RESILIENCE MEASURES FOR REDUCING THE IMPACT OF NATURE-INDUCED DISRUPTIONS IN TRANSPORTATION SUPPLY CHAINS

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Introduction

The transportation system in general and the supply chain in particular is vitally important to the economy and the quality of life. A supply chain in any country has vulnerabilities and is subject to risk of disruption. In Canada, factors such as long distances, geographical diversity, geological and geotechnical characteristics of some regions, weather extremes, and long-term climate change-induced factors pose challenges, in addition to other factors such as labour disruptions.

This paper describes nature-induced vulnerabilities in the Asia-Pacific Gateway Corridor (APGC) freight supply chain and defines resilience measures that could mitigate adverse effects on stakeholders. Supply chains are introduced for containerized commodities and coal, which is moved as a bulk commodity. Vulnerabilities are identified and characterized on the basis of historical evidence and scientific analysis. Finally, the need for inherent and dynamic resilience is noted. Due to space constraints, the analysis of vulnerabilities focuses on containerized imports.

Supply Chain Vulnerabilities and Risks

Transport Canada defines a supply chain as a connected network of suppliers, manufacturers, shippers, distributors, and retailers where transportation plays the role of the unifying link among all the actors. Depending upon the modelling task, the level of abstraction can range from the overall system to its individual components. Two examples of supply chain networks are presented. In Figure 1, one direction and one set of modal and intermodal linkages is illustrated. Also, Canadian and U.S. container traffic routinely crosses the border in both directions. In the design and operation of the supply chain for containers, fluidity, reliability, and efficiency criteria are thus accorded due importance.

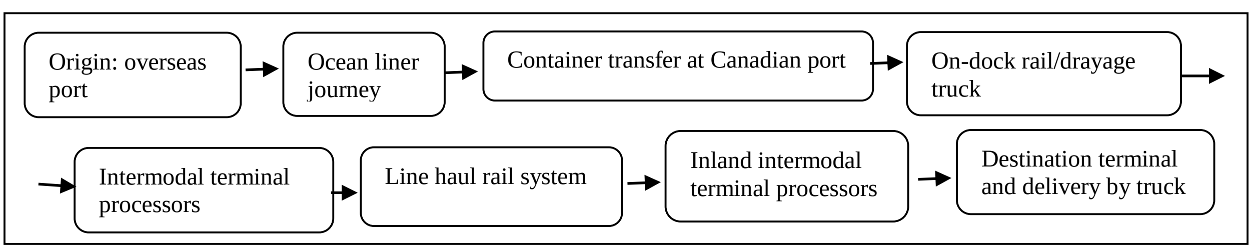

Figure 1. Transportation supply chain network (containerized marine freight imports)

The supply chain for coal exports is based on a dedicated bulk movement system design (Figure 2). Coal is a low value bulk commodity and for competitive reasons, high efficiency supply chain operations are necessary in order to lower cost and improve service. The mine-to-destination movement of coal requires dedicated terminals, unit trains and bulk marine vessels.

For modelling and analysis purposes, supply chains are characterized into links and nodes while taking into account trade, technological, physical, environmental and other relevant factors. Taking the example of containerized commodities and focussing on service characteristics for now, the marine-surface transportation part of supply chain could include the following components (Transport Canada 2013): movement of containers by liner companies, rail/pure rail via intermodal yard-drayage, transload – rail, all-truck, and transload – truck. The coal export supply chain is somewhat simpler in design, due to the dedicated nature of the service. The only interface with other freight supply chains is the use of common mainline tracks by unit trains (when applicable).

