cherries, and summer berries, things like blueberries, even avocados” (TO6). “The biggest challenge would be if [the outage] came at a time where we were already under peak pressure. So that would be clearly October or November, which is when the exporting of primary product starts kicking off in the spring and is tied in with the point in which you have construction beginning to start at the start of summer and obviously Christmas for the importing of retail. But there would also be similar challenges in late March and April, which is when we are at the peak of the dairy season from an export perspective” (PO3).

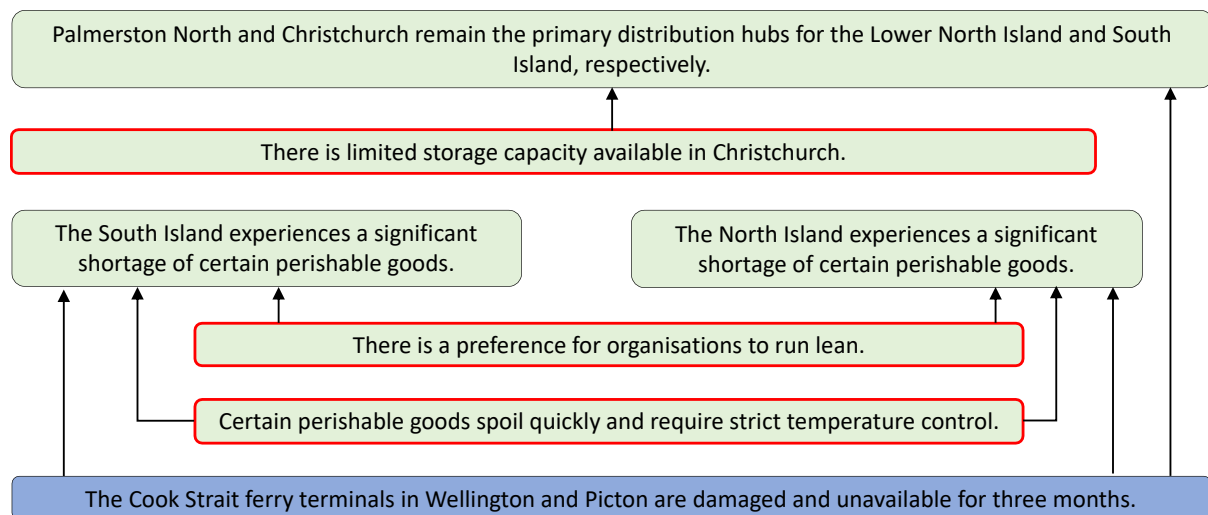


Figure 47: CRT snippet for FMCG operations

## Proposed injection

### Use Timaru as a freight hub:

Timaru would be a valuable freight hub as it has both ambient and reefer storage and rail access. As for the North Island, Palmerston North and Hamilton could be used to store additional inventory. In instances where perishables cannot be stored, preservation methods can be undertaken to prevent wastage and endure longer journeys on alternate routes, such as coastal shipping.

## 6.8 Road

### 6.8.1 Road transport capacity shortages

In the absence of roading infrastructure in Wellington and Picton and the ferry terminals, trucks would have to travel along alternate roads: “You would see a lot more heavy vehicle freight on [alternative] roads [...] because they would be picking up that volume of freight” (IR4). For example, there would be additional traffic to and from key freight hubs, such as Palmerston North: “You would see a huge bottleneck of issues in Palmerston North [...]. I think that would be a transport problem. If Wellington really got smashed with something bad, Palmy's going to end up inundated. [...] It would have to be the coordination for Wellington, et cetera, and I do not think we have quite grasped how serious that would be as a transport industry” (TU3). As a consequence of certain road closures, trucks would be travelling longer distances in some cases: “any detour increases journey length and time, and therefore that has an immediate impact on the users” (GO2).

For example, “[freight] may incur an extra cost if rather than going from Gisborne to Christchurch, it has to go north first to either Tauranga or Auckland to end up going south” (TO5). In other words, freight in the lower North Island, which would normally travel south through the Cook Strait ferries, would instead have to first travel north to access the seaports in Tauranga or Auckland before it can travel south by coastal shipping. As a result of the increased journey time, drivers would incur additional costs as there would be “extra road user chargers between the longer distances [and] extra fuel costs” (TO3).

Labour challenges would also surface as a result of the longer journeys and increased time: “Trying to manage a route that used to be one driver would get there, now he needs two drivers” (FO1). This is true of not only trucks moving FMCGs but other transport users, such as those responsible for the distribution of fuel: “If I want to get fuel from Christchurch into the Nelson geographical unit, right, I cannot [...] get my truck loaded up there and back in a 12-hour shift” (IR1). To overcome these limitations, there would be a need for additional trucks and truck drivers. However, there are likely to be shortages: “Trucks, depending on the time, capacity of trucks and drivers could be an issue” (IR1). For instance, in the Kaikōura earthquake, “we did not have enough road trailers from a resilience perspective or redundancy perspective to fully satisfy the market” (TO4).

Moreover, trucks and drivers may not be where they are needed if: “I would envisage the trucking, the land side of the supply chain in Canterbury would be where the challenge would lie. It would depend on the ability to shift the trucking that goes through the Picton ferry and whether those resources were available locally in Canterbury to be used” (PO3). Reflecting on the Kaikōura earthquake, it was noted that trucks had to be moved into the South Island to address demand: “more truck trailers actually had to be sent to the South Island” (IR1). As for drivers “if they are, for example, North Island truck drivers that come through to the South Island on a daily basis and go back again, then that resource is not going to be available in the South Island to deal with that cargo” (PO3). In other words, the ferries enable trucks and drivers to move between the North and South islands. Adding to the disruption is that there are already national shortages of qualified truck drivers. “We have got a shortage of [...] class five drivers” (TU4). The challenge with this is that “a person who drives a truck and trailer unit [...] cannot suddenly be instantly trained to drive a swing lift and be safe in operating a swing lift to support that mode change” (TU4).

To address the existing labour shortages, it was suggested that shift durations be revised: “The trucking industry could be improved by diversifying. [...] there is a lot of resource [labour] out there, but people do not want to work 12-hour shifts anymore” (TU2). This approach has worked in the context of an NZ FMCG firm: [Our firm] will job share. So if somebody's coming up to retirement, they will [have] one job, but two people will do that job, and they will share half of those shifts” (TU2).

#### 6.8.2 Roothing network capacity

As a result of the increased usage on alternate roads, they would become congested and deteriorate faster. “So your road transport network suddenly changes in a way, and you are displacing where your heavy vehicle traffic happens, and some of those roads just are not built for that volume of heavy traffic” (IR4). Reflecting on the Kaikōura earthquake, congestion occurred on access roads near seaports: “The congestion that happened at Lyttelton [port] was more on the land side than it was on the waterside” (PO3). In addition to congestion challenges, roading will deteriorate faster: “You would see a lot of road wear and tear, which you can live with for a while, but at some point then you are going to start doing some pretty expensive road maintenance and repairs” (IR4). Therefore, you will eventually “need to improve the structural performance of that pavement and the assets which function around the pavement” (GO2).

“We want to upgrade our detour routes, but obviously, there is only so much money we have” (GO2). Fortunately, there has been increased investment into improving the resilience of the road network: “Recent events have sort of triggered a lot more political interest [...] we are doing a lot more planning work, and more public funding is becoming available to do some of this work [...]. We have been getting funding of around \$40 million over three years to strengthen our network from natural hazards up to now. About six months ago, the government gave us an additional \$297 million dollars for the State Highway network to strengthen it due to natural hazards [...] \$300 million is a very, very different proposition than spending \$40 million over three years. And we can actually make some inroads into building some resilience” (GO2).

Although improving the quality of the roading network is needed, interviewees advised that road funding is not always going into the right roads: “[It is] so much more politically useful to build a really flash road, which will be highly resilient and highly safe, but only a short distance compared with picking at it all around the network. So you can spend a lot of money on resilience, and you get reasonably small but incremental gains every time you do something. You fix that slip up so it would not happen again. But the next slip will be somewhere else” (IR2). At the same time, it was suggested that transport resilience should be beyond just the road network. “We know that there is a lot of discussion about roads. Roads are good from a political perspective. Everybody uses them. That does not necessarily mean it is the right decision from a resilience perspective” (PO3). “I think it is important to ensure that [resilience is invested] across a diverse network of transports. I do not think at any point, anyone, whether it is road, rail, air or sea, should be overly favoured” (PO3).

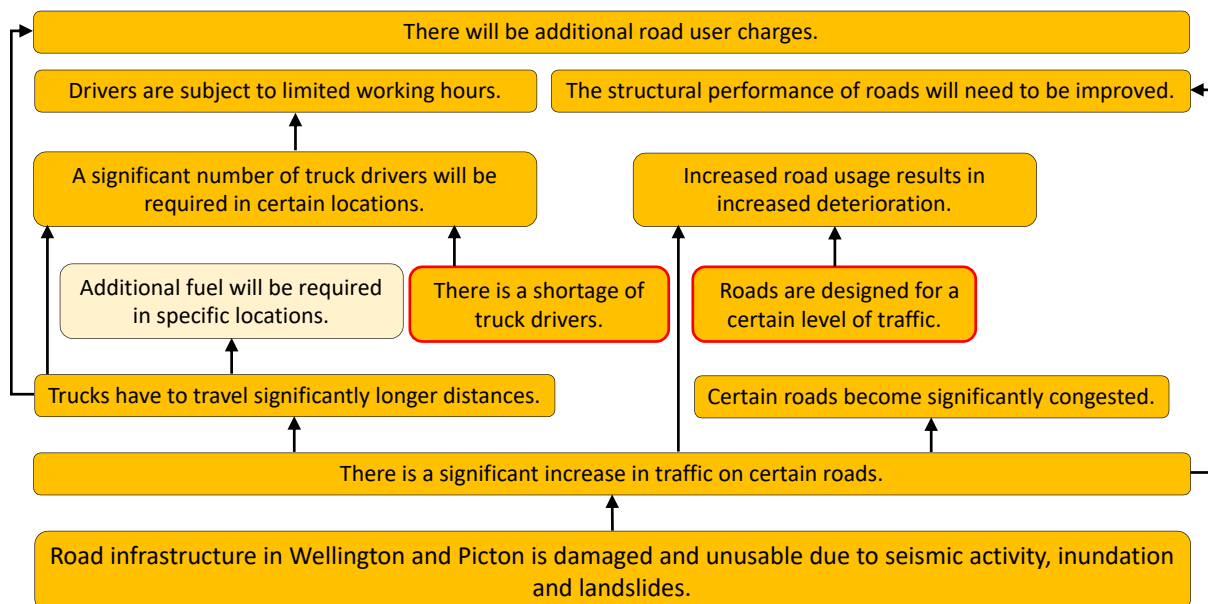


Figure 48: CRT snippet for road

### Proposed injection

Revise employment conditions:

To address the labour shortage, employers could explore offering roles with more attractive hours, where a conventional 12-hour shift is instead split between two drivers.

## 6.9 Rail

### 6.9.1 Rail transport capacity shortages

Reflecting on the Kaikōura earthquake, one interviewee noted the volume of containers that had to be road-bridged during the rail outage: “Within two days [...] we literally were taking the containers off the boat at Picton and just road-bridging it around. So, during I think it was four nights, [KiwiRail] did about 800 containers [...] so just shows you that rail absolutely plays its part north, south and in terms of up and down state highway one” (TO1). The value of rail is further emphasised through KiwiRail’s investment into intermodal assets, which supports the flexibility that road-bridging operations provide: “[KiwiRail] will put the goods on the truck and work around the obstruction, which is aided by its use of containers now. Almost entirely KiwiRail uses containers, especially for FMCGs, not waggons” (IR2). In other words, because of KiwiRail’s intermodal assets, the rail freight task can more easily be shifted between road and coastal shipping without the need for containerising freight first, as would have been done in the past.

The biggest concern interviewees had for rail was the lack of resilience in the network. “The rail system is a weak point in the freight system because of its lack of redundancies in its network” (TU2). “For almost all of the country, we have got one rail line servicing the areas that are serviced by rail” (TU4). “There are some rail services into the East Coast of the North Island, but they are not robust. The rail network really is designed to go up the spine on the East Coast of the South Island up through Picton, Wellington, basically by the ferries, and then snake its way up eventually to Auckland. It does not do great in terms of its resilience when you look horizontally across the country” (IR4). Despite the limited redundancy in the network, rail would still be critical for intra-island freight movement: “Obviously, rail could still play a role in terms of getting cargo to and from alternative ports as well. [...] [and] they still have a role to play in distributing within the island, either the South or the North Island” (TO5).

If there was increased rail usage in a Cook Strait terminal outage, there could be labour challenges: “Does rail service out of Lyttelton port, can that be ramped up? My workings with rail say that they need six weeks to make changes to their labour schedules, to be able to increase services, so [...] that is going to delay any response time” (TU4). A further advantage of using rail over other transport modes is that it does not require a substantial amount of labour: “Rail is fantastic for moving with one person driving” (TU2). In other words, rail will reduce the need for trucks and truck drivers.

Looking ahead, several suggestions were raised to improve the resilience of rail: “We need better resilience across that in both the North and South Island” (PO4). One way to do so could be to build in redundancy with a second line rather than investing in regional lines: “Have a second main trunk line going from Auckland to Palmerston North through Tauranga” (TU5). “I think maybe too often we get a little bit obsessed with should we have a bloody Gisborne to Wairoa line, there are some of these lines that sometimes people are crying out, lobbying for money to go into” (TO2). Instead, it was suggested rail might be better to operate in a hub and

spoke manner: “Maybe [rail] should just be a straight main track, do that and do it really well [...] the spokes that come off it, they can be done by trucks, and that might be more sensible that you have a great [main] link between Auckland and Christchurch [...] and if you could have that main link super reliable and maybe a bit quicker, you might have a whole lot more reliance on it. You might even get people like us using it” (TO2).

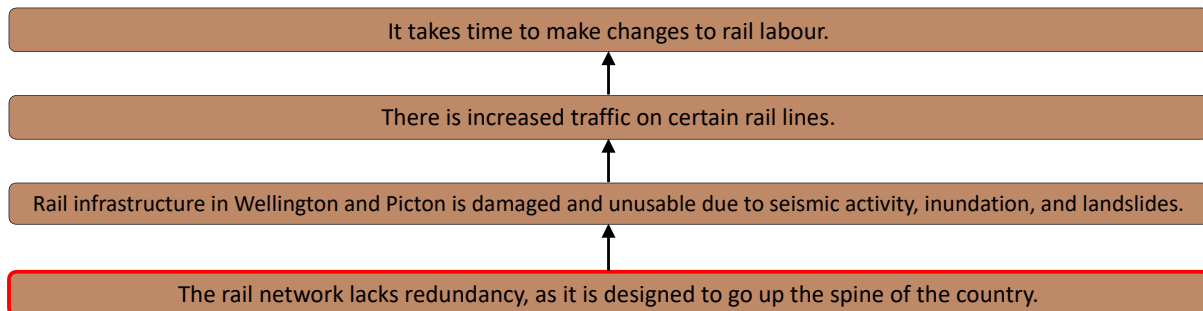


Figure 49: CRT snippet for rail

### Proposed injection

Open a second main trunk rail link:

Operating a second main trunk rail line between from Auckland through Palmerston North and Tauranga, down to Christchurch would improve the resilience through redundancy. At the same time, trucks could act as spokes to serve this line to provide the initial collection and final delivery of freight.

## 6.10 Air

### 6.10.1 Air transport capacity shortages

As mentioned earlier, air freight will be used to cater to specific freight that requires urgent delivery or those that can justify higher transport costs: “The thing about air freight is it does high value, low weight, low volume, very, very well, stuff that has a real urgency about it because that is what we do, we shift things faster than anything else” (IR3). However, freight moved by the Cook Strait ferries, in contrast, is much more feasible: “Flying everything from Auckland to Christchurch as opposed to putting it on the road, on the ferry, back on the road again, is massively more expensive” (TO2). Because of the high cost and limited carrying capacity, only specific freight would be moved by aircraft: “Air freight would be able to pick up niche areas of the freight task” (GO3). For instance, “some of it is going to be healthcare products, and it has got urgency associated with it” (TU4). Other goods would be those of high value, such as specific perishables. “It has to be light, and it has to be high value, a not that many of those products around [...] some capsicums that are a good example, very light, [...] some of those smaller more boutique-type produce you might fly” (TU3). If FMCGs were to be moved by air, the cost would ultimately be passed on to the freight, meaning FMCGs would not be available for the right price. “The consequence of that [shift to air] would be significant increases in prices” (TU5).

Unsurprisingly, airfreight runs lean and has limited capacity: “[It] is pretty cost optimised [...] so it does not have a lot of fat in the system” (IR3). As one interviewee notes: “[Our] aircraft do anywhere between 12 and 16 flights a night between Auckland and Christchurch and Palmerston and Christchurch [...] [however] it is a relatively small proportion of the total freight we move between the islands. So, the reality is we would not have the capacity in the air freight network. [...]” (TO2). In other words, air freight is not practical for absorbing the freight task of the Cook Strait ferries. “At a really rough estimate, the ten units [trucks] running per day across the Strait [...] you would be looking at about seven rotations on our Boeing 737-400, which, whilst incredibly expensive, I do not think in the real world you could do it. Not with our current crewing” (TO3). Despite the fact that the air freight industry has a buffer of labour, it would soon run out: “We carry more pilots than we typically need. We have 18 pilots on a given night; we might use eight, but pilots [...] just like truck drivers are subject to a longer number of hours [...], you would start to run out of capacity in terms of pilot hours” (TO2). Labour shortages were also raised for cargo handlers: “Because the ones you have got [...] are doing 8, [to] 12-hour shifts and there is enough of them, but there is not a huge number of them stuck in a warehouse just waiting for a job. So you would have to get those skilled people and bring them up to speed” (IR3).

