Transportation Sector Case Study: Characterizing vulnerability to Infrastructure Failure Interdependencies (IFIs) from flood and earthquake hazards

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by

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Abstract

Infrastructure systems are vulnerable to natural and human-induced disasters in such a way that failures in one system can disrupt other systems and greatly escalate a disaster's impacts. Planning for disaster-resistant communities requires that decision-makers possess knowledge about regional infrastructure vulnerabilities and interdependencies. This study's objectives are twofold. First, it intends to assess the vulnerability of the transportation sector to an earthquake hazard and a flood hazard when considering IFIs, or Infrastructure Failure Interdependencies. In addition, this study also intends to address a gap in the literature on resilience by assessing its own methodology to determine if it is applicable in other contexts. The main data sources for this study are primary sources, including judgments of infrastructure experts, and data from actual disaster events. The methodological approach consists of several research phases. It begins with compiling a database of similar past events, and developing unique scenarios for each hazard. These scenarios are then used as inputs into a semi-structured interview process with regional infrastructure representatives. Once the data from the interviews are analyzed, they are presented to the regional infrastructure providers in a structured workshop, where the participants are able to revise their expectations and come to a common understanding. Three key findings were identified for the transportation sector. The first key finding is that the transportation sector has a vulnerability to direct damage from earthquake and flood hazards. Next, the study revealed that the transportation sector is vulnerable to IFIs, especially when it comes to the electric power sector. The final key finding is that the transportation sector can enhance its resilience to earthquakes and floods through more integrated planning across modes by taking advantage of its existing redundancies.
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Introduction

The transportation sector plays an important role in a region during a disaster. The main responsibility of this sector is to build and maintain the infrastructure that allows for travel in a region. Several different modes of infrastructure exist, and each of them allow for the movement of both goods and human population. In the post-disaster timeframe, the demand for transportation services may increase as a result of disruptions to the system. To mitigate against this type of disruption, a better understanding of the vulnerabilities to this sector is required. At this point, little work has been done that considers how vulnerable this sector is to IFIs, or Infrastructure Failure Interdependencies. This study has begun to address this research gap by using a scenario-based approach to characterize the resilience of the transportation sector to two natural hazards: an earthquake hazard and a flood hazard. The earthquake scenario and the flood scenario use Metro Vancouver as an example, and are used as the basis for subsequent phases of this study, including a structured interview process, and a workshop with regional infrastructure providers. Because this study uses only these two scenarios, the overall vulnerability of the transportation sector to a wide range of disasters cannot be addressed in this report. The objectives of this study are to gain a better understanding about transportation resilience in these scenarios, including a comparison of the differences between the responses to the two hazards to determine if there are consistent patterns. A second objective is to explore the relevance of the methods used. This report provides the results of this research project, beginning with a description of the main upstream and downstream interdependencies from the transportation sector. This is followed by a short description of the methodology, and concludes with the key findings for transportation resilience.

1.0 Context

1.1 Definition of Key Terms and Concepts

Throughout this report, a number of terms and concepts will be discussed. This section will define and explain these terms and concepts, beginning with “disaster resilience”.

Disaster resilience is a concept that has been defined in many ways in the academic literature. In its most simplified form, resilience refers to the ability of an individual, organization, or system to withstand disruptions of some form, or to recover rapidly from this disturbance. The former, robustness, contributes to resilience by preventing disruptions from occurring. The latter, referred to as rapidity, increases resilience by minimizing the recovery time needed to return to normal functioning.

Since the focus of this report is on the transportation sector, disaster resilience will be considered as it relates to transportation systems. In this context, a system is resilient if transportation functionality is maintained in the post-disaster time frame with minimal reduction of services. The types of mitigations that would need to be in place to increase resilience would vary by hazard. To make a system more robust, some common strategies may include seismic retrofits of key bridges and on-ramps for an
earthquake hazard, and maintenance of dike systems in flood plains for a flood hazard. Rapidity can be addressed by developing response plans for the timeframe immediately after a hazardous event, as well as long term recovery plans to help return to normal functioning rapidly. As more research is conducted, new mitigations are discovered that can contribute to the resilience of a transportation system. Although resilience is often difficult to measure, steps can be taken to reduce the adverse impact of hazards on transportation infrastructure, which ultimately increases their disaster resilience.

