The Geospatial Dimensions of Critical Infrastructure and Emergency Response

White Paper Series

No. 1 - Infrastructure Interdependencies

GEOSPATIAL INFORMATION & TECHNOLOGY ASSOCIATION®

INTRODUCTION

In 2005, the American Society of Civil Engineers (ASCE) issued a "National Infrastructure Report Card" that provided a detailed assessment of the Nation's major infrastructure assets. Fifteen major infrastructure areas were examined for the report, including aviation, energy, public works, water, roads, and transit, among others.

An overall letter grade of "D" was given to the infrastructure by ASCE, which also noted that $1.6 Trillion would be needed just to bring the infrastructure to a "good" level. The report can be reviewed at: http://www.asce.org/reportcard/2005/index.cfm.

Since the report was issued almost four years ago, funding for infrastructure maintenance and construction has actually decreased. GITA anticipates that the next edition of the report card will provide an even bleaker picture.

As a basic understanding, GITA defines infrastructure as, "all fundamental services, activities, and operations that sustain our communities and way of life." GITA is extremely concerned about the current status of North America's infrastructure and is fully committed to advancing the use of geospatial technology to address our infrastructure-related problems. GITA's members and constituents—professionals in the gas, electric, pipeline, telecommunications, transportation, water and wastewater, and local, state and federal government sectors—are using geospatial solutions on a daily basis to do just that. These sectors, plus the spatial data infrastructure and emergency response community, are the association's primary focus.

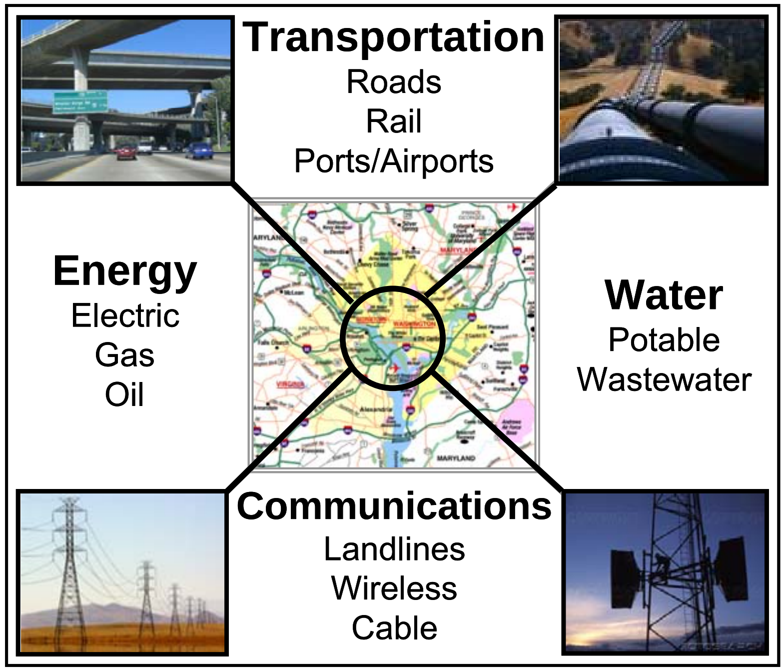
While the lack of adequate maintenance and replacement cycles that steadily degrade our infrastructure is a serious issue itself, the threat to key infrastructure assets of natural and human generated acts also requires urgent attention. No matter the cause of the emergency—terrorism, natural occurrences, or unintentional human error—the methods of responding to, mitigating, and ideally preventing reoccurrences are based on a common approach: the coordinated use of geospatial information.

In order to better understand and communicate how a failure or an event in one infrastructure sector may affect assets in other sectors, GITA's Research Committee undertook an effort to define the "interdependencies of infrastructure." The objective of this study was twofold: to establish the key connections among important parts of our overall infrastructure, and to respond to a membership call for applied research in response to recent natural and man-made disasters.

This paper, *Infrastructure Interdependencies,* is the first in a special White Paper Series entitled, *The Geospatial Dimensions of Critical Infrastructure and Emergency Response*. It is intended to provide geospatial practitioners with a summary of critical infrastructure interdependencies, reasons why understanding these relationships is vital to effective emergency response, and the important role geospatial technology, data and knowledge can play in addressing our infrastructure-related challenges.

