A FUNCTIONAL APPROACH TO CRITICAL INFRASTRUCTURE AND COMMUNITY RESILIENCE ASSESSMENT

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ABOUT THIS CONCEPTURAL FRAMEWORK

DESCRIPTION

Critical infrastructure is sometimes viewed as the physical and cyber systems so vital that their incapacity or destruction would be debilitating for a community[i]. However, it can be viewed more broadly as not only the physical and cyber systems but also the people and processes needed to operate those systems. Public Safety Canada defines critical infrastructure in this broad sense, "processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government[ii]. The former definition can lead to a narrow focus on physical and cyber assets rather than a broader focus 'people, processes and equipment' needed to provide vital goods and services to communities. Indeed, a narrow focus on physical and cyber assets leads to difficulties in that (1) detailed information of these assets is often proprietary and (2) it may be difficult to infer the implications of specific assets that are incapacitated or damaged. Inferring the implications incapacitated for damaged assets on the ability to deliver vital goods and services also requires knowledge of the business processes within an industry[iii].

The approach presented here, the National Critical Infrastructure Interdependency Model (NCIM) is one based on this broader perspective of critical infrastructure as the 'people, processes and equipment' required to provide vital goods and services. The NCIM was developed by Defence Research and Development Canada at the request of Public Safety Canada to address the problem of assessing risk due to critical infrastructure interdependencies and cascading system failures. Currently Dr. Chouinard is the only team member responsible for the NCIM as the NCIM project is being discontinued. The NCIM was designed to be applicable to local as well as national critical infrastructure settings and to be an 'all hazard approach'. Indirect losses to disasters is poorly understood and many risk assessments estimate these losses on the basis of information from historic disasters. However, this information may be incomplete and, in addition, may ignore losses that might have but did not occur. A proper risk assessment should be complete and include potential losses. The NCIM was developed to provide better insight into potential, indirect losses due to cascading system failures.

The NCIM is foremost a conceptual, analytical framework for guiding systematic analyses of risk due to cascading failures/ These cascading failures could be within an industry or across industries. The NCIM uses a taxonomy that describes the functions within each critical industry, for all ten nationally defined critical infrastructure sectors[1] and the potential relationships among the functions which describe dependencies (i.e., the provision of goods or services by 'upstream' functions to 'dependent, 'downstream' functions). This taxonomy can serve as a "checklist" for planners to minimize a critical function at risk being overlooked. In its application the NCIM conceptual framework is tailored to a given locality and hazard scenario. Only at this stage does it become necessary to identify the physical and cyber assets that are relevant and to assess the implications of their incapacitation or damage to the performance of relevant functions. While

[1] The ten Canadian critical infrastructure sectors are Energy, Finance, Food, Government, Health, Information and Communications Technology, Manufacturing, Safety, Transportation and Water.

the 'tailoring' alone can provide much insight into risks due to interdependencies, the approach allows for a variety of tools to trace cascading failures and to assess quantitative risk.

Due to the need to include industry work forces in the NCIM, the model was extended beyond the ten defined critical infrastructure sectors to include the needs of the general population; and, to ensure economic consequences are captured, it also includes the general economy[2]. This extension of the NCIM beyond the ten defined sectors provides a whole-of-community approach and, thereby, some insights into community resilience.

The NCIM was primarily intended to be used by planners to better prepare, prevent and mitigate future disasters by providing a more holistic perspective that include indirect as well as direct consequences.