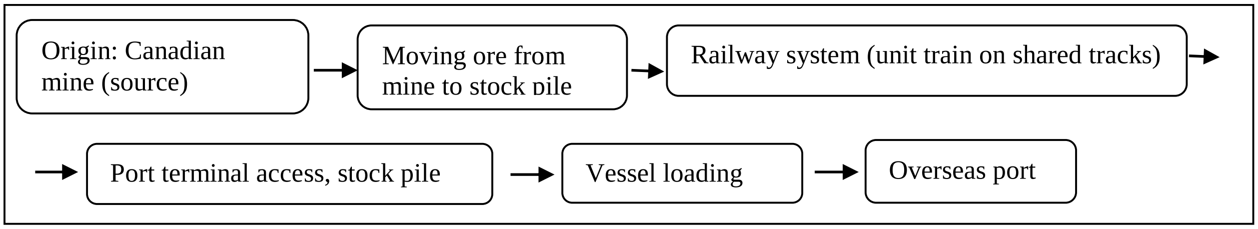

Figure 2. Transportation supply chain network for coal exports

Vulnerabilities and Risk of Disruption

A vulnerability in a supply chain is a point of weakness and/or possible threat to the supply chain network. According to Transport Canada, within the supply chain, vulnerable locations that are “at risk” if they have no or limited alternatives should a major disruption (i.e. outage of more than 96 hours) take place. The 96 hour standard is the time frame for incoming vessels to report to Transport Canada. The time standard originates with the International Maritime Organization and is known as pre-arrival information report (PAIR). Beyond this threshold, ships could potentially choose to divert to another port. In terms of practical significance, if a supply chain disruption will last longer than 96 hours, it will be considered as a major disruption.

Vulnerabilities can be classified as: nature-induced, man-made (including operational, planning and/or economic issues), and system/equipment malfunction. Risk is defined as the probability of an event or trend occurring with a negative effect on supply chain performance (e.g. major natural disaster or operational and economic issues, such as a labour disruption or bumper crop) multiplied by the impact if this event or trend occurs.

The focus in this paper is on nature-related vulnerabilities. Figure 3 illustrates risks and consequences of such vulnerabilities. The likelihood of a vulnerability leading to a disruption is presented as low probability or high probability and consequences are classified as light-to-moderate or serious-to-severe.

Nature-induced disruptions are not predictable, and for all practical purposes, cannot be controlled. However, preparatory measures can be developed in order to lessen the effects. Examples include major landslides, earthquakes, tsunamis, floods.

Effects of vulnerabilities are the consequences of supply chain disruptions, should these occur. Literature sources report evidence-based observations and also results of surveys. For example, a comprehensive survey of 532 respondents from 68 countries around the world identified and ranked consequences of supply chain disruptions. The top ten consequences are noted below in the order of importance (Punter 2013): (1) Loss of productivity, (2) Increased cost of working, (3) Service outcome impaired, (4) Loss of revenue, (5) Customer complaints received, (6) Product release delay, (7) Delayed cash flows, (8) Damage to brand reputation (image), (9) Stakeholder (shareholder) concern, (10) Expected increase in regulatory scrutiny.
As expected, productivity, service, and economic factors receive high ranks. Vulnerabilities are a known cause of supply chain unreliability and these adversely affect freight flow efficiency.

Probability	Light-to-moderate consequences	Serious-to-severe consequences
Low probability	LOW RISK • Wild fire • Volcanic ash (if applicable)	MODERATE RISK • Earth quake (major) – tsunami • Severe winds and severe cold weather • Flood: Major • Landslide: Major
High probability	MODERATE RISK • Earth quake (minor) • Flood (minor) • Avalanche (Minor), snow • Landslide (minor)	HIGH RISK

Figure 3. Nature-induced vulnerabilities and consequences

The Asia Pacific Gateway and Corridor (APGC): Vulnerabilities and Resilience

Transport Canada has identified the following gateways and trade corridors (Transport Canada 2013, Gibbons 2010): Asia–Pacific Gateway and Corridor (APGC), Ontario–Quebec Continental Gateway, and Atlantic Gateway and Trade Corridor. Among these, because of growing and high value trade trends, special attention is accorded to the APGC. It is a major gateway corridor that serves the Asia-Canada trade via the west coast ports of Prince Rupert and Port Metro Vancouver. Capacity expansions are underway and planned for both ports (Websites of ports 2016). Port Metro Vancouver is served by CP Rail, CN Rail, and BNSF Rail. Scheduled daily double stacked container trains are operated by both Canadian railways to major destinations in Canada and the U.S., (particularly to Chicago). The Port of Prince Rupert is served by CN Rail's double stacked scheduled container service.