“Transportation” is the title given to the sector that is responsible for maintaining flows of people and goods in a region through various modes of travel. This includes travel by land, air and water.

The next term to be defined is a “Dependency”. This refers to a relationship between infrastructure systems wherein one relies on another for service, to maintain its own functionality. If, for example, the telecommunications sector is reliant on the electric power sector to provide them with energy, then the telecommunications sector has a dependency on electric power. In this example, electric power is considered to be the upstream sector, since it is the service provider, and telecommunications is the downstream sector since it receives the service. In practice, nearly every sector is dependent on each other for service, creating a situation where all of the sectors have many interdependencies.

Another term that will be used in this report is “Infrastructure Failure Interdependencies”, or “IFI’s”. This term refers to, “...failures in interdependent infrastructure systems than can be traced back to some initial infrastructure failure associated with an extreme event”. In other words, failures in one infrastructure system can have spin-off effects on other infrastructure systems due to the connectivity between them. We can use the example above, this time also considering the transportation sector, which is dependent on the telecommunications sector. If a hazard event such as an earthquake causes disruption to the electric power system, this will result in a loss of service to the telecommunications infrastructure because of their reliance. In turn, a reduction of service from telecommunications will have an adverse impact on the ability of the transportation sector to communicate about traffic problems. So, the interdependencies between the sectors will have led to downstream failures. IFI’s can also occur within one sector, such as the transportation sector. Disruptions to roads and highways, for example, may have an impact on the functionality of some of the other components.

1.2 Description of Transportation’s Upstream and Downstream Dependencies

When planning for disaster resilient communities it is important to take into account the interdependencies between infrastructure sectors. The ability of an infrastructure sector to provide services is dependent, to some degree, on the inputs of one or more other infrastructure systems. Figure 1 illustrates the complex linkages that exist between various types of infrastructures. The arrows directed towards the transportation sector denote the sectors that are upstream from transportation (i.e. the sectors on which transportation is dependent). The arrows directed away from the

1 Chang, McDaniels, Mikawoz, and Reed, 2006
The transportation sector towards other infrastructures represent downstream dependencies (i.e. the sectors that depend on transportation).

**Figure 1 – Infrastructure Interdependencies Following a Hypothetical Earthquake**

* The primary data source for Figure 1 is from interview and workshop discussions with regional infrastructure providers. See Appendix A for detailed methodology.

### 1.2.1 Transportation’s Upstream Sectors

The transportation sector is dependent on a number of different infrastructure sectors, including electric power, telecommunications, government, natural gas/fuel, and water. However, the magnitude of these dependencies ranges from slight to significant. Data from this project suggests that the most significant upstream dependency for transportation is electric power. Upstream dependencies refer to sectors that provide service to another sector, which enables that sector to function. In this case, because electric power is relied upon for the operation of traffic lights and counter flow systems, it is upstream from transportation. Power is also central for the operation of public transit vehicles like trolley buses and rapid transit systems, such as the SkyTrain in Metro Vancouver.
In addition to electric power, transportation is also highly dependent on the telecommunications sector. Telecommunication services are essential in the post disaster time frame as a means to convey important information. For example, a functioning commercial telecommunications system is necessary for operating counterflows. Furthermore, technical staff require a means of communicating in order to make decisions about structural closures. However, some providers have suggested that there are back-up systems in place, such as radio, to help mitigate this dependency to some extent.

Fuel represents another area of dependency for both land and air transportation. Various kinds of fuel are required for different types of vehicles. For example, some buses use natural gas and others run on diesel. Public transit systems would be substantially affected by a disruption to fuel supply.

The water and wastewater sectors were also identified as being upstream from transportation. Although transportation is not necessarily dependent on these services, it was indicated that these sectors were important because main breaks can undermine roads and bridges. Water services are also necessary for drinking water and to support a healthy workforce.

Lastly, transportation is dependent on government services, such as the Provincial Emergency Program (PEP), in the post disaster time frame. PEP would play a role in helping to coordinate and prioritize disaster response routes and evacuation in the event of a disaster.

1.2.2 Transportation’s Downstream Sectors

The transportation sector plays a vital role in the functioning of the Metro Vancouver region. This is evidenced by the fact that transportation is upstream of several infrastructure sectors, including electric power, telecommunications, water, natural gas and health care. These downstream sectors rely on the services of transportation in order to ensure continuity in their own services.

