2 Interdependency Analysis

Critical infrastructures are frequently connected at multiple points through a wide variety of mechanisms, so that bi-directional relationships exist between the states of any given pair of infrastructures. This means that CI are highly interdependent, both physically and in their greater reliance on the information infrastructure, resulting in a dramatic increase of the overall complexity and posing significant challenges to the modeling, prediction, simulation, and analysis of CI. The information infrastructure plays a crucial role, as most of the critical infrastructures are either built upon or monitored and controlled by ICT systems, a trend that has been accelerating in recent years with the explosive growth of information technology.

An →*Interdependency* can be understood as a "bidirectional relationship between two infrastructures through which the state of each infrastructure influences or is correlated to the state of the other."[30] A →*Dependency*, on the other hand, is a unidirectional relationship.[31]

What is Interdependency Analysis?

Due to the explosive growth of information technology, the study of interdependencies and possible cascading effects in case of failures have become the focal point of research. Interdependency analysis looks to gain a better understanding of the complex (bi-) directional relationships between infrastructure components, subsystems, systems, and/or sectors.

At an initial stage, most countries have opted for qualitative, expert-based approaches to mapping interdependencies. Most countries have included in their approaches a rough analysis of dependencies and interdependencies to determine the criticality of infrastructures or sectors. Expert opinion is collected through means of working groups, →*Roundtables*, workshops, or →*Questionnaires*. However, it is generally recognized today that it is necessary to move beyond mere qualitative understanding of interdependencies and towards sophisticated modeling of cause-and-effect relationships and possible cascading failures.

A comprehensive analysis of interdependencies is a daunting challenge, though, mainly because the science of infrastructure interdependencies is relatively immature. There are many models and computer simulations

30 Rinaldi, Steven M., James P. Peerenboom, and Terrence K. Kelly. "Complex Networks. Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies". *IEEE Control Systems Magazine* vol. 21 (6 December 2001), p. 14.

31 Ibid.

for aspects of individual infrastructures, but simulation frameworks that allow the coupling of multiple interdependent infrastructures to address infrastructure protection, mitigation, response, and recovery issues are only beginning to emerge. The operational, R&D, and policy communities have accepted the importance of infrastructure interdependencies and the need to better understand their influence on infrastructure operations and behavior. Increasingly, the complex →*Agent-Based Modeling* is used to gain a better understanding of interdependencies. These efforts are partly described in chapter on →*System Analysis*. This chapter will concentrate on the more qualitative, descriptive efforts.

How to Categorize Interdependencies in Terms of their Environment

Interdependencies are a complex and difficult problem to analyze, also because the nature of interdependencies is still very little understood. An article published by a group of US scholars (Rinadli, Peerenboom, Kelly: "Complex Networks. Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies")[32] presents a conceptual framework for

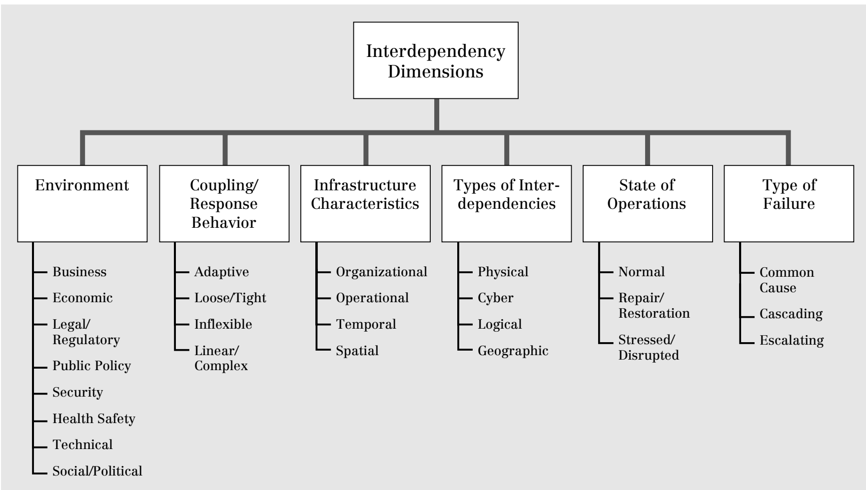

Figure 9: Interdependency Dimensions

32 Ibid. pp. 11–25.

addressing infrastructure interdependencies that is important enough to merit mention, even though it is not a country-specific approach as such. The article addresses interrelated factors and system conditions, which are represented and described in terms of six "dimensions" that complicate the challenge of identifying, understanding, and analyzing interdependencies (Figure 9):