The supply chain links and nodes are studied in terms of locations that are "at risk" - where no or limited alternatives exist should a major disruption take place. In situations where evidence of vulnerability cannot be defined due to the lack of long-term frequency of event(s), science-based knowledge is used as a basis of assessing the vulnerability of a site. In the APGC, statistics on nature-induced events such as landslides, avalanches, and floods provide evidence of vulnerability. On the other hand, a study of a major earthquake on the West Coast or a major landslide near Ashcroft (B.C.) can be based on knowledge contributed by scientists (i.e. seismologists on earthquakes, and geologists and geotechnical experts on major landslides).

High Frequency of Nature-Induced Disruptions

There is empirical and scientific evidence that the railway freight transportation supply chain in the APGC has experienced disruptions, mainly caused by nature-induced events. Nature-related vulnerabilities are present in various parts of the freight supply chain in the APGC, particularly through the mountains in B.C. and Alberta. To show the frequency of nature-caused disruptions vis-a-vis other causes, we take the Vancouver-Alberta-Prairie railway mainlines example. Data were gathered on 72 events that occurred over many years. The frequency distribution of causes of disruptions is presented in Figure 4.

Nature-caused disruptions account for about 45% of events, followed by equipment failure (about 29%). Infrastructure failure accounts for about 14% of events and the remaining events relate to collisions (e.g. with rocks and debris on track) and human factors (12%). Within nature-induced events, slides have the highest frequency. A collision with rock/debris on track may be classified as a nature-related event.

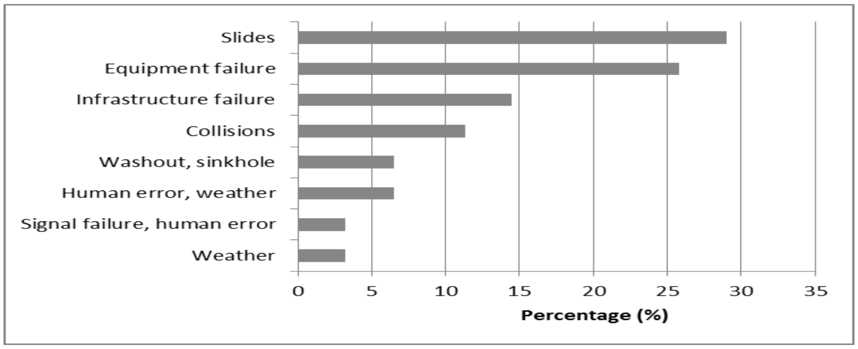

Figure 4. Vancouver-Alberta Railway Line Causes of Disruptions
Source: Khan et al. (2015)

In the following sections, analysis of disruptions is presented for the Northern and Southern B.C. Corridors. Data reported by Septer (2007) and Septer and Schwab (1995) are the main sources of information. Along both corridors, most disruptions can be expected to last for less than 2 days. In relative terms, more landslides have disrupted rail lines than floods or other causes and increasing high intensity precipitation is noted as a major contributing cause. In the absence of evidence-based information on a low probability-high impact major landslide or earthquake, science-based scenarios of disruption are briefly covered.

Nature-Induced Disruptions in Northern BC Corridor

Figure 5 shows the Northern BC freight corridor. The frequency and duration of disruptions are illustrated in figures 6 and 7, respectively.

