THE FUEL TRANSPORTATION SYSTEM IN COASTAL BRITISH COLUMBIA:

ATTRIBUTES AND VULNERABILITIES

by

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Abstract

Disasters can, and do lead to widespread disruption, often crippling transportation systems in complex ways. Transportation systems need to be designed not only to operate on an ordinary day; they need to be designed to respond to man-made and natural disasters. Proactive planning can allow transport to resume service, and deal with crises, as quickly as possible post-disaster. This thesis provides information to assist in the development of plans and protocols for emergency scenarios. Coastal communities throughout British Columbia (BC) are heavily dependent on maritime transportation for the supply of fuel, food, and other critical resources. Vancouver Island only has an estimated 3 days’ worth of food and fuel stored on the island. Without sufficient storage, or a means of producing these resources, coastal communities are highly vulnerable to maritime disruption. If transportation systems are disrupted for an extended period, communities can experience shortages to supply. This can lead to communities losing power, operations, and critical resources for survival.

Through interviews and interactive workshops with industry stakeholders, this study brings forth issues and limitations within fuel transportation in BC. Current transportation systems are potentially ill equipped to deal with large-scale events with some response plans fragmented, and the decision-making infrastructure at times ad hoc. Improving a system’s preparedness through identification of hazards, and educating the industry could significantly aid the system’s response and revitalization post-disaster. Through review of current systems and plans, this thesis highlights persistent concerns within the system and begins to explore ways to improve the resilience of fuel distribution in BC. Through analyzing mitigation options, the validity of pro-active planning can be seen. The concerns and recommendations from this thesis
could lay the foundation for building a more resilient system capable of executing effective emergency response.
Preface

The dissertation is an original product of the author, A. Brown. The field work and interviews reported in Chapter 4-7 were covered by the UBC Ethics Certificate number H14-02726.

The interviews were primarily conducted by Dr. H. Dowlatabadi, Dr. S. Chang, Bethany Dobson, and myself, with assistance from other team members in some instances. I was the lead investigator for Chapters 6 and 7 where I was responsible for all major areas of concept formation, data collection, and analysis.
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Chapter 1: Introduction

In a world driven by efficiency, reliable movement of goods and people strongly influences a population’s quality of life. Continuation of these services in extreme events is essential (Little 2003) because modern societies rely on transportation networks to meet the demand for food, fuel, and medical supplies. This study describes the current fuel transportation network in southern British Columbia (BC) between the Lower Mainland, Vancouver Island, Sunshine Coast, and remote coastal communities. With the system defined, leading concerns with the current network are discussed, and hazards and mitigation measures are established. Case studies examine current efforts to improve the system’s emergency response capabilities.

Fuel is a fundamental resource for any region. It is necessary for the movement of goods and people, as well as for providing electricity, heat, social services, and the economic stability of a community. In extreme events, such as natural disasters, fuel will be an essential resource for emergency response and recovery. Although fuel is a fundamental resource to emergency response in BC, there is limited information about the origin and distribution of fuels to communities throughout this region. Knowing how the fuel network operates will increase the understanding of the vulnerability and resilience of the current system. Awareness of the leading hazards and mitigation measures is of paramount importance to emergency planning in the region.

As a result of geographical location, many of BC’s coastal communities are exposed to both land and marine hazards. Like other coastal communities, they are vulnerable to natural disasters. The seismic activity in BC further increases the vulnerability; physical damage to infrastructure and disruption to the supply chain is highly probable after a strong earthquake.
Ports and maritime networks are particularly exposed to these events as they are frequently located in areas prone to liquefaction (RCPGP 2014).

Previous disasters throughout the world have demonstrated the destruction extreme events can have on communities and transportation systems. The consequences of these events, and the fuel and resource shortages that follow, emphasize the importance of response planning for such emergencies. In 2015, Nova Scotia, Canada, its main fuel terminal closed for 3 days. As a result, the area experienced an unexpected fuel shortage. Investigations into this event concluded that had the outage lasted for 1 – 2 days longer, public health and safety would have been affected (MacNeil and Keefe 2015). In the aftermath of the Japan earthquake and tsunami in 2011 fuel shortages occurred, further complicating their response efforts. Along with earthquakes, Hurricane Katrina in 2005 and Sandy in 2012 had a substantial impact on the availability of fuel. Electric power outages in Hurricane Katrina closed fuel pipelines, resulting in widespread fuel shortages across many states. Hurricane Sandy cause disruption to large Ports, marine terminals, and control systems. The resulting damage brought fuel facilities, marine vessels, and other operations to a standstill (Sturgis, Smythe, and Tucci 2014). Fuel shortages are detrimental to the functioning of the affected communities, and in these instances it became both a logistical and public relations problem (Smythe 2013). It is critical that BC have plans for similar events. To date the region has only faced minor fuel disruptions. In interviews, described later in this thesis, the only fuel related event participants referred to was a highway closure in Prince Rupert, Northern BC which was caused by floods in 2007. These floods temporarily halted truck deliveries to the region, stopping all incoming fuel supply. In this instance, an emergency fuel delivery by boat was arranged, and the roadway reopened some days later. Although this event incurred no fuel shortage, there is the potential for far greater fuel shortages
in the event of a large disaster, including a catastrophic earthquake. For an event of this scale the region is inadequately prepared (AIR 2013).

Running on just-in-time delivery, BC communities are reliant on constant operation of their transport systems to meet fuel, food, and medical demands. If these systems were disrupted, demand would swiftly out-weigh supply, causing problems in many communities. It is critical that BC acknowledges the vulnerability of the fuel system, and plans for the potential of such events. The greatest known preparedness and planning for emergency response occurred prior to the 2010 Winter Olympics in Vancouver. Since then further preparedness planning for fuel disruption has been limited.

In contrast to BC, United States (US) have recognized the importance of fuel preparedness, with many states and local government undertaking emergency planning exercises to prepare for the event of a fuel disruption. Near BC, Washington State has produced an Energy Assurance and Emergency Preparedness Plan (Energy Policy Office 2013), and their fuel distributors have organized a Supply Chain Resilience Workshop (RCPGP 2014). In BC the response planning thus far has been limited to individuals or small groups and organizations. Plans involving the entire supply chain have been limited. A barrier to development of these plans is the disjoint nature of the network, and a lack of description of the fuel distribution system throughout BC. With no governmental and private-public partnerships in place, the system may be vulnerable to disruption. Furthermore, there is little specific work focusing on the modelling of hazards, mitigation measures, and current operations to highlight these concerns.
1.1 Objective of Research

The objective of this work is to define the maritime transportation of fuel throughout BC. With this defined, this study seeks to assess current concerns within the fuel transportation system, and consider feasible mitigation measures to improve the system resilience. This study is part of a larger project that aims to develop knowledge and tools to enhance resilience of coastal communities to maritime transportation disruption. It has specific focus on fuel, food, and medical resources. For this thesis, resilience is defined as a system’s ability to endure and respond to disruption.

To define and review the fuel component of this study, several characteristics of the transportation network are investigated. These include how the fuel supply to communities may be affected in an extreme event, and how the system may recover. This study reviews previous natural disasters, and the disruption and consequences these can have on transportation systems. It seeks details on modes of transportation, as well as the frequency, and volume of fuel moved about BC. With the current system defined, concerns about the resilience of the fuel transportation system are highlighted. Hazards and mitigation measures are discussed, and three case studies of current mitigation measures employed by coastal communities are analyzed.

The information provided will offer details to formulate further models and research evaluating the systems behaviour. Ultimately, this research should increase the understanding of the system, providing an opportunity for BC to improve upon current response plans and aptly prepare for such disruptions. This may increase both the resilience of the network and the resilience if its subsequent communities.
1.2 Scope of Research

The extent of this study is confined to the movement of fuel from BC’s mainland to Vancouver Island, and more isolated communities along the coast of BC. This research reviews the current fuel distribution system in BC, and provides recommendations for future improvements. When considering potential hazards, this thesis will focus on disruptions that will impact the entire maritime system.

This thesis is organized as follows: Chapter 2 defines the methodology, limitations, and assumptions of this study. Chapter 3 contains a review of concerns for transportation systems, and provides examples of the impact and lessons learned from previous disasters. Chapter 4 describes the transportation system in BC. The chapter outlines principal transportation modes, and how fuel flows from wellheads to refineries and distribution centers, then through maritime transportation to local distribution centers, and ultimately the end user. Chapter 5 identifies concerns in the system described in Chapter 4, and the barriers or proactive measures in place to address these. Chapter 6 defines hazards that could impact the system, as well as possible mitigation measures to address these concerns. Chapter 7 uses three case studies of possible mitigation measures that can improve the resilience of the system. Chapter 8 concludes the findings from this study, leading to recommendations for future work.
Chapter 2: Methodology, Limitations, and Assumptions

This thesis seeks to explain the current fuel transportation system that connects to many of the coastal communities in BC. A key objective is to describe the system and evaluate current vulnerabilities. This Chapter outlines the methodological approach taken to gather the information necessary for this thesis. The leading data sources, limitations, and assumptions of this work are defined.

2.1 Data Sources

Almost all data employed in this thesis was collected through two methods: online resources and stakeholder interviews. At the outset, the publically available data online was reviewed. This work involved an extensive review of the webpages maintained by leading fuel facilities and transport agencies. This preliminary research provided information about fuel facilities, capacities, and locations. Publicly available reports on operations, past events, or previous studies were reviewed and used where applicable. Reviews, concerns, and conclusions made in these reports were then confirmed or elaborated upon through stakeholder interviews.

The primary data source for this work was stakeholder interviews, conducted throughout the Lower Mainland, Vancouver Island, and Coastal BC. The interviews were undertaken throughout 2015 and 2016. In excess of twenty industry representatives were interviewed either in person or by phone. Members of the research team conducted these interviews, with each interview lasting between 60 and 90 minutes. Of those interviewed, five members were interviewed twice to provide further information about the three case studies. The case studies focused on three elements of the system: the resilience of fuel storage, fuel transportation, and the ports. The interviewees were representatives from government agencies, emergency
response, marine response, and maritime and land transportation organizations. The company representatives were often in operations management or control roles. They provided details on their current emergency response planning, past experiences, improvements, and foreseen weaknesses in the fuel and maritime transportation systems.

All interviews started with background questions about the organization, and their role in the fuel transportation system in BC. Following this, interviewees were asked about the normal operations, and about disruptions. They identified how they would characterize a disruption, the hazards of greatest concern to them, and their response strategies. Furthermore, those interviewed discussed what they perceived as gaps in the current system, and barriers to remediate these. Finally, the interviewees were asked about the current response strategies of their organization, and the fuel transportation system as a whole. The interview questions were tailored to the interviewee, and their organizations and sectors. At the discretion of the interviewee, all interviews were recorded, and notes were taken. Following the interview, notes were transcribed, and meeting summaries were written.

At the beginning of the project an “ethics application” was submitted and accepted by the University of British Columbia allowing the research team to contact and interview industry representatives. Before conducting the interviews all interviewees were sent a consent form and a questionnaire. The consent form was signed before undertaking any interview. This allowed each individual to indicate if they allowed the interview to be recorded, and if they were to be acknowledged by name for their response. All interviews cited in this thesis were completed by May 2016. Some of those interviewed requested that they were not cited by name in this work. Respecting these wishes, and acknowledging the sensitivity of some of the information, no data from the interviews will be attributed to any individual at any time throughout this thesis. A list
of the organizations that were interviewed are cited in Appendix B and categorized by three sectors:

- Public Response Organization (Provincial & Local)
- Private Response Organizations (Transportation, Operations, Emergency Response)
- Marine Organizations (Port Authorities and Maritime Transportation)

Response organizations are split in this thesis between public and private sectors. Their operations are both land-based and marine based, and involve response or regulatory control over the system. The marine organization category comprises of private companies whose operations involve maritime transportation of fuels. The solicitation of interviews from all three groups provided an understanding of the system from differing perspectives. All the information in this thesis is from these interviews, and online resources.

The initial contacts were made through research or personal connections between the principal investigators on the project and industry affiliations. Further contacts were made through recommendations made by the interviewees. They included municipal representatives, emergency response organizations, shipping and transportation companies, port authorities, and other individuals involved within the industry. The interviews allowed the research team to develop a comprehensive understanding of the current fuel transportation network. Several of those interviewed raised concerns with the current framework and also provided recommendations to improve the resilience of the system.

In addition to the interviews, the organization that is funding the research project, i.e., the Marine Environmental Observation Prediction and Response Network (MEOPAR) facilitated an interactive workshop with public and private emergency responders, and maritime organizations. The workshop, which took place in May 2015, involved the discussion of scenario-based
response plans. A description of a disaster scenario, such as a 6.3-magnitude earthquake, was given to a group of stakeholders. After a discussion about the steps for immediate response, each person was given a questionnaire. This questionnaire had statements of emergency response protocols that would be needed to assist in the response. For example, “We will need trained personnel to operate the supply chain”, or “The private sector has the resources for response.” Recipients indicated on a five-point scale, from strongly agree to strongly disagree, the level they agreed with each statement. This offered the opportunity for industry partners to actively engage in discussions about the system strengths and weaknesses from a range of different management levels. It also allowed them to anonymously indicate their preferences in emergency response protocols. Because this MEOPAR workshop took place near the beginning of stakeholder interviews, this survey provided the research team with feedback on which areas to focus on. It indicated where the stakeholders agreed and differed in their opinions on the current emergency response preparedness, and the current resilience of the maritime transportation system.