Future White Papers will address GITA's primary constituent markets within the geospatial industry, as well as other critical infrastructure protection and emergency response initiatives being undertaken by GITA. A compendium of research recommendations, designed to provide support to infrastructure sectors, emergency response organizations, government agencies, the geospatial community, and related disciplines, will be published following GITA's Geospatial Infrastructure Solutions Conference, April 19-22, 2009.

The importance of critical infrastructure protection and interconnectedness was highlighted in 1998 when the Presidential Commission on Critical Infrastructure Protection[1] recognized that the security, economic prosperity, and social well-being of the nation depend on the reliable functioning of our increasingly complex and interdependent infrastructures. These include water supply and wastewater systems, energy systems (electric power, oil, and gas), communications, transportation (road, rail, air, and water), banking and finance, and emergency and government services. The commission also noted that “mutual dependence and interconnectedness made possible by the information and communications infrastructure lead to the possibility that our infrastructures may be vulnerable in ways they never have been before." Failure to understand how disruptions to one infrastructure could cascade to others, exacerbate response and recovery efforts, or result in common cause failures, leaves infrastructure owners and emergency response personnel unprepared to deal effectively with the impacts of such disruptions.



Understanding, analyzing, and sustaining the robustness and resilience of the critical infrastructure and their interdependencies requires modeling tools to assess the technical, economic, and security implications of technology and policy decisions designed to ensure their reliability and security.

Historically, interdependencies have been considered to be either *physical* or *geospatial* in nature. An example of a physical interdependence is that the water supply infrastructure depends on electric power to operate its pumps while, at the same time, the electric power infrastructure must have water to make steam and cool its equipment. Geospatial interdependencies arise when infrastructure components, e.g., transmission lines, water pipelines, gas pipelines, and telecommunications cables, share common corridors thus increasing the vulnerabilities to and consequences from disasters in the same geographic area.

In addition, the proliferation of information technology, the increased use of automated monitoring and control systems—such as Distribution Automation and Supervisory Control And Data Acquisition (SCADA) systems—and the reliance on the open marketplace for purchasing and selling of infrastructure commodities and services, have linked infrastructures in new and complex ways and have created new vulnerabilities. The dependence of the new energy

[1] President’s Commission on Critical Infrastructure Protection, Critical Foundations: Protecting America’s Infrastructures (1997). http://www.ciao.gov

marketplace on the Internet and other e-commerce systems, and the complicated links to financial markets, highlight the extent of *cyber* and *logical* interdependencies.

Rinaldi, Peerenboom, and Kelly (2001) classified infrastructure interdependencies as being one of four types: physical, cyber, geographic, or logical. Physical interdependencies involve disruptions that physically impact one or more other infrastructures. The risk of failure from normal operating conditions in one infrastructure will be a function of risk in another infrastructure. Cyber interdependencies occur when the operation of one infrastructure is dependent upon another infrastructure via information or communication links. This is the type of complex system whereby control of a networked system is dependent upon the transmission of information. Geospatial interdependencies involve the physical proximity of one infrastructure to another. An event such as an explosion of a gas main in an urban area could create correlated disruptions with other infrastructures, such as water and electric services to a community. Logical interdependencies mean that the state of one infrastructure is dependent upon another, due to some economic or political decision. An example of this is the logical interdependency between the cost of fuel and the number of vehicles using the transportation infrastructure. The capability of geospatial technology as a means of linking physical, cyber, logical and geospatial interdependencies is perhaps its greatest power.