The six dimensions that can be distinguished are:

- Environment: The environment influences normal system operations, emergency operations during disruptions and periods of high stress, and repair and recovery operations. Examples for parameters related to the environment are: Economic and business opportunities and concerns, public policy, government investment decisions, legal and regulatory concerns, and social and political concerns.
- Coupling/Response Behavior: The degree to which the infrastructures are coupled, or linked, strongly influences their operational characteristics. Some linkages are loose and thus relatively flexible, whereas others are tight, leaving little or no flexibility for the system to respond to changing conditions or failures that can exacerbate problems or cascade from one infrastructure to another.
- Infrastructure Characteristics: Infrastructures have key characteristics that figure in interdependency analyses. Principal characteristics include spatial (geographic) scales, temporal scales, operational factors, and organizational characteristics.
- Types of Interdependencies: These linkages can be physical, virtual, related to geographic location, or logical in nature.
- State of Operation: The state of operation of an infrastructure can be thought of as a continuum that exhibits different kinds of behavior during normal operating conditions (which can vary from peak to off-peak conditions), during times of severe stress or disruption, or during times when repair and restoration activities are underway. At any point in the continuum, the state of operation is a function of the interrelated factors and system conditions.
- Type of Failure: Infrastructure disruptions or outages can be classified as cascading, escalating, or common-cause failures.[33]

Even though the listed dimensions are very broad, the approach is a first step towards a comprehensive set of interdependency metrics. In a way, it is a holistic approach incorporating technical as well as socio-political issues.

33 Ibid.

Examples of Interdependency Analyses

Very often, the determination of interdependencies is closely related to the identification of vital processes and core components within sectors. During this procedure, dependencies of core infrastructure components that could lead to cascading effects of failure can be determined, with a special focus on ICT components due to their special role when it comes to interlinking other infrastructures. The identification of nodes and linkages between sectors helps to establish the degree of interdependency: Interdependencies can exist between components, but also between functions or resources; they can have different characteristics (i.e. physical, virtual, related to geographic location, or logical in nature) and may differ in degree. Other important factors to be considered include the impact of the effect caused by the dependency, time lags, redundancy, etc.

In the following, two examples are described more closely:

- Example 1 (Australia) – PreDict Interdependency Analysis (PreDict)
- Example 2 (Canada) – Critical Infrastructure Protection Task Force Dependency Analysis (CIPTF)

Example 1 (Australia) – PreDict Interdependency Analysis (PreDict)

♦ The PreDict approach is also described in
Chapter 1: Sector Analysis, and in
Chapter 5: Vulnerability Assessment.

In 1998, government officials decided to analyze the Australian national defense-related infrastructure in order to develop strategies to remove, ameliorate, or avoid identified vulnerabilities. In a first phase, the study identified vulnerabilities in fifteen infrastructure sectors and highlighted their interdependence (at the sector level). This was then used as a basis for the development of industry vulnerability profiles for each of the ten sectors (➞see also Chapter 5 on *Vulnerability Assessment*).

Sector interdependencies were discussed and rated by experts (both industry and defense representatives). The interdependencies were charted over the three periods of 1999, 2005, and 2020, with additional summary pages detailing the nature of the interdependency and reasoning behind each rating. Initially identified sector interdependencies were classified as critical, significant, or moderate. The findings were shown in ➞*Interdependency Charts* (Figure 10), which were further commented in detail.

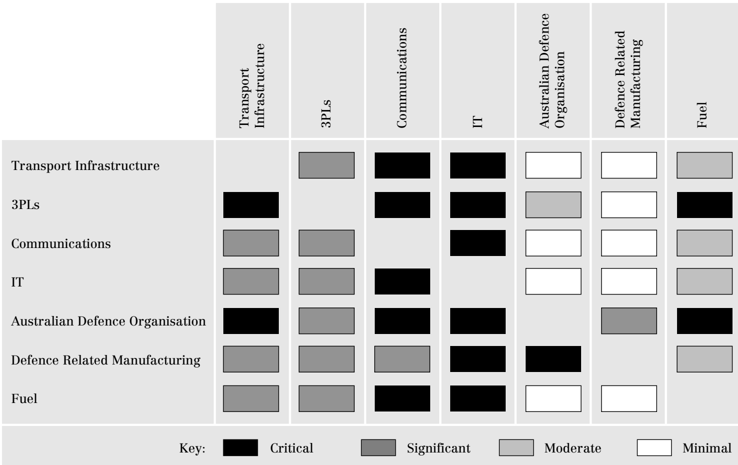

Figure 10: Section of an Interdependency Chart

Example 2 (Canada) – Critical Infrastructure Protection Task Force Dependency Analysis (CIPTF)

- ♦ The CIPTF approach is also discussed in *Chapter 1: Sector Analysis*, and in *Chapter 3: Risk Analysis*.