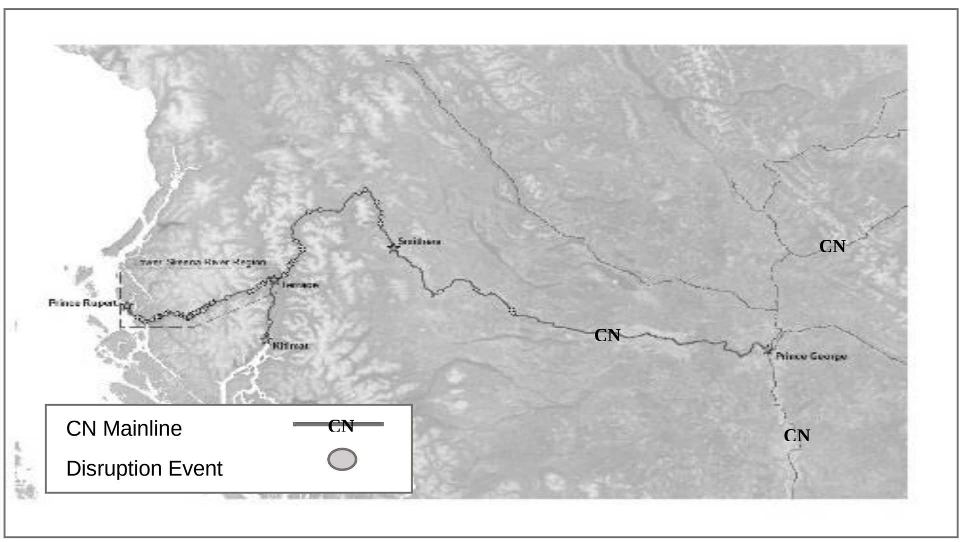

Figure 5.Northern B.C supply chain route and CN mainline track.
Source: Khan et al. (2015)

Using available long-term frequency data on disruptions in the Northern BC Corridor, for which the primary cause is nature (i.e. rain storm, snow, flood, etc.) along the Prince Rupert-Prince George route (covering the 1891-2006 time period), on average, less than two events per year can be expected. However, should a nature-induced event of this type occur, the probability of disruption of 4 or more days is significant. Out of a total of 143 incidents, duration information was available for 100. There is a probability of 0.28 for a disruption with a duration of 4 or more days, and a probability of 0.16 for a disruption with a duration of 7 days or greater. The present-day ability of railroads to get in heavy equipment rapidly to restore service may lower these probabilities.

A majority of incidents (52 out of 100) disrupted the railway route for less than 2 days. Out of these 52 events, 37 incidents caused a disruption of less than one day. The Lower Skeena River Region has the highest number of disruptive events (i.e. 109 out of 143). At the most vulnerable locations, the railway line is close to steep slopes and large-scale flooding locations on the bank of the Skeena River.

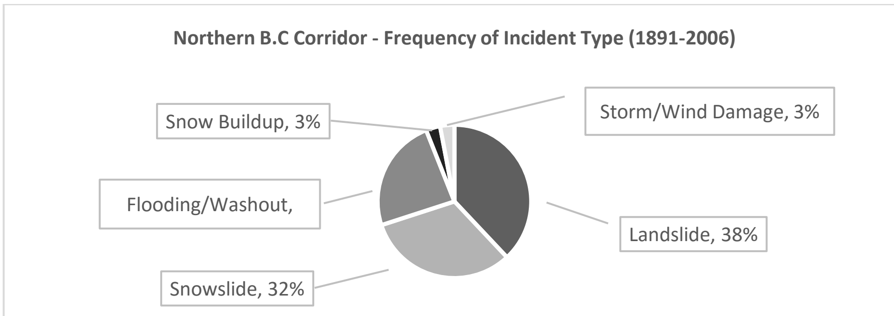

Figure 6. Rail line disruption events within the Northern B.C corridor, categorized by incident type. Source: Khan et al. (2015)

Clearly, the most vulnerable single area of concern within the Northern B.C. corridor is the Lower Skeena River Region. Using the Transport Canada definition of vulnerability, in terms of more than 96 hours of disruption at sites where no or limited alternatives exist, the Prince Rupert-Prince George line is vulnerable. It is a single track line operated by a single carrier – CN Rail.