Other air freight companies may have enough capacity to adjust existing schedules: “There might be some capacity domestically to operate overnight, which is often when a lot of the engineering and maintenance is done [...] you could add a stretch, stand up some additional flying then” (TO6). Although this would provide some relief, it is inefficient: “All of these planes are set up to carry passengers and cargo, and to utilise them in this cargo-only fashion is incredibly inefficient because [...] you are getting half of the capacity for the full operating cost” (TO6). As a result of the limited capacity available domestically, it is likely that the NZ Air Force will assist with freight movement: “I think it would be serious enough that things like the Air Force would have to get involved. I think you would have no choice to keep trying to move things because it fundamentally could destroy people's livelihood” (TU3).

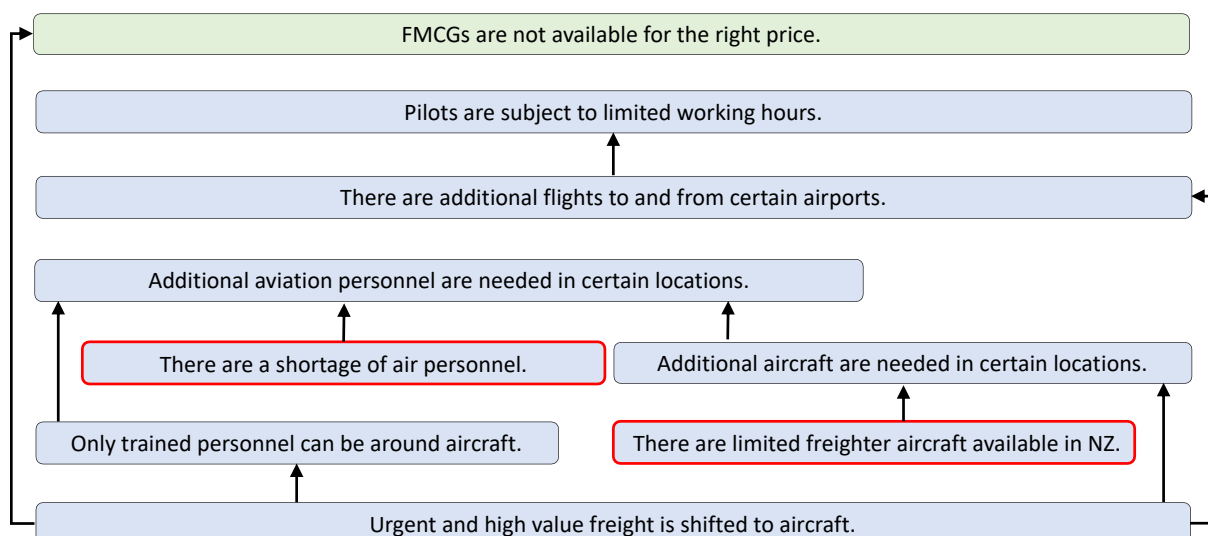


Figure 50: CRT snippet for air

## 6.11 Sea

### 6.11.1 Freight task of the Cook Strait ferries

Details provided by interviewees estimate that for FY19, the ferries moved around 81,100 TEU worth of rail wagons annually and 170,625 trucks. Of the 81,100 TEU, around 56,850 TEU worth of freight is containerised in 10', 20', 25' and 40' containers, with the remaining 24,250 TEU worth of rail freight in wagons. Importantly, some trucks and wagons return empty due to the imbalanced freight flows mentioned earlier. Furthermore, due to seasonal fluctuations, the freight volumes moved over Christmas would be greater than at other times. In the context of a three-month Cook Strait ferry outage, there would be a nominal impact on around 42,656 trucks and 20,275 TEU of rail freight, as shown in Table 7.

Trucks and rail freight moved by the Cook Strait ferries FY19						
Unit	Annual	3 Months	1 Month	1 Week	Daily	
Rail freight (TEU)	81,100	20,275	6,758	1,560	222	
Trucks	170,625	42,656	14,219	3,281	467	

*Table 7: Freight task of the ferries in TEUs and truck units*

### 6.11.2 Re-routing the Cook Strait ferries

Interviewees acknowledged that there is a lack of resilience around the Cook Strait ferries and the movement of inter-island freight. “If we had an outage in the Cook Strait, the biggest weakness is we do not have decent contingencies at all [...]. The country needs to look at other alternatives to make it resilient” (TO1). Because the only linkspans are in Wellington and Picton, trucks and rail wagons would be impacted by an extended Cook Strait ferry terminal outage. “Lyttelton does not have the capability of hooking into a rail network” (PO3). “Neither Napier [...] Nelson, Taranaki [...] Auckland [...] [or] Tauranga” (PO4). In the absence of rail-enabled linkspans, rail freight could be road-bridged, and the ferries could be Mediterranean moored, although the process is less efficient: “We used to work a service out to Napier [...] and you have to Medi[terranean] Moor” (FO1). “What that generally means is the [...] [ferries] would rely heavily on tugs. So then it comes down to the capacity of the tugs and the people [...], the availability of the tugs and the tug operators” (PO1). Moreover, not all seaports are suitable for Mediterranean Mooring: “There is not an awful lot of other places that we could load a role on in the North Island” (PO3). Expanding on this, one interviewee had explored operating out of Port Taranaki instead of Wellington, although the port is often not suitable: “[Port Taranaki] closes for days at a time where the surge coming in there” (FO1).

In any case, re-routing the ferries increases the transport time, which is inefficient: “If your scenario is both terminals have been taken out rather than just one, then you're probably talking a quite incredible transit time” (PO3). “[The ferries are] not suitable for long distances. They're inefficient in terms of cargo space use. You just look at them. It is all designed for a quick transfer” (IR2). Because the ferries are designed for a fast transfer, the carrying capacity is often not fully utilised: “The ship has actually 2,200 lane metres in it [...], in reality, you can probably get 1,800 lane metres on, but the last 200 will take you an hour to try to get them to fit in” (FO1). In other words, to fully utilise the ferries, the schedules would be disrupted: “So

typically it is about a three and a half hour crossing and a two and a half hour turnaround. So that is a six-hour link across, and so you can do two returns per day, but if you have a really big load and then you blow out by half an hour your turnaround, you will never catch up, or it is really, really hard to catch up” (FO2).

Several interviewees raised the need for backup linkspans to improve resilience: “Have some backup linkspans around the country, so strategically just we do not have all your eggs in one basket, and you could even have a barge [...] you would probably need two of them just in case both ports get taken out” (FO2). “With a barge and a link-span [the ferries] will presumably survive [...], and you can put the link-span on the barge and tow it somewhere else. [...] we are not talking huge money” (FO1). As opposed to a fixed structure, this would enable the ferries to be re-routed to different seaports: “[a floating linkspan] could be distributed anywhere. It could be towed [...] anywhere that has the draught to cater for the Cook Strait ferries, and you go on and off that” (PO1). Because the asset is nationally significant, it would need government funding, as opposed to a single stakeholder paying for it: “Because we're a commercial entity, my responsibility is under the Ports Act to try and make the best commercial return I can for our shareholders. Ultimately, it would need government intervention” (PO1). Given the importance of having a linkspan, it was noted that KiwiRail could fund such infrastructure: “It is probably the thing that should sit on their balance sheet. And if they have to charge everyone another dollar a lane metre or whatever it is to fund the cost of capital on \$5 million bucks, it would not even be a dollar a lane metre” (TO2).

### 6.11.3 Sea transport resource shortages

Several interviewees mentioned a modal shift from road and rail to sea in response to an extended Cook Strait ferry outage, provided the freight could withstand the longer transit. “Air freight is not really an option. It is bloody expensive. Do not get me wrong, when it is needed, it is needed. But other than that, nah” (TO1). As opposed to the normal Cook Strait ferry service, moving freight by alternate modes requires containerisation. “If you do not have RoRo, then that is going to be problematic because [...] you are talking a lot of LCLs [Less than Container Load] [...] so palletised stuff” (IR1). The problem is that most of the moved by the Cook Strait ferries is not containerised: “When we send stuff to the South Island at the moment, it is mostly in trucks or rail wagons rather than shipping containers” (TU5). “The biggest challenge [...] would be more the domestic hauliers with curtain siders up and down the country, those who are positioning regularly [...] between [...] North Island and Christchurch” (TO7). Therefore, “palletised cargo on curtain side trucks, I would expect the majority of that to switch to containerisation” (PO3). As a consequence of this, “you might find that there is a [...] shortage of shipping containers” (TU5).

The shortage of containers is further emphasised by the fact that NZ already experiences shortages: “NZ is generally a container deficit country, so we do not have enough import containers to support our export volume, so it is not like we have got massive container parks full of containers just waiting for something to happen” (TU4). Because of this deficit, empty containers have to be repositioned to the seaports that require them: “Port Chalmers, [...], Bluff, Nelson, Napier and Tauranga are all deficit ports where there are not enough containers

coming in with imports to balance the exports” (TO7). Perishable goods would be especially impacted if there are shortages of reefer containers: “If demand pushed up [and] you did not have the refrigerator gear to move it, you are in trouble” (TO2).

To determine the number of containers necessary to absorb FMCGs moved by the Cook Strait ferries, quantitative insight revealed that 2.5 TEU would be required to substitute a quad trailer and 3TEU to substitute a truck and trailer unit, as shown in Figure 51. Table 8 provides a breakdown of the equivalent number of containers based on non-containerised rail freight (wagons) in TEU and the two types of trucks. However, the shortage does not take into account intermodal rail wagons and container-carrying trucks, such as swing lifts.

Containers required for trucks and rail wagons					
Equipment required	Annual	3 Months	1 Month	1 Week	Daily
Truck and trailer (3 TEU)	567,125	141,781	47,260	10,906	1,554
Quad trailer (2.5 TEU)	481,813	120,453	40,151	9,266	1,320

Table 8: Freight task of the ferries converted to TEUs

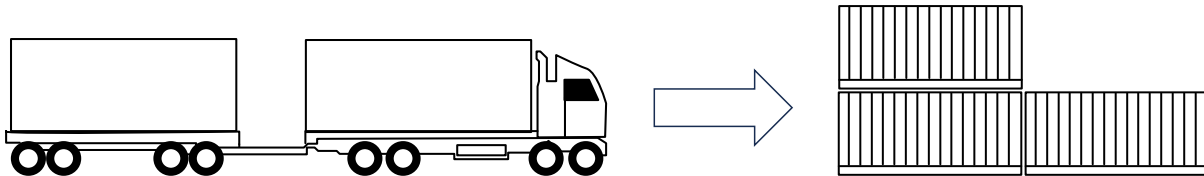


Figure 51: TEUs needed for each truck and trailer unit carrying FMCGs

Once the freight is containerised, additional resources would be required to move freight to and from the seaports: “You have got to make sure you have got enough trucks, and the trucks are kind of the optimal scale” (IR3). “We have got enough swinglifts (trucks that can load and discharge their own containers) to move the containers that are currently moving in the country, and that is all. Otherwise, we would have swing lift operators going out of business every five minutes” (TU4). In the context of reefer containers, they would need to be powered by generators. However, in the aftermath of a disaster: “There is always a shortage of generators” (ER1). Even with sufficient resources, moving freight will be less efficient when compared with the RoRo Cook Strait ferry service: “You have got an absolute delay in getting [freight] to the ships, getting it on the ships, getting it to the other end, and then you have got exactly the same process at the other end [...] so it is going to be slower, going to be less efficient, going to be more costly” (TO2).

#### 6.11.4 Domestic coastal shipping capacity shortages

With the Cook Strait ferry terminals unavailable, the domestic coastal shipping services will play a key role in keeping goods moving between the North and South Islands. “Coastal shipping has a critical role to play in supply chain resilience because we are a long stringy country [...] prone to earthquakes and [...] severe weather events which are going to get more frequent and more volatile as we go forward. [...] Coastal shipping can bypass a lot of that [landside disruption]” (IR4). Despite the ability of coastal shipping to keep goods moving following a disaster, there are only two vessels, and their carrying capacity is limited. “The

amount of volume that moves on those Cook Strait ferries every single day is [...] definitely a lot more than what Pacifica has [the] capacity to handle” (TU4).

Quantitative details revealed that Pacifica’s domestic coastal ships, the Moana Chief and Takutai Chief, operate at around 80% capacity when calling into Lyttelton Port and around 40% when going North. In other words, capacity is often available on northbound calls, not southbound. Table 9. provides an estimate of the domestic coastal freight task that is available.

Approximate weekly domestic coastal carrying capacity			
Available capacity	Total domestic fleet	Moana Chief	Takutai Chief
Total (100%)	3,114	1,740	1,374
Southbound (20%)	623	348	275
Northbound (60%)	1,868	1,044	824

Table 9: Approximate weekly carrying capacity of Pacifica’s domestic coastal ships

Looking ahead, interviewees raised the need for additional vessels in the domestic fleet, which would reduce the dependence on international lines: “The number of domestic vessels would need to grow as well to build resilience. So coastal feeders, we currently have a couple [...] call different ports, [...] so having the ability for two or three vessels around the coast, or even four [...] to reduce the number of international vessel calls” (PO4). The need to reduce dependence on international lines is elaborated on in the subsequent section. By increasing the domestic vessel fleet, more frequent services could be established between NZ’s leading seaports: “If we wanted to have real resilience around coastal shipping, [...] we need to have more [coastal] capacity on core routes, which runs Auckland, Tauranga, Christchurch” (TU5).

One of the barriers to increasing the domestic coastal shipping fleet in NZ is a lack of clarity around what fuels future vessels will need to run on: “The investment horizon for a new ship is 25 to 30 years [...] so you do not want to invest millions of dollars in such a long-term project and find in 10 years, that the [fuel] technology might be obsolete because everyone is going for [...] hydrogen rather than methanol” (TO5). Another obstacle is the lack of infrastructure in NZ: “we can order and buy dual fuel ships now, but we do not have the refuelling infrastructure for that in New Zealand either. So even if I came here with a methanol-powered ship, I could not find fuel” (TO5). Consequently, there is a reluctance for firms to purchase new vessels: “So there is a really difficult moment in time of how are we transitioning when there is a lack of available alternatives to transition to” (IR4). The market for vessels is also limited, with most vessels running on diesel: “Even if our guys go and buy a new or a near new second-hand vessel, it is about 95% certain you are buying a diesel ship. [...] If you think about what the price of carbon is going to be over the next 20 years, suddenly the [diesel] ship you are thinking of buying, you just cannot afford to buy it because, in 10 years time, you probably cannot afford to run it” (IR4).

As a result of these barriers, organisations may “put off buying a ship for 5, 10 years. And then your whole fleet ages to the point where potentially it becomes less safe because you cannot afford to replace it, or there is so much uncertainty that it would be unwise to replace it right

now. Because you take a punt on [purchasing] a hydrogen ship and then it turns out we have no hydrogen-supplied capability developed in New Zealand. So, where do you get your fuel from? You had the wrong bet, and now you are out of business” (IR4).

#### 6.11.5 International shipping

Given the limited capacity available in the domestic coastal shipping fleet, there is a dependence on international lines to accommodate following a major disruption. However, interviewees acknowledged that NZ is often the last stop for international shipping lines: “We [NZ] are specs, and [...] if [an international] ship misses its slot through the Panama Canal, then that is a further delay of five days” (FO2). Because NZ is not a priority for international ships, there can be sudden changes to schedules: “We often see weird freight flows in NZ [...] to make up time [international vessels] either skip NZ altogether or they do one port call and then at short notice, they will request all these containers from the South Island to be in Tauranga or Auckland or something like that” (FO2). Expanding on this, it was noted that international lines would not add additional services to NZ as it would impact existing commitments: “The international lines definitely have [carrying] capacity. They just do not necessarily want to slow themselves down through the NZ leg of their travel with extra domestic moves” (PO3). In short: “we run a very vulnerable shipping network in NZ ” (TU5).

Therefore, rather than increasing the time international vessels are visiting NZ seaports, there would instead be changes to the existing schedules: “[International lines] would not increase services. They would utilise their existing capacity. They do not make money out of putting more services on” (PO1). “[We have] numerous vessels transiting up and down NZ’s coastline, we have the ability, subject to need, to adjust NZ’s supply chain internally [...] we are talking about the coastal net, and we can do that [...] amongst our international commitments [...] pretty quickly. (TO7). If the port calls were to be changed, there would be added costs: “What would need to be factored in is the ability for importers, exporters to fund that difference to go [...] to another port, be it [...] Tauranga, be it Auckland” (TO7).

In addition to adjusting port calls, the repositioning of empty containers can be utilised: “We move a heck of a lot of empty containers between points in NZ. It is a part of our domestic repositioning requirements. So, our imports are largely in the top half of the North Island, and our exports are heavily weighted throughout the country [...], so if there was the ability to move boxes between Auckland to Lyttelton, it could be a bit of a saving in terms of repositioning and utilising space, which ordinarily would have been empty” (TO7).

Another solution raised was to utilise vehicle carrier vessels: “We would probably have to get some vehicle carriers [...] with the quarter deck that comes down onto the wharf” (FO2). However, finding suitable vessels takes time: “There are plenty of vessels around with quarter ramps. You just look at the car carriers. They go in a movement from north to south as well, or at least from Wellington to Nelson and so on. I do not see why somebody should not use those for emergency transfer of freight. The decks would not be designed for fully loaded 30-tonne containers, but then most FMCGs are not. So I think that would be something that I would try pretty quickly” (IR2).