GEOSPATIAL DIMENSIONS OF CRITICAL INFRASTRUCTURE

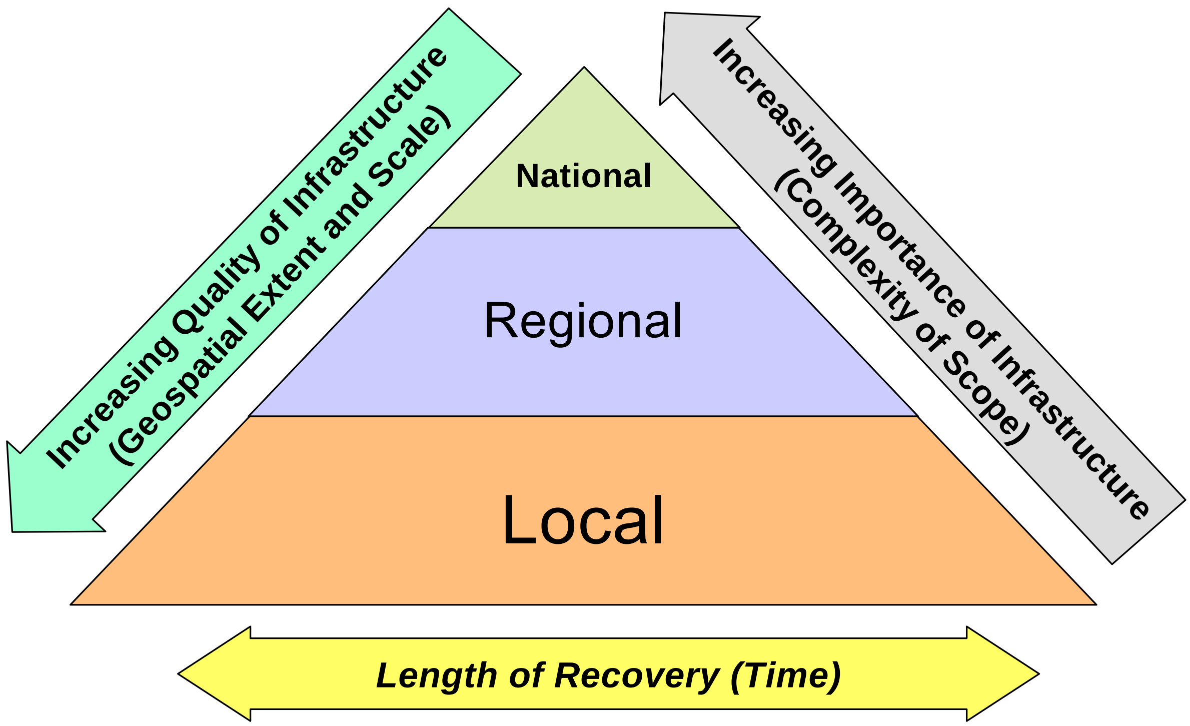
The geospatial dimensions of the relationships between and among of critical infrastructures can take several forms. As noted previously, infrastructures are geographically (i.e., geospatially) interdependent if a local environmental event can create state changes in all of them. Geospatial interdependency occurs when elements of multiple infrastructures are in close proximity. Given this proximity, events like an explosion or fire could create correlated disruptions or cascading changes in these geographically interdependent infrastructures. Such changes are not due to physical or cyber connections between infrastructures; rather, they arise from the impact the event exerts on all the infrastructures at the same time.

For example, an electrical line and communication cable hung under a bridge connect (geospatial) elements of the electric power, telecommunications, and transportation infrastructures. The interdependency in these cases is due to proximity; the state of one infrastructure does not influence the state of another. Traffic across the bridge does not influence the flow of electricity or transmission of communications. Because of the close spatial proximity, however, physical damage to the bridge could create correlated disruptions in the electric power, communications, and transportation infrastructures. Some interdependencies and their effects on infrastructure operations are caused by a natural event, whereas others result from human intervention and errors.

In the case of interdependencies, it is also important to note that the geospatial aspects of critical infrastructure are also scale, time, and scope dependent. Consider complexity of scope—when compared to our Nation’s size, Hurricane Ike impacted a relatively small area in September 2008. Failure of local infrastructure (roads, bridges, water systems) had the largest effect on response, yet occurred at the smallest geographic scale and its restoration will take the longest period of time. Further, failure of regional infrastructure (electric) proved to be the basis for a potentially overarching threat of national significance—failure of 25% of the petroleum industry. In turn, this relates to a time issue—how long can we go without power to those refineries (not long, and so the restoration period will likely be much faster than that of local infrastructure). In other words, we're not just talking about interdependencies of infrastructure, but their corresponding interdependencies of scale and time.