An important downstream sector of land transportation is electric power. In the post disaster time frame, clear transportation routes are required to move crews and equipment around for repairs of power outages. A functioning system also enables staff to get to work. Similarly, the telecommunications sector has a reliance on transportation in order to access and repair damaged lines.

The natural gas sector is dependent on transportation for access to damaged lines as well as in person gas shut-offs. Furthermore, in order to restore services after a disaster, natural gas crews must visit each customer to assess for damages and relight pilot lights. It is important to note that the linear nature of the system limits the ability to prioritize service restoration at specific facilities.

In addition to supporting the movement of repair crews, a functioning transportation infrastructure is also important for the movement of critical supplies. For example, the water sector relies on transportation for the delivery of chemicals, such as chlorine, for water treatment. Without receiving these supplies, drinking water may not be treated to meet health and safety standards, which could create public health concerns for the region.
Lastly, the health care sector is dependent on transportation for the movement of human resources and supplies. Health care workers rely on land transportation to reach hospitals and labs. If these highly trained medical professionals cannot travel to their health care facilities, services could be disrupted. In addition, ambulances and emergency crews rely on roads to transport injured people to hospitals or to transfer patients if a specific site is damaged by a disaster event. Hospitals and other sites also require a range of medical supplies and food. Damage to transportation infrastructure can reduce access to these supplies. More details on the linkages between health care and transportation can be found in the Health Care Sector Case Study.

Overall, it is evident that many infrastructure sectors rely on transportation to enable staff to access and repair damage to their systems. Accessible transportation routes are also important for the delivery of critical supplies. Given the multi-modal nature of transportation in the region, other forms of travel, such as rail, air and marine, may play a significant role in enabling the movement of people and supplies if road networks are damaged during a disaster event.

1.2.3 Conclusion

The discussion of the transportation sector’s upstream and downstream relationships with other infrastructure systems exposes the interdependent nature of regional infrastructure. It is important to note that the sectors that are upstream of transportation are also downstream as well. For example, transportation relies on electric power for traffic lights and counterflow systems, but power relies on transportation to move crews and equipment for system maintenance and repair. Moreover, the systems on which transportation relies are in turn reliant on other upstream sectors. Figure 1 clearly shows the vast number of direct and indirect linkages between systems. Consequently, if one system in disrupted in a disaster event, there can be implications for many other sectors. In order to foster disaster resilient regions, the tendency for cascading impacts should be recognized and cooperation between sectors should be encouraged.
2.0 Methodology

In order to gain insight into potential regional disruptions to infrastructure systems in the event of a disaster, a linked, sequential approach was developed. This approach consisted of the following five steps, with each one described in more detail in Appendix A:

1) Database of Extreme Events

The first phase of the methodological approach involved the collection of background information on Infrastructure Failure Interdependencies (IFIs) that have occurred in various types of disaster events, including: blackouts, ice storms, floods, and earthquakes. This database was based on newspaper reports from the region of impact for each of the extreme events and verified against other types of data sources, such as government reports.

2) Hazard scenario and background information

Two hypothetical hazard scenarios were developed for the Metro Vancouver region. The first was for an M7.3 earthquake that directly damaged infrastructure in the region, while the second was a flood hazard that occurred in Chilliwack (100 km east of Vancouver), but caused impacts through infrastructure interdependencies. Both scenarios were accompanied by maps of the impacted area. This data was used in conjunction with the database of background information on similar disaster events.

3) Expert interviews

Interview questions were developed that used the hypothetical hazard scenarios to frame the thinking of the respondents. Representatives were selected from many sectors in the Metro Vancouver region because of their knowledge of their own infrastructure system, their knowledge of the impacts of the hazard on their systems, and their role within their organization. The interviews were semi-structured, and allowed the interviewees from each sector to discuss their infrastructure vulnerabilities and their dependencies on other sectors.

4) Data synthesis

At this phase of the research, data from the interviews was combined with the existing information from the database of other hazards. Analysis of the data provided a better understanding of the key vulnerabilities from a regional perspective. The results were used to develop graphs and tables that would convey the findings in a simple to understand way. These figures would form the basis of the presentations at the workshop.