#### 6.11.6 Seaport infrastructure constraints

In any case, even if coastal shipping and the Cook Strait ferries were used, adequate seaports would need to be available: “The resilience of freight and supply chains rests on the resilience of our port infrastructure” (IR4). One interviewee noted the lack of incentive to improve resilience: “[The] linkspans and wharves in Picton and Wellington are owned by the harbour companies. And so, if there is something wrong with the wharves, then it is their job to fix them” (FO2). Because “ports are owned by [the] regional council [they] see them as a revenue source to subsidise rates. [Therefore] maintenance is often deferred, and that is why we have got 120-year-old berths [...]. So, if we lean heavily against one of these wharves and we do damage to the wharf, it is an insurance claim. You need to repair the wharf” (FO1). In a recent example, “Cook Strait ferries have clipped the edge of the wharf [...] the ferry was basically undamaged, and the end of the wharf just turned into dust. Just fell apart. So there is certainly an issue around the country where there is some port infrastructure that needs to be made more resilient now, either that is replacing it or upgrading it [...], some investment would certainly go a long way there (IR4).

The quality of seaport infrastructure was raised following the Kaikōura earthquake, which damaged infrastructure at CentrePort: “There is a reasonable amount of port infrastructure that is not in good condition. So, for instance, when CentrePort was out [...], you could go to Whanganui, but the primary wharf in Whanganui is being allowed to deteriorate into such a state you cannot put a crane on it to unload freight [...]. It is often the smaller or more provincial ports that need that assistance, and that is the key infrastructure” (IR4). In other words: “We [NZ] [...] have not really invested much in port infrastructure” (TU1). In the context of Port Whanganui, the lack of resilience is attributed to a lack of funding: “[Whanganui] cannot put a proper crane on their wharf [...] it is very difficult for them to afford to essentially replace a wharf because they are a relatively small council with limited funds” (IR4).

At times, seaport constraints are not physical, such as a lack of funding to improve resilience, but are instead policy constraints. For example: “In Tauranga, they are trying to get a resource consent for three or four years. And to me, those are more stroke of the pen exercises [...] because someone else is quite happy to put up the money. So, making sure that the ports are able to keep up with growth and that is not just for resilience, I think that is [so] we as a country can grow, and as a trading nation, we need that, especially in our big ports. You need to create the framework that people can invest in the infrastructure” (TO5). In any case, it is important that seaports are resilient: “Ensuring that the ports are in a position to maintain [...] resilience, I think, is what is key” (PO3).

#### 6.11.7 Seaport capacity shortages

Another potential constraint at seaports is the capacity, which is already constrained, such as the available yard capacity at seaports. “Some of those [port] operations around the country are relatively maximum capacity now” (TO1). “You look at Auckland; it is pretty [much] at capacity as I understand it” (IR1). “Can [Nelson] port handle that increased capacity? I am pretty sure the answer would be no; they will not be profitable businesses if they have got the

asset structure and the capacity to just turn that on” (TU4). Two of the seaports interviewed provided estimates of their current yard capacity: “On average, it is probably sitting at 85%” [...] That is pretty normal if I averaged out, I guess, the last few years” (PO4). The other seaport noted: “We tend to aim to run [...] about 80% [...] more than 80% you get very congested and you get into a position where you are moving cargo to get to other cargo, rather than it being a natural flow [...] if it was a 10 or 15% increase for a month or two, we would be able to accommodate that [...]. It would move us from a normal amount of volume to a peak or just above volume. It would take close management. Our service level, no doubt, would not be at premium level [...] because there would be some additional congestion” (PO3).

Another constraint at seaports is productivity, which impacts the number of ships that can be serviced: “Each shipping line in the ports has a number of moves allocated by the container cranes [...] for discharge or for loading [...], and that includes empty container repositioning [...], so, we are generally maxing out on the move counts in each port rather than on the ship capacity” (TO5). “Infrastructure is our problem, and productivity [...] we are struggling to get what we need to get done efficiently, we could do more, but the problem is the landside productivity” (TO7). As a result of this poor productivity, schedules have been adjusted: “Until March this year [2023], [we] called four ports each week [...] [now it is] three ports per week [...] we have also condensed the distance the ship travels. [...] [due to] more frequent [weather] events and the poor [port] productivity [...] so for us, we have adjusted our service offering to build a bit more resilience into our own schedule, but [...] we have seen a lot of disruption over the past few months. So, it is basically a weekly, if not daily, challenge to address schedule disruption” (TO5).

Another challenge raised is the cascading disruptions through seaports: “If there is a trouble spot [such as a congested seaport], we might avoid that, go somewhere else first, which has its own issues because, of course, when we stow vessels for discharge, it is normally in vessel discharge port order” (TO7). The consequence of this is that vessels need to perform “restows, which [is when] you have to pick up a box that is blocking a box that you need to access. That is not a normal feature of the way that we would stow our ships, and is [...] related to a delay and or problems getting into a port [due to] delays and congestion at that port or the inability to perhaps complete a discharge at that port” (TO7). In other words, “one inefficiency in one significant port then just flows right through the whole system. So, [...] as soon as you have got a delay in a ship trying to pick up freight in Auckland [...], then you lose [...] your berth at Tauranga, which is your next port. So [...] you do not know when you are going to get into Tauranga, which means then you lose your stopover in Napier, then you lose your stopover in Wellington, [...] Christchurch and Timaru and Dunedin, they all go, and you have got no certainty about when you are going to get into any one of those ports. And any delay in any one of those ports, that means you lose any other bookings you have got all the way down the coast again in a second time” (IR4).

Another issue with congestion is its flow-on effects: “Port Chalmers has an on-flow effect from Lyttelton’s congestion, and then cannot take all the vessels and then have a build-up of containers. Within 24 hours, they shut their port [and we are] almost stopping production”

(TU2). Adding to the disruption is the fact that: “it is still pretty common for coastal ships not to know when they can actually sail into a port and have a berth” (IR4).

To reduce such disruptions, seaports need to be productive: “There is always one bottleneck. [...]. At the container terminal, it is very much our productivity and our crane intensity on the wharf. So, the speed at which you handle vessels is [determined by the] berth rate, how quickly you are turning a vessel around, and that is a combination of how fast your cranes are working and how many cranes are working at any one time. So, we are very comfortable with the speed that our cranes work at [...]. Our capacity is limited by our crane intensity, so that is probably the limiting factor [...]. At the moment, the headcount will only stretch as far as X number of cranes per day, and if you want to do more than that, you need to increase the head count, which obviously comes with recruitment training and cost” (PO3). “For profitability reasons, you do not have extra headcount if you do not need them. So, there is a fine line between how you grow your headcount and your fleets of container handlers alongside the predicted growth, both natural and any additional trade that is coming through” (PO3).

One of the issues in the sector is that there are retention issues with skilled labour: “We do lose people to Australia, for instance; they get paid more over there. So, we are kind of a bit of a training ground here in NZ in that aspect” (PO4). Retention issues were also noted to occur domestically due to labour shortages: “The issue with coastal in my mind is there is not the right amount of people or calibre of people in NZ, so you need masters, you need tuggers, you need engineers, you need maritime people [...] all that is happening is they are fighting, and they are employing people off the likes of the Cook Strait ferries” (PO1). At the same time, there is a shortage of labour within the sector globally: “[There is] a global shortage of seafarers. So NZ does not even produce a decent fraction of the seafarers we use domestically [...]. We have got a very aged workforce [...] more people still working in the seventies than we do in their twenties” (IR4). Therefore, if there was a sudden need to increase coastal services, the labour sector would fall short. In other words “there are some really severe constraints around our ability to really ramp up the coastal service” (IR4).

Moreover, these roles require skilled labourers, who have to be trained through a seaport: “You cannot train for being a crane driver or a straddle driver anywhere outside but in a port [...] there is no Unitec or university type facility outside that actually provides that sort of training” (PO4). Furthermore, training takes time: “There is obviously a lag in the time that it takes to get people trained up to a standard [...] It would be a challenge in terms of what you are asking about if we had to suddenly increase it” (PO3).

One suggestion to reduce the dependence on international seafarers and an aging workforce is to attract younger people to the sector, despite perceptions it is unattractive: “It is not the most attractive industry possibly for school-leavers to go into [...] [however] you could tell someone, say in year 11 [high school] who may not be super academically inclined, they could go into shipping, whether it is fishing, coastal freight, whatever. And within two years, they will be earning eighty to one hundred thousand dollars a year and 50% of the year is paid holiday time, and while you're working, all your food and accommodation and everything paid

for” (IR4). Despite the attractiveness of the sector from this perspective: we are not having a great number of New Zealanders entering the system” (IR4). “And if [a major earthquake] happened, again, you will get to where we were in Tauranga [during COVID-19], where they were all sitting out waiting for a week to be unloaded” (TO1).

The ability of the seaports to accommodate additional port calls also depends on the time of year: “If [the earthquake and tsunami] was outside of, say, [the] start of October through to the middle of December [...] there is generally capacity in both the shipping and in the terminal. So [...] we would be more than capable of stepping up to go because we have that level of seasonality anyways, and we obviously need to be able to serve our customers at peak season, so you have some labour capacity the rest of the time” (PO3). In some instances, seaports may have to take drastic measures to accommodate increased port calls: “How do you create room for more coastal freight ships to move all the freight that the Cook Strait ferries move into [...] Tauranga or in Auckland? unless you cancel some things, they just do not fit. [...] You would see massive disruption at pretty much every other significant port in the country. [...] [If] suddenly you had to ramp up the vessels coming into those ports [...] you would have to look at some pretty dramatic things. Do you just cancel? Does the government intervene and basically cancel cruise ships for a whole year? That will free up freight ships getting into those berths, for instance” (IR4).

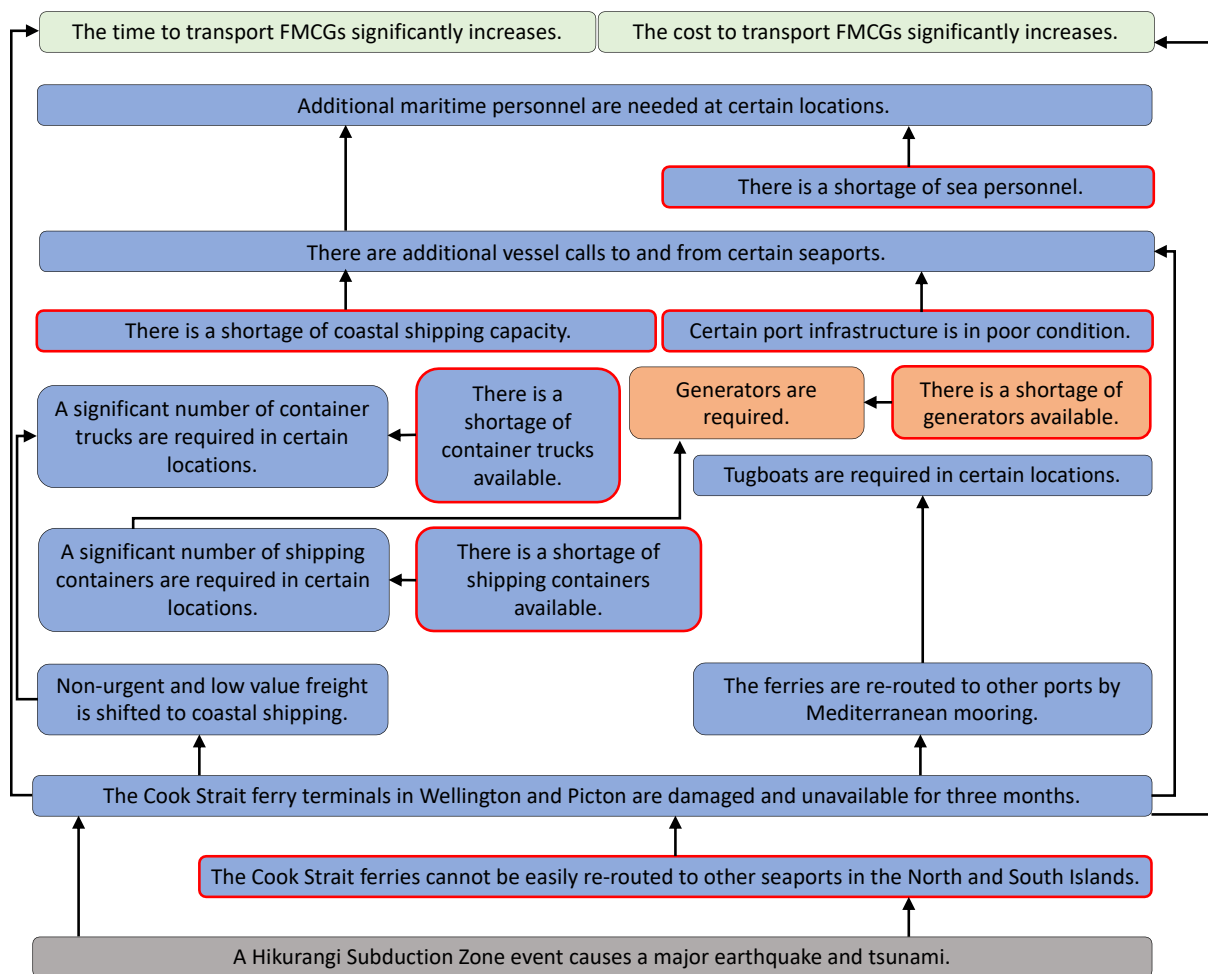


Figure 52: CRT snippet for sea constraints

## Proposed injections

### Acquire floating linkspans and a barge:

To overcome the need to Mediterranean moor (manually moor) the Cook Strait ferries, which is inefficient. Having backup floating linkspans and a barge at alternative seaports would enable the ferries to be easily rerouted to other seaports, reducing the time it takes to move goods between the North and South Islands.

### Address barriers to purchasing new vessels:

Clarity is given around future marine fuels in NZ.



## 6.12 Root causes

The final CRT diagram was constructed using each of the CRT snippets identified. As discussed earlier, the relationships between each of the UDEs underwent a set of 6 stages (Scheinkopf, 1999). Throughout this process, two additional root causes were identified as being responsible for the UDEs mentioned by interviewees. The additional root causes include:

- Key service stations do not have backup power sources available
- Key cell towers do not have backup power sources available

Root causes by sector	Constraint
<b>Electricity</b>	
Key service stations do not have backup power sources available	Physical
There is a shortage of generators available.	Physical
<b>Telecommunications</b>	
Key cell towers do not have backup power sources available	Physical
<b>Fuel</b>	
Fuel infrastructure in Kaiwharawhara is not resilient.	Physical
There is a shortage of onshore fuel holdings.	Physical
<b>Data</b>	
There is no single source for essential information following disasters.	Physical
Systems are largely not interoperable and data cannot be shared easily.	Physical
There is no prioritisation system for post-disaster freight movement.	Physical
<b>FMCG operations</b>	
Certain perishable goods spoil quickly and require strict temperature control.	Physical
There is a preference for organisations to run lean.	Physical
<b>Road</b>	
Roads are designed for a certain level of traffic.	Physical
There is a shortage of road personnel.	Physical & policy
<b>Rail</b>	
The majority of the rail network is single-track and lacks redundancy.	Physical
<b>Air</b>	
There are limited freight aircraft available in NZ.	Physical
There is a shortage of air personnel.	Physical
<b>Sea</b>	
There is a shortage of container trucks available.	Physical
There is a shortage of shipping containers available.	Physical
The ferries cannot be easily re-routed to other seaports in the North and South Islands.	Physical
There is a shortage of coastal shipping capacity.	Physical & policy
Certain port infrastructure is in poor condition.	Physical & policy
There is a shortage of sea personnel.	Physical

Table 10: Root causes by sector

## Chapter 7: Discussion

*This chapter reviews the findings and existing literature to address the research questions and explore solutions and recommendations for the identified constraints. By exploring potential solutions, the chapter shows the construction of the ECs and the FRT.*

### 7.1 Structure of the discussion chapter

This chapter provides a number of EC diagrams, which were used to build the final FRT at the end of the chapter. The solutions (injections) used in the ECs and FRT were identified either in the interview data or in the existing literature. Again, the colour schemes from the categories identified in the qualitative data were used, and to represent injections, coloured borders were used. As shown in Figure 54, blue borders were used to represent short-term solutions, green for long-term solutions and purple for when work is already underway. The types of these solutions are included in the diagrams throughout this chapter and in the final FRT at the end. The subsequent sections detail the value of TOC TP in post-disaster freight systems, the short-term solutions, long-term solutions, and those that are currently underway.

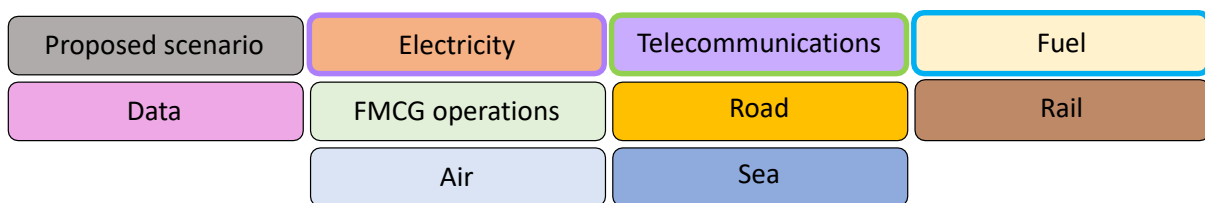


Figure 54: Types of categories identified in the qualitative data and the identification of injections

As shown in Figure 55, this chapter finishes addressing the second research question through the development of the ECs and addresses the third question through the development of the FRT. At the end of this chapter, the final FRT, which is a primary research output, is provided.