To fill in some of the gaps in our findings about the current maritime transportation system in BC, satellite-based Automatic Identification System (AIS) data was obtained through the MEOPAR-Exact Earth partnership agreement. This provided an overview of the frequency of ship traffic to many ports. Most commercial shipping vessels are required to have an AIS receiver installed, which enables satellite tracking of vessel locations in near real-time. The data acquired was used to assess the movement of vessels transporting fuel between the Lower Mainland and Vancouver Island. C. Hilliard at MEOPAR conducted this data analysis. The maps and trajectories, presented later in this thesis, indicate the volume of traffic flows between key locations within the system.
2.2 Geographical Extent

The geographical extent of this study is between the Lower Mainland of BC, Vancouver Island, and other isolated coastal communities. The area in concern for this project can be seen in Figure 1, indicated by the red line. This study focuses on the transportation of fuel originating from Vancouver and extending north to Hartley Bay, Haida Gwaii, and Masset. The populations of the communities considered range from cities in excess of 80,000, to small remote communities with populations of less than 200.

![Geographical extent of study](http://www.openstreetmap.org/copyright)

Figure 1: Geographical extent of study (Base map is a copyright of © OpenStreetMap contributor. Retrieved 11/05/16)

2.3 Key Assumptions

The information presented throughout this research is based upon information provided at the time of the interviews. Some data and information was either unavailable or unable to report due
to confidentiality. This work does not consider specific types of fuel other than diesel and gasoline. All risks, hazards, and mitigation measures focus on those addressed during the interviews conducted for this research. When considering mitigation measures, these are focused on a response with a duration exceeding two weeks. For this work, it is assumed the level of storage and alternative energy capability include all publically identified locations. Only storage facilities of a known location and capacity are considered. Any private or unconfirmed volumes of storage and supply are beyond the extent of this research.
Chapter 3: Concerns in Transportation Systems

Transportation systems face a myriad of uncertainties, including the supply and demand of products, which can change instantly. The objective of this chapter is to summarize vulnerabilities and complexities prevalent in resource supply systems. This chapter acknowledges lessons from history in an attempt to understand why, and how, the resilience of communities can be improved.

An example of why this is important is the New York terrorist attacks of September 11, 2001. Following those terrorist attacks all borders and flights were shut down, immediately impacting transportation and supply chains. With modern “just-in-time” delivery systems the cancellation of shipments and halting of operations saw significant costs to companies and communities. To cope with disruptions like these, transportation systems need redundancy and flexibility. Addressing a system’s resilience, i.e., a system’s ability to respond to a disruption (Sheffi and Rice Jr 2005), the concerns and uncertainties must be identified.

In BC, road, rail, pipeline, and marine modes are all engaged in the transfer of fuel from refineries and distribution centers to the end user. Each of these modes relies upon infrastructure and equipment, such as vehicles, ports, ships, and storage, which are exposed to a myriad of hazards.

Due to geographical isolation, coastal communities often have limited connectivity to mainland supply. With no independent way to meet needs they are reliant upon surplus resources and the preparedness of others. In short, the security of the coastal communities depends on a sound supply chain, and upstream communities. With just-in-time inventory becoming normal practice, communities often hold between one and three days of excess supply (RCPGP 2014). This means that resource shortage in isolated areas would be imminent if transportation systems
fail, as they often have no means of alternative delivery. Leaving communities without critical resources, such as food and fuel, will lead to economic and social suffering.

Due to the proximity to the ocean a number of hazards, both land and sea, must be considered when assessing the maritime transportation system in BC. Environmental hazards include earthquakes, floods, tsunamis, rock fall, landslides, and sea level rise as a result of climate change. Maritime transportation infrastructure can experience vessel fires, terrorism, industrial accidents, sinking or collision of ships, oil spills, mechanical failures, labor shortages, and blockage of shipping channels. Furthermore, the truck-ship intersection could sustain structural damage, isolated ground failure, impassible roads, liquefaction, broken pipeline connections, inoperable wharves, and damage to cranes and rail.

3.1 Characteristics of Maritime Transportation

Analysis of transportation system demand and alternate modes of transport within cities has been thoroughly researched (Andrey et al. 2003; Scanlon 2003). Many researchers have discussed hazards and the susceptibility of port infrastructure to disruption (Hungr, Evans, and Hazzard 1999; Na, Chaudhuri, and Shinozuka 2008). Furthermore, within maritime networks some research has been done to assess shipping methods and safety (Soares and Teixeira 2001), however there is limited information about maritime transportation systems as a whole.

Land and marine transport systems differ substantially, although they both undertake transportation of goods. Ships are efficient for long distances, and trucks are utilized for shorter distances, and their multiple pick up and distribution capabilities (Bektas and Crainic 2007). Trucks are credited with the unique ability to be flexible, change frequency, and run at a low cost to match changing demand (Bektas and Crainic 2007). In contrast, maritime vessels have greater
variation in travel time, and are more dependent on weather and environment. As discussed by Christiansen et al. (2004), the management of flexible time windows and cargo quantities makes it possible to increase the flexibility of shipping vessels, addressing this concern. Additionally, there is some flexibility within the system where alternate paths or routes can be created and utilized. Supporting this, marine vessels have the unique ability to operate when other transport modes are inoperable. The use of maritime transport when land transport fails has been used multiple times throughout history. During the aftermath of Loma Prieta earthquake in 1989, critical bridge passages collapsed and ferry systems were instated. These shuttled people across the water, releasing the pressure of the road network, and by-passing the obstacle (McDonnell 1993). Similarly, during the immediate aftermath of September 11 attacks, most Manhattan streets were blocked. In response, an unplanned convergence of marine vessels occurred on the seawall of Manhattan. The congregated vessels proceeded to ferry public across the water. In the following several hours, up to 500,000 person were moved (Wachtendorf, Quarantelli, and Kendra 2003). Adaptive responses such as these displays the flexibility maritime transportation can offer. This flexibility is fundamental to response success.

However, there are limitations in the operations because of technology and regulation. Advancement in technology has seen more automated systems, reducing manual requirements. With fewer people needed for regular operations, there is a smaller population of trained employees to call upon in response situations. An example of a technology-based practice is underwater surveying. With modern technology as little 2-3, employees are trained to operate this system in some areas. This reduces the level of redundancy of this operation. Depending on the location and availability of skilled professionals, certain controls or systems may be
unworkable during recovery. This could hinder the activation of this procedure, delaying response.

To appreciate the scale of vulnerabilities and feasible mitigation measures requires a broad understanding of how the system works. The maritime transportation of fuel in BC can be considered a ‘system of systems’ (Little 2003) of differing scales. Every community’s fuel supply has the same origin and transportation components, but the volume of fuel demand dictates the size and redundancy of each of these supply chains. The components of the system create a reliant network, where each aspect of the system, (i.e. port, vessel, tank farm) cannot work without the input, or output, of another. It becomes a situation where a single disruption to a single component can affect the entire system.

3.2 Defining Risk

Risk has many interpretations (Thywissen 2006). The definition of risk in this thesis is the probability of loss or disruption, and measured in terms of magnitude, duration, and frequency of an event (Thywissen 2006). A formal approach to quantifying the risk in maritime transportation has lagged behind many other industries (Soares and Teixeira 2001). Safety and prevention measures are often motivated by the high consequence of failure. When assessing marine transportation risk, this is heavily focused on the risk of the ship itself. There have been advancements made to assessing and managing vessels risks in recent years. These include the introduction of international safety management codes that are there to ensure personal and crew competence.
3.3 Learning from Past Experience

Historical events have emphasized the importance of planning for disaster, particularly in coastal communities. Dependent on maritime transportation for resources like food and fuel, these communities must learn from experiences to build a more resilient system. In recent years, the impact of extreme events (earthquakes, tsunami, hurricanes), on marine infrastructure (ports, pipelines) and their productivity has been well documented (Litman 2006; Vigdor 2008).

Learning from these events has increased the awareness of potential hazards to fuel supply, and its transportation infrastructure.

Frequent super storms in recent years have shown how these events can hinder the operability of facilities and services of transportation systems. Many scientists have linked climate change to the evolution of recent super storms, like hurricane Sandy (Greene, Francis, and Monger 2013). With growing evidence that the changing climate may be attributing to the increasing frequency of extreme events, society should expect more of these in years to come. Both land and marine operations are vulnerable to these events, which have the ability to cripple infrastructure and economies.

In addition to storms, catastrophic earthquakes and subsequent tsunamis can cause considerable damage to marine infrastructure, particularly at large ports. Many facilities and operations become inoperable, condemned, or left in significant disrepair (Kobe 1995, Chile 2010, Christchurch 2011). In certain earthquakes (Christchurch 2011, Kobe 1995), large ports have had to shut down entirely, closing communities off from Maritime transportation, and significantly restricting their access to the outside world and its supply. In extreme circumstances, extensive damage to port ramps and berths can result in the port being incapable of docking ships and unloading cargo, leaving the entire port motionless. Instrumental to marine
transport, the fundamental cause of failure in port infrastructure comes from ground failing and liquefaction. This is due to many ports being built on reclaimed or unstable soils (Brunet et al. 2012). In most instances, ports begin to rebuild and resume operations as quickly as possible. However, it can take years before these locations became fully functional again. Once returned to full capacity, the competitiveness of the market can result in these locations losing significant prominence in their trade (Chang 2000). There was evidence of this following the 1995 Kobe earthquake. This earthquake inflicted total devastation to many of the ports and their surrounding communities. Port of Kobe suffered extensive ground failures and damage to berths and port infrastructure. Service lines and bridge access were also disrupted. Due to the damage, the port was closed, and would not fully reopen for almost two years (Chang 2000). The cost of this was predicted at 30 billion yen per month (Chang 2000), however, the eventual loss to the port and economy far exceeded the duration of rebuild. Prior to the earthquake, Kobe was sixth in the world ranking for cargo throughput. It never regained this prominence. This example enforces that the recovery and restoration of infrastructure, does not directly result in recovery of business (Chang 2000). In these cases, the true cost of disaster far exceeds the expense of the rebuild. In addition to the financial loss, port closures cut communities off from Maritime transportation, significantly restricting their access to the outside world and resource supply.

In some circumstances, redistribution of loads or activities can create a partially productive port in the immediate aftermath of disaster. Following the Maule Earthquake in Chile, 2010, the South Coronel Pier (SCP) remained operable due to its seismically isolated construction (Brunet et al. 2012). This structure’s response to the earthquake was superior to all alternate port structures in the area. Although still in operation, this reduced capacity still presents a large economic loss to the area.
3.4 Secondary Effects of Disruption

Disruption to any element of the system inherently impacts others, creating a ripple effect and significant consequence. Secondary impacts of disruptions cause additional strain to a communities’ social and economic stability. Such phenomena occurred during the Californian power outage (2001). The loss of power created prolonged loss to a society, resulting in a shortage of supply to critical industries, and extensive loss of productivity. The Californian disruption idled key industries, and led to billions of dollars of lost productivity, stressing the entire Western Power Grid (Rinaldi, Peerenboom, and Kelly 2001).

Furthermore, following earthquakes and hurricanes subsequent tsunamis, tidal surges, and submerged debris impact on marine network operations. Hurricane Sandy resulted in coastal towns experiencing a 14 feet storm surge (Sturges, Smythe, and Tucci 2014) that devastated some areas. Communities in line with Hurricane Katrina also experienced storm surges, with the extent of damage leaving communities in disrepair. The chain reaction, as a result of Katrina, lead to near abandonment of New Orleans due to the devastation (Vigdor 2008). These storm surges can infiltrate electrical systems and damage waterfront facilities. Infiltration of saltwater can corrode electrical systems, destroy power transformers, and cargo controls (Sturges, Smythe, and Tucci 2014). The effects of hurricane Sandy were so extensive they halted refineries, and brought containership and passenger vessel terminals operations to a stop (Sturges, Smythe, and Tucci 2014). Additionally, displaced infrastructure can create submerged and floating debris in the harbors. This could damage, block, or isolate marine movements. If key marine passages are impassible, massive volumes of inventory become inaccessible.

In the event of disaster, electricity loss further complicates recovery operations. Absence of power can result in services being unable to perform routine tasks. Without power, emergency
generators installed to support actions in the event of power-outage are required. In past events, generators have become damaged or flooded in storm events, rendering them inoperable (Sturgis, Smythe, and Tucci 2014). In the Christchurch Earthquake, 2011, generators were activated, however ground shaking had disturbed these; causing them to fail repeatedly (Ardagh et al. 2012). Failing generators can leave critical fuel and medical services without power, adding to the challenge of immediate recovery.

3.5 Interdependency in Systems

Literature acknowledges transportation as a complex, interdependent system (Amin 2000; Little 2003; Rinaldi 2004). A complex system is any system that has the capacity to significantly impact the economic, and social aspect of a population (Little 2003). When defining these systems, the system can be considered a compilation of many interacting components (Rinaldi, Peerenboom, and Kelly 2001). The interaction between components is interdependency. Interdependency is known as the bidirectional relationship between infrastructures (Rinaldi 2004). This is the operating definition of interdependency throughout this thesis. Examples of interdependent transport system components include ship, port, pipeline, and truck. For example, when a pipeline is ruptured, it not only affects the pipeline, but the trucks and vessels that it supplies. Beyond obvious effects, the interdependencies lead to subtle relationships creating unintended behaviours in the system. This can significantly alter the predicted consequence.

3.6 Preparing Transportation Systems for Future Risk

Often, catastrophic disasters like those discussed throughout Chapter 3 will occur with little or no warning, affecting critical infrastructure, and systems. Pre-planning for priority resource
distribution is fundamental to recovery. Previous disasters have shown there will be difficulty transporting goods or services post-event. Depending on the location and extent of the damage, prominent areas could become severely isolated.

Moving forward, pre-established public and private partnerships will be fundamental in planning resilience measures (RCPGP 2014). Assessing current systems, reports indicate that these partnerships are a major break in the current planning framework. There is a definitive ‘need to have mechanisms in place for jurisdictions private and public to work together during disaster’ (RCPGP 2014). These relationships could see a coordination of emergency management between alternative routes, locations, and transportation modes.