ALIGNMENT WITH THE SENDAI FRAMEWORK

The NCIM supports the Sendai Framework's priorities for action as follows:

1. Understanding Disaster Risk: Typically risk assessments have focussed on the direct consequences – physical damage, casualties, etc. and have relied on limited historical disasters to estimate indirect losses. The NCIM allows for a more systematic, explicit approach to identifying and assessing key indirect losses whether they affect the economy, the environment or people.
2. Strengthening Disaster Risk Governance: While the NCIM does not directly contribute to disaster risk governance it supports governance by providing a means for exchanging information among critical infrastructure owners and operators, emergency management planners and the wider community.
3. Investing in disaster risk reduction for resilience: The NCIM is well suited for evaluating the risk reduction potential of investment options through the evaluation of the impact for each option on improving the resilience of a community's vital functions.
4. Enhancing disaster preparedness for effective response and to 'Build Back Better': Similar to the evaluation of disaster risk reduction for resilience, the NCIM can evaluate 'Build Back Better' options. The NCIM also includes, within the Safety Sector functions, preparedness and incident response and recovery functions, which allows for the evaluation of options to improve those functions for more effective response and recovery.

THE EFFECT ON PRACTICE

Prior approaches to assessing risk from the 'failure' of critical infrastructure has started with comprehensive inventories of critical infrastructure physical assets and then assessing risk arising from a 'single-point-of-failure' for each asset. This approach has several limitations which include:

- The reluctance of critical infrastructure owners and operators to divulge information on their key assets, which makes a community wide assessment difficult and leads to a fragmented assessment by individual owners and operators; that is by those who deliver vital goods or services and not by those who require those goods or services – i.e., by those who bear the risk if the goods or services are unavailable;
- Single-point-of-failure is an inadequate approach when an industry is affected by multiple failures as would be the case for an event like an earthquake;

[2] The NCIM functions are linked to the North American Industry Classification System which is the framework by which Statistics Canada collects data related to economic activities in Canada.

- Risk due to interdependencies (i.e., mutual dependencies between critical infrastructure industries) becomes impossible to determine when the assessment is done by individual owners and operators;
- Dependencies are contextually dependent – i.e., they depend on situational factors at a given time. For example, the dependency on fuel for a backup power generator depends on whether or not there has been an extended blackout;
- A comprehensive list of assets can quickly become outdated, especially for rapidly growing industries; and
- Even if it is possible to collect a comprehensive list of assets it can still be difficult to assess the effect of a disabled or damaged asset.

The NCIM approach starts with a comprehensive taxonomy of functions and the potential dependency relationship across those functions. Critical infrastructure functionality is a far more stable starting point than an asset list as functionality evolves at a slower pace than asset construction and replacement. In addition, functions can easily include the 'softer' components (i.e., personnel, processes and information) which are as important as physical assets for the delivery of vital goods and services. These 'softer' components can be as vulnerable or even more vulnerable than physical assets – particularly for a traumatic event such as a serious earthquake.

The NCIM taxonomy consists of over 800 functions associated with 50 industries for the ten critical infrastructure sectors defined by the *National Strategy for Critical Infrastructure*[iv]. The list is not intended to be definitive but a starting point to be adapted for the needs of a given community. The taxonomy provides a comprehensive 'checklist' which can be used in disaster and resiliency planning to ensure that a vital goods or service is not overlooked. The taxonomy can also be used to guide an assessment of local assets over which the community may have some control – i.e., they need only focus on the availability or unavailability of goods or services provided externally. This promotes resilience as it leads to questions of what can community do if the goods or services are unavailable.

The NCIM taxonomy is also linked to the North American Industry Classification System (NAICS), the framework by which Statistics Canada collects data. Access to the Statistics Canada data can provide valuable economic and demographic information which can be used to assess the implications of the disruption of a critical infrastructure function.

In addition to the taxonomy, the NCIM also has a set of potential dependencies for the taxonomic set of functions (i.e., functional relationships). There are over 5,000 potential relationships among the NCIM functions, but not all will be relevant for a given community or situation. To view these relationships requires some type of database software that allows a user to filter the relationships and view only those that are pertinent. This would then allow a user to trace key dependencies and thereby identify high risk, cascading 'failure' pathways.