5) Workshop

Representatives from infrastructure sectors in the region, including all of the interviewees, were invited to attend a workshop. The workshop provided an opportunity to facilitate discussion amongst the sectors. Two separate workshops were conducted for this study. The first was based on the earthquake hazard, while the second focused on the flood hazard. Both workshops allowed the participants to modify their own expectations based on the responses of
the other sectors. As a result, the participants of the workshop were able to better understand sectoral vulnerabilities and impacts from a regional perspective. Also, the workshop gave the representatives of each sector a chance to network with each other with the hope that it could help lead to increased coordination down the road.
3.0 Key Findings

3.1 Transportation is Vulnerable to Direct Damage

Each component of the transportation sector is vulnerable to damage caused directly by a hazard. Direct damage occurs when a piece of the hard infrastructure of a system is impacted straight from a hazard. A hazard can be natural or man-made, but in this study, the focus is solely on two natural hazards: an earthquake hazard and a flood hazard. Evidence from past events has shown that the cause of the damage from these two hazards vary because of their unique nature. This section will describe the types of direct damage from these an earthquake and a flood.

3.1.1 Earthquake Damage

One of the primary modes of transportation in any region is via highways and roads. This linear infrastructure is the most common out of all of the transportation modes, passing through residential, commercial, and industrial areas. Because the system is so expansive, there are many redundancies built in. However, disruptions to the main passageways, such as highways and main roads, can be quite disruptive to regular traffic flows. In the Kobe earthquake of 1995 and the Nisqually earthquake of 2001, significant damage occurred to road structures as a direct result of the earthquake. The Kobe earthquake also left debris on the roads, which caused impediments for motor vehicle traffic and had an adverse impact on land travel.\(^2\) Debris on the roads would also be an impediment to the services of local public transit providers. The result would be a change, or even a suspension, in some routes. Depending on the magnitude of the earthquake, shaking can also cause direct damage to roads and bridges. In the Kobe earthquake, the Northridge earthquake of 1994, and the Loma Prieta earthquake of 1989, there was severe damage to bridges, with moderate damage in the Nisqually earthquake. The severe damage resulted in entire bridges collapsing in some instances. Expectations are similar in Metro Vancouver, where the bridges and their on-ramps are expected to be especially vulnerable to an earthquake hazard. Since the region is so heavily dependent on bridges and tunnels to move between cities, damage to this infrastructure would be extremely disruptive. The Ministry of Transportation in British Columbia has expressed concerns that damage or disruption to one road may impact the entire transportation system.

The railway system plays a key role in regional transportation, especially when it comes to transporting supplies. Rail lines are typically important for maintaining the supply chain into a region. Railway infrastructure has also been shown to be vulnerable to direct damage through ground failure in an earthquake. In the Kobe earthquake, the rail structures were damaged to such an extent that it took seven months for full restoration.\(^3\) In some cases, such as the Northridge earthquake, direct damage to

\(^{2}\) Nojima and Kameda, 1996

\(^{3}\) Nojima and Kameda, 1996
the rail infrastructure system led to train derailment, which caused a dangerous Hazmat spill.\textsuperscript{4} Smaller earthquakes, such as the Nisqually earthquake, have also led to damages to the railway system, although less severe.

Damage to the infrastructure because of ground movement is also a major concern for the functionality of airports. As shown in some similar previous earthquake events, the key pieces of infrastructure that are especially vulnerable for air travel are runways and terminals. San Francisco International Airport was closed for 13 hours because of the Loma Prieta earthquake of 1989.\textsuperscript{5} Also, the Nisqually earthquake in Washington State directly damaged the Sea-Tac Airport’s control tower, while also damaging the Boeing Field runway due to liquefaction damage. This airport was not able to return to full functionality for three months after this event.\textsuperscript{6} In addition, airports require the terminals to be useable so that passengers can be directed into the correct planes. Structures that are not built to withstand an earthquake will severely disrupt the regular functioning of air travel. With disruptions or closures to one airport, service would need to be re-routed to the others in the region. This has the potential to overwhelm the other airports and reduce the functionality of air transportation.

The final mode of transportation in this region is water travel. Vancouver is a coastal city that is surrounded by rivers, lakes, and the Pacific Ocean. The ports in Vancouver are responsible in part for receiving and distributing supplies throughout the region. The main concern for this sub-sector is the terminals, which are very vulnerable to direct damage from ground failure. If there is damage to these terminals, the result will be less functionality, which could potentially cause a reduction in the supplies that would reach Vancouver. The Kobe earthquake provides an example of this, as the port sustained major damage from this event. Full restoration of this facility took 26 months to complete.\textsuperscript{7} Minor damage to local ports also occurred from the Loma Prieta and Nisqually earthquakes. Full functionality of ports is also reliant on intermodal connections to highways and railways for freight transport.