To improve recovery, extensive emergency planning and programs are required. Communicating alternate supply or priority distribution plans may increase the order and control response. Although these plans may not resolve the issue entirely, management of adversity can offer a great benefit to these societies. Strategies like these will improve the performance of the system and its recovery in extreme events. Improving resilience of these communities is about minimizing the risks, and enabling the system the ability to respond.
Chapter 4: The Fuel System in British Columbia

There is void in current information about how the fuel transportation system works. The intent of Chapter 4 is to fill this gap in current literature. This chapter describes parts of the fuel transportation system in BC, focusing on the supply and distribution of diesel and gasoline. The principal transportation modes are explained, including fuel transportation from wellhead to distribution centers, local distribution networks, system relationships, and the leading companies involved. As mentioned earlier, the information in this chapter is a result of interviews with key stakeholders within the system. The information stated in this section can be attributed to these interviews.

Although fuel is fundamental to coastal BC’s functionality, there is limited knowledge of its origin and the distribution patterns within the region. With increasing populations, and no local supply, BC is dependent on imported fuel to satisfy demand. This imposes significant risk because BC’s coastal communities are increasingly dependent on fuel for transportation, heat, and power. Furthermore, in extreme events, such as natural disasters, fuel will be essential to emergency responders, and restoration of businesses. Understanding the fuel network, its resilience, and its ability to recover from extreme events is paramount in emergency planning throughout the region.

With many BC communities relying on maritime transportation, there is a critical need to plan for potential fuel, and resource disruptions. While the region faces many hazards that could disrupt the supply of fuels, it has had comparatively little direct experience with significant fuel shortages. To date, planning for fuel emergencies has been limited, with no plans involving both public and private organizations involved in the fuel supply chain. A key barrier to this progress is that there has been the lack of basic description of the fuel transportation system.
In Canada, the transportation sector accounts for 30% of total energy usage. Furthermore, in BC, an excess of 44% of energy consumption is refined petroleum products (Whiticar 2012). Table 1 indicates the total energy usage of refined petroleum products, as of 2009, throughout the provinces of Canada (Ministry of Industry 2013). This consumption can be categorized into three leading sectors: Industrial, Transportation, and Other. The category “Other” includes, but is not limited to; pump sales, agricultural, residential, public administration, and other institutional means. Table 1 also indicates the consumption per capita.

Table 1: Table of refined petroleum product usage per province (Ministry of Industry 2013)

<table>
<thead>
<tr>
<th>Province</th>
<th>Population</th>
<th>Total (megalitres)</th>
<th>Industrial (megalitres)</th>
<th>Transport (megalitres)</th>
<th>Other (megalitres)</th>
<th>Per Capita (L/yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Foundland &amp; Labrador</td>
<td>514,536</td>
<td>1,760.4</td>
<td>258.7</td>
<td>1,135.7</td>
<td>366.1</td>
<td>3421.3</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>140,204</td>
<td>443.9</td>
<td>21.5</td>
<td>272.1</td>
<td>150.3</td>
<td>3166.1</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>921,727</td>
<td>2,717.3</td>
<td>181.4</td>
<td>1,731.8</td>
<td>804.1</td>
<td>2948.1</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>751,171</td>
<td>2,006.7</td>
<td>198.1</td>
<td>1,475.5</td>
<td>332.5</td>
<td>2671.4</td>
</tr>
<tr>
<td>Quebec</td>
<td>7,903,001</td>
<td>17,546.8</td>
<td>1,311.3</td>
<td>13,876.2</td>
<td>2,359.30</td>
<td>2220.3</td>
</tr>
<tr>
<td>Ontario</td>
<td>12,851,821</td>
<td>27,344.7</td>
<td>1,580.8</td>
<td>23,835.5</td>
<td>1,918.40</td>
<td>2127.7</td>
</tr>
<tr>
<td>Manitoba</td>
<td>1,208,268</td>
<td>3,376</td>
<td>345.6</td>
<td>2,348.3</td>
<td>682.1</td>
<td>2794.1</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>1,033,381</td>
<td>5,970.1</td>
<td>440.3</td>
<td>3,678.2</td>
<td>1,851.60</td>
<td>5777.2</td>
</tr>
<tr>
<td>Alberta</td>
<td>3,645,257</td>
<td>15,658.2</td>
<td>1,733.6</td>
<td>12,230.7</td>
<td>1,693.90</td>
<td>4295.5</td>
</tr>
<tr>
<td>British Columbia</td>
<td>4,400,057</td>
<td>10,506.3</td>
<td>1,075.3</td>
<td>8,938.2</td>
<td>492.8</td>
<td>2387.7</td>
</tr>
<tr>
<td>Yukon, Northwest Territories</td>
<td>107,265</td>
<td>385.7</td>
<td>161.4</td>
<td>143.6</td>
<td>80.7</td>
<td>3595.8</td>
</tr>
</tbody>
</table>

In any system, the current state must be characterized before steps can be identified to increase its resilience. Significant features of fuel flows in and around coastal BC include fuel sources, methods of conveyance, paths from suppliers to customers, local demand, storage, and frequency
of supply. Each of these supply-chain elements can attribute to a system-wide strength or weakness when responding to different disruptions. Ensuring resilience of the fuel supply network is vital to minimizing impacts of disruptions, and resumption of social and economic activities. Without sufficient forethought, coastal communities could find themselves under substantial duress if supply were interrupted.

4.1 Coastal Communities of British Columbia

With a population exceeding 750,000, Vancouver Island is home to many of the larger coastal communities in this study. In addition, there are many smaller communities spread along the coastline of BC, with populations ranging from 20,000 to 200. Ferry is the predominant means of reaching these communities. Many of the coastal communities have no road networks connecting them to the Lower Mainland in BC, thus roads are an unfeasible way to transport goods.

Table 2 provides a sample of populations and estimated fuel consumption of five BC communities included in this study. The volume of refined fuel products consumed is calculated using usage-per-capita, with an average consumption of 8.6 liters per capita per day (Canadian Association of Petroleum Products 2015). By the law of large numbers, these estimates are more accurate for larger populations, such as the entire BC province, and less accurate for small communities like Hartley Bay. Hartley Bay is a community with high reliance on diesel for electricity generation; hence, the true volume of fuel per capita is likely to be higher there than in a larger city population. Thereby, the overall fuel consumption in these areas may be higher than indicated in Table 2.
Table 2: Overview of populations and fuel consumption. (Canadian Association of Petroleum Products 2015; Government of Canada 2011)

<table>
<thead>
<tr>
<th>Population</th>
<th>Refined fuel use (billion liters per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>4,683,100</td>
</tr>
<tr>
<td>Metro Vancouver</td>
<td>2,464,000</td>
</tr>
<tr>
<td>Vancouver Island</td>
<td>748,937</td>
</tr>
<tr>
<td>Powell River</td>
<td>13,165</td>
</tr>
<tr>
<td>Hartley Bay</td>
<td>200</td>
</tr>
</tbody>
</table>

For the general public, Vancouver Island is also reached by passenger ferry. Once on the Vancouver Island, there are road networks between many of the island communities. Vancouver Island receives ferries from the Lower Mainland in BC, as well as Port Angeles, and Anacortes in Washington State. There are multiple port locations offering daily services between Vancouver Island and the Lower Mainland. Most of these ports are located on the Eastern side of the Vancouver Island. For transportation of dangerous goods and resources, such as fuel, additional routes and vessels are used. Bulk cargo is also transported daily to and from Vancouver Island. In 2014, Duke Point in Nanaimo became the first container terminal on the island. This had significant impact on the island’s ability to import and export to global markets (Renshaw 2014).

In addition to sea transportation, there is an international airport in Victoria, and a smaller domestic airport in Nanaimo. The community of Comox on the island has a shared military and civilian airport whose routes include domestic flights within BC, as well as flights to Calgary and Edmonton in the neighbouring province of Alberta almost daily. This location has an international flight to Mexico once a week. As well as these locations, there are multiple smaller airports throughout Vancouver Island that are able to receive private aircrafts.
4.2 Origin of Fuel in British Columbia

BC’s crude and refined oil is supplied by Alberta, Eastern Canada, and Washington State. Nearly all imports arrive already refined, although some crude oil continues to be refined at Chevron’s refinery in Burnaby. Most fuel that is destined for Vancouver Island and the coastal communities is delivered via the Trans-Mountain Pipeline (TMPL). Further fuel arrives by marine tankers, rail, and truck to Lower Mainland locations. These modes carry fuel to several large storage and distribution facilities within the Lower Mainland.

Pipelines are considered an efficient form of fuel transportation for both crude and refined oil. This transportation mode produces fewer oil spill incidents per volume of conveyed fuel than any other transportation mode (Green and Jackson 2015). The capacity of a pipeline, and the minimal staff requirements contribute to this being the most cost-effective transportation option. It also has the unique ability to react to changes in demand (National Energy Board 2008).

Operated by Kinder Morgan, the TMPL links BC to Alberta’s oil production, providing BC with approximately 300,000 barrels of crude oil and refined fuels daily (Kinder Morgan 2015a). The TMPL alone carries over 50% of Vancouver’s petroleum product demand (Government of Canada 2015). It conveys refined, semi-refined, and crude oil through a single pipeline in batches. Extending 1,150km, the TMPL supplies fuel through 23 pump stations, and to its terminus facilities in Burnaby and Westridge Terminal in Port-Metro Vancouver. The storage capacity at these two facilities is shown in Table 3. In addition to supplying BC, the pipeline delivers some crude oil and distillates to refineries in the Puget Sound in USA.
Table 3: Capacity of TMPL storage facilities (Kinder Morgan 2015a)

<table>
<thead>
<tr>
<th>Storage Facility</th>
<th>Number of Tanks</th>
<th>Capacity (m^3)</th>
<th>Capacity (Bbl.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burnaby Terminal</td>
<td>13</td>
<td>268,000</td>
<td>1.685 M</td>
</tr>
<tr>
<td>Westridge Marine Terminal</td>
<td>3</td>
<td>63,000</td>
<td>395 k</td>
</tr>
</tbody>
</table>

Rail is another alternate form of transport used to supply BC’s mainland facilities. Similar to pipelines, rail cars can carry a significant volume of fuel. Rail transports approximately 8% of BC’s fuel, with predictions of significant increase in the coming years (CAPP 2015). In 2013, about 3.6 million tons of petroleum products were transported via rail in BC, including diesel, propane, and aviation fuel. The volume of crude oil was less, at about 262,000 tons (Pynn 2015). The majority of crude oil comes by rail from Saskatchewan, with the rest being transported from Alberta or within BC (Pynn 2015). Vancouver Island also uses rail for fuel transportation, although in less significant amounts. Figure 2 shows the Canadian National Railway, a leading railway line in BC. Other rail networks include Canada Pacific Railways, and Burlington North Santa Fe rail routes. It is unknown to what extent they assist in transportation of fuels throughout the region.
Figure 2: Canadian National Railways Corridor, Lower Mainland (Government of Canada 2013) Sourced from http://www.asiapacificgateway.gc.ca/investments-map/minimap_altmaps_e.html

Although most fuel is sourced within Canada, supplementary supply is imported from Washington State refineries. Washington’s refineries primarily receive their crude supply from Alaska’s North Slope via marine tankers through the Strait of Juan de Fuca. As noted previously, they too receive additional volumes through the TMPL (CEPA 2015). Given its central role, the TMPL constitutes a critical transportation system component for the BC consumer. British Petroleum’s Cherry Point is a leading international supplier of fuel to BC, and the largest oil refinery in the state of Washington, refining 9,000,000 gallons of crude oil each day (British Petroleum 2015). Further supply comes from Shell’s Puget Sound Refinery and Tesoro’s Anacortes. All three Washington State refineries are significantly larger than the
refineries in BC. Table 4 displays the relative production capacities of five Washington State Refineries, compared to the single Chevron Refinery in BC. Washington State exports about 14% of its refined product, mostly to BC (State Energy Office 2013). This is approximately 92,100 barrels per day (Energy Policy Office 2013).

Table 4: Capacity of Washington refineries (Tesoro Corporation 2015; Shell 2015; State Energy Office 2013)

<table>
<thead>
<tr>
<th>Washington Refinery</th>
<th>Production Capacity (Bbl./day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Petroleum (Cherry Point)</td>
<td>234,000</td>
</tr>
<tr>
<td>Shell Puget Sound (Anacortes)</td>
<td>149,000</td>
</tr>
<tr>
<td>Tesoro (Anacortes)</td>
<td>125,000</td>
</tr>
<tr>
<td>Phillips 66 (Ferndale)</td>
<td>108,000</td>
</tr>
<tr>
<td>U.S. Oil &amp; Refining (Tacoma)</td>
<td>42,000</td>
</tr>
<tr>
<td><strong>British Columbia Refinery</strong></td>
<td></td>
</tr>
<tr>
<td>Chevron, Burnaby</td>
<td>55,000</td>
</tr>
</tbody>
</table>

While pipelines and rail provide the majority of fuel movement about the Lower Mainland, water transportation is another significant delivery mode in supply and distribution to communities.

Port Metro Vancouver alone receives in excess of one fifth of the country’s marine cargo (CERA 2013), making it Canada’s busiest port. Within it, there are four additional petroleum terminals, owned by independent fuel companies which receive fuel by barge (CERA 2013). Once fuel is at Lower Mainland locations, marine transportation becomes the central delivery mode to Vancouver Island and BC coast.

**4.3 Refineries and Distribution Centers**

Once fuel has arrived in BC, there are a number of fuel distributors, from large and well-known fuel providers, to local trucking companies. Large fuel companies including Suncor (Burrard
Products Terminal), Imperial Oil & Esso (IOCO), Kinder Morgan (Westridge Marine Terminal), Shell (Shell Burmount Distribution Terminal), and Chevron (Chevron Burnaby) all have storage facilities in the Lower Mainland. The locations of these facilities are displayed in Figure 3. Aforementioned, Shell has an additional refinery in Anacortes, alongside British Petroleum (Cherry Point) in Washington State. All facilities receive fuels from Alberta, predominantly via the TMPL. The BC facilities also receive fuels from Alberta and Washington State by rail, and marine vessel.