It is intended that the NCIM be used in the context of a 'scenario' or 'hazard situation', such as 'day-to-day operations', post-earthquake, flooding, etc. In addition to the normal, day-to-day functions the NCIM includes incident response functions – e.g., on-site command, casualty operations, incident logistics, emergency relief, etc. Using the NCIM with a scenario also provides greater focus for identifying critical assets and for determining which of these assets might be affected by hazards within the scenario or by the unavailability of goods and services upon which an asset depends (e.g., repair parts, utilities, inspections, etc.).

Deeper assessment of risk with the NCIM requires more sophisticated tools and experienced analysts. The set of NCIM functions and their relationships constitutes a complex network, even if the number of functions and relationships are significantly reduced. The application of the NCIM for the seismic scenario defined in the DRR Pathways will illustrate what may be required for a deeper risk assessment:

- A significant seismic event across the Metro Vancouver region, with 2.5 million people, represents a very large, complex scenario. As a result, tailoring the NCIM functions and relationships for this application of the NCIM resulted in a minimal reduction of about 5% of the functions and 15% of the relationships;
- Natural Resources Canada had already collected data on regional assets such as hospitals, bridges, etc. which were categorized according to the NCIM taxonomy;
- In addition to the asset data Natural Resources Canada had collected, publicly available business registration data was collected. This comprised about 120,000 registrations. The registrations included NAICS information but

about 25% of the information was too ambiguous. However, semantic information was used to classify these ambiguous registrations;

- Since the business registrations had addresses, it was possible to link NCIM functions to individual buildings. Note that in some cases a given building might be associated with more than one NCIM function – a good example is the heath care industry where doctor's offices, laboratories, drug stores may all be located in a single building. Using their damage assessment software, OpenQuake, Natural Resources Canada was able to assess building damage and the estimated time for the repair and recovery of each building;
- The University of Victoria, using the Graphical Model of Resilience, was able to provide detailed information for the restoration of power, water and wastewater services. Using the building address data, it was then possible to determine which of the NCIM functions would be affected by the disruption of these utility services;
- The Natural Resources Canada and University of Victoria data provided input data for the commercially available network analysis program, RiskLogik[v], which allowed an assessment of risk 'propagation' (i.e., an assessment of cascading risk) across the NCIM network of functions and relationships. While direct seismic damage and the disruption of utilities for a given industry were among that industry's vulnerabilities, the network analysis was able to highlight other significant vulnerabilities such as supply chain disruption; and
- The results of the network analysis ranked the risks across the NCIM functions. Figure 1 shows the top twenty (20) risks[3]. This allowed further analysis to generate vulnerability profiles for those industries at greater risk. These vulnerability profiles can provide guidance for what initiatives would have more impact at risk reduction. Figure 2 provides an example for the hospital 'industry' within the region[4].

With the end of the DRRP, the analysis was completed as stated above. However, further analysis could have been performed to assess risk reduction options to determine which options have greater benefits. It is also possible to use the NCIM to assess incident response plans and capabilities. This would, of course, require greater involvement with planners than was possible with the DRRP.

It should be noted that the NCIM could be used in a collaborative 'table-top' exercise with key critical infrastructure owners and operators. In such an exercise, each critical infrastructure owner or operator need not divulge asset information to other exercise participants. Instead they need only provide information on which areas or customers may be affected by a disruption. In turn, the other participants can do their own assessment on what the disruption means of each of their industries. This process can continue until the participants have a deeper understanding of the key vulnerabilities and what collective action can be taken to reduce both overall and individual industry risk.

As was indicated initially, the NCIM starts with functions and not assets. However, as shown above, vital assets are still important, as is an understanding of the vulnerability of assets to not only hazards but also to the disruption on upstream functions on which an asset depends.

Finally, the NCIM includes not only the ten sectors defined by the National Strategy but also functions related to the population – such as housing, personal transportation, etc. – and the remainder of the economy not captured by the ten sectors. This allows a more holistic assessment of the impact of a disaster on a community and its neighbourhoods – not only immediately after a seismic event but also during an extended period of recovery, for which other functions, such as social or mental health functions have a critical importance.