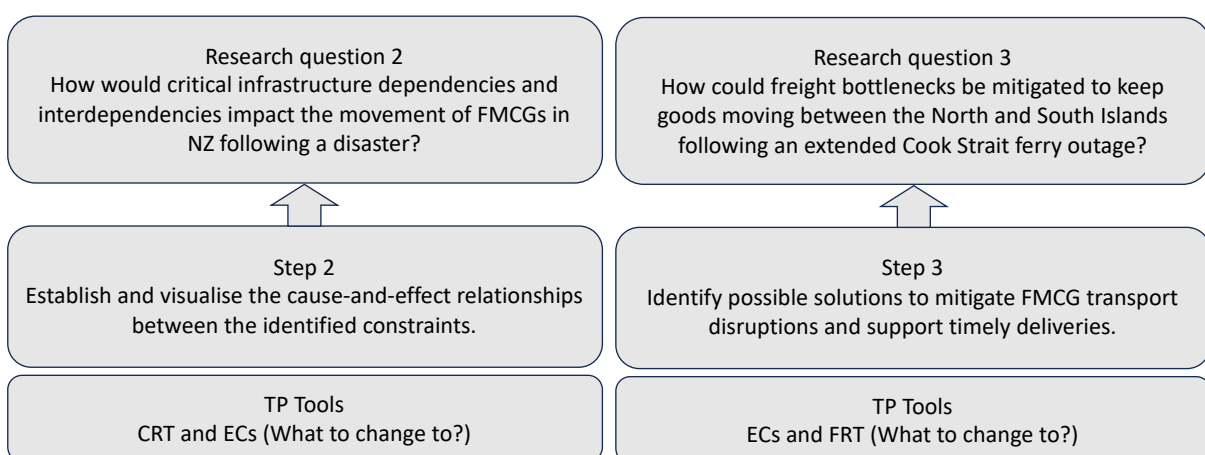


Figure 55: Addressing research questions 2 and 3

## 7.2 Using TOC TP to make sense of complex post-disaster freight systems

As the findings chapter has shown, the CRT can help make sense of complex post-disaster freight systems by identifying causal relationships between UDEs and the root causes responsible for them. As the CRT was constructed as the interviews took place, initially, transport users expressed that in a Cook Strait ferry outage, freight would be shifted to coastal shipping, which would become the primary constraint. Although interviews with coastal shippers revealed that the constraint is not the capacity of coastal shipping, as already they are unable to fully load and discharge vessels. Instead they are constrained by the container moves assigned at seaports. However, seaports then revealed that the constraint underlying this was ultimately productivity, which can stem from labour, or in the case of NZ's largest seaport, the challenge is gaining resource consent to extend its berth and introduce an automation project (Port of Tauranga Limited, n.d.). Figure 56 provides an overview of these insights. Therefore, as the TOC literature states, constraints that appear to be physical (bottlenecks) can actually be the result of underlying policy (Dettmer, 2007). Therefore, rather than trying to address and remove the physical constraints, policy needs to be revised or replaced (Dettmer, 1995).

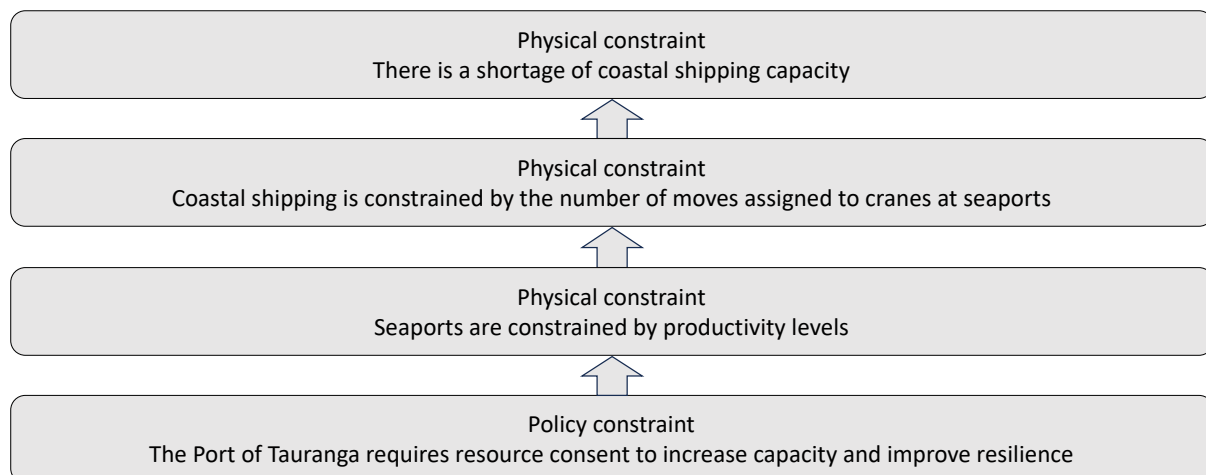


Figure 56: Identifying underlying policy constraints

## 7.3 Short-term solutions and challenges

### 7.3.1 Prioritisation system

As the findings show, a prioritisation system will need to be established. Such a system can be expected to have two stages. First, an initial response system can be set up so that emergency needs, such as emergency management requirements, can be taken care of. The Wellington Earthquake National Initial Response Plan (WENIRP) outlines a system for air, sea and land movement prioritisation, as seen in Table 11 and Table 12 (Civil Defence, 2018a). Notably, such a detailed system does not appear to exist for a Hikurangi Subduction Zone event. Therefore, in the proposed scenario, it can be expected that similar priority will be given to freight as outlined in the WENIRP. In other words, food and water will receive initial priority. However, in addition to an initial prioritisation system like WENIRP, there would need to be another one to determine longer-term prioritisation of freight. The findings showed that this proved to be challenging during COVID-19, as police checkpoints were required to determine

if freight was critical. As an alternative, it was suggested that the government could work with seaports to determine what goods are prioritised. As a current system does not exist, there may be the ability to incorporate such a system into AMDS, which is discussed at the end of this chapter in section 7.5.

Movement prioritisation - air				
Priority	Inbound			Outbound
	Helicopters without freight capacity (4-6 people)	Helicopters with up to 1 tonne lift capacity	Helicopters with greater than 1 tonne lift capacity and fixed wing aircraft	All Helicopter types
1	Emergency response personnel	Airborne firefighting	USAR (deployment and sustainment)	Patient evacuation — as prioritised by clinical staff.
2	Reconnaissance	USAR (deployment and sustainment)	Emergency Medical Teams, including equipment and consumables Emergency Supplies	NCCMC and NCC Staff Relocation of Government, if required
3	VIP (including international) and media	Emergency supplies	Priority commercial needs	Emergency response personnel
4	Transport of data	Emergency response personnel	Emergency response personnel	Visitors and members of the public - as prioritised by Wellington Region ECC/EOCs
5	Priority commercial needs	Emergency Medical Teams, including equipment and consumables		
6		Priority commercial needs		

Table 11: Prioritisation system for air movement (adapted from Civil Defence, 2018a)

Movement prioritisation - sea and land		
Priority	Inbound	Outbound
1	Diesel (fuel tankers and barrels on flatbeds)	Patient evacuation (if appropriate and as directed by NACCC: see section 4.3.3 Patient movement on page 41)
2	Earthmoving equipment (until sufficient road access is available)	Personnel critical to the functioning of government and management of the response
3	Supplies for population (water, food, shelter, LPG for cooking)	Empty trucks for reloading
4	Emergency services (Police, Fire, Ambulance) and CDEM personnel	Evacuation of the visitor and vulnerable - as prioritised by Wellington Region ECC/EOCs
5	Urban Search and Rescue	
6	Medical supplies, equipment and personnel	
7	Fire-fighting supplies, equipment and personnel	
8	Lifelines (poles and wires, water bladders, telecommunications)	
9	All other requests	

Table 12: Prioritisation system for sea and land movement (adapted from Civil Defence, 2018a)

### 7.3.2 Extending the shelf life of perishables

Unsurprisingly, coastal shipping, including re-routing the ferries, would not be suitable for a lot of freight due to increased travelling distances and limited power slots, while air freight has limited capacity and high costs. In light of this, the findings acknowledged that certain produce would need to undergo treatment to extend its shelf life. To achieve this, ‘putting to sleep’ (preserving) or freezing certain produce may be possible. One way to achieve this is through ‘modified atmosphere packaging’, which is used to prolong the shelf life of fresh or minimally processed goods by changing the composition of the air around the food. This is done through a combination of gas mixtures (O<sub>2</sub>, CO<sub>2</sub> N<sub>2</sub>), and the technique can be used on a wide range of produce, including stone fruits, kiwifruit, strawberries, broccoli and mushrooms (Sandhya, 2010).

Alternatively, pre-storage exposure to short-wave ultraviolet radiation (UV-C) has been shown to extend the shelf-life of fresh strawberries for up to 7 days (Ortiz Araque et al., 2018). Furthermore, freezing offers another way to extend the shelf-life of produce. However, unlike other preservation methods, moving produce to a frozen state negatively impacts the quality of the produce (Chaves & Zaritzky, 2018). Given it typically takes four days to move freight by coastal shipping (Hyder Consulting, 2008), these solutions could enable certain perishables to withstand the longer journey of coastal shipping.

### 7.3.3 Storage and distribution of FMCGs

Given the inefficiencies of rerouting the Cook Strait ferries, interviewees acknowledge that coastal shipping will be essential in keeping freight moving between the North and South Islands. To facilitate this shift, suitable distribution hubs (intermodal terminals) and adequate storage facilities will be required. The findings show that Palmerston North would serve as the primary distribution hub for the lower North Island and Christchurch. However, it is likely that Christchurch would not have sufficient capacity. In this case, it was proposed that Timaru could be used as a secondary site due to its access to the rail network and ambient and reefer storage facilities. In any case, the availability of ambient and refrigerated storage facilities will play a key role. However, the majority of the existing storage facilities are owned by private companies, and therefore, future research would be needed to determine the available capacity following a major disruption.

### 7.3.4 Utilising air freight capacity

Interviewees revealed that ten trucks worth of freight (around 25 to 30 TEU) would roughly equate to 7 Boeing 737-400 flights or around 4TEU per flight. However, because air freight runs lean, there is not sufficient labour available domestically to significantly increase the services, nor would it be feasible for most FMCGs. Therefore, given that air transport is significantly more expensive than other transport modes and is limited in its carrying capacity, air freight will primarily cater to urgent goods and higher-value goods that can absorb the added costs. Although there has been an increase in freight aircraft, participants noted that there is still likely to be a shortage of both aircraft and skilled personnel.

To address this issue and ensure critical goods can continue moving, freighter aircraft could be wet-leased from overseas. Doing so provides a flexible solution that removes the need to purchase aircraft and find and hire crew (Hsu et al., 2013). In other words, a wet lease would enable a timely response to the disruption, overcoming shortages of aircraft and personnel. It is also expected that the NZ Air Force will utilise its available assets to help move priority goods in addition to the emergency response.

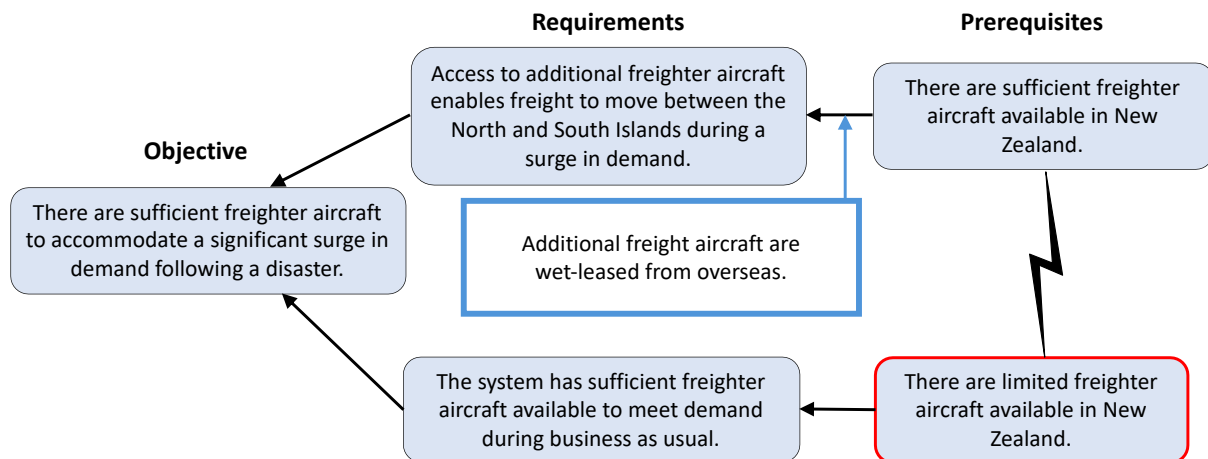


Figure 57: EC for freighter aircraft

### 7.3.5 Re-routing the Cook Strait ferries (Mediterranean mooring)

Despite the significance of the Cook Strait ferries, interviewees expressed that the ferries could not be easily re-routed to alternate seaports due to the absence of linkspans or, in some cases, the quality of the linkspans. In the absence of this infrastructure, the ferries would have to be Mediterranean moored, which is achieved by securing the stern of the ship perpendicular to the pier with tug boats. Figure 58 provides a comparison of berthing with a linkspan and Mediterranean mooring. The reason the ferries have to berth this way is because the loading ramp is at the stern of the ship. Not only is this approach more complex, but it is inefficient as it can prevent the remainder of the seaport from being used (Civil Defence, 2018). Consequently, this would mean that if the ferries were re-routed to alternate seaports, existing seaport operations would be impacted, as normally, vessels would berth parallel to the pier.

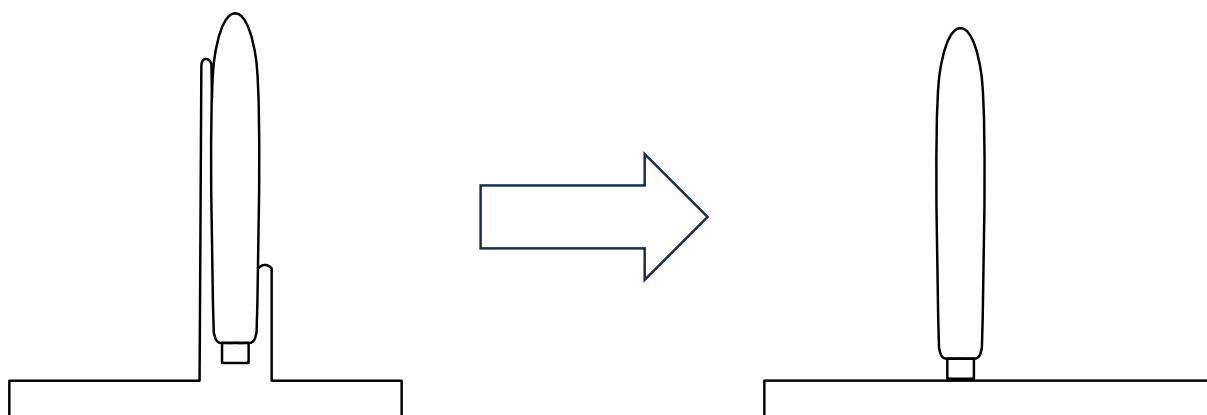


Figure 58: Comparison of berthing with a linkspan and Mediterranean mooring

In the absence of the Wellington and Picton ferry terminals, interviewees acknowledged a service could potentially be run between Port Nelson and Port Taranaki. This route would be the most attractive, as it provides the next shortest distance between suitable seaports in the North and South Islands. At a speed of 19 knots over 145 nautical miles (Land Information New Zealand, 2022), it will take about 8 hours and 15 minutes to sail one way, which includes around 30 minutes for manoeuvring (King et al., 2017). Even if the ferries could berth, load and unload freight in the typical two-and-a-half-hour window, a return sailing between the North and South Islands would take around 20.5 hours to complete, as opposed to the traditional 12 hours, an increase of at least 70%. Another challenge identified with this service is the surge at Port Taranaki, which could close off access to the port for three days out of seven (Civil Defence, 2018).

From a financial perspective, past research into valuing the time and reliability of ferry freight (retail, manufacturing, and other higher-value commodities) revealed that, on average, per truck per hour had an associated value of \$21.87 NZD (Wallis & King, 2020). Therefore, if the ferries were to be rerouted to the next shortest distance, there would be an associated loss of value at around \$185.89 per truck as a result of the additional 8.5-hour journey.

Alternatively, in the absence of Napier Port and Eastland Port, the next closest seaport in the North Island would be the Port of Tauranga, which, based on the earlier calculations, would take around 65 hours to complete a return trip from Port Nelson (Land Information New Zealand, 2022). The limitation of operating the ferries over longer distances is that they have a limited carrying capacity, at a maximum of 275 trucks and 80 TEU of rail freight, as seen in Figure 59 (Ministry of Transport, 2022a). In other words, as one interviewee notes, the ferries are designed for a quick turnover of freight and are inefficient in operating over long distances. In contrast, the replacement iReX vessels would have been better suited to longer journeys. For instance, as opposed to Interislander’s three vessels, the two new ferries would have a carrying capacity of 300% more rail freight and almost double the number of trucks of the existing three ferries (iReX, n.d.a).