The following figure illustrates the complexity of the scope from a national level down to the local level.

Figure 1: Complexity of Scope of Critical Infrastructure



While the interdependencies within an individual infrastructure network are often well understood, the region of interest in interdependencies and effects modeling is the influence or impact that one infrastructure can impose on another. The key effects to model and gain the most understanding from are the chains of influence that cross multiple infrastructure sectors and induce potentially unforeseen effects.

CRITICAL INFRASTRUCTURE INTERDEPENDENCIES

Figure 2 on the following page illustrates examples of interdependent relationships among electric, water/wastewater, gas and oil, communications, and transportation infrastructures. These complex relationships are characterized by multiple connections among infrastructures. The connections create an intricate web that, depending on the characteristics of its linkages, can result in a cascading effect across multiple infrastructures that can impact a community's economy and security.

Figure 2: Critical Infrastructure Interdependency Examples

Critical Infrastructure Interdependencies					
Type of Inter-dependency	**Energy – Electric**	**Energy - Gas/Oil**	**Water**	**Communication**	**Transportation**
Energy - Electric	Highly connected and interdependent infrastructure for business and economic security	Power for control systems, pumping stations, storage, compressors, and facilities	Power for control systems, pumps, lift stations, and facilities	Power for switches and communication facilities	Power for signaling, switches, and public transportation
Energy - Gas/Oil	Fuel for heat, generators and lubricants for electric facilities	Highly connected and interdependent infrastructure for business and economic security	Fuel for treatment, heat, pumps and lift stations, and facilities	Fuel for heat, generators, and facilities	Fuel and lubricants for vehicles and facilities
Water (Potable and Wastewater)	Water for cooling and emissions control	Water for production, cooling and emissions control	Essential and highly dependent infrastructure for health and safety	Water for cooling facilities	Water transport for emergency response and construction
Communication (Landline, Cellular, Cable)	Distribution automation, EMS, and SCADA communication, and customer service and crew repair communication	SCADA communication, and customer service and crew repair communication	Control system and SCADA communication, and customer service and crew repair communication	Highly connected and interdependent infrastructure for business and economic security	Signal and control system communication, and crew repair communication
Transportation (Roads, Rail, Ports/Airports)	Transport of fuel and shipping of goods and materials, and inspection	Transport of fuel and shipping of goods and materials, and inspection	Transport of water and inspection	Transport of goods and materials, and inspection	Highly connected and interdependent infrastructure for business and economic security

The important point is that it is impossible to adequately analyze or understand the behavior of a given infrastructure in isolation from the environment or other infrastructures. Rather, we must consider multiple interconnected infrastructures and their interdependencies in a holistic manner.

In chaotic environments, such as emergency response to catastrophic events, decision-makers need to understand the dynamics underlying the infrastructures involved. Failure to understand those dynamics will result in ineffective response and poor coordination among emergency responders and infrastructure operators responsible for rescue, recovery, and restoration. It could also cause the mismanagement of resources, including supplies, rescue personnel, and security teams. This interrelationship among infrastructures and its potential for cascading effects was never more evident than in late July 2001 when a freight train carrying hazardous chemicals derailed in Baltimore's Howard Street Tunnel, resulting in a fire.

This disaster, in addition to its expected effect on rail system traffic, automobile traffic, and emergency services, caused a cascading degradation of infrastructure components not previously anticipated. For example, the fire in the tunnel caused a water main to break directly above the tunnel. The break also caused localized flooding in the surrounding area. As a direct result of the flooding, an electrical outage affected several thousand Baltimore residences. Fiber optical lines running through the tunnel were also destroyed. This resulted in major disruptions to phone and cell phone service, e-mail service, Web services, and data services to major corporations. Disruption to rail services and its effects on the Middle Atlantic States included delays in coal delivery and also limestone delivery for steel production.