[3] In the figure, RPP means 'Refined Petroleum Products'.

[4] For the purpose of vulnerability and recovery profile, vulnerability = degradation of an upstream function X the strength of the dependency relationship. The degree of vulnerability reflects that impact on the hospital operations due to the given vulnerability alone. The recovery colour coding indicates the degree of availability for a function from very low to normal.

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Figure 1. Top Critical Infrastructure Risks

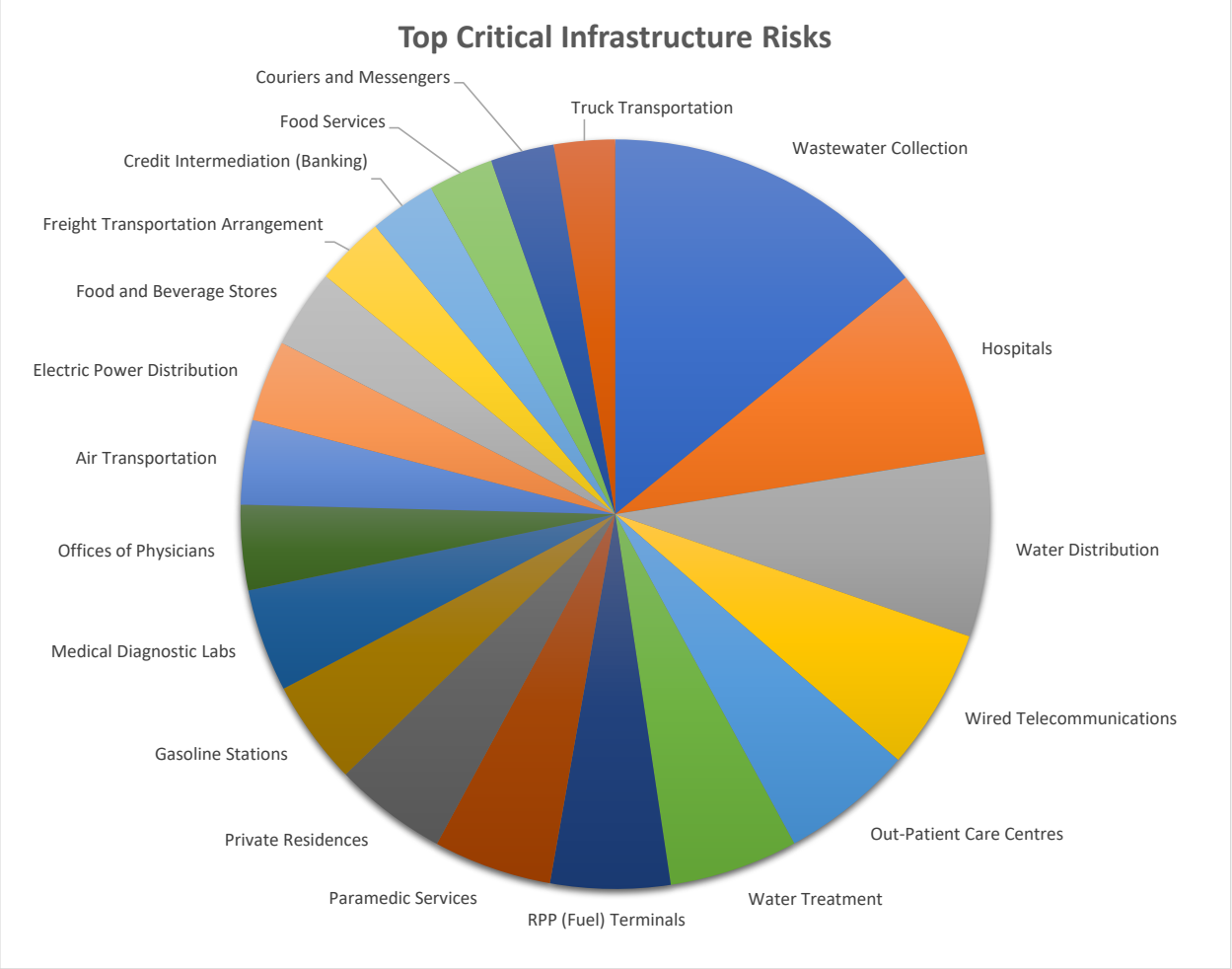

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Figure 2. Hospital Vulnerability and Recovery