\subsection*{3.1.2 Flood Damage}

The types of disruptions caused by a flood are much different when compared to an earthquake. An earthquake has the potential to have a direct impact over a large area, due to shaking throughout a region. In comparison, flood hazards are typically more localized in one area, causing concentrated pockets of disruptions from direct damage. For example, all infrastructures that are situated in a floodplain will be vulnerable to damage. This is especially true of roads. If flood waters overtop the height of major roads and highways, they can impact the integrity of the roads and prevent them from being used. The presence of water on and around roads can lead to washouts, where the ground is

\textsuperscript{4} California Seismic Safety Commission, 1995

\textsuperscript{5} United States Geological Survey, 1998

\textsuperscript{6} McDonough, 2002

\textsuperscript{7} NCEER, 1995
eroded. Railways are susceptible to the same types of damage from a flood. Within the floodplains of the study region, roads and railway lines are situated close to the Fraser River. Despite the fact that they are raised, or placed behind dikes, they are still vulnerable to floods. In the Iowa Flood of 2008, flooding led to the closure of some bridges and highways, and also affected commuter and cargo rail transportation due to flooded tracks and stations.

Air travel is expected to suffer less of a direct impact because of flooding, unless an airport is built in a floodplain. Water transportation, however, can be expected to be impacted as the result of a flood event. During the 2008 Iowa Flood, barge traffic along the Mississippi River was stopped. The same can perhaps be expected during a flood in the Metro Vancouver region, where traffic along the Fraser River would be impacted.

### 3.1.3 Damage to Collocated Infrastructure

It should be noted that in some cases, linear infrastructure lines are collocated, increasing the vulnerability of these systems if there is damage to one. Some bridges in Metro Vancouver provide an example of this, since these are locations where infrastructure lines such as electric power, water, and natural gas are collocated with transportation infrastructure. Damage to transportation infrastructure as a result of spatial proximity can also happen from a flood hazard. During the Iowa Flood of 2008, roads in some areas had to be closed because of overflowing sewage drains.

### 3.2 Transportation is Vulnerable to Infrastructure Failure Interdependencies – Especially from Power

Damage to transportation infrastructure may occur as a direct result of a disaster (e.g. highway flood), or may result from failures in the critical infrastructures on which transportation relies. As discussed in Section 1, the transportation sector is dependent on the inputs or services of a number of different sectors to ensure normal functioning and recovery from disaster events. Findings from both the earthquake and flood studies suggest that the transportation sector’s most significant dependency is on electric power. Moreover, this finding is supported when evaluating the impacts of past disaster events on the transportation sector.

Electric power is important for many components of the transportation system, particularly land transportation and public transit. Traffic control systems, such as traffic lights and counterflows, require power to operate. These systems help to ensure the safe and efficient movement of vehicles, without which congestion and accidents may occur. Documentation from 2004’s Hurricane Charley showed that traffic light outages were responsible for traffic jams and accidents, some of which resulted in deaths. Similar impacts were seen following the Kobe Earthquake of 1995. Power is also necessary to pump fuel at gas stations and other sites. The movement and travel of motorists is restricted when gas stations close after a loss of power. Following Hurricane Rita fuel was difficult to find in impacted areas and motorists were left stranded. The Metro Vancouver region’s public transit system is heavily reliant on power as well. Trolley buses and SkyTrain both need electricity to function. For buses that operate on natural gas, power is also necessary for compressing the gas. Moreover, these systems do not have
back-up power sources. The 2003 Northeast Blackout caused significant disruption to buses, commuter trains and subway systems. Given the volumes of people rapid transit systems like the SkyTrain move, it is clear that disruption to power could have substantial impacts to the region’s transportation services.

Electrical failures may also lead to disruptions to rail and air transportation systems. The 1998 Ice Storm in eastern Canada had implications for the functioning of cargo and commuter rail because crossing signals, operational signals, switches and the stations themselves all require electricity. There is documentation of flight delays and cancellations following the 2003 Northeast Blackout. Without power, passenger ticketing and processing capabilities were suspended, leaving passengers stranded at airports.