This example, one of many, illustrates that all disasters are local and that emergency responders, including police, fire, and EMS, along with utility and telecommunication crews must have access to the same information and data resources when planning for and responding to a disaster. Breaking through this barrier of data sharing and collaboration between emergency responders and private utility and telecommunication companies is the primary purpose of another of GITA's infrastructure-oriented initiatives, entitled "Geospatially Enabling Community Collaboration," or GECCo. This is the subject of a future White Paper in this series.

EMERGENCY RESPONSE INTERDEPENDENCIES ON CRITICAL INFRASTRUCTURE

While GITA constituencies typically associate electric, gas, water, transportation, and similar systems as critical infrastructure, sometimes emergency response elements are not fully considered. It is vital that they be included. Further, the definition of emergency response as it applies to critical infrastructure must address and include those components, which meet the planning, mitigation, response, and recovery phases of any potential crisis or disaster. As such, the definition of emergency response services extends beyond police, fire, and EMS to include non-governmental organizations, such as the American Red Cross, Salvation Army, utility repair crews, and similar elements. By way of example, after initial rescues were performed during Hurricane Katrina, the Red Cross was responsible at the Mississippi Emergency Operations Center (EOC) for establishing and maintaining shelters for displaced persons and coordinate with Salvation Army and affiliated agencies to ensure that adequate food and water were available while maintaining contact with utility companies to obtain adequate electric and gas services for preparing those meals.

The geospatial dimensions of emergency response as incorporated and applied to critical infrastructure possess several unique characteristics:

1. Emergency response assets are responsible for the protection of all other infrastructures and are therefore the single most important component of critical infrastructure.
2. Emergency response infrastructures, under most conditions, are heavily reliant upon each other. For example, a house fire cannot be fought by a fire department alone—electric and gas companies must respond in some fashion to secure utility connections, water utilities must be up to the task of providing adequate water flows to hydrants (special requests are often processed during large fires to accommodate this need).
3. Emergency response infrastructure is, by and large, portable whereas the overwhelming majority of other critical infrastructure elements are stationary. This portable nature has lent itself to a recognition and adoption of standards to a much

greater extent than other elements of infrastructure. For example, a fire truck from Denver, Colo., will be able to hook to a fire hydrant in Baltimore, Md. Likewise, following a large natural disaster like a hurricane, electric utility crews from most anywhere in the US can and will respond to assist with the restoration of power, even though each utility network likely has unique systems.

4. Emergency response infrastructure is highly dependent upon local infrastructure during a time of crisis. The condition and ability of local infrastructure to support emergency response will heavily influence the outcome of a crisis. Therefore the ability to mitigate potential failures of other infrastructures of larger scales (such as elements of the national power grid or major pipelines) is heavily dependent on the condition and support status of local infrastructure. For example, a major pipeline traversing rural areas must be accessible by roadway with bridges that are of sufficient capacity to support response vehicles.

SUMMARY

It is important to recognize that our infrastructure assets are inexorably tied together in myriad ways in a vast network that provides the foundation for our quality of life, economic well being and overall security. An understanding of these ties, or interdependencies, is crucial to effective response, mitigation and recovery in times of emergencies caused by natural occurrences, or those resulting from intentional or accidental human activity.

This White Paper on *Infrastructure Interdependencies* is the first in a series of publications intended to convey this central concept. Future White Papers will address the specific interdependencies from the perspective of primary industries that comprise GITA's membership and various constituencies—energy (electric, gas and oil pipelines), water and wastewater, telecommunications, and transportation. Public sector (local, state and federal) relationships will be addressed in each applicable sector.

The Geospatial Information & Technology Association is focused upon infrastructure in the belief that geospatial technology is a key tool in addressing the serious challenges of infrastructure degradation, critical infrastructure protection and emergency response. For more information on the *Geospatial Dimensions of Critical Infrastructure and Emergency Response White Paper Series*, as well as related initiatives, please contact GITA, or visit the GITA website at www.gita.org.

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About the Geospatial Information & Technology Association

The Geospatial Information and Technology Association is a non-profit association focused on providing education, information exchange, and applied research on the use and benefits of geospatial information and technology worldwide. Its membership includes federal, state, and local government agencies, utilities, infrastructure management organizations, and private sector companies.

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