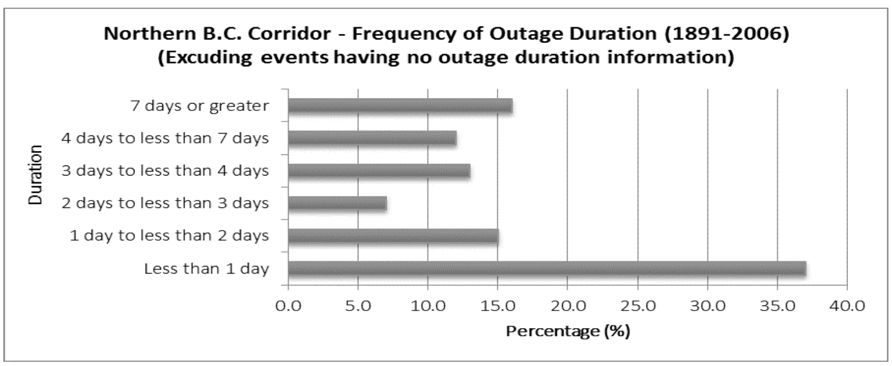

Figure 7. Rail disruption events within the Northern B.C corridor (excluding events where no duration information was available) Source: Khan et al. (2015)

Southern B.C. Freight Corridor

Figure 8 shows the Southern BC corridor. The frequency and duration of disruption are illustrated in figures 9 and 10, respectively. In the Southern B.C. corridor that connects Vancouver with Alberta, 138 events were recorded during the 1891-2006 time period. Similar to the Northern B.C. corridor, in the Southern B.C. (Vancouver-Alberta) corridor, less than two events per year can be expected. Landslides were most prevalent as compared to other incidents.

Out of the 138 events, duration data was available for 97. Out of 97 events, 24 incidents lasted 4 or more days, which results in approximately 0.25 probability of a disruption being major. There were 15 incidents that resulted in a railway line outage of 7 or more days. However, as noted earlier, the present-day ability of railroads to get in heavy equipment rapidly may lower the service outage days. On the other hand, less than 2 days of disruption was caused by 51 out of 97 events (probability amounts to about 0.53). There were 26 events out of 97 that caused a disruption of less than 1 day.

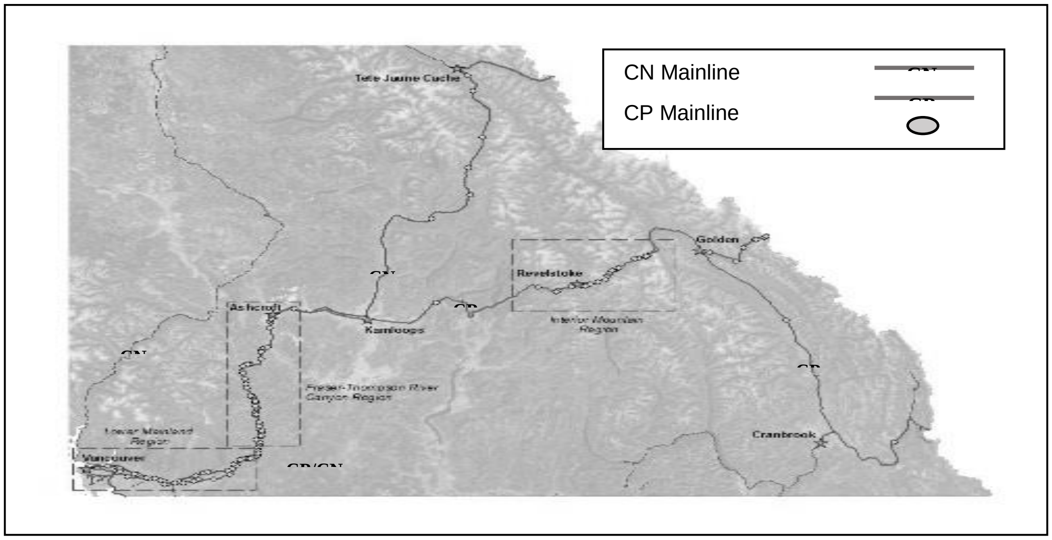

Figure 8. Southern B.C. Corridor. Source: Khan et al. (2015)