Figure 2

![Figure 2](image)

Figure 2 illustrates the significant dependence that transportation has on power. The figure also shows how power is dependent on the upstream sectors of telecommunications, health care, government, natural gas, and transportation. Interestingly, both the power and transportation sectors have a significant dependency on one another. A functioning land transportation system enables crews to move around to different components of the system. Without this ability the required switching in the
system cannot be done. Furthermore, accessible transportation routes are needed after a disaster to transport crews for repairs. Damage to either power or transportation has the potential to create disruptive feedback loops that may slow recovery from disaster events. Another noteworthy upstream sector for power is telecommunications. The power sector relies heavily on cell phones for daily operations. Therefore, if telecommunications services are disrupted there could be downstream impacts on the power sector which may in turn impact transportation.

The gray shading in Figure 2 indicates that the hypothetical flood is expected to cause no disruption to transportation or power. However, given the strong dependencies between the two sectors it can be surmised that if one of these sectors were impacted by the flood, the other sector would also experience some disruption in service. During the workshop process described in Section 3, concerns emerged that the impacts to transportation from the hypothetical flood may actually be more severe than those presented. Participants suggested that highways which service the region could be flooded, rendering the roads unusable. If this were the case, upstream sectors, such as power, may reevaluate their expectations of disruption for their own sectors.

In contrast, results from the earthquake scenario indicate that power is estimated to experience severe disruption. Furthermore, telecommunications, a key upstream sector for power, also expects significant service disruption. Disruption of this scale could have considerable impacts on the transportation sector, which already expects to sustain extensive direct damage from the hypothetical earthquake.

Although the transportation sector is downstream from a number of other infrastructure sectors, its main vulnerability is the electric power sector. For some components of the transportation sector, this dependence on power can be mitigated through back-ups, such as diesel generators. For other, such as rapid transit, mitigations for power loss may be more challenging to implement. Combined with the potential for direct impacts from a disaster event, this significant dependence on power creates vulnerability in the transportation sector. Therefore, efforts to increase redundancy in the power sector may help strengthen the resilience of the transportation system.

### 3.3 Transportation Resilience Through Planning

#### 3.3.1 Resilience through Redundancy

Resilience can be characterized in many ways with definitions that often vary. Within the disaster literature, resilience definitions typically are concerned with the ability of some entity to withstand a disruption to its regular functioning and/or recover from this shock in a short amount of time. This entity can be an individual, an organization, or a system, whereas the disruption refers to a hazard that may occur. This study is concerned with the transportation sector as a system. So, resilience of this system occurs when transportation modes experience minimal disruption because of an earthquake or flood, and are able to restore full functionality in a short time frame.
A key component of disaster resilience is the concept of “redundancy”. A system can increase its redundancy by considering the extent to which alternative systems or elements of a system can be used if the main functionality is disrupted. In other words, redundancy refers to developing and implementing multiple options to maintain service if the regular functioning of a system is interrupted. An example lies in telecommunications, where redundancy is built by ensuring the availability of multiple methods of communication. If a system primarily uses landline telephones for communications, they can have a redundant system by also using alternatives such as cellular phones, satellite phones, the internet, and other forms of communication in the event that service to the landline system is interrupted. By developing redundancies in a system in this example, steps are taken to enhance the resilience of the system.

3.3.2 Multi-Modal Nature of Transportation

As discussed in earlier sections, the proper functioning of the transportation sector is very important to ensure functionality in other sectors due to the dependencies on transportation. Disruption to transportation service would certainly have impacts on all of the other infrastructure systems in a region. This is also true of Metro Vancouver, where transportation pathways are important to maintain the flow of people and goods.

Fortunately, the transportation sector in Metro Vancouver and elsewhere is naturally redundant due to the variety of modes that are available for use. The mode that is most often used by the population of this region is road transportation. The mode that is most often used by the population of this region is road transportation. Roads and highways can be used for cars, trucks, bicycles, public transit vehicles, and foot traffic. Because they are used so often, the integrity of the roads is critical to maintaining transportation in this region. The network of roads and highways is very extensive, extending to every area that has human settlements. Some roads, such as highways and other main arteries, are more crucial to maintaining functioning than are the smaller residential streets. In the post-disaster timeframe when some main roads are damaged, alternatives exist in many cases where other routes can be used. This is not true at water crossings such as bridges and tunnels, because there are limited ways to travel across the rivers that separate the cities of Metro Vancouver. However, this natural redundancy of the road network would help to alleviate traffic issues that may otherwise arise.