In contrast to the other four facilities; Westridge Marine Terminal distributes a significant proportion of its fuels to international markets (Ministry of Industry 2013). Almost 30% of the Trans Mountains 300,000 daily oil barrels are transported via marine tanker from Westridge.
Terminal. On average 80% of tankers are bound for California, 10% to gulf coast and 10% for china (Stewart 2013).

Of the five locations, Chevron Burnaby is the only facility that has active refining capabilities. It has a capacity of 55,000 Barrels per day, producing a third of BC’s transportation fuel. It also produces 25% of the province’s commercial diesel (Burnaby Public Library 2016). Of petroleum products received, over 85% of crude oil is delivered by pipeline, with 6,500 barrels by rail, and a further 1,000 barrels by truck (Donnelly 2013). In 2013, the refinery failed to be secured as a “priority destination” for crude oil from TMPL (Financial Post 2013). As a result, they must continue to rely on alternative modes of transportation to maintain fuel supply. Alternative transportation modes like rail are more expensive than pipelines, an action the refinery was trying to avoid (Frittelli et al. 2014).

4.4 Storage

Majority of major fuel companies have a tank farm facility on Vancouver Island. Suncor and Imperial Oil both have tank farms near Nanaimo, and Imperial Oil has an additional tank farm near Powell River. Chevron operates a tank farm at Cobble Hill, and Shell has one near Chemainus. There is a tank farm at Esquimalt, although the owner of this is unknown, and it may be privately held or belong to the Navy base situated nearby. Distribution of fuels to these tank farms is through pipelines from local marine terminals. Figure 4 displays the location of the
distribution centers, and the tank farms these facilities have on Vancouver Island.

Figure 4: Map of fuel terminals and distribution centers, Vancouver, and Vancouver Island (Source: C. Hilliard, MEOPAR)

4.5 Land Transportation about Lower Mainland

Transportation from distribution centers and tank farms to end-users is accomplished through similar modes as wellhead transportation. Typically, refined fuel is either collected from racks at the refinery by truck, or pumped directly through pipelines to storage tanks or barges. Table 5 provides a summary of these leading storage facilities, and their various transportation modes for receiving and distributing fuels. Some of the cells are left blank as the information was unavailable for this study.
Table 5: Capacity, storage and transport modes of BC fuel facilities (Kinder Morgan 2015a)

<table>
<thead>
<tr>
<th>Refinery</th>
<th>Volume/day</th>
<th>Storage (bbl.)</th>
<th>Truck</th>
<th>Pipeline</th>
<th>Barge</th>
<th>Railcar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burnaby Chevron</td>
<td>50,000-55,000</td>
<td>1.685 Million</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Suncor, Burrard Products Terminal</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Imperial Oil Corporation/EssO (IOCO)</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Shell Burmount Distribution Terminal</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Westridge Marine Terminal</td>
<td>81,000</td>
<td>395,000</td>
<td>Minimal</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
</tr>
</tbody>
</table>

Pipelines are prevalent in the transfer of oil from storage facilities to barges and marine tankers, and from docked vessels to nearby tank farms. In addition to the TMPL, there is a 41 km Jet Fuel pipeline between Chevron Burnaby, Westridge Marine Terminal, and Vancouver International Airport to meet the airports aviation fuel demands. Figure 5 indicates the location of the TMPL, and the smaller Jet Fuel pipe in the Lower Mainland. It also includes the Puget Sound Component of the TMPL; an additional distribution service to Washington State (Kinder Morgan 2015b).
Trucks are often the last link in fuel delivery, and account for the majority of local distribution. In the case of tanker vessels, fuel is pumped through pipelines onto, and off the vessel. Upon arrival at a port, fuel is piped directly into storage. From here trucks collect fuel from the tank farms to deliver fuel-to-fuel depots and end-users. For roll-on roll-off vessels, trucks are vital at both ends of the supply chain. Trucking accounts for most of the community fuel distribution, and the flexibility of trucks to use the road infrastructure leads to them being used as a mechanism of incremental supply.
Regionally numerous companies transport fuels to and from storage facilities. The majority of these companies are contracted to large industry representatives who manage the fuel distribution and schedule from racks to trucking companies. Trucks transport fuel to petrol stations, local businesses, and dispense fuel to the capacity of the recipient’s onsite tanks.

Parkland Industries Ltd manages a large proportion of fuel distribution from fuel facilities. The fuel contract is held between Parkland and the refinery, which determines the locations, and volume of fuels available. Independent companies then hold contracts with Parkland, who allocate the fuel resource between their customers. At any time, Parkland may hold contracts with multiple refineries, allowing flexibility of supply in the event of a minor disruption at a fuel center. As a result, trucking companies can pick up and deliver fuels from more than one fuel supplier.

Redistribution events have occurred in recent years. For example, Imperial Oil has experienced an unexpected rack failure that required redistribution of fuel supply. During this failure, Parkland redirected some of its clients to Shell refinery to meet their fuel requirements. The interchanging between two companies has no effect on overall relationships, and the end user is not affected by this disruption.

In the Lower Mainland there are a further twelve registered companies who advertise fuel transportation capabilities. Of these, several distribute exclusively from refineries and storage facilities throughout the Lower Mainland. The others service the mainland as well as island and coastal communities. The majority of these are independently owned, although some companies are a subsidiary of a larger fuel company, and transport their products exclusively.

Columbia Fuels and Coastal Mountain Fuels are two of the larger fuel transportation companies to the general public. With 22 locations, Columbia Fuels is the largest, exclusively
Shell Fuels distributor in BC (Columbia Fuels 2015). They have outposts in Vancouver, Sunshine Coast, and Powell River.

Aside from Vancouver located services, there are additional trucking services between Cherry Point, Washington State, and prominent locations in BC. Vancouver International airport, receives fuel by a combination of pipeline, marine vessel, and trucks. Chevron provides 40% of the aviation fuel directly to the airport, with a similar volume of fuel delivered by tanker to Westridge Marine Terminal to supply YVR (Burnaby Public Library 2016; VAFFC 2008). Unable to meet demand, this current system has become inadequate, and a new fuel delivery system is under development (VAFFC 2008). During peak demand, supplementary supply is provided by truck from Cherry Point refinery in Washington State. The trucks carry fuel from Cherry Point Refinery to Vancouver International Airport via Interstate 5, and Highways 91 and 99. On average this service provides an additional 25 to 35 fuel trucks to YVR, with even more during seasonal peak demand (VAFFC 2008). This is the only known land border crossing of fuels identified in this study.

4.6 Moving Fuel across the Georgia Straight

Without refineries or large storage capabilities on Vancouver Island, the Strait of Georgia acts as a marine highway connecting communities to the fuel supply of the Lower Mainland. Marine vessels ferry fuel directly from both BC and Washington State to Vancouver Island and its surrounding communities.

Fuel intended for Vancouver Island, or the Sunshine Coast, is transported from distribution centers in the Lower Mainland to nearby marine docks by pipe, rail or truck. If the fuel is not barged directly from the distribution facility, leading maritime transport companies
have docks situated near Tilbury and Richmond. Upon receiving fuel, marine vessels transport oil and refined fuels across the Strait of Georgia to various locations along Vancouver Island’s East Coast.

Fuel barges and marine tankers are both utilized in fuel transportation to BC’s coastal communities. Some marine transport companies use roll on roll of inventory, and their vessels carry fuel in trailers. The larger, fuel focused corporations have marine tankers. These vessels are loaded and unloaded at a dock through underground pipes. Once the tankers have reached their destination, fuel is transported by pipeline directly from the vessel to nearby tank farms. As discussed in Section 4.4 many of these tank farms are owned by large fuel companies that also manage a storage facility in the Lower Mainland. Once fuel has reached a tank farm, it is collected from the site by truck and distributed to end-users. For the most part, the transportation between storage and vessels is independently organized by the fuel organization or subsidiary.

Alternatively, fuel trailers are also used. In the event of roll on roll off inventory, most trailers are detached and transported as ‘dead cargo’ across the Strait of Georgia. Upon arrival to the island, fuel trailers are connected to live truck-heads, and dispensed to their final destination. The ‘dead load’ trailers of the roll on roll off system reduce the cost of transportation due to minimal personnel required during the crossing. Furthermore, it reduces employee hours, and eliminates the occurrence of mainland drivers being left on the island at the end of their shift. Roll on roll off also simplifies the transfer process, as they do not require cranes for loading or unloading at the ports.

Marine transportation provides flexible transportation options to meet the needs of different end-users. They require far less fixed infrastructure than road or rail, but do require
cleared shipping lanes, safe harbors, and docks to deliver fuel and cargo to shore. Each vessel will have specific requirements to allow them to dock safely.

Most docks are capable of receiving a variety of different ships or barges. However, there are a number of different techniques for securing vessels to docks, and as a result not all locations are interoperable. The most prominent discrepancy is that some locations require a ‘pin’ to connect a ship to the dock when berthed. Historically, this enabled the loading of railcars onto the ships. Rail demanded a greater accuracy of alignment to ensure smoother loading and unloading of vessels. These docks are still used today; however, some ships are unable to reside at certain locations. Furthermore, ramp heights can limit ships from berthing at some sites. Many ramps can be electrically controlled for each vessel. This is an accurate and effective system provided there is uninterrupted electricity supply. Otherwise, in the event of an electrical outage, ramps may become unusable without standby generators or alternative power means.

4.7 Maritime Transport

Vancouver Island has an abundance of ports located along both its East and West Coast. Similarly, many smaller coastal communities along the BC coast have ports or docking capabilities to receive fuel. Many of the leading ports contain large volumes of storage capacity, making them critical links in the maritime system. Table 7 summarizes four prominent locations for fuel delivery. A full list of the ports and docking locations included in this study can be found in Appendix A. The values provided in Table 6 are estimates of the number of distinct vessels, and the frequency of these vessels to each site over the course of year. The values provided are estimates, inferred from AIS vessel tracking data. This data was supplied to this research by C.
Hilliard at MEOPAR. In addition to this, Figure 6 is a visual map of the relative density of vessel traffic to each site.

Table 6: Prominent Ports on Vancouver Island

<table>
<thead>
<tr>
<th>Dock</th>
<th>No. of Distinct Vessels</th>
<th>Visits over the year (From Canadian Vessels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanaimo, Departure Bay – ESSO</td>
<td>7</td>
<td>121 +/- 10</td>
</tr>
<tr>
<td>Nanaimo – Suncor</td>
<td>7</td>
<td>82</td>
</tr>
<tr>
<td>Chemainus – Shell</td>
<td>8</td>
<td>21-25</td>
</tr>
<tr>
<td>Cobble Hill – Chevron</td>
<td>10</td>
<td>94-95</td>
</tr>
</tbody>
</table>

Figure 6: Map showing density of fuel vessel tracks (Source: C. Hilliard, MEOPAR)

It appears that Vancouver Island terminals receive deliveries anywhere from every other week to as frequently as 2~3 times per week. All vessel information was gathered through AIS software,
and the volume of ships, and frequencies of visits, are approximate. There are some limitations in the AIS analysis as only ships that are equipped with AIS satellite were detected throughout the study. There may be smaller vessels in and around these locations that also have fuel capacity. Although revealing of the frequency of large deliveries, another limitation is that this information does not indicate the volume of these vessels, or the fuel they carry. There is also some ambiguity between the docks. Some of the locations appeared to have ships berth within close vicinity of one another, but not always in the same location. Furthermore, there was a difficulty in differentiating fuel vessels from other unrelated (timber/food) barges. This research does not include vessels without AIS transponders, or any vessels not properly operating their transponder devices.

Vessels transporting fuel to Vancouver Island and up the Sunshine Coast operate independently of passenger ferries, and the marine carrier dictates their docking locations. Island Tug and Barge, Seaspan, City Transfer, and North Arm Transportation are four of the dominant marine transportation enterprises for this area.

Island Tug and Barge (ITB), with an annual capacity of 1.6 billion liters, is the largest carrier of refined fuel to Vancouver Island. It is part of a family of companies run by the Island Tug and Barge Marine Group (Island Tug and Barge Ltd. 2016). Similarly, Seaspan also provides fuel to Vancouver Island. They too are a collection of marine groups. Seaspan’s subsidiary, Marine Petro Bulk, supplies bunker fuels to vessels entering ports in the Lower Mainland. Seaspan Marine and Seaspan Ferries have mainland terminal locations at Tilbury and Surrey, with island terminals at Duke Point and Swartz Bay. Seaspan’s ship schedules change weekly, however they attempt to run at greater than 90% of capacity during routine shipments (Seaspan 2015). Seaspan Ferries predominantly uses roll on roll off and drop trailers as its
methods of transport, although tractors load some resources. Seaspan’s docks and ships are not equipped with crane facilities. Uniquely, Seaspan still have barges that use a pin and donut system, which makes some of their vessels and docks unapproachable by most other companies. Almost no docks require this form of fixture to secure the vessels to the docks. Complications may arise if other marine transporters including Island Tug and Barge, and BC Ferries were to occupy these facilities in an emergency. Table 7 provides an overview of the Seaspan fleet including the vessel names and capacities. Of the shown shipping capacities, only a fraction of this is fuel. Seaspan takes a large percentage of bulk goods, with approximately one in every forty trailers assumed to be fuel.