Hosptial Recovery Timeline									
HOSPITAL DEPENDENCIES (Functions)		Week				Months			
Internal Hospital Functions	**Vulnerability**	**1**	**2**	**3**	**4**	**2**	**3**	**6**	**12**
Hospital Operations	N/A								
Hospital Staff	**Medium**								
Hospital Supplies and Equipment	**High**								
Hospital Facilities	**Very High**								
Other Health Sector Services	**Vulnerability**	**1**	**2**	**3**	**4**	**2**	**3**	**6**	**12**
Ambulatory Health Care Services	**Medium**								
Nursing and Residential Care	**Low**								
Medical Diagnostic Laboratories	**High**								
Health Supply Chain	**Medium**								
Incident Mutual Aid - Health Sector	**Very Low**								
Non-Health Sector Functions	**Vulnerability**	**1**	**2**	**3**	**4**	**2**	**3**	**6**	**12**
Electric Power Distribution	**Low**								
Petroleum	**Very Low**								
Natural Gas	**Low**								
Steam Heating	**Very Low**								
Financial Services	**Very Low**								
Food	**Low**								
Government	**Very Low**								
Telecommunications	**Low**								
Cyber and Information Services	**Very Low**								
Manufacturing	**Low**								
Waste Management and Remediation	**Low**								
Safety	**Low**								
Road Access	**Very Low**								
Water Distribution	**Medium**								
Wastewater Collection Network	**High**								
Population (Labour)	**Low**								

Vulnerability

Very High	51-100%
High	26-50%
Medium	11-25%
Low	2-10%
Very Low	0-2%

Recovery

	Normal
	91-99%
	61-90%
	31-60%
	0-30%

RECOMMENDATIONS

The NCIM consists of the following products:

- A set of twelve volumes documenting the NCIM. These consist of ten reports describing each sector and its included industries and NCIM functions plus a user's guide and a close out report documenting the development of the NCIM and its application in case studies;
- An Excel file that lists and describes each NCIM function;
- An Access database file with the functions, the relationships among the functions and their relationships to the NAICS; and
- A RiskLogik file for use with the RiskLogik software.

In addition for the DRRP seismic scenario, there are the following:

- An Access database file with scenario parameters;
- A RiskLogik file with scenario parameters;
- The output of the RiskLogik software;
- Vulnerability profiles for selected high risk industries; and
- A report, to be sent to Natural Resources Canada, documenting the application of the NCIM for the seismic scenario.

Defence Research and Development Canada (DRDC) does not have a mandate to provide an analytical service for critical infrastructure interdependency analysis. While there is a public portal for publications, DRDC does not provide a public portal for data files. The involvement of DRDC was to develop the NCIM, at the request of Public Safety Canada and the National Cross-Sector Critical Infrastructure Forum. This included testing the NCIM with several case studies[5], most of which restricted due to client confidentiality.

The DRDC publications portal is located here:

https://www.canada.ca/en/defence-research-development/corporate/publications.html

The twelve reports all have the title *National Critical Infrastructure Interdependency Model* followed by a volume number. A search on the keyword, *Interdependency*, will produce the list of volumes.

The availability of the general NCIM data files and DRRP products is an issue. If one or more of the DRRP partners is willing to host the NCIM data files and DRRP products, these files and products will be transferred to those partners. At the very least the Excel file, along with the reports available through the DRDC publications portal, can be useful for practitioners in understanding each of the critical infrastructure sectors.