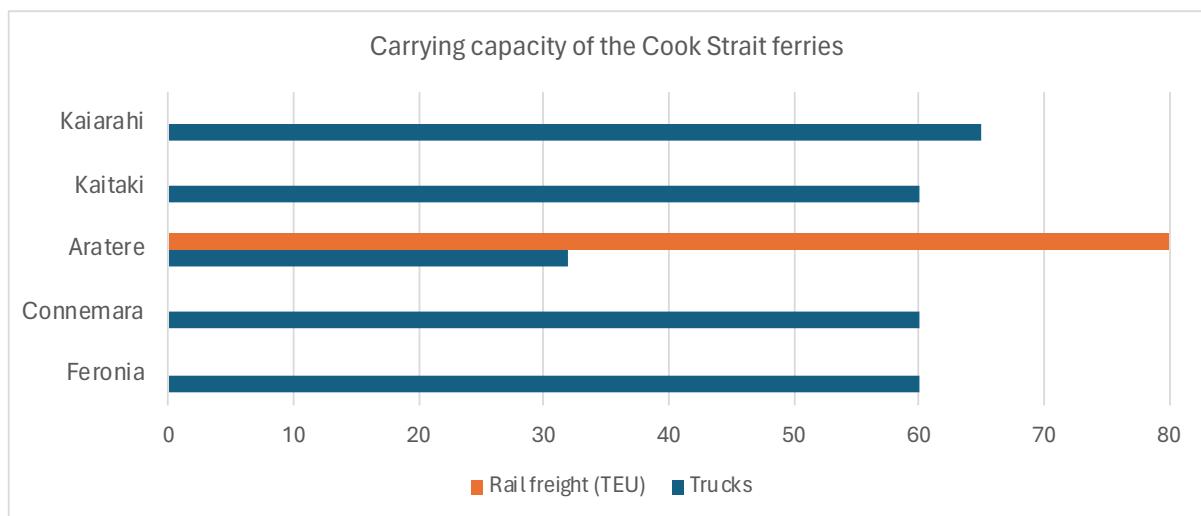


Figure 59: Carrying capacity of the Cook Strait ferries

A further limitation of rerouting to alternate seaports is that the Wellington and Picton ferry terminals have specific facilities to support road-bringing operations for handling rail freight (KiwiRail, 2017a). Therefore, if the Aratere were to move rail freight through alternate seaports, the time required to road-bridge freight would increase beyond the typical two and a half hours. It is also possible that not all five vessels would be available as a result of scheduled maintenance, where the ferries have to go overseas for around one month, with a return sailing journey of around 28 days (Scoop, 2024). The reason for this is that NZ does not have a suitable dry dock to cater for the ferries (and domestic coastal vessels) (Pacific Marine Management Ltd, 2021a).

### 7.3.6 Utilising empty container repositioning

However, shifting RoRo freight to coastal shipping requires containerisation, meaning the right quantity and type of shipping containers will need to be available in the right place (Twede & Clarke, 2004). Generally, NZ runs at a container deficit due to exporting more goods than it imports (Stats New Zealand, n.d.). At the same time, most imports arrive into the North Island through the Port of Tauranga and the Ports of Auckland, while exports are generally more evenly spread throughout the country, as seen in Figure 60 (Ministry of Transport, 2023c).

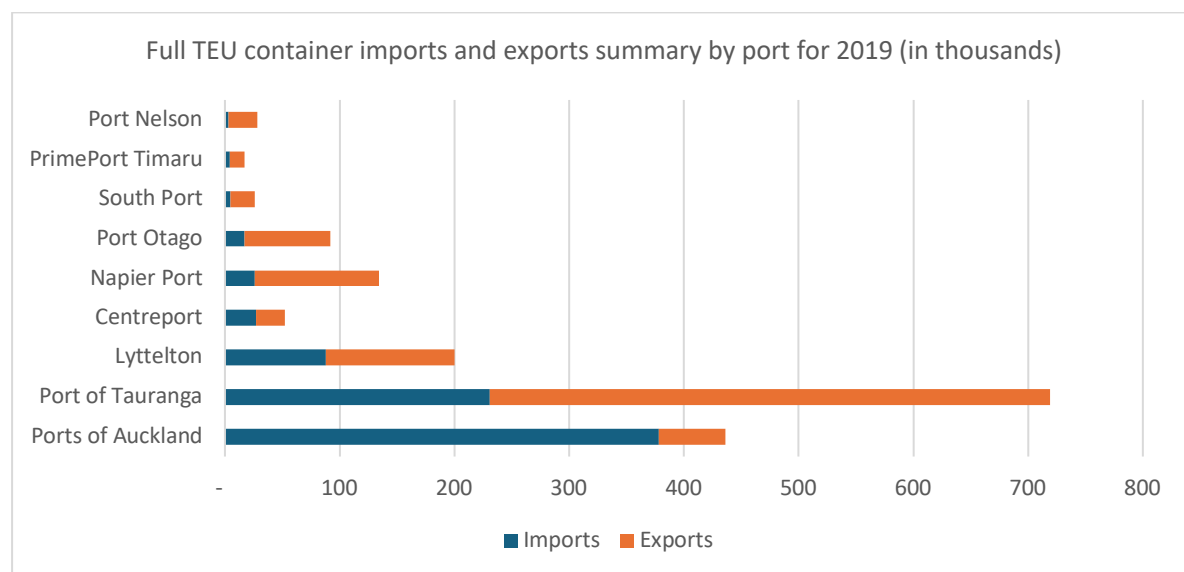


Figure 60: Full TEU container imports and exports summary by port for 2019 (in thousands) Adapted from (Ministry of Transport, 2023b)

Because of this imbalance, empty container repositioning is a significant component of the coastal shipping task (Pacific Marine Management Ltd, 2021a). As the interviewees note, repositioning empty containers, which is generally inefficient, would be favourable in an extended Cook Strait ferry outage, as freight could be loaded into containers that would otherwise be travelling empty. When quantifying the empty carrying capacity across domestic and international vessels, around 39,058 TEU was moved over a three-month period for FY19. Of this, around 88% of empty container movements were performed by international vessels, highlighting the dependence on international lines (Pacific Marine Management Ltd, 2021a).

Although this solution would overcome the need to source empty containers, it would also impact port operations. For instance, rather than an empty container arriving at the Ports of Auckland to then be repositioned to the South Island, it would need to be taken offsite, loaded with freight and brought back into the port as a full container. As a result, there would need to be container trucks and drivers available to support this, which interviewees acknowledged there would be shortages of. A further limitation is that reefer containers are limited to the number of power slots on the vessel. For instance, the two domestic vessels have a total of 558 power slots (Pacifica Shipping, n.d.). Therefore, this solution would be best suited to preserved freight or freight that can handle the typical 4-day journey (Hyder Consulting, 2008).

### 7.3.7 Utilising available coastal shipping carrying capacity

Another solution was to utilise the available carrying capacity on vessels. Based on the estimated available capacity on existing domestic vessel schedules, Pacifica’s two dedicated container vessels could move around an additional 2,491 containers weekly. However, because of the general imbalance of freight flows, 60% of these containers would be northbound and just 20% southbound. The limitation of this is that northbound freight is often perishable freight, which would have to be preserved due to the limited power slots on the vessels. Conversely, non-perishables typically travel southbound would sustain the longer journey but are constrained by the available carrying capacity. Figure 61 provides an overview of the available TEU capacity from utilising empty container repositioning and the spare capacity available on domestic vessels in contrast to the TEU equivalent of freight moved by the Cook Strait ferries during business as usual (based on the assumption that 2.5 TEU is required per truck as revealed in the findings).

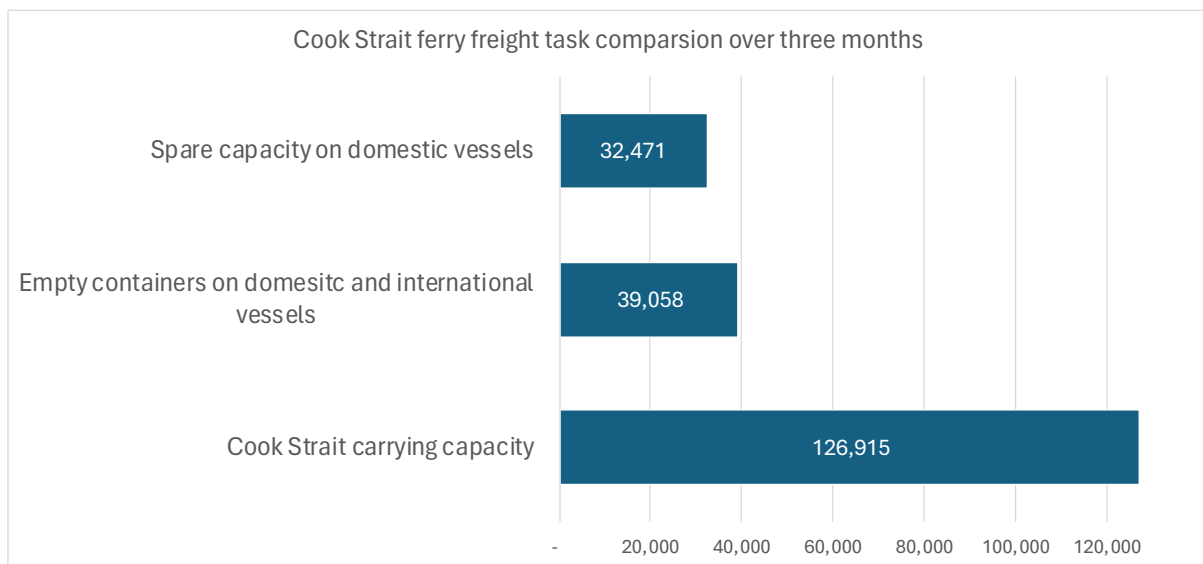


Figure 61: Cook Strait ferry freight task comparison over three months

As for international vessels, interviewees explained that the lines would not add additional services but instead re-arrange existing seaport calls in line with their international commitments. In other words, because of NZ’s geography, the country has weak international connections (Landfall Strategy Group, 2022). This was further evidenced by interviewees noting that international vessels have been known to skip seaports, require containers to be

moved to alternate seaports for collection, or reduce the frequency of services. One example of the reduction in service frequency can be observed in Maersk’s decision to withdraw its dedicated NZ coastal shipping service after less than one year of operation, as NZ is typically a low priority for international lines (Barry, 2023). The trend of fewer international voyages can be seen in Figure 62 (Ministry of Transport, 2023c), which supports the argument that NZ is viewed as a lower-priority country in the international context.

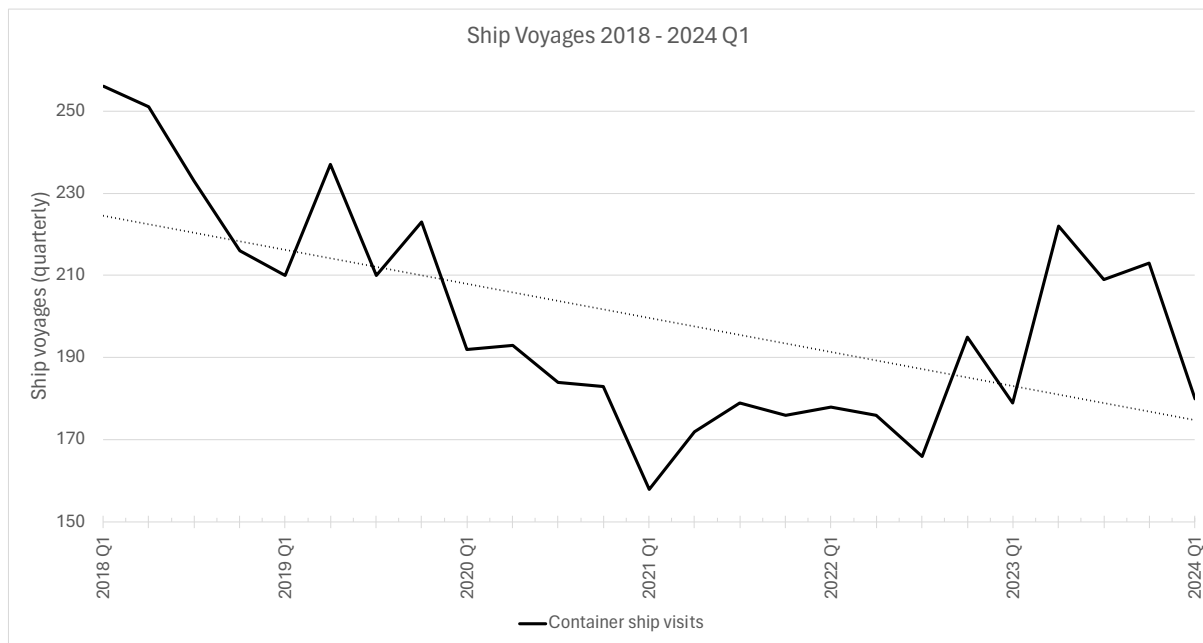


Figure 62: Ship voyages in New Zealand from 2018 - 2024 Q1 (adapted from Ministry of Transport, 2023c)

The use of car carriers was noted as a potential solution, although the available carrying capacity when they call into NZ seaports and whether or not they could extend the time in NZ is unknown. Moreover, as with international ship visits, there has been a decline in the number of vehicle carriers calling into NZ seaports, decreasing from 201 annual visits in 2018 to just 153 in 2023 (Ministry of Transport, 2024). Therefore, it can be expected that there will be a nominal 38 vehicle carriers calling into NZ seaports over a three-month period. Given how irregularly these vessels call, the available capacity is unknown. In any case, further research is needed to understand how practical this would be as a solution. A further suggestion was to charter a vessel from overseas, as was done by Interislander chartering the Valentine in 2022 (Moffiet, 2021). However, as the findings show, there is a global shortage of vessels, and finding a suitable vessel can take months, as was the case when chartering the Valentine.

### 7.3.8 Maritime resource shortages

In any case, the ability to use container vessels comes down to the availability of container trucks, qualified drivers, and containers, which interviewees advised there would be shortages for all three. To demonstrate the severity of the shortages, the findings estimate that the Cook Strait ferries moved on average 3,281 trucks each week for FY19, and if 2.5 to 3 TEU is required to absorb the FMCGs being moved, it would equate to around at least 8,203 containers per week. As for rail freight, around 466 rail wagons were moved each week for FY19. Assuming 59% of these wagons are intermodal (KiwiRail, 2018), a total of 8,394 containers

would be required weekly to keep goods moving. To provide perspective, the Kaikōura earthquake resulted in shortages of container trucks, containers and truck drivers (L'Hermitte et al., 2023), despite only the rail network being completely unavailable, which makes up around 17% of the Cook Strait freight task (Pacific Marine Management Ltd, 2021a). In other words, if the ferries themselves were taken out, the resource shortages would be significantly more severe than they were following Kaikōura.

A further obstacle to containerisation is that FMCG organisations generally operate curtain-side trucks rather than container trailers, (L'Hermitte et al., 2023) as they can be loaded from the side by a small forklift, as opposed to a container with end doors (Pacific Marine Management Ltd, 2021a). In other words, FMCG organisations would struggle to load standard containers. One way to overcome this is through the use of curtain-side containers, which are used by local organisations such as the CODA Group and Royal Wolf. The value of these containers is that, like curtain-side trucks, freight can be loaded from the sides, and, in some instances, the containers include a mezzanine floor (CODA Group, n.d.; Royal Wolf, n.d.). Therefore, the containers provide the access advantages of curtain-side trucks when loading and unloading freight, as well as the modality benefits of containerisation, as they can be easily shifted between road, rail, and coastal shipping (Inghels et al., 2016). Despite the value of these assets, it is unclear how many would be available following a major disruption, such as a Cook Strait ferry outage.

Although redundancy can be achieved by purchasing additional resources, such as shipping containers and container trucks, such a decision requires substantial capital investment, and there is no certainty about when these additional resources would be needed. As a result of this high cost and lack of clarity around the return on investment, long-term equipment decisions would require government funding (L'Hermitte et al., 2023). If containers were to be purchased to serve as a buffer, it would be worthwhile for them to be curtain-siders due to the intermodality benefits discussed in this thesis. In any case, further research is needed to explore who should bear the cost of such resources (L'Hermitte et al., 2023).

In summary, during business as usual, NZ generally has sufficient capacity across freight-related resources. However, following a disaster, there is a sudden surge in demand for limited resources, resulting in shortages (Saleh et al., 2021). Consequently, these goods will need to be sourced from overseas to address this shortage, and due to the size of these resources, they will need to be moved by sea, incurring long lead times as was observed following the Kaikōura earthquake, where new containers ordered from China entailed a five-week delivery time (L'Hermitte et al., 2023). Furthermore, these resources will still need to be repositioned when they arrive in NZ so that they are available where they are needed.

### 7.3.9 Seaport yard capacity

Even if there were sufficient resources, the solutions discussed earlier are only viable if the seaports have the capacity to accommodate the additional throughput. At the time of the interviews, insight from one of NZ's largest seaports acknowledged they were operating around 80% yard capacity and could accommodate a temporary increase of up to 15%, which equates to around 17,000 TEU over three months. Another major seaport reported operating at around 85% yard capacity, which, if they too could support a similar increase, would equate to around 20,000 TEU. As for the Port of Tauranga, it can handle around 1.5 million TEU annually (Port of Tauranga Limited, 2022), which, based on 2023 volumes of 1.18 million TEU (Port of Tauranga Limited, 2023), means that the port operates at around a nominal 78.5% capacity.

The implication of seaports already operating near maximum capacity is that, eventually, ships will need to be rerouted to other seaports that have sufficient capacity available (Komaromi et al., 2022). This can be observed in NZ, where other seaports have had to take on excess capacity from affected ports. For example, Northport and the Port of Tauranga took on excess capacity from the Ports of Auckland when it was congested, while Napier and other ports absorbed capacity when CentrePort and Lyttelton had been out due to earthquake damage (Port Company CEOs Group, n.d.). As a consequence of diverting freight from CentrePort, there were knock-on implications for road transport to and from Napier Port and the Ports of Auckland (Herbert et al., 2018). Although NZ's network of seaports has proven flexible following past disruptions, it is unclear how capable the network would cope in the event of a Hikurangi Subduction Zone, given that Napier Port and Eastland Port would be badly damaged (Popovich et al., 2021), requiring available seaports to accommodate a significant increase in throughput.