Table 7: Summary of Seaspan vessels (Seaspan 2015)

<table>
<thead>
<tr>
<th>Seaspan Ferries</th>
<th>Age</th>
<th>Capacity (1000L)</th>
<th>Capacity (53ft Cont.)</th>
<th>Depth Required (ft.)</th>
<th>Specialization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier Princess</td>
<td>1974</td>
<td>3471</td>
<td>32</td>
<td>20</td>
<td>Roll on Roll off</td>
</tr>
<tr>
<td>Princess Superior</td>
<td>1973</td>
<td>3579</td>
<td>33</td>
<td>20</td>
<td>Roll on Roll off</td>
</tr>
<tr>
<td>Seaspan Greg</td>
<td>1964</td>
<td>2386</td>
<td>22</td>
<td>7</td>
<td>Roll on Roll off</td>
</tr>
<tr>
<td>Fraser Link (Pushed by Amix Marine)</td>
<td>1968</td>
<td>4772</td>
<td>44</td>
<td>-</td>
<td>Tug/Barge Unit</td>
</tr>
<tr>
<td>Van Isle Link (Pushed by Amix Marine)</td>
<td>1968</td>
<td>4772</td>
<td>44</td>
<td>-</td>
<td>Tug/Barge Unit</td>
</tr>
<tr>
<td>Georgia Link (Pushed by Amix Marine)</td>
<td>1057</td>
<td>3687</td>
<td>34</td>
<td>20</td>
<td>Tug/Barge Unit</td>
</tr>
</tbody>
</table>

Sunshine Coast and smaller gulf island communities are supplied by services directly from the Lower Mainland. There are some supplementary fuel supply services to these communities from Vancouver Island. In these instances, fuel deliveries are transported through Nanaimo and other leading ports before being transported to the community for local distribution.
Powell River does not receive fuel from the island; instead they are supplied by City Transfer. City Transfer offers a truck and barge shipping service between many water bound communities. City Transfer departs from Port Mellon, before heading to Richmond to collect fuel, and finally to Powell River. The barges do not have a set schedule but deliver to Powell River when ordered. In general, they arrive two to three times per week.

Similar to City Transfer, North Arm transport caters directly to the mid and north coast of BC. They dispatch two voyages monthly. One shipment supplies the mid coast, and the other supplies the northern communities. Many of their consumers are first nation communities, as listed below. Figure 7, displays the location and spread of these communities along the Coast of BC. From this figure, it is seen that many of these areas are isolated by both land and sea. The terrain behind them is rugged, and there are no large communities in close proximity to these locations. Remote communities serviced by North Arm Transportation include:

- Klahoose, Toba Inlet
- Wuikinuxv, River’s Inlet
- Heitsuk, Bella Bella
- Gitga’at, Hartley Bay
- Gitxaala, Kitkatia
- Lax Kw’alaams, Port Simpson
- Kitasoo, Klemtu
- Masset
- Haida Gwaii
- Bella Coola
- Shearwater
- Prince Rupert
- Campbell River
Figure 7: Locations of coastal communities, serviced by North Arm Transportation (Base map is a copyright of © OpenStreetMap contributor (http://www.openstreetmap.org/copyright). All additional adaptations are by the author. Retrieved 11/05/16)

All known fuel transportation is carried out by either ITB, Seaspan, City Transfer, or North Arm Transportation. Vancouver Island is serviced by ITB and Seaspan, and the smaller City Transfer and North Arm Transportation deliver fuel to coastal communities. Another large maritime transportation company in this area is BC Ferries’. BC Ferries’ is the largest passenger vessel company in the region. If needed, BC Ferries’ capacity could be utilized to move fuel, although they have additional regulations for moving “dangerous cargo.” Generally, these additional
regulations are cost-prohibitive and trucking companies prefer to use other marine transportation options. To summarize these companies’ roles in fuel transportation Figure 8 provides an overview of the current routes undertaken by these companies on a frequent basis.

![Figure 8: Routes of maritime transportation leading companies. (Base map is a copyright of © OpenStreetMap contributor (http://www.openstreetmap.org/copyright). All additional adaptations are by the author. Retrieved 11/05/16)](image)

4.8 Community Storage

In semi-remote communities such as Powell River, additional resilience has been built by having large storage tanks at local fuel stations. At a single location, these tanks have a storage capacity
of 170,000L for diesel, and 155,000L for petroleum. These stations continuously hold additional fuels on premises, with management restocking fuel stores as soon as there is sufficient room available for a new shipment. The supply is delivered in volumes of 50,000L and 40,000L respectively, which is estimated to be two weeks’ worth of fuel for their community if supply was disrupted.

In Powell River, City Transfer trucks fuel from the port to two Columbia Fuel stations where fuel is stored in their independent storage tanks. There is an additional tank farm at Powell River, serviced by Imperial Oil, located near the docking facilities. This location is predominantly used for commercial business demands throughout the district.

Other remote communities, such as Hartley Bay, also have community tank farms. These tanks have substantial capacity, but contrasting Powell River, only a fraction of the storage capacity is utilized. As a community of less than 200, they are defined as ‘off the grid’, and rely on monthly shipments for their diesel, to ensure continual power generation. In 2010 Hartley Bay participated in the Remote Community Electrification contract with BC hydro, however this program was suspended in 2015 (Pollon 2016). Many of the smaller communities have some means of fuel storage. However, the extent of personal storage throughout these locations is largely unknown.

4.9 Communities Dependent on Maritime Transportation

Due to the isolation from the source of fuel supply, BC’s societies have a greater reliance on maritime transportation than mainland areas. Observations have shown that most resilient systems must possess some level of redundancy (Little 2003). Redundancy can refer to a backup of supply, infrastructure, or alternate routes. A way of increasing the redundancy within the fuel
system would be for communities to have additional fuel storage. Ultimately, all supply to these communities originates in the Lower Mainland, at one of the five distribution centres in Burnaby. From there, each community has an individual approach to fuel supply with their own delivery, storage, and distribution methods. Each community’s system attains to their personal needs and convenience. Fuel and resource is delivered daily to larger island communities whilst more remote communities may be serviced once per month. In many communities on Vancouver Island, there is minimal excess fuel available. Because of the limited amount of storage, these communities require the constant shipping of fuel to meet their demands.

It is evident that different communities have varying scales of demand. When analyzing the fuel network in BC, and the relative resilience of communities, the system should be separated into several smaller categories based on size. Table 8 displays the population, frequency, and number of ships transporting fuel to communities of varying populations. Each community has different fuel demand and they each possess very different levels of fuel reserves.

Table 8: Table of population density and frequency in supply throughout BC (Government of Canada 2011)

<table>
<thead>
<tr>
<th>Community</th>
<th>Population</th>
<th>Frequency of Delivery</th>
<th>Number of Ships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver Island</td>
<td>750,000</td>
<td>Daily</td>
<td>Multiple</td>
</tr>
<tr>
<td>Powell River</td>
<td>16,700</td>
<td>Two – Three Times per week</td>
<td>One</td>
</tr>
<tr>
<td>Mid Coast</td>
<td>6600</td>
<td>Monthly</td>
<td>One</td>
</tr>
<tr>
<td>North Coast</td>
<td>6700</td>
<td>Monthly</td>
<td>One</td>
</tr>
</tbody>
</table>
Throughout many interviews, it was an assumption that those with infrequent supply will have increased storage capacity. Some smaller remote communities accept their relative insignificance within the larger system. Knowing this, they accept they are not guaranteed priority supply in the event of a disruption or fuel shortage. Although most communities interviewed have never experienced ‘no supply’, these areas have experienced short delays in their resource delivery during adverse weather or other minor disruptions. For this reason, they have increased their storage, reducing the reliance on immediate supply, which will benefit them in the event of a large disruption.

Should a disruption impair fuel supply, alternative delivery methods for fuels will be required. This will involve re-routing of vessels and fuel stores. There is significant scale difference between communities like Vancouver Island and coastal BC settlements, and sharing of facilities and fuel stores could be severely limited. The shipping vessels of larger populations cannot necessarily be “reduced” to accommodate smaller communities. Attempting to use a Vancouver Island servicing ferry to facilitate Hartley Bay would be an inefficient use of resource. Vice versa, a smaller population has limited capacity to support the larger communities when in short supply. Issues would include infrastructure logistics such as berth structure, ship size, docking location, depth, route flexibility, and unloading capabilities. Although each community has the same delivery system, there is limited options for operability between them. Improving the resilience of each system’s process will provide greater benefit.

To increase resilience focus should be on the robustness of each individual community supply chain. Understanding how fuel is transported to and around southern BC is the first step towards increasing these systems’ resilience. This information is necessary to analyze the system’s vulnerabilities as well as explore options and plans to increase robustness.
4.10 Fuel Movement throughout Coastal Communities

This chapter provides an overview of the fuel system throughout the Lower Mainland, BC. The information provides a summary of the movement of the fuel about the region, as displayed in Figure 9.

Figure 9: Overview of fuel system in BC (Base map is copyright of © OpenStreetMap contributors [http://www.openstreetmap.org/copyright]. All additional adaptations are by the author. Retrieved 11/05/16)
Understanding the system logistics, and how each of the transportation modes link and relate to one another, is fundamental to accurate and efficient evaluation of vulnerabilities in the system. The information provided in this work has created a view of the entire system. This whole system approach allows for the identification of the system behaviours, strengths, and weaknesses. From this research it can be seen how each step in the supply chain links to another. If one location in the system is removed or impacted, it can affect other aspects of the system. The secondary effects, where one aspect is affected, and impacts on another area can be difficult to predict. Leading concerns in the current system and proposed changes are explained in Chapter 5.
Chapter 5: Concerns for the Current System

With knowledge of the capabilities and limitations of the system, defining what needs to be done—and where—becomes more apparent. This chapter summarizes concerns about the current physical and managerial elements of the fuel transportation system, as defined by representatives within the industry. Vulnerabilities discussed included hazards and weaknesses. A hazard is any event that will influence the system, while a weakness is an area or aspect of the system that is prone to disruption. These vulnerabilities can often be attributed to either managerial and organizational concerns, or physical concerns involving infrastructure, environment, and people.

Throughout the interviews there was extensive discussion about current emergency response plans, although many of the plans discussed were still at surface level. All of those interviewed expressed concerns with the current preparedness of the maritime transportation system in the event of disruption. Irrespective of his or her company’s personal preparation for disruption, each interviewee agreed that further planning and action is required. Figure 10 shows the four most commonly identified key gaps in the organization of the current system, and the percentage of interviewees who raised each concern. These key gaps were:

1. Planning is on a high level. In some cases there is limited follow through with plans progression in some areas. There is a lack of continuity plans in some organizations.

2. There are limited plans for fuel prioritization. There is no fuel distribution hierarchy that would ensure critical resources for response receive fuel before others.

3. There are instances where regulations can cause delays in planning for recovery, and at times some ambiguity differing levels of government.
4. Limited communication and knowledge share between leading stakeholders. There is also some uncertainty on who is in charge, and what roles and responsibilities many entities have in differing circumstances.

Figure 10: Key Gaps in the current fuel system that were raised throughout interviews

5.1 Fuel Prioritization

As seen in Figure 10, a leading concern within these interviews, also raised within literature, is the lack of prioritisation in relief activities (Ferreira Pedroso et al. 2013), specifically in how fuel supply will be satisfied and prioritized in a disruption. Decision making in the aftermath of a disaster is difficult. This difficulty is increased with limited, or inconsistent information (Ferreira Pedroso et al. 2013). Having a pre-planned fuel prioritisation plan was recommended by 89% of respondents. This would ensure fuel is distributed in the most advantageous way. Fuel prioritization will allow emergency responders and high demand activities to receive the necessary fuel to undertake response procedures. Any remaining volumes can be distributed.
through rations for less critical activity. To ensure the prioritisation list is effective, this must be communicated in advance. Ensuring all fuel suppliers are notified and provided compensation for the fuel they distribute during an emergency will guarantee the availability of these fuel stores in the event of an emergency. This pre-planning would reduce confusion and wasted time, and increase efficiency in the response.

5.2 Emergency Response and Continuity Plans

Organization is a vital aspect of emergency preparedness, especially for the coordination of response. Emergency preparedness plans that minimize disruption and coordinate recovery are an integral part of response. Continuity plans, a strategic plan focusing on the resumption of normal operations post disruption are equally as important. Most organizations had individual business continuity plans, or emergency response procedures in place. All of plans considered the impact of a large earthquake. The level of detail in these plans varied significantly between organizations. General response procedures for large disruptions, or business continuity plans were common. These plans were tailored for emergencies within the organization. In many instances additional impacts including employee availability, loss of supply, electricity, or communication were not considered. In contrast, some other organizations had extensive protocols in place to consider multiple scenarios of differing severity. These scenarios included oil spills, environmental disruptions, fires, or technical issues. For each type of incident there were specific situation dependent response plans. In several instances, emergency response plans were practiced as annual deployment trainings, or tabletop exercises. Exercises such as these are further explained in Section 5.8.
5.3 Coordination of System

In certain aspects of emergency response planning there is limited coordination between industry and the general public. Without sufficient awareness between responders and the public, recovery operations can be significantly slowed. Not knowing who or what resources are available in an emergency creates an additional barrier to ensuring a fluid recovery operation. When questioned about each interviewee’s part in a large disaster response, like an earthquake, there is ambiguity toward roles and responsibilities of each organization. This is a result of the lack of sharing of information and communication between companies, the private sector, and emergency response organizations. An exception to this is Port Authorities, who proactively engage with one another, sharing knowledge and expertise to improve their collective resilience. Many ports are exceedingly active in their planning and development of emergency measures.

Knowing who is responsible and liable is crucial to a synchronized response. There is concern about which organizations will be in control in disruption events. The hierarchy of emergency responders is situation dependent. In BC, there is additional complexity of water being under federal jurisdiction, and the land a provincial declaration. In the event of an emergency, the ‘British Columbia Earthquake Preparedness: Consultation Report’ (Renteria 2014) indicated EMBC should be given legislated authority in events of large disruption. EMBC would be in control, organizing the emergency and coordination center. However, they can only act once a provincial declaration has been instated. In the event of a smaller disruption, or an event where no provincial declaration is declared, there appeared to be an ambiguity about who assumes immediate control.

Another constraint to emergency response is an absence of agreements or plans between industry and private entities. Public-private partnerships would cluster resource supply and
facilities together. There is no evidence contractual agreements are in place, only informal agreements between businesses. These are based upon organization history and personal relationships. Evident from interviews and workshops, some organizations have robust relationships, keeping them involved and updated with information and developments. However, industry companies who are difficult to engage, or lack history and repertoire with others, are excluded from this sharing of communication.