In spring of 2000, the *Critical Infrastructure Protection Task Force* (CIPTF) was established within the *Canadian Department of National Defence*. The CIPTF developed an extensive process to review critical infrastructures in Canada. One of the goals was to better understand and picture interdependencies. Based on six sectors identified as crucial (Government; Energy and Utilities; Services; Transportation; Safety; Communications), the CIPTF developed a multi-dimensional →*Layer Model* that takes into consideration the responsibilities at five levels, namely at the international, federal, provincial, municipal, and private levels. The CIPTF used this model to draw up a detailed dependency analysis, based on input from approximately sixty experts (Figure 11).[34]

34 See Grenier, Jacques. "The Challenge of CIP Interdependencies". *Conference on the Future of European Crisis Management* (Uppsala, 19–21 March 2001). http://www.ntia.doc.gov/osmhome/cip/workshop/ciptf_files/frame.htm.

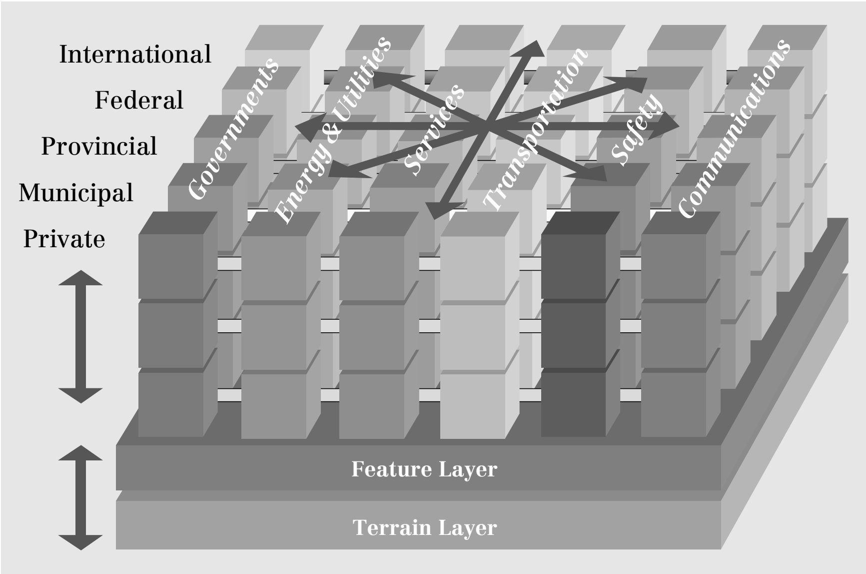

Figure 11: Canadian Critical Infrastructure Model: Dependencies

It became immediately obvious that the large number of interdependencies could not be plotted concisely this way. To better show and evaluate the level of interdependency between the different infrastructure elements, a →*Dependency Matrix* was developed (Figure 12). The extent of direct dependency between infrastructure elements is described using the →*Values* "high", "medium", "low", and "none".[35]

An application called *Relational Analysis For Linked Systems (RAFLS)* was developed for measuring and modeling the cascading effects of these direct dependencies. RAFLS, which is based on an algorithm, uses scored interdependencies and iteratively determines dependencies and impacts. It shows high and medium degrees of dependencies and can reveal second-, third-, fourth-, and fifth-level dependencies. It also helps to trace linkages and potentially interdict a path in time of crisis.[36]

35 Ibid.
36 Ibid.

Sector	Element	Energy & Utilities					Services		
		Electrical Power	Water Purification	Sewage Treatment	Natural Gas	Oil Industry	Customs and Immigration	Hospital & Health Care Services	Food Industry
Energy & Utilities	Electrical Power		L			M			
	Water Purification	H				M			
	Sewage Treatment	M	H			H			
	Natural Gas	L				L			
	Oil Industry	H	L						
Services	Customs & Immigration	H	L	L	L	L		L	
	Hospital & Health Care Services	H	H	L	H	H	M		H
	Food Industry	H	H	H	L	M	M	L	

Key: H High M Medium L Low

Figure 12: Section of the Indefinite Matrix