### 7.3.10 Seaport productivity trends

Even if the seaports have capacity available, they are constrained by the seaports' productivity. In NZ, two of the most common productivity measures at seaports are ship and vessel rates. The ship rate is the number of containers moved on and off a container ship per hour, measuring the hourly productivity across all cranes, while the vessel rate measures the number of containers moved on and off a container ship per hour, measuring the hourly labour productivity (Ministry of Transport, 2011). Interviewees acknowledged that although their vessels have the capacity to move more containers, they are constrained by the productivity at seaports, where vessels are assigned a limited number of container moves. Consequently, vessels are often unable to complete the required loads and discharges. These concerns can be observed in Figures 63 and 64, which show that with the exception of CentrePort (which has increased after recovering from the 2016 Kaikōura earthquake), the remaining seaports have seen a decline in vessel and ship rates since 2020 (Ministry of Transport, 2022a). As a result of decreased port productivity, the efficiency of vessels is impacted, which can result in uneven distribution of vessel rotations (Fox, 2024). In order to address the underlying issues at seaports, a long-term strategy is required, which is discussed later in this chapter.

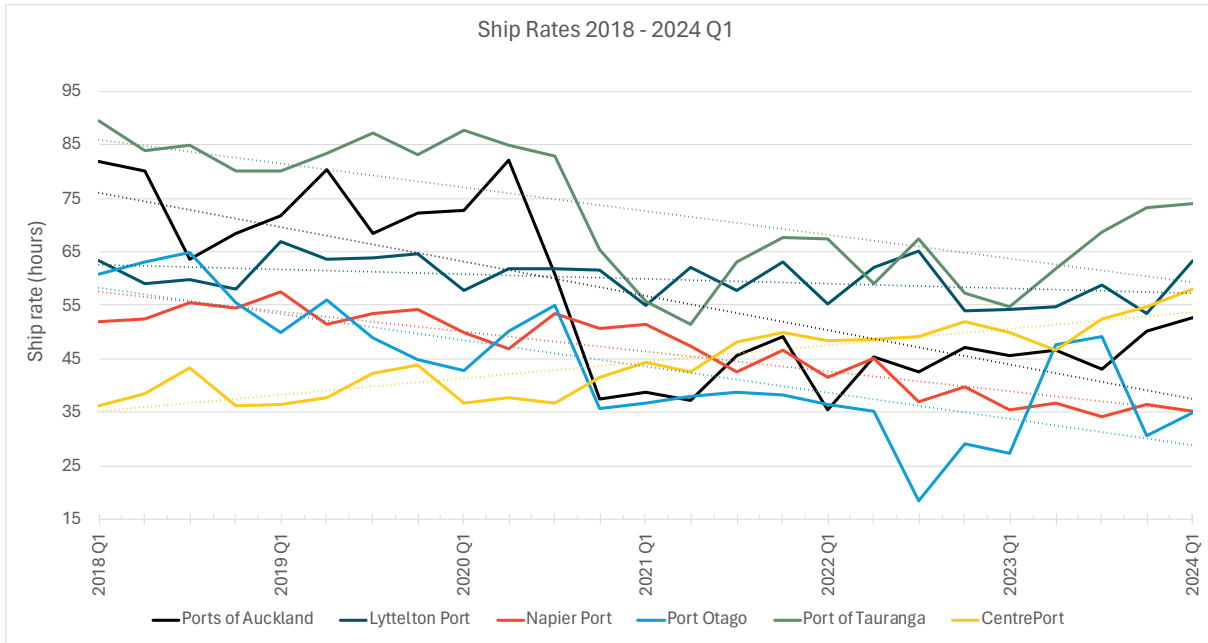


Figure 63: Ship Rates between 2013 - 2023 (adapted from Ministry of Transport, 2023c)

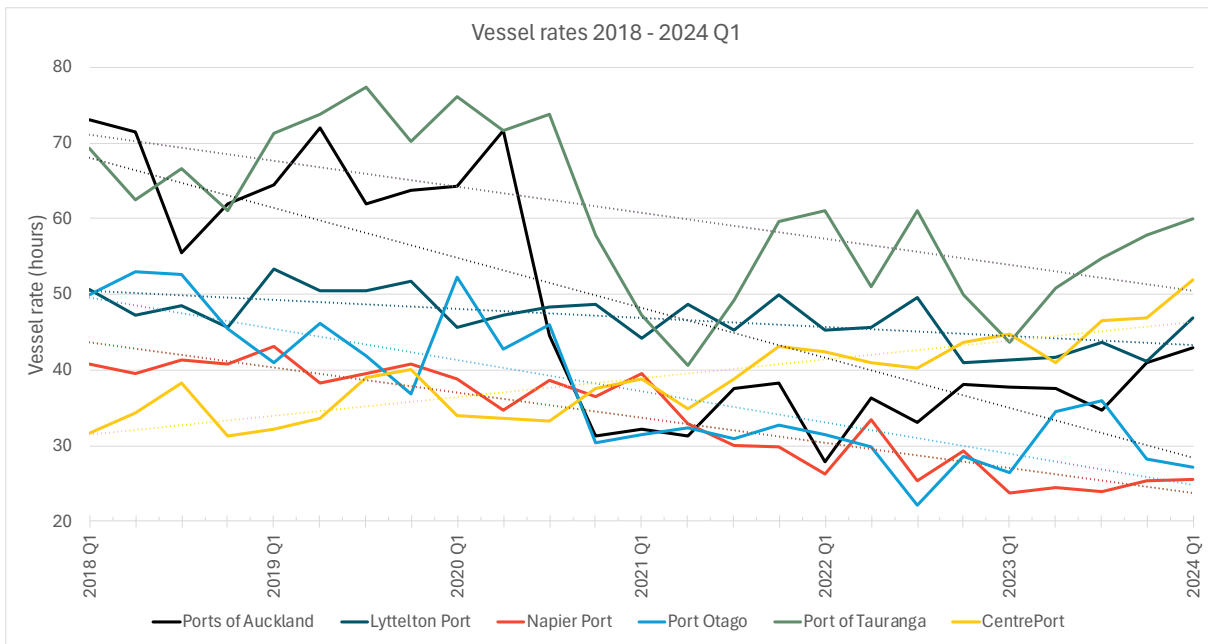


Figure 64: Vessel rates between 2013 - 2023 (adapted from Ministry of Transport, 2023c)



## 7.4 Long-term solutions and challenges

### 7.4.1 Inventory management

Interviewees acknowledge that it is hard for organisations to justify moving away from JIT inventory management due to the greater associated cost and the lack of benefit the added inventory provides until it is needed when a disruption occurs (Sheffi & Rice Jr., 2005). Even if FMCG organisations carried a buffer of inventory for redundancy, it would provide little value if the transport system is unavailable to replenish inventory when it is depleted. Therefore, this research supports the argument that the freight transport system should be resilient so that alternate transport modes can be used to keep goods moving, as opposed to relying on inventory buffers (Hamilton & L'Hermitte, 2022). However, such resilience requires long-term planning, which is discussed in section 7.4.7.

### 7.4.2 Backup power at service stations

Without electricity, service stations would be unable to operate pumps unless backup power sources, such as generators and fuel were available. However, for service stations to run on generators, they must have the appropriate wiring in place for the generator to be connected (McMahon, 2022). Research into the lower North Island's Manawatu-Whanganui region revealed that only a limited number of fuel outlets have a backup power supply and the ability to use 'plug-in' generators, with the majority of outlets in the region having neither (Manawatu District Council, 2020). The underlying cause for not having alternate power options is that the responsibility for service stations having an alternate power supply is up to the individual store owners (Waikato Lifelines Utilities Group, 2018).

In other words, decisions on resilience are made on a commercial basis, and investment is made JIT rather than just in case (New Zealand Lifelines Council, 2023). Presently, the West Coast Civil Defence Emergency Management group is exploring what is necessary for all service stations to run on generators in the case of an Alpine Fault earthquake (Civil Defence, 2023a). Although, it remains unclear how many service stations can use 'plug-in' generators in Wellington, Picton and other regions. It would be worthwhile to explore the preparedness of service stations to run on generators at a national level.

In any case, even if service stations have the ability to run on generators, there still needs to be a sufficient supply available. However, in a widespread electricity outage, NZ would only have enough generators available for hire to address the number of service stations in one region (New Zealand Lifelines Council, 2020). Cyclone Gabrielle provided some insight into the severity of these shortages, where critical businesses did not have generators, and the demand for generators exceeded the available supply (Bush International Consulting, 2024; Department of Internal Affairs, 2024). Consequently, service stations could not operate pumps and payment systems, and cell towers could not be brought back online, impacting all transport modes, including trucks used for the distribution of fuel and FMCGs (Department of the Prime Minister and Cabinet, 2023). Given the significance of generators and the limited supply available to hire, it would be worthwhile to see how many key service stations have backup

generators available onsite. Work is needed to improve preparation around alternate power supply resilience (Manawatu District Council, 2020). Therefore, it would also be worth learning how many service stations have backup generators.

In the international context, the US passed legislation requiring New York service stations near highway exits or evacuation routes to have the ability to deploy generators within 24 hours of losing power, which was supported through \$5.1 million USD in federal funds (Schwartz, 2014). If similar requirements were implemented in NZ, it would provide greater security in the event and would reduce the pressure on already scarce resources, which other critical infrastructures also require (Sharkey et al., 2016).

#### 7.4.3 Telecommunications infrastructure

As interviewees noted, in a telecommunications (and electricity) outage, dependent systems, such as Eftpos terminals, would cease to operate. From a transport perspective, even if Eftpos had power, truck drivers would only be able to refuel with cash, as Cyclone Gabrielle has shown (Department of the Prime Minister and Cabinet, 2023). One way to overcome this disruption is through the use of manual (offline) EFTPOS terminals (Ali, 2023).

Interviewees noted the importance of telecommunications networks (copper, fibre, and cellular), which, in their absence, would reduce or stop the movement of freight between the North and South Islands. To overcome such disruptions, one interviewee suggested the use of satellite internet, such as Starlink. The value of this technology can be observed following Cyclone Hale and Gabrielle in 2023, which took out fibre cables, resulting in Foodstuffs North Island losing internet connectivity with stores in the affected regions. To address the outage, the company purchased Starlink satellite devices and EFTPOS units, which overcame fibre outages (Foodstuffs, 2023). Banks and other retailers also use Starlink, although they depend on a small generator for power (or a battery) (Speidel, 2023). However, these devices depend on electricity to work. Therefore, if organisations had electricity and a Starlink terminal, terrestrial communication outages could be overcome, and the disruption would be minimised, as shown in Figure 66.

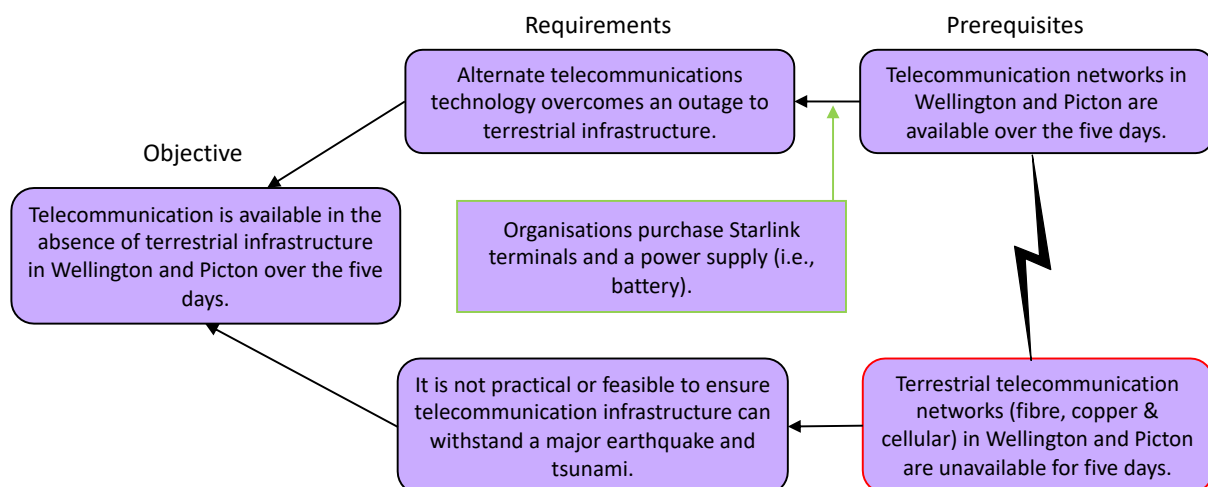


Figure 66: EC for telecommunications infrastructure

A further challenge is the interdependence of electricity (or fuel for generators) on telecommunication networks (Civil Defence, 2018a). For example, in an electricity outage, cell towers, exchanges, and roadside cabinets will need alternate power sources in place. In other words, generators and fuel will be needed to keep the telecommunication infrastructure powered. As mentioned earlier, it is expected that NZ would not have sufficient generators in such a scenario. A shortfall of generators at cell towers was already acknowledged following Cyclone Gabrielle (MBIE, 2021a).

In the context of Wellington, it has been estimated that a \$11.65 million dollar investment into key cell sites in Wellington would ensure there are sufficient backup generators available, supplying around two weeks' worth of power to the region before needing to be refuelled (WREMO, 2019), although this has not yet been implemented. When looking abroad, following California's wildfires, the government required regulators to ensure that their cell towers had backup power available for a 72-hour period for facilities exposed to known natural hazards (fire) (California Public Utilities Commission, n.d.). Despite the importance of having resilient communications systems, it can often be challenging for private entities like Spark and Vodafone to invest in resilience over alternate investments, such as tech upgrades like 5G (Pennington, 2023).

#### 7.4.4 Kaiwharawhara fuel infrastructure

Interviewees acknowledged the age of the Kaiwharawhara fuel infrastructure in Wellington, which stores diesel and fuel oil and is the primary supply of the Cook Strait ferries (Hale & Twomey, 2017). Because the storage tanks are situated next to steep slopes, earthquake-induced slope failures have the potential to damage these tanks and the pipelines running between Kaiwharawhara and Aotea Quay (Brabhakaran et al., 2003). Therefore, if the infrastructure fails, then the Cook Strait ferries and other vessels would be unable to refuel out of Wellington, and fuel would need to be sourced from the next closest fuel terminals, which would be Taranaki in the North Island and Nelson in the South Island. Consequently, the fuel supply for Wellington could be reliant on trucked road fuel for months if the terminal is damaged, putting further pressure on the roading network (Civil Defence, 2020).

#### 7.4.5 Onshore fuel holdings

A further concern raised was the supply of fuel, which threatens all transport modes. To address this, minimum onshore fuel holdings throughout the country were suggested, which would enable greater fuel security in a disaster. The government is currently in the process of implementing a minimum stockholding obligation to provide security around the supply of petrol, diesel and jet fuels to prevent disruption to the transport system. The increased stockholding serves as a buffer of current levels, which provide around 20 days of gross inventory of fuels on average. Figure 67 provides a list of the different minimum stockholding levels explored in 2022 to improve resilience (MBIE, 2022).

	Option 1 (Minimum at current level)	Option 2 (Australian level)	Option 3 (Double current level)	Option 4 (European level)	MFAT's suggested option
Days of cover	20 days	24-28 days	40 days	60 days	110 days
Additional onshore fuel storage costs (conservative estimates only)	Negligible	\$ 22 million NZD annually	\$ 80 million NZD annually	\$ 168 million NZD annually	\$ 388 million NZD annually

Figure 67: Proposed minimum onshore fuel stockholdings (adapted from MBIE, 2022)

Notably, the proposed minimum fuel storage obligations, which will be introduced in January 2025, will see onshore fuel holding levels increase to 28 days of use of petrol, 24 days of use of jet fuel and 21 days of use of diesel (MBIE, 2023). However, this buffer is based on the average daily consumption of fuel over the past two calendar years (MBIE, 2022a). In other words, should a Hikurangi Subduction Zone event occur, the demand for fuel would be far greater, and the need for additional fuel would be exacerbated if the fuel terminals in Wellington and Napier were taken out (New Zealand Lifelines Council, 2020), given Wellington supplies the lower North Island, and Napier supplies the East Coast. In any case, increasing the existing buffer is essential to creating redundancy, which is especially critical for countries that lack strong domestic energy sources, such as NZ (Thomson & Boey, 2013).

#### 7.4.6 Interoperable systems

As interviewees acknowledged, one of the biggest challenges in a disruption is the inability to share data easily, which is partly due to a lack of interoperability and sensitivity concerns. In the existing literature, there have been a number of publications that acknowledge the need and challenges of implementing such a system. For instance, the need for standardised data formats was raised in the current national freight and supply chain strategy, which acknowledges that there is a need to focus on data sharing and interoperability over the next 3-years (Ministry of Transport, 2023). However, some of the obstacles to overcome and implement such a system is that the exchange of information depends on trust between entities and confidence that information will not be shared beyond the intended recipients because these disclosures could result in legal liabilities, implicate competitiveness or breach anti-trust legislation, reveal vulnerabilities, or lead to reputational damage (Civil Defence, 2023). In addition to sharing information, organisations are reluctant to adopt common standards due to competition and fragmentation among one another (Ministry of Transport, 2022a).

These challenges are not new and have surfaced in past disruptions. For instance, the Kaikōura earthquake highlighted that communication and data sharing between ports can be a challenge as a result of commercial sensitivities and competition (Trotter & Ivory, 2019). Consequently, data was not available to those who needed it due to commercial sensitivities, incompatibility, discoverability or inaccessibility challenges, and, in some instances, certain transport groups not being included in government-level communication channels (Blake et al., 2019).

If systems were more interoperable, with a centralised platform, it could provide a ‘one-stop-shop’ for information and communication tools, simplifying data sharing among all actors involved (Šakalys & Palšaitis, 2006). Thereby enabling faster and more accurate responses, as

the standardisation of data would enhance the speed of information sharing, and enable stakeholders to make better decisions and respond to disruptions more effectively, which is especially important in the post-disaster context (Ministry of Transport, 2023).

