A. T. Murray
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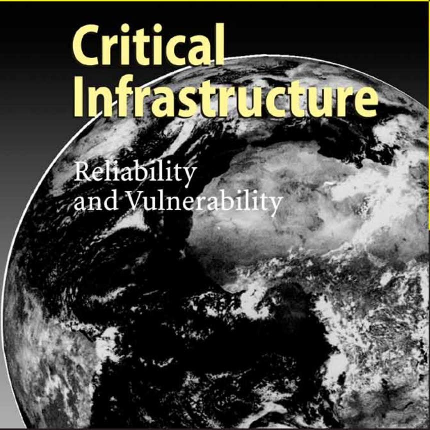
Editors

Critical Infrastructure

Reliability and Vulnerability



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(Editors)

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With 66 Figures
and 51 Tables

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Preface

The aim of this text was to bring together differing geographic perspectives in modeling and analysis designed to highlight infrastructure weaknesses or plan for their protection. This began initially as the outgrowth of a series of lectures we organized for the Regional Science Association International conference in Seattle, Washington on November 10-13, 2004, and expanded substantially beyond this to include researchers in other disciplines and other countries. We are pleased with the final product and greatly appreciate the efforts of the contributors, referees, and the publisher.

January 2007

Alan Murray
Tony Grubesic

Table of Contents

1 Overview of Reliability and Vulnerability in Critical Infrastructure

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1.1 Introduction

The concept of *interconnection* is an important one for a wide range of social, economic and political issues. Broadly defined, interconnection refers to a state of reciprocal connection. In this context, two or more interconnected entities can exchange ideas, currency, information and other valuable goods with each other, often for mutual benefit. For example, telecommunication backbone providers frequently interconnect at points of presence (POPs) or Internet exchanges (IXs) in order to accommodate peering relationships between large networks or to provide data transit for smaller systems. One obvious benefit accrued through this type of practice is extending the geographic reach of each backbone involved with the interconnection arrangement, providing access to new markets and potential customers. Over time, these interconnections can strengthen or decline, depending on the benefits acquired through interconnectivity. If the relationship between entities strengthens significantly, the condition of interdependency can emerge. In this context, the entities involved require the reliable operation of their interconnected partner(s) to function properly. If the relationship between entities weakens significantly, connections may be disbanded.

In recent years, the interdependencies of many infrastructure systems have increased dramatically. In the White House (2003) report titled "National Strategy for the Physical Protection of Critical Infrastructures and

Key Assets" problems associated with increased levels of interconnectivity between critical infrastructure systems are noted:

"the challenges and uncertainties presented by critical nodes and single-points-of-failure within infrastructures, as well as increasing interdependencies that exist among the various infrastructure sectors both nationally and internationally… are often difficult to identify and resolve, as are the cascading and cross-sector effects associated with their disruption" (White House 2003, pp. 33)

Perhaps the most notable problem with these increased levels of interdependencies is the potential for cascading failure across mutually dependent systems. Cascading failure occurs when an event triggering a collapse produces a series of secondary failures in interdependent infrastructures (Carreras et al. 2002; Little 2002; Albert et al., 2004; Talukdar et al. 2003; Houck et al. 2004). For example, if the electrical grid is significantly disrupted, it is likely that telecommunication services will also be disrupted. This, in fact, occurred during the massive electrical blackout in the Northeastern U.S. and portions of Canada in 2003 (Grubesic and Murray, 2006). Nearly 2,500 telecommunication networks were disrupted (*ibid*). Not surprisingly, with each disruption to a critical infrastructure system, accidental or otherwise, attempts are made to reevaluate the degree to which many of these engineered systems are able to maintain some type of operational continuity. The results of these evaluations are often used to fortify or protect existing systems, plan and construct newer, more resilient infrastructure, motivate new public policies regarding critical infrastructure and its expected performance and to help in the development of hazard mitigation plans.

1.2 Critical Infrastructure

Societal functions are highly dependent on networked systems in the developed world. Even the most basic day-to-day functions involve interaction with a variety of critical infrastructure systems. For example, millions of Americans utilize transportation infrastructure to get to work, school, or the local mall. Telecommunication infrastructure is used to maintain contact with family and friends, shop or perform financial transactions. Energy infrastructure is used to heat our homes, power local industries and deliver fuel to our automobiles. While these basic activities are relatively easy to comprehend, the magnitude of infrastructure use is less obvious. For instance, over 19 billion tons of freight valued at $13 trillion dollars was moved through the multimodal transportation system and its associated networks in the United States during 2002 (USDOT, 2006). Where telecommunication networks are concerned, U.S. backbone traffic exceeded 100 petabytes per month in 2002 (SVBJ, 2002). Assuming an average email is 25 kilobytes, this translates into 45,035,996,273 emails per month. Finally, the daily delivery capacity of the U.S. natural gas grid is 119 billion cubic feet, with yearly consumption estimated at 22.8 trillion cubic feet during 2002. Considering the degree to which industrialized societies are reliant on such critical infrastructure systems, their importance should not be underestimated. Moreover, because the operability of these systems can be vulnerable to disasters, accidents and intentional harm, there is a need to understand how critical infrastructure and its functionality might be impacted when subjected to disruption. Thus, there is a need to develop strategies for planning networked systems capable of surviving and performing under duress.

As a response to the growing threat of terrorism in the late 1990s, the U.S. federal government established the President's Commission on Critical Infrastructure Protection (E.O. 13010). This executive order defined "infrastructure" as (E.O. 13010):

> The framework of interdependent networks and systems comprising identifiable industries, institutions (including people and procedures), and distribution capabilities that provide a reliable flow of products and services essential to the defense and economic security of the United States, the smooth functioning of government at all levels, and society as a whole.

More importantly, E.O. 13010 (1996) suggests that "…certain national infrastructures are so vital that their incapacity or destruction would have a debilitating impact on the defense or economic security of the United States." The concept of "vital" or "critical" infrastructure is important for establishing national security benchmarks. Basic inventories of critical infrastructure are often subdivided into sectors, and include (E.O. 13010, 1996; White House, 2003):

- telecommunications
- electrical power systems
- gas and oil storage
- transportation
- banking and finance
- water supply systems
- emergency services (including medical, police, fire, and rescue)
- continuity of government.

Similarly, a group of key assets were also highlighted:

- National Monuments and Icons
- Nuclear Power Plants