The criticality of areas within this corridor can be defined by the number of disruptive incidents: Fraser-Thompson River Canyon Region (70 incidents), Lower Mainland (45 incidents) and Interior Mountain (30 incidents). The Fraser-Thompson River Canyon Region is subjected to more slides than other locations and the Lower Mainland Region experiences flood events (Figures 9 and 10).

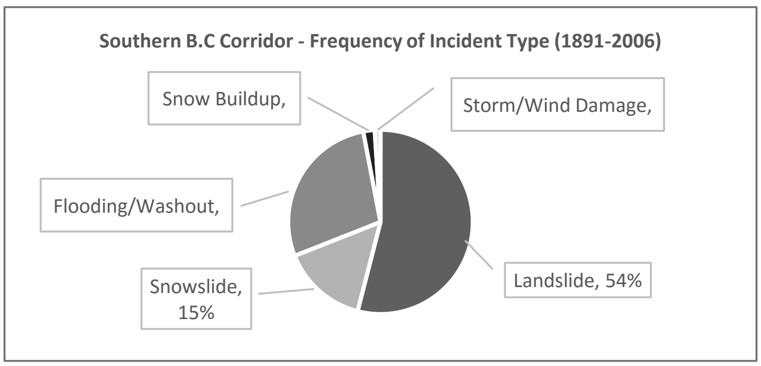

Figure 9. Rail disruption events within the Southern B.C. corridor, categorized by incident type. Source: Khan et al. (2015)

In the southern corridor, the probability of a major slide occurring near Ashcroft (B.C.) is not high. On the other hand, the rail line outage time (affecting one or both CN Rail and CP Rail) around Ashcroft will be high in case a major slide occurs (BGC Engineering 2012, Bunce and Quinn 2012). If one carrier is affected, CN and CP can run trains over each other's lines (and do so). If both lines are out through Ashcroft at the same time for a duration more than just a few days (a highly unlikely scenario), the options could be: (i) divert freight to Prince Rupert and/or to a U.S. port, (ii) Use BNSF line, (iii) use Vancouver-Prince George-Alberta route (in the case of container freight, only single stack trains can be served).

Although a major earthquake that is likely to occur (over a defined period of many years) has the potential to have highly adverse-to-severe consequences in terms of disruption of port, intermodal terminal and rail lines in Vancouver, the probability on a yearly basis is low. Inferences drawn from a simulation study suggest that port and intermodal facilities will recover about 70-80% capacity to serve intermodal containerized freight within a few days (AIR Worldwide 2013, Wei et al 2013). There is no historical evidence of a vulnerability in the case of the Prince Rupert Port and its intermodal facilities. Also, there is no historical evidence of a vulnerability in the case of the Prince George's intermodal facilities. Although simulation-based predictions are not available for the Port of Prince Rupert and associated intermodal facilities, the application of Port Metro Vancouver predictions can be justified.

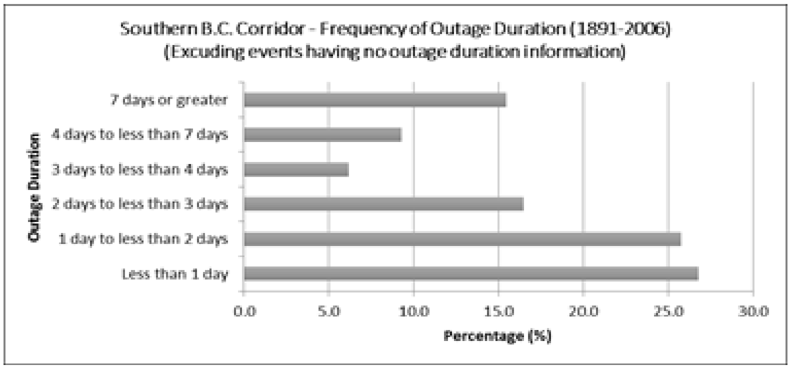

Figure 10. Outage durations within the Southern B.C. corridor, excluding events where no duration information was available. Source: Khan et al. (2015)