To overcome challenges around trust, the findings note that data could be supplied at a granular level so as not to reveal commercially sensitive details yet still provide some visibility into the likes of capacity and demand information. In other words, it is better to have access to some information rather than none (Trotter & Ivory, 2019). In any case, the government might be the most appropriate entity to oversee a system to share data due to having fewer conflicting interests when compared to a private entity. Such systems have already been implemented overseas, enabling sensitive information to be shared between certain stakeholders, such as the government, regulators, critical infrastructure owners and operators (Department of the Prime Minister and Cabinet, 2023). Examples include Australia's Trusted Information Sharing Network and the United States Domestic Security Alliance Council. Nevertheless, there is no easy solution to addressing these challenges, and future research into this area would be valuable.

#### 7.4.7 Mode neutral transport planning

Several interviewees expressed concerns about the existing road and rail infrastructure. For instance, it was noted that the alternate routes in the roading network could be more resilient, as they often do not have sufficient capacity to be viable alternatives without upgrades (Davies et al., 2017). However, despite the need for upgrades, funding is limited, and upgrades are costly. For instance, following the Kaikōura earthquake, funding of \$60 million was allocated to ensure alternate routes were fit for purpose, which included the widening of shoulders and the resurfacing of roads (Herbert et al., 2018). On the other hand, the biggest concern raised for rail was the lack of redundancy in the network, given it is designed to primarily run vertically down the country's spine. To address this, it was suggested in the long run that there could be a second main trunk line, which would strengthen the “spine” of the rail network. In any case, it is not feasible to extensively upgrade alternate routes to create redundancy, as NZ has limited funding and a thin population distribution (New Zealand Lifelines Council, 2020). Moreover, road and rail networks can still be taken out in a disaster, as was observed with Cyclone Gabrielle in 2023 and the Kaikōura earthquake in 2016.

Therefore, it is important that a holistic approach is taken when creating a resilient freight system (Hamilton & L'Hermitte, 2022). In other words, a resilient system should enable goods to continue moving in times of disruptions by using alternative transport modes or routes while ensuring there is sufficient capacity in the system (Ministry of Transport, 2023). For instance, if road and rail (and, by extension, the Cook Strait ferries) are unavailable, there needs to be sufficient capacity to move the necessary goods by sea and air. As the findings support, the development of such a system requires all transport modes and options to be considered and evaluated to find the best solution for the system as a whole (Ministry of Transport, 2018). In other words, every mode of transport has a role to play following a disaster, and a resilient transport system should use a combination of modes, as seen in Figure 68.

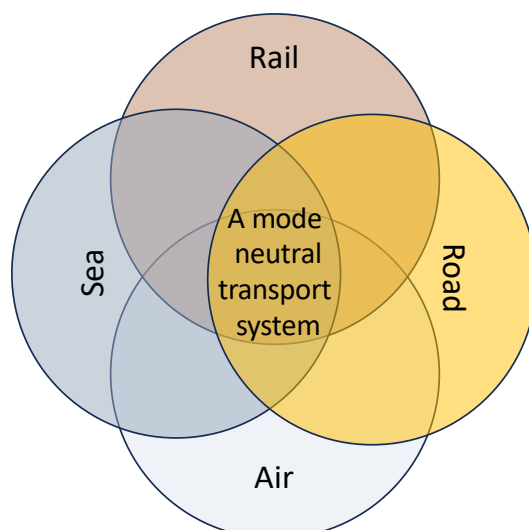


Figure 68: Overview of a mode-neutral transport system

#### 7.4.8 Obstacles to upscaling the domestic coastal shipping fleet

As the findings have shown, coastal shipping will be essential to keeping freight moving between the North and South Islands in a Cook Strait ferry outage. However, there are a number of root causes that need to be addressed in the coastal shipping sector. One of the issues raised was the shift to alternate marine fuels. Generally speaking, a vessel has a life span of 20 - 30 years due to economic, technical and regulatory requirements (Yin & Fan, 2018). Therefore, the acquisition of vessels requires a long-term view, and given net-zero carbon emission targets by 2050, investment into vessels needs to shift away from existing fuels to alternate fuels, such as electricity, hydrogen, and biofuels (MBIE, 2020). However, as the findings show, the country lacks the necessary infrastructure to support alternate fuels. In other words, should a firm purchase a diesel ship, the vessel could end up being susceptible to future taxes and regulations, as was discussed in the EU as a measure to drive a shift to low-emission vessels (European Commission, 2021).

Another issue raised is that there is a global shortage of vessels, and most available operate on diesel. For instance, within the global fleet, only 1.2% of vessels operate on alternative fuels, and of those using alternate fuels, LNG and Battery/Hybrid account for 97.8%, with Methanol and LPG making up the remaining 2.2%. Similarly, LNG and Battery/Hybrid orderbook vessels accounted for 92%, with LPG, Methanol and Hydrogen making up the remainder (UNCTAD, 2023). However, despite the production of these new vessels, the World Bank considers ammonia and hydrogen the most promising zero-carbon fuels available in the maritime sector (World Bank, 2021). Similarly, in the NZ context, it is likely that ammonia and hydrogen will be the best low-carbon fuel options for shipping in the long term (MBIE, 2021). Despite this, no viable, sustainable, low-carbon bunker fuel supply exists (Climate Change Commission, 2021). Additionally, NZ does not have an established large-scale production or supply chain for hydrogen, and new infrastructure would be required at ports (Ministry of Transport, n.d.).

To address these concerns and provide clarity, further work needs to be done to explore the best decarbonisation options for the shipping sector (Climate Change Commission, 2021). With greater clarity and guidance, organisations may feel assured in switching to alternate fuels, resulting in additional vessels entering the domestic fleet. Swire has recently discussed the use of alternate fuel ships and is currently considering producing dual-fuel vessels for its NZ coastal trade (Swire, 2023). In other words, it is important that there is a plan and ongoing communication between the public and private sectors to enable this transition and ultimately improve NZ’s transport resilience.

#### 7.4.9 Re-routing the Cook Strait ferries (Linkspans)

Given the many constraints in performing a modal shift to coastal shipping, the Cook Strait ferries will play a key role in keeping rolling stock moving between the North and South Islands. However, as the findings support, there is a lack of redundancy in the ability to easily re-route the Cook Strait ferries due to the absence of backup linkspans, and Mediterranean mooring is inefficient. To address this, interviewees acknowledged the need for two backup linkspans, one in the North Island, one in the South Island, and a barge to move them to different seaports. Unlike previous suggestions of having a backup linkspan situated in Napier (Herbert et al., 2018), the proposed solution would enable the ferries to be easily re-routed to other seaports in the event both terminals are taken out.

Interviewees acknowledged the obstacle to acquiring such assets is that it is hard to take on the financial burden, particularly when it is a non-revenue generating asset that would be utilised by numerous stakeholders if the terminals are taken out. Given the Cook Strait is considered an extension of SH1 (Environmental Protection Authority, 2022), and state highways are government-owned and funded (Rockpoint, 2009), it was suggested it would make sense that the government is responsible for acquiring such a nationally significant asset. Figure 69 shows the role of backup linkspans in the movement of inter-island freight.

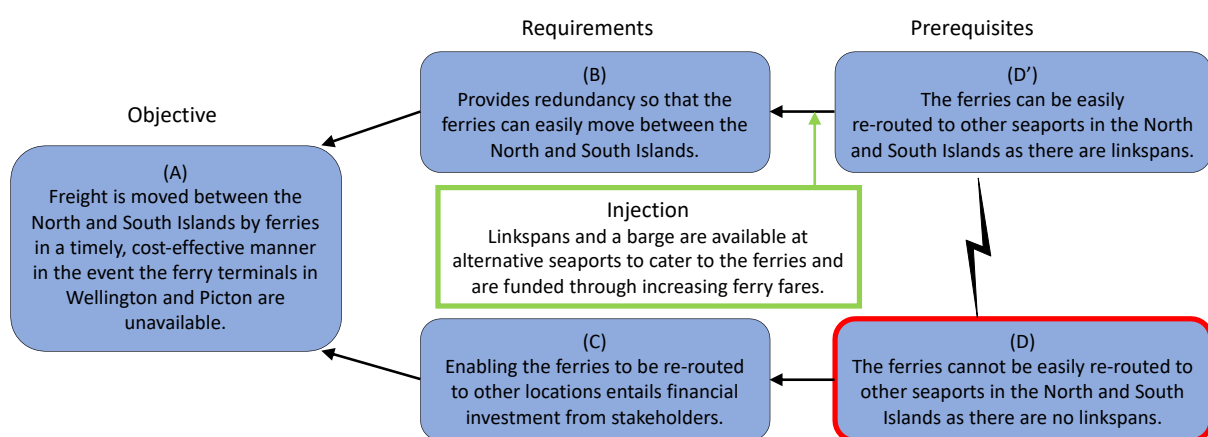


Figure 69: EC for backup linkspans

Alternatively, as raised by another participant, funding for resilience projects could come from increasing the lane-m cost charged to freight moved by the ferries. For example, a \$1 increase in the cost per lane-m would provide in excess of \$1.8 million annually (KiwiRail, 2021). The need for backup linkspans is further enhanced with the cancellation of the iReX project, which

was specifically designed to overcome the need for linkspans due to attachable stern ramps, which would have enabled the ferries to berth at alternative berths and seaports (Boffa Miskell Limited, 2022). Even with the acquisition of backup linkspans, the constraints at the seaports need to be addressed, as discussed in subsequent sections.

#### 7.4.10 Seaport infrastructure

The quality of seaport infrastructure varies greatly from port to port (Maritime NZ, n.d.), with many of NZ's seaports situated on low-quality reclaimed land, oftentimes not engineered (Ragued et al., 2011). The findings acknowledge that Port Whanganui lacks resilience, as the wharf is not of a standard that can support a crane, meaning that only small geared vessels would be able to call into the port (East Coast Lab, 2020), of which are calling at NZ seaports less frequently (Pacific Marine Management Ltd, 2021a). If Port Whanganui could support a crane, containers could be loaded and unloaded there. Although perhaps more importantly, with the appropriate upgrades, Port Whanganui could be used to cater to the Cook Strait ferries.

A peer-reviewed feasibility study in 2017 explored the introduction of a second inter-island ferry service that would operate between Port Whanganui in the North Island and Motueka in the South Island (King et al., 2017). Although the review identified a number of assumptions and the need for further research from a feasibility perspective, the connection could prove valuable in a Cook Strait ferry outage, as it would provide an alternate way of moving rolling stock between the North and South Islands. Although Port Whanganui would sustain some damage in a Hikurangi Subduction Zone event, it is likely to be usable following inspection due to its positioning along the West Coast (East Coast Lab, 2020). Moreover, Port Whanganui already has a KiwiRail CT site nearby and is close to Palmerston North, the freight hub of the lower North Island (Central Economic Development Agency, 2021). However, as the findings show, smaller provincial ports like Motueka and Whanganui have limited funds, and such upgrades would likely require funding from the central government.

In other instances, improving seaport resilience is not a physical constraint (i.e., a need for funding) but rather a policy constraint. As one interviewee noted, the Port of Tauranga is still awaiting resource consent to extend its berth, despite lodging the consent application in May 2021 (Port of Tauranga Limited, n.d.). The consequence of the delay has meant that the Port of Tauranga has run out of berth capacity and is unable to take on new shipping services to America and Europe (Fox, 2024a). A further implication is that the delay is impacting a planned automation project, which includes the introduction of the first automated stacking cranes in NZ (Bell, 2022). Should consent be granted, the berth could accommodate additional vessels. The introduction of automated stacking cranes would increase port productivity (Notteboom, 2018) and increase the current yard capacity limit from around 1.5 million TEU annually to 3 million (Port of Tauranga Limited, 2022). In other words, NZ's national seaport would be in a far better position to respond in a major earthquake and the need to accommodate additional vessels.

#### 7.4.11 Labour shortages

Several interviewees raised concerns about labour shortages, which could become bottlenecks following an extended Cook Strait ferry outage. If existing labour shortages are addressed, the challenge could be reduced. For instance, the shortage of truck drivers and other logistic sector workers in NZ is on track to increase from around 4,700 to 17,900 by 2028, should there be no policy change or targeted initiatives (Deloitte, 2023). At the same time, the freight volume is expected to continue to increase by 55% from 237 million tonnes in 2012/13 to 366 million tonnes in 2042/43 (Ministry of Transport, 2017a).

To address the shortages in NZ, the government announced a work-to-residence visa in 2022 to address labour shortages in certain areas (Beehive, 2022). Some of the roles under the programme included truck drivers, aircraft refuellers, tanker drivers, ship masters and deckhands. In the year the programme was announced, the industry reported a shortage of 3,449 truck drivers, and as a result of the programme, almost 4,300 drivers applied for the work-to-residence programme between July 2022 and April 2024. As a result, the programme was closed off to all transport roles except ship's masters and deckhands in 2024 (Immigration New Zealand, n.d.), despite industry urging the programme to remain open (Blackwell, 2024). The reason for the cancellation was that the government wanted to address unsustainable net migration and focus on the local labour market first for such roles (Radio New Zealand, 2024).

To address the shortage using local labour, one interviewee advised their firm had success in splitting roles for truck drivers, offering two 6-hour positions as opposed to one 12-hour position. Although this can address shortfalls, the implication this has is that there is greater separation between the driver and the vehicle during shift change, reducing overall productivity (Karis & Dinwoodie, 2005). A further opportunity is around increasing the number of female employees, who, as of 2021, represented less than 30% of employees in the logistics sector (Organisation for Economic Co-operation and Development, 2022). Currently, work is being done in the trucking sector to increase the number of drivers by attracting a more diverse workforce (Road to Success, n.d.). Despite these efforts, the findings highlight the need to address an increasing labour shortfall.

## 7.5 Work underway

### 7.5.1 Post-disaster updates and information sharing

As interviewees noted, one of the challenges in a disaster is that there is no single source for essential information. Fortunately, work is underway to address this through NZTA's Asset Management Data Standard (AMDS) multimodal network mode, which seeks to provide "a single source of truth to enable better planning and management of Aotearoa NZ's transport networks". This will be supported by providing outputs in standard formats, such as Extensible Stylesheet Language (XLS) and Portable Document Format (PDF) so that they can be used by the industry. The network model will also enable several data types to be visualised on a map, including direction of traffic flow, modes of flow, route planning, navigation, asset location and restrictions (NZTA, n.d.).

AMDS will also be able to show where rail freight can get on and off rail networks, optimise routes, estimate travel times, evaluate accessibility across different modes of transport and advise the latest restriction information available in detour rerouting. At the same time, it will be able to analyse unplanned national disasters by using geonet data to specify the earthquake location and shake intensity, which can be used to analyse affected network assets. I.e., shaking intensity may reach a pre-determined threshold, notifying the need for a road to be closed until inspections by engineers can be conducted. This enables asset awareness and re-routing to occur on a national level. The tool also allows multiple scenarios to be prepared, which can be activated when required, enabling a plan to access, which can be shared, published and monitored for all transport modes nationally (Waka Kotahi NZ Transport Agency, 2023). However, it is clear that there is still work to be done around building trust, sharing data in real-time and moving towards more interoperable systems.

### 7.5.2 Seaview fuel infrastructure

Fortunately, work is underway to improve the resilience of the Seaview fuel site, which stores petrol, diesel and some jet fuel and is the primary fuel supply for the lower North Island (Hale & Twomey, 2017). The project is expected to be completed by 2026 (Seaview Project, n.d.).



<b>Root causes by sector (CRT)</b>	<b>Potential solutions (FRT)</b>
<b>Electricity</b>	
Key service stations do not have backup power sources available.	Ensure key service stations can run on generators, enabling trucks to refuel at key service stations.
There is a shortage of generators available.	A small buffer of generators is available. Shortage is reduced by having fuel stations provide their own generators and is again reduced if the ferries (RoRo) can be re-routed and overcome the need for reefer containers.
<b>Fuel</b>	
Fuel infrastructure in Kaiwharawhara is not resilient.	Upgrades are made to improve the resilience of the fuel infrastructure at Kaiwharawhara.
There is a shortage of onshore fuel holdings.	A minimum required buffer of onshore fuel holdings is implemented so there is sufficient fuel available post-disaster.
<b>Data</b>	
There is no single source for essential information following disasters.	A government-led platform is available for disseminating post-disaster information from a single location (AMDS).
Systems are largely not interoperable and data cannot be shared easily.	Standard formats and documentation processes are agreed upon between stakeholders, making systems interoperable and data easily sharable.
There is no prioritisation system for post-disaster freight movement.	A government-led prioritisation system is implemented to keep goods moving.
<b>FMCG operations</b>	
Certain perishable goods spoil quickly and require strict temperature control.	Certain perishable goods are stored in existing cool stores to extend shelf life, while others are frozen, canned, or preserved.
There is a preference for organisations to run lean.	N/A (This is addressed through enhancing the resilience of the freight system itself).
<b>Road</b>	
Roads are designed for a certain level of traffic.	Investment has been earmarked for upgrading certain roading infrastructure.
There is a shortage of road personnel.	A national strategy is created to address the growing shortage of domestic operators in the logistics sector.
<b>Rail</b>	
The majority of the rail network is single-tracked	A second main trunk line is implemented.

Air	
There are limited freight aircraft available in NZ.	Aircraft are wet leased from overseas.
There is a shortage of air personnel.	N/A The labour shortage is only in a post-disaster context and wet leasing overcomes these shortages.
Sea	
There is a shortage of container trucks available.	A small buffer of container trucks is available. Shortage is reduced by using alternate transport modes and re-routing the ferries.
There is a shortage of shipping containers available.	A small buffer of shipping containers is available. Shortage is reduced by re-routing the ferries.
The ferries cannot be easily re-routed to other seaports in the North and South Islands.	Linkspans and a barge are available at alternative ports to cater for the ferries so they can be easily re-routed to other seaports in the North and South Islands.
There is a shortage of coastal shipping capacity.	Clarity is given around future marine fuels in NZ. Coastal vessels adjust their schedules.
Certain seaports are not resilient.	Investment is made for smaller ports, and policies are reviewed for other ports (the Port of Tauranga).
There is a shortage of sea personnel.	A national strategy is created to address the growing shortage of domestic operators in the logistics sector.