Many of those interviewed are aware of these concerns and actively working towards establishing solutions to these issues. Respondents highlighted underlying barriers in resolving some of these current issues. A leading barrier in improving response is the discontinuity of representatives throughout planning and response events. In an emergency scenario constantly changing representatives, can add to confusion. Anecdotal examples emphasized the impact this can have on recovery. In a recent response activity, some response organizations’ representatives were changing daily. The recovery was carried out over three days, and had a single ‘command’ room where response plans were organized. When an un-briefed representative appeared on site, there was an information gap between them and the rest of the response team. Moreover, tardiness or truancy at response briefings meant information was missed, or had to be unnecessarily repeated. These delays create time lags and complications in the operation, which can lead to substantial impact on the community and environments involved. A robust communication sharing system, that links departments, and industry, would be essential to rectify such issues.
5.4 Redundancy in the System

Lack of redundancy within the fuel system is another barrier to addressing several leading concerns. The fuel transportation system has become a specialist network of experienced companies. For many parts of the system there is a single option, without alternatives.

Examples within the fuel transportation system that limit its redundancy include:

- No local or onsite fuel generation in BC
- A single supplier for fuel and generators to multiple locations
- Small communities’ have only one dock location
- Isolated tank farms
- No private sector engagement

Transportation of fuels to many areas of Vancouver Island, and along the coast relies solely on a single fuel distribution service. Single fuel docks and tank farms further amplify the isolation of some communities. Should a single truck, vessel, dock, or tank farm be impaired this will significantly impact fuel supply to these areas.

A limitation in rectifying the low redundancy of the system is the lack of engagement of the private sector. There was unanimous agreement that private sector held significant resource and expertise in transportation, and management of fuel supply. With additional boats, people, and resource, the private sectors involvement could amplify the redundancy of the system. Interviews highlighted an expectation of private industry involvement. Contradicting this, at the time of the interviews, no one had made contact with these private parties to confirm this assumed assistant or capability.
5.5 Available Personnel

The availability of emergency responders is vital to response measures. Location and availability of emergency responders will have a large impact on response. In some instances, 60% of staff are dispersed throughout the lower mainland; separated by oceans, rivers, and bridges. Should a disaster occur, and personnel be unable to report to work there would be an inability for response operations to progress. This risk is further increased by operations that require trained personnel at remote locations.

5.6 Physical Infrastructure and Operations

Evident from both past experience and interviews, physical and operational disruptions are as important as the management of the system. In the event of disaster, ferries and maritime transportation are regarded as a key transport modes to coastal communities (Ferreira Pedroso et al. 2013). The integrity of the infrastructure required to accommodate maritime transport is crucial. Without infrastructure, this will hinder the ability for resource to be supplied and transported to in-need communities. History has shown physical damage to port facilities, ships, and pipelines, are a common impact of natural disruption - particularly in earthquakes, as seen in Kobe in 1995, Christchurch in 2011, and Chile in 2010.

Electricity is another physical concern. The likely disruption to electricity and communication systems would have a profound impact on the coordination of response. Communication lines, and large infrastructure, such as bridges and traffic operations, integral to a population’s daily routine, could experience difficulty. In the event of disruption these locations would need generators, or electrical alternatives to ensure continued service. Without
sufficient levels of alternatives, operations will be effectively ‘stuck’ in a disaster, unless external resources can be acquired.

5.7 Subsurface Ground Movement

Ground movement, liquefaction, and underwater landslides can create widespread impact, stranding vessels and isolating port locations. Earthquakes can significantly change the typography of a sea floor, impacting the path of vessels. In BC, underwater ground movement risks marine vessels becoming damaged or stranded in the Fraser River, Strait of Georgia, or alternative water channels. In the event of suspected subsea movement, initial responders must survey the floor to check for changes to the landscape, ensuring these passages are safe to travel. Because of increasing technology, modern monitoring of the sub-sea floor requires few personnel. With fewer operators trained in a specific task, there was concern expressed that in the event of a disruption, there is no guarantee the technology, or the controller, will be available.

5.8 Pro-active steps Toward Resilience Planning

A critical system, fuel supply is essential for economic, environment, and societal function. Resilience is vital to ensuring the efficient resumption of normal social and economic activities in communities throughout BC. Learning from previous disasters, the maritime transportation system in BC has begun developing some resilience plans. A number of organizations within the industry has executed real exercises, including equipment deployment and tabletop exercises. These involve simulating a real world scenario, and running through response procedures as if they are in fact in a real life emergency. Exercises greatly improved an organizations familiarity and preparedness. Some companies went even further, having readily available response actions worksheets preplanned and ready for execution should the need arise. These stepped through the
appropriate actions to take in the event of an emergency. These plans and practices provide punctual recovery operations in the event of an emergency.

There is also evidence of pro-active planning in the safety of fuel ships. In recent years’ transportation agencies have adjusted regulation and safety guidelines for large vessels. Now, only double-hulled barges are able to transport fuel. This is a leading technical advantage of modern day vessels. It has been reported that up to 85% of historic oil spills could have been avoided if double hulled barges had always been a requirement for fuel transportation (CERA 2013). Other safety regulations include vessel traffic services, and escort tugs. Each measure reduces the likelihood of spills, and provides a platform of quality assurance amongst marine transportation members.
Chapter 6: Hazards and Mitigation Measures

The objective of this chapter is to critically analyze the information provided, and review hazards and possible mitigation measures that will address concerns and gaps within the current system. A hazard is defined as an event that will disturb the supply chain and create an economic or social impact on the system. Mitigation measures address, and minimize, the consequence of these hazards. Improving the resilience of the current state enhances the system’s ability to respond to disaster. To advance resilience of the fuel transportation system, focus should be on improving the integrity and redundancy of supply, flow, and distribution of fuel.

Using the vulnerabilities outlined in previous chapters, prominent hazards in the system are identified. Defining these weaknesses, mitigation measures can be established. The mitigation measures considered in this study will address several aspects of the supply chain. Mitigation measures discussed in this work are from reviewing past maritime disruptions, and suggestions made during the interview process.

6.1 Defining Hazards

Many of the vulnerabilities identified revolved around key areas of the system. These key features of fuel transportation include source of supply, methods of conveyance, storage, frequency of resupply, and local demand. Each of these supply-chain elements impact on system-wide strengths and weakness. This impact on response can vary in different disruptions.

The severity of a hazard or disruption varies depending on where the hazard occurs, and whether a hazard is spatially localized, affecting a single element, or a system wide impact. A localized hazard would be of isolated scale, and have limited impact to communities. Examples of this include isolated oil spills such as the Marathassa in 2015. A localized incident this did not
affect the maritime transportation of fuel or resource. In contrast a larger hazard, such as an earthquake, would have a system wide effect. This form of disruption will have a longer duration of recovery, exceeding days or weeks, and substantial impact on multiple communities.

For smaller disruptions, like isolated oil spills, the recovery options are better understood and manageable. Corporations in charge of spill response carry out routine exercises and response planning activities. This is reflected in the capable and efficient response to such accidents. Although recent spills in Western Canada have been small in volume, the organization of response within these companies is compelling evidence that their planning and proactive preparation will enable them to competently respond to oil spills events. With larger scale disruption there is the added complexity of reliance on more than one responder or action. Strategies and planning for these events does not appear to have the same level of detail.

Another factor related to the extent of any hazard is the timing and duration of the consequence. As disasters cannot be predicted, there is no knowing whether the disruption is to occur when a community is fully prepared, or when they are enduring their last days of fuel before a renewal of supply. This impact is more pronounced in the more remote communities. For areas who receive supply monthly, if a disruption was to occur near the end of the month, their tanks would be severely depleted comparatively to if a disaster was to occur within 2–5 days of fuel rejuvenation. The duration of the disruption will also affect the severity of a hazard. For bad weather, delays may only effect a system for 6–24 hours. If flow is re-established quickly, many areas will not experience significant consequences. In contrast, larger events have the potential to impact a system for many days or weeks. When assessing the hazards, community, frequency, and severity of consequence will be considered. Looking at the population affected
the physical and social cost this may have on their living can be an indicative measure of ‘impact’.

Not all hazards carry the same risk or consequence to a system. Evaluating the impact of a hazard can be described as the cost incurred which includes potential profit lost. This would be the cost incurred due to the disruption, as defined in a later chapter.

6.2 Prominent Hazards to the System

From the information gathered throughout this study, a compilation of hazards; both short and long term can be seen in Table 9. The true list of all hazards would be substantially greater. For the purpose of this study, these hazards focus on concerns raised, and addressed throughout this research. Each hazard is defined as having a short term or long-term impact. Short-term hazards are isolated events, with a definitive recovery period. Typically, long-term hazards will have a larger spatial impact, and will significantly impact the operability of the system for an extended period. These could be an earthquake, or a ship sinking that then blocks a vessel channel. For long-term hazards, it is assumed that the recovery period will extend beyond a period of two weeks.

Each of the hazards listed will have a negative impact on the fuel system. This impact could be economic, a failure of operation, inability to supply fuels, significant delay, or exhaustion of resource. Not all disruptions will entirely stop the supply of fuel, or cause all fuel stores to be depleted. The list of hazards, displayed in Table 9 below has been established from both interviews and literature.
### Table 9: Short and long term hazards

<table>
<thead>
<tr>
<th>System Elements Disrupted</th>
<th>Spatial Extent of Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single Location/Short Term</td>
</tr>
</tbody>
</table>
| Supply, Demand and Landside Delivery: | • Fuel pipeline failure  
• Rack failure  
• Industrial accident  
• Loss of supplier  
• Road congestion | • Pipeline rupture  
• Uncontainable leak  
• Terrorism at multiple locations  
• Earthquake  
• Storage facility failure |
| Port Outage | • Infrastructure failure  
• Isolated fire  
• Power outage  
• Repair or part replacement  
• Flooding | • Berth damage  
• Loss of loading facilities  
• Storm surge flooding  
• Earthquake  
• Tsunami |
| Transport/Route Failure | • Road block  
• Navigation channel blockage  
• Oil spill  
• Debris  
• Rock fall | • Undersea slumping  
• Outage of navigational telecommunications system  
• Sunken ship  
• Bridge collapse  
• Underwater mudslide |
| Vessel Outage | • Mechanical  
• One Board, localized, fire | • Grounding, blocking a vessel channel  
• Collision  
• Sinking  
• Labour strike (ships)  
• Labour outage |
| Power Outage | • Administrative systems  
• Use of electrical powered docks and cranes  
• Pump capabilities  
• Lights and services | • Network wide coordination  
• Delays in transportation  
• Lack in delivery of supply |

### 6.3 Potential Mitigation Measures

For greatest benefit, actions to build resilience focus on areas of the system most prone to disruption, and areas that would experience a greater consequence. Many of the hazards in Table 9 can be attributed to either the storage, transportation, or infrastructure aspect of the supply.
There are numerous mitigation solutions to avert these hazards. Suggested mitigation measures to address common concerns are shown in Table 10.

Table 10: Mitigation actions to improve resilience

<table>
<thead>
<tr>
<th>Mitigation Option</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Additional Storage</td>
<td>• More tank farms&lt;br&gt;• Hold maximum capacity in storage tanks</td>
</tr>
<tr>
<td>2 Additional Port Capacity</td>
<td>• More berths&lt;br&gt;• Generic ship berth mechanism system at all docks</td>
</tr>
<tr>
<td>3 Additional Ships</td>
<td>• Maintain old ships&lt;br&gt;• Have ‘extra’ barges for emergency&lt;br&gt;• Use other industries ships for fuel</td>
</tr>
<tr>
<td>4 Additional Source of Supply</td>
<td>• Alternate origins of fuel&lt;br&gt;• More Refineries</td>
</tr>
<tr>
<td>5 Additional Personnel</td>
<td>• More training/backup for leading skill services (I.e. dredging)&lt;br&gt;• Retraining of retirees</td>
</tr>
<tr>
<td>6 Increase Independent Resilience</td>
<td>• Generators at stations&lt;br&gt;• Catalogue of who has generators/hand pumps/can extract fuel without power&lt;br&gt;• Recovery packages</td>
</tr>
<tr>
<td>7 Increase Conveyance/Transition of Land and Marine</td>
<td>• Emergency berth&lt;br&gt;• Seismically designed structure</td>
</tr>
<tr>
<td>8 Increase Public Education</td>
<td>• Engage commercial businesses&lt;br&gt;• Public meetings to outline what is being done.</td>
</tr>
<tr>
<td>9 Increase Communication</td>
<td>• Public and private partnerships&lt;br&gt;• Offer tax incentives&lt;br&gt;• Promote information sharing and response collaborations&lt;br&gt;• Create and circulate hierarchal and priority users for fuel</td>
</tr>
</tbody>
</table>

With the purpose of improving a community’s ability to operate post disaster, each mitigation measure addresses a different element of fuel transportation. The types of measures suggested in Table 10 mirror the concerns raised in Chapter 5. Mitigation Measures 1 – 7 address physical
changes that can be made to the way fuel is transported, and measures 8 and 9 are community or managerial changes.

6.4 Comparing Mitigation Measures

Mitigation measures are introduced to prevent or remove hazards from the system. Often the consequence of disruption extends beyond the point of immediate impact. When a single component fails in the system, like a port berth, this can trigger a cascading consequence throughout the system.

Due to the scale of the fuel transportation system, complete elimination of all threats is an unattainable task. It is not feasible to make the entire system indestructible. Similarly, increasing resilience in a single aspect of the system and creating an indestructible component, would be a wasteful use of investment. This would ensure robustness of a single location, ignoring the importance of system-wide flow.