Resilience Measures to Counter Vulnerabilities and Reduce Impact of Nature-Induced Disruptions

The inherent resilience of the supply chain attempts to prevent a disruption from occurring, or barring prevention, reduces its effect. In the case of APGC, inherent resilience can be investigated for each category of vulnerability covered in this paper. For example, high standard designs can prevent rock slides from causing damage to railway lines. The dynamic resilience goes beyond inherent resilience by employing all available resources in order to adapt to the disruption condition, including development of the ability to recover quickly. Examples of dynamic resilience in the event of a major landslide near Ashcroft, B.C., are track sharing by the railway companies, re-routing of trains, and re-routing of cargo to alternate ports. Taken together, the resilience measures assist in overcoming vulnerabilities. Since nature-induced events are not predictable and to a high extent these cannot be controlled, resilience enhancement is key to reduce damage.

Conclusions

Nature-related vulnerabilities are in almost all parts of the freight supply chain in the APGC. Nature-caused disruptions account for about 45% of events. Within nature-induced events, slides have the highest frequency. The historical analysis of nature-induced disruptions in the B.C. corridors indicates the occurrence of land slides, snow slides, flooding/washouts, snow buildup, storm/wind damage, and weather (e.g. extremely cold). Along B.C. corridors, most disruptions can be expected to last for less than 2 days. In relative terms, more slides have disrupted rail lines than floods or other causes and increasing high intensity precipitation is a major contributing cause. In the Northern B.C. corridor there is a probability of 0.28 for a disruption of 4 or more days. The most vulnerable single primary area of concern within the Northern B.C. corridor is the Lower Skeena River Region. In the Southern B.C. corridor, there is approximately 0.25 probability of an incident of 4 or more days. In this corridor, the Fraser-Thompson River Canyon Region is the critical area for slides and the Lower Mainland Region experiences flood events.

Research is required in the following subjects for enhancing resilience of the supply chain and encouraging stakeholder collaboration:

- Closer examination of measures that can enhance inherent resilience of the supply chain; inferences on these drawn from actual or potential disruptions.

- Dynamic resilience measures such as quick response, institutional support, communications and information systems.
- Resilience of adaptive capacity, depending upon the vulnerability and location.
- Supplementing inherent resilience with adaptive capacity to maintain part of service throughput while enhancing the recovery process.
- Potential mitigation measures that include collaboration (e.g. sharing infrastructure and services), cargo diversion, stockpiling, labor agreements, prioritizing response activities by cargo types, recipients, and suppliers, potential barriers and gaps (e.g., jurisdiction, authorities, ownership, modal competition and connectivity, and social and environmental constraints).
- An information system for monitoring vulnerabilities and informing stakeholders.
- The value of information about disruptions for stakeholders from the perspectives of initiating dynamic resilience actions including service restoration measures.
- Joint investigation of fluidity and resilience.
- Evaluation of recovery measures in order to identify efficient and effective alternatives for use in emergency preparedness plans.
- Methods and metrics to quantify resilience as an indicator of recovery capability in the supply chain.
- Upstream propagation of capacity-reducing shock wave of an inland railway or intermodal terminal disruption on port and associated facilities.
- With public- and private-sector stakeholders already recognizing the importance of supply chain resilience-related research, strengthening of partnerships for identifying key issues, to analyze these, and corresponding mitigation measures.

Acknowledgements

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