*Table 13: Root causes by sector and potential solutions to address them*

## 7.6 Key recommendations

In addition to the solutions presented earlier, the key recommendations discussed in this chapter are:

- Acquire backup linkspans and barge to more easily re-route the Cook Strait ferries
- Review the Port of Tauranga berth extension from a national resilience perspective
- Provide clarity on the future of maritime fuel in NZ
- Reinstate funding for coastal shipping under the NLTP (mode neutrality)
- Review the Port Whanganui proposal to accommodate the Cook Strait ferries

## Chapter 8: Contributions

*This chapter addresses the value the research can have for practitioners and policymakers and the contribution to knowledge.*

### 8.1 Contribution to practice and policymaking

This research provides a number of contributions to practice and policymaking. For instance, the thesis includes a number of maps detailing critical infrastructures in the domestic freight transport system, the positioning of the main FMCG distribution centres, intermodal terminals, seaports, airports and inland ports. These maps provide a visual overview of how multiple infrastructures are geographically exposed to the same hazard types.

The application of the TOC TP tools resulted in the construction of easy-to-read visual diagrams that provide an overview of the many bottlenecks, causal relationships, and root causes that would surface in a post-disaster freight system. At the same time, it shows that constraints that appear to be physical can sometimes be the result of an underlying policy that needs to be revised or replaced. Moreover, the insight provided in these diagrams is not exclusive to a Hikurangi Subduction Zone event, as the same bottlenecks are likely to surface in other disruptive events or already exist in the current freight system. Therefore, these diagrams provide valuable insight into existing issues, which, if addressed, can provide value in other future hazard events, such as storms and cyclones. In any case, these diagrams help practitioners and policymakers to better understand the cause-and-effect relationships that exist throughout the freight system.

In addition to the diagrams, the discussion section highlights a number of potential solutions (recommendations) to address the root causes identified in this research and a number of suggestions to further improve the understanding of current vulnerabilities in the freight system. Of the recommendations discussed, those which were deemed to be the most important insights are provided in section 7.6.

Because this research is centred around the Cook Strait ferries, it provides a detailed level of insight that could be used to inform future decision-making, particularly around improving the resilience of the Cook Strait connection, given the cancellation of the iReX project in 2023. Similarly, because the research details the criticality of the coastal shipping sector and its significance to the resilience of the country, these insights could help aid future decisions around policy and funding into the sector, such as future funding into existing programmes such as Arataki and the NLTP.

## 8.2 Contribution to knowledge

This is the first piece of research that looks specifically at the impact of a Cook Strait ferry outage on the freight system and the potential disruptions that would follow. By addressing this gap, the research enhances the understanding of the role the Cook Strait ferries play in the NZ freight system. It shows that the NZ freight system comprises a number of interconnected critical infrastructures and that a disruption to one can cascade through the system, exacerbating the impact. This research is further enhanced by understanding the role critical infrastructure interdependencies have on the movement of FMCGs following a disaster and shows how a Cook Strait ferry outage can be exacerbated by the failure of other critical infrastructures, ultimately leading to FMCGs not arriving at the right place, at the right time and for the right price. Furthermore, as discussed earlier, by identifying potential bottlenecks, this research details how they can be addressed to keep goods moving between the North and South Islands.

This research provides the first contribution where ECs and an FRT have been used in the freight sector. It shows the value that the combination of the CRT ECs and FRT can provide by firstly identifying real-world constraints and the causal relationships between these constraints and the development of practical solutions to address these constraints.

## Chapter 9: Limitations and future research

### 9.1 Timeline

With interviews being conducted between October 13<sup>th</sup> 2023, and December 11<sup>th</sup> 2023, the iReX project to upgrade Interislander's Cook Strait ferries and ferry terminals was underway with the expectation the new vessels would arrive in August 2025 and May 2026. The introduction of these ferries would have provided greater flexibility, as they could be more easily re-routed to alternate seaports, improved reliability, and far greater carrying capacity than the existing fleet. Following the interviews, the central government made the decision to cancel the project on December 12<sup>th</sup> 2023. Given the significance of the Cook Strait ferries and the national resilience the iReX project would have provided, it would be worthwhile to capture stakeholder sentiment around the decision to understand the impact the cancellation will have on transport operations going forward.

### 9.2 Scope of the research

This research focused on a Cook Strait ferry terminal outage, and although other critical infrastructure outages were included to serve as parameters, there are several limitations in the details included in the information sheet provided to interviewees. The scenario notes an electricity outage of 2 days and a telecommunications outage of 5 days. However, in reality, it is estimated that the electricity outage would be greater, taking around 7-10 days to repair local electricity infrastructure (East Coast Lab, 2020). Although Lyttelton Port is proposed to remain operational, research suggests the seaport and related infrastructure, such as the primary fuel supply for the South Island, would be impacted in a Hikurangi Subduction Zone event (Popovich et al., 2021). In short, the Hikurangi Subduction Zone event was primarily used as it is capable of taking out both Cook Strait ferry terminals. Future research could seek to better understand the wider impacts on the freight system, such as the availability of the road and rail network and airports.

From the freight perspective, this research focused on the domestic movement of FMCGs and did not take into account the impact the disruption would have on the export of these goods. Capturing the impact on the export market would enhance the understanding of the event's impact on the economy and could provide insight into the financial implications a Cook Strait ferry outage could have.

### 9.3 Data

Because this research took a qualitative approach, rich, detailed information was captured. This uncovered a range of constraints and cause-and-effect relationships, insights that may have previously been overlooked or not well understood. Therefore, the findings from this research could be used to inform future quantitative research through modelling to better understand the complexity and impact of issues that otherwise may not have been explored.

Given the qualitative focus and commercial sensitivity to accessing freight data, the quantitative component of the research is limited and was included to begin to understand the scale of freight moved by the Cook Strait ferries and the ability of the domestic freight system to keep goods moving in a disaster. Therefore, the quantitative component of this research are estimates only, and if these findings were to be used in the real world, additional information would be required to provide a true representation of the impact. The data obtained by stakeholders on the Cook Strait ferry freight volumes was from FY19. Consequently, it is unclear how these insights have changed over the subsequent years. Moreover, details on the Cook Strait freight volumes do not account for empty trucks, rail containers and wagons, or whether these units are full or not. It is also unclear how many of the rail containers and wagons are intermodal. Lastly, calculations for the three-month period were taken from the annual figures and do not account for seasonal peaks.

The conversion for the number of containers required per truck would vary based on the specific vehicle. The available seaport capacity was supplied as an estimated percentage for two seaports. Similarly, insight into available domestic coastal shipping capacity was provided in estimated percentages. Therefore, this research would benefit from more accurate quantitative data, which could also help lead to quantitative modelling in future research. Nevertheless, in the absence of publicly available data, the quantitative details included provide a starting point for future efforts that can better understand the Cook Strait freight task and the ability of the domestic freight system to adapt.

#### 9.4 Potential solutions

Although a number of potential solutions were raised to address the root causes that were identified, further research is necessary to explore them in detail. For instance, additional research needs to be conducted to understand the barriers to sharing information following a disaster.

#### 9.5 Theory of Constraints

As mentioned earlier, of the five TOC TP tools, only the CRT, FRT and ECs were used. The remaining two TP tools, the PRT and TT, were not included. The limitation of this is that the solutions identified in the FRT and ECs serve as suggestions, but to be implemented in the real world, the solutions would need to undergo the remaining two tools. Therefore, future research could use the PRT to identify all of the obstacles and required responses that must be overcome in order to implement potential solutions. On the other hand, the TT could be used to lay out the step-by-step implementation necessary to implement the solutions in the real world (Dettmer, 2007).

## Chapter 10: Conclusion

This research further emphasises the national significance of the Cook Strait ferries and the role they play in the movement of FMCGs between the North and South Islands. The findings show that in a Cook Strait ferry outage, a number of bottlenecks will surface as a result of dependencies and interdependencies within the freight transport system. These bottlenecks will then cascade through the system, significantly disrupting the movement of FMCGs and ultimately resulting in shortages of goods on shelves and increased prices. Visual diagrams constructed using the TOC TP tools provide a clear overview of the many cause-and-effect relationships that would surface following a major disaster, as well as those that already exist and would exacerbate the disruption. This research has shown that what appears to be a physical constraint can instead be the result of underlying policies requiring review. As it stands, this research shows that the domestic NZ freight system is vulnerable and exposed. Although past disasters have provided some insight into the fragility of the domestic freight system, the consequence of an extended Cook Strait ferry outage would be far more significant, and the impact would be felt throughout both the North and South Islands.

# Appendices

## Appendix 1 – Participant information sheet.



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### PARTICIPANT INFORMATION SHEET

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**Mitigating FMCG transport bottlenecks following an extended Cook Strait  
ferry outage in Aotearoa New Zealand.**

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## 1. Invitation

This research explores the aftermath of a major earthquake which would take out the Wellington and Picton ferry terminals, resulting in an extended Cook Strait ferry outage of three months. Following the event, numerous constraints and bottlenecks would disrupt New Zealand's freight system, impacting the movement of fast-moving consumer goods (FMCGs). To make sense of this complexity, the research will capture the many post-disaster freight constraints and bottlenecks, as well as the potential solutions to keep goods moving between the North and South Islands. Details about the research scenario are provided in Section 10.

You are invited to participate in this study because of your position, experience, and expertise in New Zealand's transport operations.

Interviews will be conducted with key informants across a broad spectrum of the transport and FMCG industries. These interviews will be conducted at the participants' premises or via online communication platforms (Zoom or similar).

## 2. Researchers

This research is being conducted by postgraduate student Nathan McDonald and supervised by Cécile L'Hermitte, both from the University of Waikato Management School, with funding from Te Hiranga Rū QuakeCoRE, the New Zealand Centre for Earthquake Resilience.

## 3. Research objectives

The objectives of this study are to:

- Identify the constraints and bottlenecks in New Zealand's FMCG transport system following an extended Cook Strait ferry outage.
- Establish the cause-and-effect relationships between these constraints and bottlenecks.
- Identify possible solutions to mitigate FMCG transport disruptions and support timely deliveries between the North and South Islands.

## 4. Your contribution

We would like you to participate in an interview and comment on the impacts of an extended Cook Strait ferry outage and potential solutions. The discussion will draw upon your expertise, and questions will be adapted accordingly. Participation in this interview will take approximately 45-60 minutes. No specific preparation is needed. Our conversation will be recorded with your permission to accurately capture what is discussed.

## 5. Outputs and benefits

A diagnostic map visually representing the intricate reality of the New Zealand freight system during an extended Cook Strait outage will be developed. This map will provide a fine-grained understanding of the multiple constraints and bottlenecks affecting transport functionality and the web of cause-and-effect relationships between these elements. Following this, a map visually representing the ways to improve the current system will be created.





Because of the practical nature of this research, the findings are expected to provide real-world value to a range of stakeholders, especially the owners and users of the New Zealand freight system. These findings will inform their decision-making by highlighting vulnerabilities, enabling organisations to have a stronger understanding of the impacts a major disruptive event will have on critical transport infrastructure and how these impacts can be addressed.

#### 6. Potential risks

We anticipate that your participation in this study presents no specific risks.

#### 7. Change of mind

Your involvement is voluntary. We are pleased to have you participate, but we respect your right to decline. You are able to discontinue your participation without providing an explanation. You may request to withdraw within one month after the interview date. Any data you have supplied will be removed from the study.

#### 8. Data storage

All data will be stored on a secure University Cloud account. Only the two above-mentioned researchers will have access to the folder. Recordings will be deleted immediately after being transferred to the University Cloud account. All data will be held for 5 years from the date of first publication. After 5 years, the materials from this study will be destroyed (unless otherwise required by journals).

#### 9. Presentation and publication of the results

The interviews constitute the source of primary information and data for this research. Findings will be presented and/or published at conferences and other academic spaces, including journals and a student thesis. A non-academic summary of the results will be emailed to you at the end of the study.

All information will be treated confidentially, and your name will not be used in any publication arising out of the research. We will remove all references to personal information that might allow someone to guess your identity. To do this, the data will be de-identified before it is analysed, and a numeric pseudonym will refer to you. Your name and contact details will be kept in a password-protected file separate from any data you supply.

#### 10. Research scenario

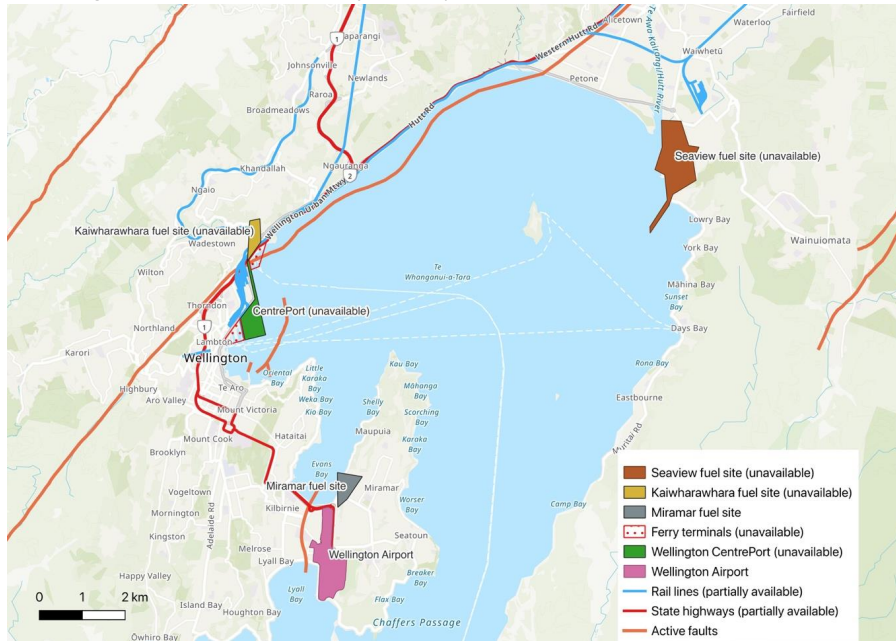
A major fault event occurs along the Hikurangi Subduction Zone, causing damage to the Wellington and Marlborough regions. Consequently, the Picton and Wellington ferry terminals, Marlborough Port, CentrePort, and two fuel terminal storage facilities (Seaview and Kaiwharawhara) are badly damaged and unusable for three months. Key transport infrastructure around the ferry terminals, including sections of SH1, SH2, rail lines and bridges, are damaged and unavailable for the initial 14 days. Power in Wellington and Picton is unavailable for the initial two days, while communication infrastructure, including fibre (internet) and cellular (phone), is unavailable for the initial five days. The Cook Strait ferries remain operational. Maps displaying this scenario can be seen below.



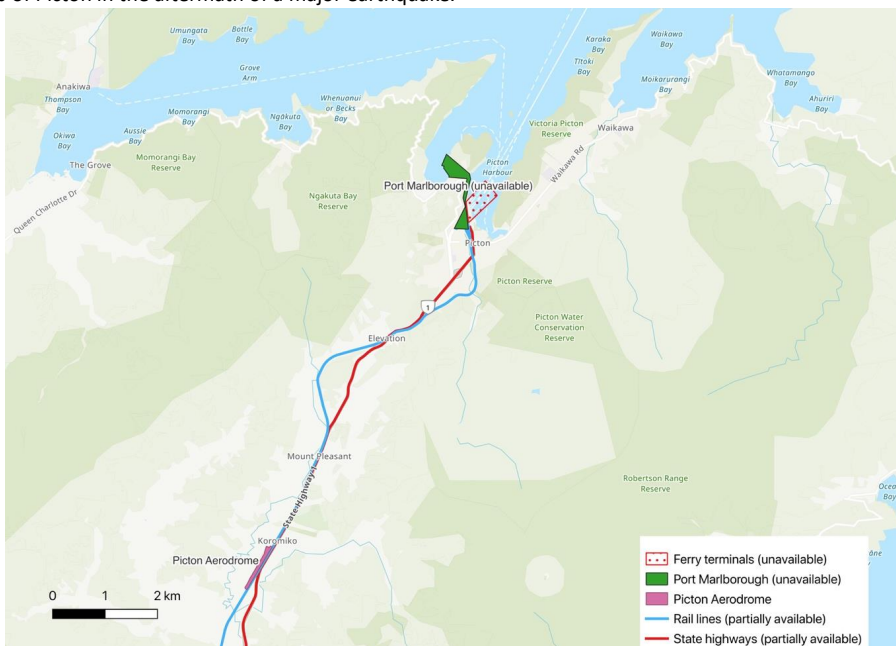
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Map of Wellington in the aftermath of a major earthquake.



Map of Picton in the aftermath of a major earthquake.





#### 11. If you have any questions about this study

If you would like to discuss any aspect of this study before or after the interview, please contact the researchers:

Nathan McDonald  
The University of Waikato  
Waikato Management School  
Email: [nm237@students.waikato.ac.nz](mailto:nm237@students.waikato.ac.nz)

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The University of Waikato  
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This research has been approved by the Research Ethics Committee of the Waikato Management School. If you have concerns or complaints about the conduct of this study, please contact Amanda Sircombe (Research Manager) on +64 (0)7 838 4376 or email [amanda.sircombe@waikato.ac.nz](mailto:amanda.sircombe@waikato.ac.nz). Please quote ethics reference number WMS 23/170.

*Thank you for taking the time to consider this study!*



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