Improving overall system resilience is not a panacea to rectify an individual issue. System resilience is the establishment of fundamental measures to protect supply, transportation, storage, and demand of a community. Even a localized disruption can create extensive failures. This is due to areas, like ports, having many other elements relying on them. If a port's infrastructure is affected, this can have considerable implications on other aspects of the system, including vessel traffic and pipelines. The interdependency between these components represents a consequence of a cascading hazard. The same is true for mitigation measures. A mitigation measure can increase the resilience of a single component without addressing other effects on the system. Consequently, the benefit gained by a resilient measure can extend beyond the single hazard it was introduced to prevent. Introducing a single measure, such as emergency berths at
ports, will improve the reliability of several parts of the system. This would create a benefit far greater than the hazard it was designed to resolve.

When comparing mitigation measures, the cost and benefit of them should be considered. The monetary cost of introducing a resilience measure can be assumed as the cost of installation. When assessing the benefit of an investment, this is defined as the loss averted. To justify an investment, the benefit an action provides must exceed its cost. Simply, the cost of creation and implementation must be less than the loss averted.

As storage, transportation, and transfer of fuel are significant factors in the system, this study focusing on improving the reliability of these. Sufficient tank farm storage, shipping flexibility, and improved port infrastructure are three ways to address these concerns. This work will provide a case study into each of these parts of the system looking at the current management, or potential improvements to these areas.

6.5 Evaluating Mitigation Measures

Reducing the risk of a hazard to the system increases its reliability, and ability to endure and respond to disruption. Aforementioned in Chapter 4, the nature of the fuel has similar networks of varying scale. Communities can be differentiated by the volume of supply, the frequency of supply, and overall demand. Increasing the resilience of the storage and transportation of fuel to each community will provide the greatest benefit due to these being fundamental components of the supply chain. The consequence of many hazards could be a loss of operations, infrastructure, and personnel. To recover there must be consideration of the cost of lost time, loss of operations, social cost, and recovery procedures.
Similar to the cost: benefit gained from the introduction of a mitigation measure is not purely economic value. Evaluating the economic cost of rebuild and social cost must also be considered. Social cost is the total cost or impact a disruption will have on the community. It is the complete private cost, including external cost. External costs include, but are not limited to:

- Monetary value placed upon having continual access to resource.
- Loss of business revenue
- Human cost
- Inflation at fuel stations due to short supply
- Cost of not having un-interrupted supply of fuel
- Disruption to essential services (i.e. healthcare)

Equating an exact monetary value of immediate impact, loss of economy, and social costs is beyond the scope of this study.
Chapter 7: Case Studies of Mitigation Solutions

With hazards and mitigation measures discussed previously, this chapter will examine three case studies on vulnerable areas of the system. Whilst all the hazards mentioned pose a threat to the fuel system, the leading hazard considered during the following analysis is an earthquake. Of the hazards mentioned, an earthquake will have the greatest spatial impact. It is likely such an event in BC will significantly impair routine operations, and the recovery will take an extended period of time. The case studies will look at current or proposed mitigation measures to improve the resilience of the fuel transportation system. The first and third case studies are reviewing current system activities that can effect resilience. The second case study evaluates several potentially feasible options to further improve the resilience of this aspect of the system. Simple cost benefit-analyses of will give an indication of the monetary impact each of these mitigation options and strategies will have on the system and the communities it serves. It is acknowledged that accurate validation of the cost or benefit for such measures is complex, and beyond the purpose of this preliminary study. The values calculated in this chapter will provide an indication of the practicality of each mitigation measure. The purpose is to establish which options appear feasible, and suggest cases where further investigation should be pursued. If they appear viable, solutions presented will require more detailed investigation to confirm accurate cost and benefit values.

7.1 Adequate Tank Farm Storage

For most locations resources are delivered on an as need basis with limited storage available. As a result, fuel stores can deplete quickly post disaster, and the society can experience significant economic loss during the aftermath. Ensuring sufficient storage in remote communities can
enable them to be unaffected, or only marginally compromised by short to midterm fuel supply disruptions.

For almost all communities in the scope of this study, their fuel is stored in tank farms. Throughout interviews, the volume, maintenance, and location of community tank farms were under scrutiny. Many tank farms were built decades’ ago, and the redevelopment of the surrounding land has left them located in now populated areas. Moving existing tanks, or building new, both come at significant cost. Improving the integrity, safety, and management of existing tank farms is a less cost intensive option.

To evaluate how the storage of fuel provides resilience to a community, a case study of two coastal communities with pre-existing tank farms is undertaken. This case study examines the management of existing tank farms. It is not considering the construction of new tank farms, or relocation of existing facilities. For this study, the two communities are Powell River, and Hartley Bay, with populations of approximately 16,700 and 150 respectively (Government of Canada 2011). Powell River is serviced every 2-3 days, on an as need basis, whereas the smaller Hartley Bay is serviced monthly. Although both locations have ample storage capacity, the management of the tanks differs significantly. Powell River utilizes all the spare capacity of the tank farm, keeping fuel tanks full at all times. Hartley Bay uses only a percentage of its tank farm capacity; maintaining, but not using excess storage volume. Highlighting current tank farm management, this study outlines the relative merits and drawbacks of each approach to fuel storage.
7.1.1 Hartley Bay

Hartley Bay is a remote coastal community, only accessible by boat. An off the grid community, it relies on diesel generation for electricity and home heating. Hartley Bay has three large tanks, but not all tanks are utilised. Under the operation of BC Hydro, all tanks are maintained and remain in service-use condition, but only two are regularly used. The third is called upon when required. The two larger tanks have a capacity of 168,000L, while the smaller tank has capacity for 98,000L. One large tank holds petroleum, whilst the other two tanks are for diesel. Previously all three tanks were in use. The change in operation was due to cost and infrequency of orders.

All fuel delivered to Hartley Bay is by North Arm Transportation. Upon arrival, it is pumped from the barge, directly to the tanks. From here, fuels are then distributed to the community. There is no fuel delivery schedule, but they receive deliveries approximately once per month. Neither of the two in-use tanks are filled to capacity, and each new order is around 40,000-50,000L. The tanks can get as low as 15,000L before additional fuel is delivered. Those interviewed estimated that at this minimum volume they would have enough fuel for one to two weeks without the need for additional supply.

7.1.2 Powell River

Powell River district is a larger coastal community of around 16,700 (Government of Canada 2011). Contrasting many other areas, they have extensive emergency response planning already in place, and preparedness strategies that far exceed regulatory requirements. When interviewed it became apparent that Powell River’s response initiatives surpass the norm. They have additional emergency supplies, inventory, vehicles, and coordination between businesses.
Furthermore, they have frequent emergency planning meetings involving representatives from all response organisations, leading businesses, and companies within their community.

Powell River has two tanks with capacities of 170,000L and 155,000L, which hold diesel and petroleum fuel respectively. The managers of these have adopted the “keep full” mentality. They receive fuel barged to Powell River by City Transfer, and accommodate a shipment two to three times per week. They receive diesel and petroleum in 50,000L and 40,000L allotments respectively. As soon as the tanks have enough available capacity to store another shipment volume, more fuel is ordered. This means they always have maximum supply available. At a minimum, the two tanks do not fall under approximately 120,000L, and 115,000L. Over a monthly period, they receive 500,000L of diesel and 400,000L of petroleum.

7.1.3 Comparison of Powell River and Hartley Bay

While one community is carrying large overhead cost to ensure excess supply, the other is reducing this cost by holding minimal fuel volumes. To compare the two communities Table 11 provides statistics on each community’s relative size, tank farm facilities, frequency, and volume of supply. Details about Hartley Bay were harder to obtain. The overall volume of supply is known, however the relative volume of petroleum and diesel is not.

Table 11: Comparison of Powell River and Hartley Bay’s fuel storage behaviours (Government of Canada 2011).

<table>
<thead>
<tr>
<th></th>
<th>Powell River</th>
<th>Hartley Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>16,700</td>
<td>150</td>
</tr>
<tr>
<td>No. of Tanks</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Tank Capacity</td>
<td>325,000 L</td>
<td>432,000 L</td>
</tr>
<tr>
<td>Tanks in Use</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Refuel strategy</td>
<td>As full as possible</td>
<td>40,000 L</td>
</tr>
<tr>
<td>Frequency of Supply</td>
<td>2-3 /week</td>
<td>Monthly</td>
</tr>
<tr>
<td>Volume of Supply</td>
<td>50,000 L Diesel 40,000 L Petroleum</td>
<td>40,000L</td>
</tr>
<tr>
<td>No. of Ships</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
The volume of fuel delivered each week, or month, is used to calculate the average volume of consumption for both communities. The average consumption and available storage of fuels is calculated in Table 12. The calculation assumes Powell River is supplied with three deliveries each week, and Hartley Bay receives fuel once every 30 days. The number of days each community could survive without fuel supply is calculated assuming the tanks are full on the day of a disruption.

Table 12: Supply, consumption and storage of fuel to coastal communities

<table>
<thead>
<tr>
<th>Ship Company</th>
<th>City Transfer</th>
<th>North Arm Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest Volume (before replenished supply)</td>
<td>120,000 L (diesel) 115,000 L (petroleum)</td>
<td>15,000 L</td>
</tr>
</tbody>
</table>

In a best-case scenario, each community would run out of fuel within a matter of days. This is a conservative estimate, as it assumed all tanks were full and intact when a major event occurs. In reality, the tanks could be depleted, or significantly damaged, and the days of fuel stored could be substantially less.

### 7.1.4 Cost of Fuel Storage and Loss of Supply

To understand the two management approaches, the cost and benefit to the respective communities should be considered. To evaluate the cost to each community to store fuel, a comparison of fuel volume and fuel prices are shown. Table 13 is calculated using the online
available terminal rack price from Petro Canada (Petro-Canada 2016). The prices used were from Nanaimo BC, to best emulate the cost at coastal communities. Regular gasoline is 67.40 cents/litre, where diesel is 69.00 cents/L cost per litre. As Hartley Bay uses diesel generation to supply its community it is assumed the volume of fuel stored is diesel. This is an inventory cost of $27,600 to keep 40,000L stored. In contrast, Powell River keeps 170,000L diesel and 155,000L petroleum onsite, at a cost of $221,770. Table 13 indicates total volume and cost, as well as the volume and cost per capita to each community to store their fuel. As the two communities have different populations, the cost and volume of storage per capita provides a representative comparison.

Table 13: Cost of fuel storage to Powell River and Hartley Bay

<table>
<thead>
<tr>
<th></th>
<th>Powell River</th>
<th>Hartley Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Stored (L)</td>
<td>325,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Liters/person (L)</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Over Head Cost ($)</td>
<td>221,770</td>
<td>27,600</td>
</tr>
<tr>
<td>Cost/person ($)</td>
<td>13.3</td>
<td>138</td>
</tr>
</tbody>
</table>

From Table 13 it could be concluded that it is in fact Hartley Bay that has the more conservative fuel storage operations per capita. However, this table does not consider the demand, or cost of no supply to each community. Looking at the economic value of each community, an approximate cost to the population, per day without fuel, is established.

From the statement of operations for the year ending December 31 2014, Powell River has an estimated economic value of $17,574,098 (Powell River District 2015). This is an indicative measure of the value of Powell Rivers economy, and the economic loss they would experience without fuel. This is assuming that a no fuel scenario will result in a total economic shutdown. Without access to fuel, this would result in an adverse cost of $48,148 per day. If
Powell River were to be without fuel for 2 weeks, this would cost an estimated $674,075. With an investment of $221,700 and a loss of $674,075, the overhead investment could be justified in this situation. However, with approximately 8-9 days of fuel stored, even if they were without renewed fuel supply for two weeks, they would only endure 5-6 days without fuel. Conservatively assuming that they had 8 days of fuel remaining, they would endure 6 days with no available fuel. The advertised loss of five days without supply is $288,888. A value that still exceeds the cost of investment.

This is a substantial investment and there are other options Powell River should consider. As the voyage to Powell River is a single day, even in extreme events it is reasonable to assume that Powell River would receive a shipment within a week of disruption. With current storage patterns, they have sufficient fuel to endure this time without resupply. With reduced storage they would still be capable of enduring this time period. Another concern is the fragility of the full fuel tanks in an earthquake. Full tanks will perform worse in an earthquake than emptier tanks (O’Rourke and So 2000). Reducing the fuel volumes in their tanks will increase the chance of the tanks remaining intact, and useable in the event of an earthquake. As an example, storing 45,000 L less of both gasoline and diesel would provide a cost saving of $61,000. This may be considered a more realistic value to hold, and reduce the risk of tank failure during an earthquake.

This estimate of the financial impact on the community of Powell River has assumed that the tank farms are intact and operational post disruption. It is an upper bound limit for the short-term loss to the community. It does not consider there to be any time substitutability for activities: activities that can be postponed, but still completed later. It is not representative of the additional long-term effects of having no economy, such as loss of suppliers, customers, and
consumers going elsewhere. This does not consider other social costs, other means of fuel, or personal storage.

Contrasting Powell River, Hartley Bay is a community with a small formal economy and a large informal economy. An off-grid community they rely on diesel generation for power. They have a 1.1kw generator supplied by BC Hydro, that provides electricity to the community (BC Hydro 2015). Historically they have experienced long lasting power cuts, like the one in 1975. In this event it was weeks before the power returned (Pollon 2016). It is assumed that the fundamental use of fuel at Hartley Bay is for electricity.

Due to the remoteness of the community, Hartley Bay is self-sufficient, and residents store entire years’ worth of food in personal and community freezers. The largest asset at risk during fuel disruption and a loss of electricity is the loss of food. If fuel runs out, and a blackout occurs up to a year’s worth of the communities’ food could be spoiled. The adverse cost of no fuel can be assumed as the value of providing the community with a year’s supply of food. The standard government per diem expense for food is $51 (Canada Revenue Agency 2015). This is an indicative value, as for remote communities like Hartley Bay this could be substantially higher when travel expenses are considered. With 148 people, this is a cumulative total of $7,548 per day for the community, $2,755,000 for a year. Due to the nature of their storage, should they receive no fuel and as a result have no power, there could be a total loss after the freezers thaw. It can take a week to travel to the community, by which point their freezers would be defrosted and contents spoiled. This research has assumed there are no personal generators. It has also assumed that the fuel for the local boats will not be accessible.