The railway network is the other main form of ground transportation in this region. Although rail lines are usually used for moving supplies in Metro Vancouver, they are also used to transport people. There is significantly less redundancy in the rail system, since there are only two main lines that service the region. In the event that one is disrupted, the other may experience an increased demand for service. This could cause a delay in the distribution of supplies to the region. Translink also operates its SkyTrains as part of the public transit system. There are three main lines in the region that are important for commuters in and out of the downtown core.

Air transportation has some degree of redundancy also built into its system because of the number of airports in the region. Vancouver International Airport (YVR) is the main hub for passenger air travel from the region. In addition, other smaller airports in the region, such as Boundary Bay and Abbotsford Airports, are also able to handle some increased demand if YVR has some diminished service load.
Other airports across the American border in Bellingham and Seattle could also handle some of the increased demand.

Metro Vancouver’s water transportation network also has some redundancy in place. Major ports are built into Burrard Inlet at the north end of Vancouver and Deltaport in Tsawwassen, just south of Vancouver. These two ports are located some distance from each other and could handle some increased demand if one of them was to experience a loss of service because of an earthquake or a flood.

### 3.3.3 Need for Integrated Planning

The transportation sector is fortunate to have many redundancies built into place. Each of the modes of transportation in the Metro Vancouver region have some degree of redundancy, including alternate road and rail pathways for ground transportation, multiple airports for air travel, and more than one port for water travel. Moreover, some of these modes of transportation are aware of their redundancies and have considered them when developing emergency plans. For example, the Ministry of Transportation has conducted seismic assessments of the bridges in the region to determine which are the most likely to withstand an earthquake. Using some knowledge of traffic patterns, alternatives for diverting traffic flows have been considered. The air transportation system has also utilized their redundancies in planning by shifting demand to other local airports. In the case of Abbotsford Airport, they have also planned to supplement airplane travel with helicopters if there is disruption to runways.

Planning at this point has typically considered redundancies within each mode of transportation. A gap where redundancies have not fully been explored is through integrated planning between modes of transportation. In this study, many of the participants in the interviews and workshops discussed how they would shift their normal travel practices from one mode to another if the situation required it. For example, a sector may choose to transport their supplies by rail if the roads are not useable because of a hazard. However, this approach assumes that the hazard that disrupted the roads will not have an impact on the rail network. Moreover, if other sectors make the same assumption, they may overwhelm the rail system, which itself only has limited redundancy.

The redundancies that are built into the system can be better used to enhance resilience if they consider more integrated planning between modes of transportation. Based on the data from this study, it appears that the planning between modes has not been implemented into emergency plans as much as planning within each of the modes. An example lies with Translink, the public transit organization in Metro Vancouver. Their emergency plans for transporting commuters includes shifting passengers between SkyTrains, buses, trolleys, and even sea buses if the need arises. In doing so, Translink is better able to maintain their functionality, even if the passengers travel in a different way from their normal routine. Planning is less complicated for Translink since they are able to develop their plans internally in their own organization. However, their practices have revealed the strengths of integrated planning between transportation agencies in the region. The Provincial Emergency Program (PEP) in Metro Vancouver provides another example by developing plans to use water travel as an alternative to the existing system of roads as the only Disaster Response Routes. Planning between all of the modes of
transportation is especially critical for the post-disaster timeframe since there is so much uncertainty about what may happen. With increased information sharing about expectations for disruption, each of the modes can better understand their own contingency plans for using other modes and rely less on assumptions. This type of multi-modal planning should enhance resilience by ensuring the redundancies in the transportation sector are used in a disaster to better the chances of reduced disruption.
4.0 Conclusion

This case study report provides an overview of the transportation sector’s vulnerability to IFIs. In addition, it suggests that resilience in this sector could be enhanced by addressing infrastructure interdependencies in disaster planning and mitigation efforts.

The key findings discussed in the report are as follows:

1. The transportation sector has a vulnerability to direct damage from earthquake and flood hazards.
2. The transportation sector is vulnerable to Infrastructure Failure Interdependencies, especially when it comes to IFIs from the electric power sector.
3. The transportation sector can enhance its resilience through more integrated planning across modes, in particular by taking advantage of the redundancies built into the system.