CHALLENGES

As noted above Defence Research and Development Canada will be closing the NCIM project. There is, as yet, no organization within Canada that will take on the NCIM and further its development – in particular the development of user-friendly tools for practitioners. Currently the NCIM requires experienced systems or operations research analysts.

[5] The case studies have included floods, ice storms, earthquakes, cyber-attacks and the disruption of natural gas. They have also included an all-hazards assessment of a regional hospital's vulnerability and the evaluation of drone capabilities for first responders in a flooding scenario.

However, the NCIM is fully documented and available on Defence Research and Development Canada's publication website.

It should be recognized that the NCIM was a prototype or 'proof-of-concept'. In that regard it has demonstrated that it is possible to develop a conceptual model of critical functions that can be applied locally, regionally or nationally to better inform risk assessments. Typically, 'proofs-of-concept' do not result in 'ready-to-use' tools. Developing such tools takes more investment but also a user community-of-practice that can provide feedback on both desirable tools and on concepts-of-use or best practices for applying a conceptual model of critical functions.

RESOURCES OR SIMILAR PROJECTS

BC AND CANADA

Resources in BC and Canada:

1. Defence Research and Development Canada. "Publications - Defence Research and Development Canada". Accessed 9 June 2021. https://www.canada.ca/en/defence-research-development/corporate/publications.html. The NCIM is fully documented and available on the Defence Research and Development Canada publications website.
2. Public Safety Canada, "Critical Infrastructure Resources." Accessed 9 June 2021. Public Safety Canada provides information and resources for enhancing critical infrastructure resilience.
3. Public Safety Canada. "All-Hazards Risk Assessment." Accessed 9 June 2021. Public Safety Canada provides an all-hazards risk assessment approach which includes the consideration of different categories of losses.
4. RiskLogik Inc. "Risk Analysis and Management: trusted by those you trust". Accessed 9 June 2021. https://www.risklogik.com/. RiskLogik Inc. provides software tools as well as analysis for analyzing risk for complex networks such as the NCIM's set of related functions.

INTERNATIONAL

1. Cyber and Infrastructure Security Agency, Department of Homeland Security. "National Critical Functions". Accessed 9 June 2021. https://www.cisa.gov/national-critical-functions. The United States Cyber and Infrastructure Security Agency has recently adopted a 'critical function' approach to critical infrastructure resilience.
2. Homeland Security Today.US. "Here Are CISA's 55 Make-or-Break National Critical Functions, Setting Stage for 'Risk Register'". Accessed 9 June 2021. https://www.hstoday.us/subject-matter-areas/infrastructure-security/here-are-cisas-55-make-or-break-national-critical-functions-setting-stage-for-risk-register/. Homeland Security Today.US provides a review of the United States national critical functions set.
3. Lewis, L. P. and Petit, F. "Critical infrastructure interdependency analysis: Operationalising resilience strategies". Contributing Paper to GAR 2019, Accessed 9 June 2021. https://www.undrr.org/publication/critical-infrastructure-interdependency-analysis-operationalising-resilience-strategies. The authors, associated with Argonne National Laboratory provide a general framework for analyzing critical infrastructure interdependencies.

ENDNOTES

[i] "Infrastructure Security", accessed 8 June 2021, https://www.cisa.gov/infrastructure-security.
[ii] "Canada's Critical Infrastructure", accessed 8 June 2021, https://www.publicsafety.gc.ca/cnt/ntnl-scrt/crtcl-nfrstrctr/cci-iec-en.aspx.

[iii] Schaefer, Rudi. “CI related Modeling & Simulation in Germany”. Paper presented at the Workshop on Modeling and Simulation of Critical Infrastructures, JRC Ispra, Italy, 4-6 May 2009.
[iv] National Strategy for Critical Infrastructure”, accessed 11 June 2021, https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/srtg-crtcl-nfrstrctr/index-en.aspx.
[v] “RiskLogik: Risk Analysis and Management”, accessed 11 June 2021, https://www.risklogik.com/.