There are additional options for Hartley Bay to receive fuel, which will reduce the financial loss. An alternative for Hartley Bay would be to helicopter in fuel requirements. The
cost of a helicopter can be assumed similar to rescue helicopters. These helicopters have an average cost of $4000 per hour \( \text{(Cook 2014)} \). For a single workday of eight hours, this would cost approximately $32,000, plus fuel. The cost of receiving fuel by helicopter, before a barge reached them would be substantially less than the value lost due to food loss. They could also resist opening freezers, or smoking meat to preserve their food stores and minimize waste.

7.1.5 Findings and Recommendations

Powell River appears to have ample supply, at a high overhead cost. Powell River could reduce the volume they have in their tanks, as described previously. This would allow lower overhead cost, while still ensuring they would be able to manage in the event of a disruption.

From the preliminary assessment of Hartley Bay, they have minimal storage, and experience significant adverse cost in the event they run out of fuel. There are possible alternatives to address this loss of supply, without increasing on-site fuel storage. If there was an event that resulted in a loss of supply, or destruction of their tanks, they will require external help. It would be recommended they have these alternate plans in place to obtain further fuel before a disaster occurs. Whether these plans are by the means suggested above is at their discretion.

It is acknowledged the limitation of this study. This highlights the relative values of the current actions, and suggestions for possible mitigation options to improve these measures. There are contingencies beyond the scope of this study that could influence both positively and negatively on these areas, and further investigation would be required to identify and quantify these.
7.2 Additional Shipping Capacity

Maritime vessels are an important component of resource supply to coastal communities in BC. Ensuring maritime fleets are maintained for response needs is fundamental to emergency response activities. Maritime vessels are in demand for the continual transportation of regular fuel volumes to communities. Furthermore, in post-disaster people may stockpile excess resource as a precautionary measure. There is substantial anecdotal evidence of this phenomena (MacNeil and Keefe 2015), further enforcing the importance of additional shipping capacity in the aftermath of disaster. There are multiple options to add redundancy to the maritime transportation shipping capacity that were suggested throughout interviews:

- Additional ships on hand so there is always additional capacity
- Ships from other industries (I.e. Forestry)
- Ships from outside of BC (Washington State)
- Use of smaller ships, or ships owned by the company that are not usually used for transportation of fuels (I.e. Single Hulled Barges)
- Maintaining retired ships
- Use of privately owned ships and vessels
- Use of passenger ferries

Having additional capacity or flexibility in the transportation of fuels will enable supply to meet changing demand where needed. In a just-in-time market, having excess capacity for a ‘just in case’ scenario is uncommon. Current shipping volumes and flexibility in the current system were discussed with leading maritime fuel transport companies. These conversations addressed many of the suggestions above. Speaking to these companies, several options were considered.
7.2.1 Maritime Transportation Companies Response

From interviews, four suggested alternatives to meet post-disaster demands were discussed. Each of the proposed options would be of value in a scenario, likely an earthquake. In the aftermath of such disaster, some ships may be inaccessible or unusable. A flexibility in the current maritime transportation scheduling will enable maritime transportation companies to manage a sudden change in demand and availability of vessels. Of each proposed alternative, the maritime companies indicated the likelihood of each option being viable. The responses are shown in Figure 11.

![Maritime Transport Response to Proposed Mitigation Measures](image)

**Figure 11: Response from maritime transportation companies about alternative vessel capacity options.**

There was unanimous agreement or disagreement with majority of the proposed options. The concept of having excess barges is an unfeasible option within maritime transportation. Maintenance costs of some vessels exceed $200,000-$300,000 per year. The use of old vessels was also deemed unfeasible for the same reason. Furthermore, all new ships are planned within
business contingency plans. New vessels replace ageing or non-compliant vessels, and the older vessels are retired. Many no longer meet sector regulation, and are unusable for fuel transportation, so maintaining them is not considered a viable option.

Fuel transportation is a select group of companies. Due to protocol and standards for the transportation of fuel, using vessels from forestry or other industries is severely limited. One company did acknowledge that this might be a consideration, if needed. However, this would only be in an extreme situation where these emergency actions, against normal regulation, may become viable options.

Prioritization of resource was an option that all respondent agrees was a viable and effective approach to increase fuel capacity in a time of need. Especially with companies that carry fuel and cargo. Most cargo is transported dependent on current demand. Prioritizing fuel over other goods can accommodate an increase in fuel demand. Lower priority resource would be delayed to enable critical resource to be shipped to needed areas.

Another viable option is to look for help from within the industry, or bring in a tug and barge from elsewhere. This has been done successfully in the past by some of those interviewed, albeit with an increased cost to them. Other options include speeding up vessels, and increasing frequency of trips. Assuming all vessels are capable of sailing, all these options could cover a significant increase in demand.

7.2.2 Concerns and Recommendations

Raising their own concerns, the leading problems with the current fuel transportation network are largely environmental. Maritime transportation is more vulnerable to tides, current, and weather than many other transport modes. This was also evident in their concern about the supply chain,
and the limitation of the capacity it can provide. In a disaster, there will be a threshold in the capacity of fuel supply. In extreme conditions, weather, and tides can dictate which vessels and routes are accessible to use.

It is evident that the maritime transportation companies are a specialist fleet of vessels. The relationship between each organization is strong, and they appear willing and able to help each other out when required. To conclude these findings, the two most efficient way to increase the resilience of transportation would be:

- Prioritization of resource. Enabling critical resources such as fuel and food to be transported in large quantities when required.
- Having the ability to increase the frequency of ship sailing. This would be through either increasing vessel speed, or reducing downtime of vessels, so they are continuously moving goods.

From speaking to transportation companies, both of these recommendations are currently considered viable options. The availability of resource supply and port access is required for either of these two solutions to be beneficial. In the event of a disruption, and there is supply readily available, activation of either option will minimize the potential of limited resource to communities.

7.3 Increasing Port Resilience

The intersection of land and sea, port resilience is another fundamental aspect of the fuel system. In the aftermath of a disaster, restoration of port functions, and shipments of critical resource become economic priorities (Sturgis, Smythe, and Tucci 2014). The failing of port infrastructure, or inability to use docks, causes significant disruption. If a port is significantly damaged, there
are several options to ensure fuel can still transition from maritime vessels onto land, these include:

- Floating tank farms which ferry fuel to shore on small ships
- Alternate landing locations with roll-on-roll-off capabilities
- Ships equipped with cranes to transfer cargo to land
- Emergency berth structures

Alternative landing locations has historically been used in disasters for the movement of people, not cargo. This is due to the restricted volume of resource that can be loaded and unloaded in this manner. It would be a labor intensive and costly operation. Instilling crane capabilities on vessels is a similarly money intensive exercise. Upon talking to industry, improving the integrity of the berthing structure is the most beneficial. Nanaimo Port Authority, a leading port on Vancouver Island, is currently upgrading its port infrastructure to provide a seismically resilient and accessible dock for emergency situations.

7.3.1 Emergency Berth Structure

Nanaimo Port Authority has taken the lead in response preparedness. They are currently undertaking an expansion project over the next five years. This is to increase a single one of their terminals. The upgrade will increase the base area, and there will be additional dock faces added. All work undertaken will reach government earthquake standards, and this infrastructure will be used under emergency situations.

As well as safeguarding the port infrastructure, Nanaimo Port Authority have created emergency marine highways. These routes are on water, and allow operations to move between various points throughout their port jurisdiction in the event of road closures on land. They have created a personal inventory of where docks and berths are, and there is a record of the respective
capabilities of each location. Capabilities considered include roll-on-roll-off, which locations require cranes, and how each of these locations can be connected to other locations by land and water. These plans provide a structured and informed response plan. Communicating this to all involved parties will ensure continuation of resource to the area even in the event of a large disruption.

7.3.2 Cost and Benefit of Berth Expansion

The cost of this expansion project is estimated to be $60 - $70 million dollars (Norbury 2016). If this were to be a completely new berth location, the project would be closer to $100 - $125 million. Nanaimo gross profit is $665 million (InterVISTAS Consulting Inc. 2014). Assuming that the port was to close, this would be at a cost to the Port of $1.8 million per day. From previous events, it has shown that often ports take months, or years to regain full functionality (Kobe, Christchurch). If the port were to remain closed for an entire month, this would be at a cost of approximately $56.5 million. Even once restored, competitive markets can hinder the restoration of port trade. This calculated cost has assumed that the port has not partially re-opened during this time, which could reduce the above cost. However, it does not consider the additional, indirect impacts to the surrounding economy, social cost, or the loss of trade and relationships. With these taken into account, the true cost of closure could be substantially higher.

Installing an emergency berth, with attached marine highways allows Nanaimo the flexibility to maintain movement of goods in adverse conditions. This forethought can save the port and communities excess of the $60-70 million it cost to build. From examining the basic cost
and benefit of such a measure, the adverted loss (benefit) far exceeds the capital cost of proactive planning.

7.4 Case Study Conclusions

These three case studies suggest that there is some proactive planning occurring within the system. Tank farms increase the personal resilience of a community, reducing the impact of supply delay. Considering the tank farm management of both communities, each will have sufficient fuel to service their communities in the immediate aftermath. The study concluded that there might be more economic ways to manage these tank farms while remaining resilient. This analysis operates on the generous assumption that the tanks are intact. Should the fuel run out or become inaccessible, this could severely impact on the communities. It is recommended they have alternate supply plans in place to ensure fuel continuity.

When addressing additional shipping capability there are limited options, as many measures are not feasible. Increasing frequency of shipping and prioritization of resource are two solutions that can maximize shipping capacity. Again, it is strongly recommended that pre-defined plans and arrangements for these possible changes be made.

Robust port facilities will ensure continued distribution of resource to communities. In ports, an emergency berth structured is a proactive and promising resilience measure. Port of Nanaimo’s actions will significantly increase the resilience and continuity of the port in the event of a disruption. It is strongly recommended that other ports consider these steps to safeguarding infrastructure for operation during emergency response.

Of the mitigation measures discussed, the case studies have verified there are actions in place to better the current system. Some of the approaches throughout these case studies were not
necessarily the economic or efficient way to safeguard fuel supplied. It is recommended that more organizations involved in the maritime transportation of fuel are considering plans such as those outlined in this chapter. Further analysis is encouraged to verify the cost effectiveness of these measures, minimizing sunk investment and maximizing benefit.
Chapter 8: Conclusion

Living at the intersection of land and sea, coastal communities throughout BC are vulnerable to a myriad of natural and manmade hazards. Without an independent source of fuel, food, or medical resource, they rely on maritime transportation for continual supply. This work provides a targeted overview of the current fuel transportation system throughout BC. This study has described the normal operations and flow of fuel throughout this region. The system description indicated the interdependency of this network, critical transportation routes, and storage facilities throughout the system. This work outlined prominent hazards to the system, and possible mitigation measures to address these. The study used three case studies to explore current or potential mitigation measures to improve the system’s resilience. These case studies were a review of tank farm management; the potential of additional shipping capacity in the event of disruption; and improving a port’s resilience to ensure its functionality post disaster. The case studies and their findings are necessary to further educate industry members, and the public about current preparedness, and provide information about introducing more efficient means of resilience.

Future work should use the information from this thesis for a more detailed understanding of the system. Recommendations for further work include addressing key data gaps and investigating the demand side of the system. This work should consider possibilities of additional resources, and flexible fuel demand post-disaster. More information is needed on households' and businesses' preparedness, reserve levels, fuel demands, and behavioural flexibility in the event of a disaster. This will provide a greater understanding of the interrelationships within the system, and the behaviour of the system in emergencies: an understanding that is needed to develop effective strategies to reduce risk and enhance regional

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resilience. In particular, future planning should address how to prioritize and control available fuel supply in the aftermath of a large disaster.

Extending from this study, a model, encapsulating the fundamental elements and behaviour of the system can be made. This work aimed to provide this model with details of the system’s normal operations. It is hoped that future work builds upon the information provided, and eventually produces a detailed analysis of the concerns and alternatives to all hazards prevalent within the system.

Awareness of current operations, and feasible improvements to the transportation of fuel is vital to a community’s ability to respond. Details of the current system, and concerns and recommendations made throughout this work provide the first step towards greater preparedness planning. Minimizing harmful consequences, response preparation will safeguard economic assets and preserve the quality of life of communities experiencing extreme events.
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## Appendices

### Appendix A  Location of Ports and Capabilities.

<table>
<thead>
<tr>
<th>Port Name</th>
<th>Lat.</th>
<th>Long.</th>
<th>Lat. Decimal</th>
<th>Long. Decimal</th>
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<th>Bunkers</th>
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Appendix B  List of Contributions

Public Organization (Provincial & Local)
EMBC, Representative 1
EMBC, Representative 2
Ministry of Transportation
Integrated Public Safety
Powell River Regional District, Representative 1
Powell River Regional District, Representative 2
Powell River Regional District, Representative 3
Powell River Regional District, Representative 4
Powell River Regional District, Representative 5
City of Powell River, Representative 1
City of Powell River, Representative 2
North Shore Emergency Management Offices
Hartley Bay Council
IPREM

Private Organizations  (Transportation, Operations, Emergency Response)
BST Transportation Group
Independent Consultant, Emergency Response Planning
Independent Consultant, Emergency Response Planning
Chamber of Shipping BC, Representative 1
Chamber of Shipping BC, Representative 2
WCMRC, Representative 1
WCMRC, Representative 2
British Columbia Trucking Association

**Marine Organizations (Port Authorities and Transportation)**

Nanaimo Port Authority, Representative 1
Nanaimo Port Authority, Representative 2
Island Tug and Barge
North Arm Transportation, Representative 1
North Arm Transportation, Representative 2
Contribution, Maritime Transportation
Contribution, Maritime Transportation