These insights were gleaned through the application of a scenario based approach to characterizing the resilience of the transportation sector to hypothetical flood and earthquake events. While the main objective of this study was to gain deeper insight into the resilience of the transportation sector, a secondary objective was to explore the relevance of the applied methodology. Feedback and reflection on the approach indicates that it could potentially be applied with different disaster scenarios or in different regions as a tool to explore regional vulnerabilities to disaster.
References


Appendix A: Methodology

The approach for this study was composed of five phases:

1) Database of Extreme Events
2) Hazard scenario and background information
3) Expert interviews
4) Data synthesis
5) Workshop event for information-sharing among infrastructure system owners and operators

1) Database of Extreme Events

The first phase of the methodological approach involved the collection of background information on Infrastructure Failure Interdependencies (IFIs) that have occurred in various types of disaster events, including: blackouts, ice storms, floods, and earthquakes. This database was based on newspaper reports from the region of impact for each of the extreme events and verified against other types of data sources, such as government reports.

2) Hazard Scenario and Background Information

The next task of the approach was the creation of basic hazard scenarios. The hypothetical scenarios served to frame the tasks to follow. For the purposes of this project, two hypothetical...
scenarios were developed for the Metro Vancouver region (pop. 2,200,000): 1) an earthquake, and 2) a flood. The first scenario characterized an M7.3 earthquake with an epicentre location under the Georgia Strait, 18km southeast of Gibsons, resulting in strong to severe shaking in most of the study region. The second scenario characterized a flood on the lower Fraser River, breaching dykes and causing extensive flooding in Chilliwack, a community 100 km east of Vancouver with a concentration of linear infrastructure assets (electrical transmission lines, rail, highway etc.). The scenarios can be viewed at: http://www.chs.ubc.ca/dprc_koa/practitioner_reports.html. Although they were not developed to be forecasts, the scenarios are meant to represent a realistic base case and were vetted by experts in the field.

3) **Expert Interviews**

In-person interviews were conducted with representatives of a variety of infrastructure sectors: utilities (electric power, water, wastewater, natural gas); transportation (bridges and highways, public transit, airports, seaports); telecommunications; health care (regional health authorities, hospitals); and provincial, regional, and local governments. One set of interviews used the earthquake scenario and the process was repeated two years later using the flood scenario. Participants were presented with a hypothetical scenario and asked to characterize infrastructure vulnerabilities and intersectoral interdependencies in the region. The objective of this phase was to collect information about the ability of infrastructures to withstand and recover from extreme events.

4) **Data Synthesis**

The data synthesis step of the process involved analyzing the data from the interviews and developing a succinct means of communicating the findings. Service disruption diagrams were created to visually represent the severity of expected service disruption for major infrastructure sectors in a region over time (0 hours, 72 hours, 2 weeks). The colour coding of the diagram is based on the estimated severity of disruption. Figure B depicts a sample of a service disruption diagram, based on impacts in the Red River Flood of 1997. Figure C illustrates the service disruption scale used to rate the levels of disruption.

Figure B: Service Disruption Diagram
Two dimensions are rated from low to high in order to determine the overall level of service disruption: spatial extent and severity of impact. The spatial area of the disruption constitutes the extent dimension of the scale. The impact represents both the severity of the consequences and duration of the disruption. For example, a disruption resulting in a single death would be classified as having a high impact but low extent, situating it in the moderate disruption category.

5) Workshop Event

The final step of the process was a workshop event wherein the synthesized data from step 4 was used to facilitate discussion among infrastructure representatives. Two workshops were convened during the course of the project: one to discuss possible earthquake related impacts and one focusing on the hypothetical flood. The purpose of the workshops was to present the interview and database findings to participants and attempt to develop a shared understanding of potential infrastructure failure interdependencies in the scenarios. The grey box in Figure A outlines some of the key areas of discussion for the workshop events, including cross-sectoral expectations and regional concerns. This last phase of the approach enabled infrastructure representatives to learn from another and modify expectations where appropriate, thus forming a foundation for further discussion on potential mitigation efforts.

Conclusion

The transportation sector is an important element of the regional infrastructure network. Representatives were from different components of this sector, including from ground, air and water modes. Data from the interviews and workshops, as well as information from the database on interdependencies and impacts, form the basis of this case study report.