# The Geospatial Dimensions of Critical Infrastructure and Emergency Response

White Paper Series

## Spatial Infrastructures

GEOSPATIAL INFORMATION & TECHNOLOGY ASSOCIATION®

# Spatial Infrastructures

*A Better Understanding of Infrastructure Interdependencies Through Spatial Information*

## 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. The next edition of the report card promises an even bleaker picture.

GITA is extremely concerned about the current status of the Nation's infrastructure and ways to begin to address this increasingly serious problem. There are important social, political, and economic development considerations that impact our ability to make progress in this area—and severe ramifications of our failure to do so. GITA defines infrastructure as, "all fundamental services, activities, and operations that sustain our communities and way of life."

GITA is fully committed to advancing the use of geospatial technology to address our infrastructure problems. GITA's members and constituents—professionals in the gas, electric, water/wastewater, pipeline, telecommunications, and local, state and federal government sectors—are using geospatial solutions on a daily basis to do just that.

### Critical Needs for Infrastructure Investment

A Presidential Decision Directive issued in May 1998 highlights the importance of critical infrastructure to both security and economic interests of the nation:

> The United States possesses both the world's strongest military and its largest national economy. Those two aspects of our power are mutually reinforcing and dependent. They are also increasingly reliant upon certain critical infrastructures and upon cyber-based information systems.
>
> Critical infrastructures are those physical and cyber-based systems essential to the minimum operations of the economy and government. They include, but are not limited to, telecommunications, energy, banking and finance, transportation, water systems and emergency services, both governmental and private. Many of the nation's critical infrastructures have historically been physically and logically

separate systems that had little interdependence. As a result of advances in information technology and the necessity of improved efficiency, however, these infrastructures have become increasingly automated and interlinked. These same advances have created new vulnerabilities to equipment failure, human error, weather and other natural causes, and physical and cyber attacks. Addressing these vulnerabilities will necessarily require flexible, evolutionary approaches that span both the public and private sectors, and protect both domestic and international security.

In looking at this level of importance along with the deteriorating conditions of many components of the physical infrastructure in the U.S., we can see that the past practices of deferring investments in infrastructure maintenance, operations, and protection has left many communities vulnerable to disruptions of service, threats to public safety, economic uncertainty, and to a lower quality of life.

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. Because our economy is increasingly reliant upon interdependent and cyber-supported infrastructures, non-traditional attacks on our infrastructure and information systems may be capable of significantly harming both our military power and our economy. No matter the cause of the problem or emergency—lack of maintenance, excessive wear and tear, 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.

## Economic Stimulus

Critical infrastructure accounts for a significant amount of the dollars spent by governments and business. For example many sources have estimated that China's current infrastructure expenditures are approximately $150 billion a year or roughly 9% of its gross domestic product. The U.S. percentage is much less and has been in a decline for many years. However as noted above, the U.S. has reached a point where massive infusions of investment are necessary to restore the infrastructure to a safe, fully functioning, and environmentally sound state of operation.

Infrastructure investment is often a rapid economic stimulus for job creation and a boon for the economy. If well planned, these investments can be more than a temporary stimulus, providing a solid foundation for long-term economic growth and for the promotion of sound environmental stewardship. While future budgets and economic stimulus plans are currently being discussed, it is almost certain that the U.S. will invest large sums of public funds into critical infrastructure construction, repair, and maintenance over the next few years as part of its national strategy for economic recovery. In November 2008, meanwhile, Canada's government announced it would accelerate a 2007 commitment to "the largest infrastructure development program in (Canada) in over half a century[1]," increasing investment in

[1] PM speaks to the International Conference on Gateways and Corridors, http://pm.gc.ca/eng/media.asp?id=1645 (2009)

infrastructure renewal as a specific response to the downturn in global markets[2]. Additionally, one billion dollars has been committed for Canada's Asia-Pacific Gateway initiative. A comprehensive understanding of the needs and benefits of such projects can be enhanced by the use of spatial information to ensure an increased probability of positive impacts of investments both locally and nationally.

## GITA WHITE PAPER SERIES

GITA is extremely concerned about the current status of the infrastructure in North America. The Association is dedicated to developing and promoting effective ways to begin to address this increasingly serious problem, by leveraging what it feels are ideal tools: geospatial information and technology. GITA's membership is concerned with infrastructure, i.e. "all fundamental services, activities, and operations that sustain our communities and way of life" in five fundamental critical infrastructure sectors: energy-electrical, energy, gas/oil, water, communications, and transportation.

GITA's geospatial focus is an all encompassing one. GITA understands that "everything is somewhere" and views geospatial information and technology as an enabler of increased understanding of critical infrastructure, its interdependencies, and its relationship to building and maintaining economically, socially and environmentally livable and sustainable communities across the nation. In this context, GITA believes that geospatial information and technology are becoming an information infrastructure and as such are part of the growing cyber infrastructure that supports and is intertwined with all other elements of critical infrastructure.

GITA strives to be the leading information resource and community for anyone who has a vested interest in the use of geospatial information. As part of being a thought leader for geospatial and to contribute significantly to helping address infrastructure challenges, GITA is endeavoring to increase awareness and promote policies and practices to enhance the role of geospatial technology, information, and infrastructures in sustaining our invaluable infrastructure assets. In order to better understand and communicate how a failure or an event in one infrastructure sector may affect assets in other sectors, GITA is undertaking an effort to publish a series of white papers to define and discuss the "interdependencies of infrastructure." It is intended to provide geospatial practitioners with a summary of critical infrastructure interdependencies, reasons why understanding these relationships is vital to effective critical infrastructure management, operations, and emergency response, and the important role geospatial technology can play in addressing our infrastructure-related challenges.

### Why This Paper in the Series?

This paper, *Spatial Infrastructure: A Better Understanding of Infrastructure Interdependencies through Spatial Information*, is one in a special White Paper Series entitled, *The Geospatial*

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[2] PM, premiers agree to speed up infrastructure investment, CBC News. http://www.cbc.ca/canada/story/2008/11/10/harper-premiers.html (2008)

*Dimensions of Critical Infrastructure and Emergency Response*. The series will provide geospatial practitioners with a summary of critical infrastructure interdependencies, a better understanding of these relationships and the important role geospatial technology, data and knowledge play in addressing our infrastructure-related challenges. *Spatial Infrastructure: A Better Understanding of Infrastructure Interdependencies through Spatial Information* is intended to help readers understand spatial data infrastructures, their value in managing, using, and sharing spatial information and services, and how they can assist citizens and their corporate, academic and government institutions in addressing some of the vital issues confronting our nation and its communities.

**What Is a Spatial Data Infrastructure?**

A spatial data infrastructure (SDI) is an information system to assemble and use geographic/geospatial information to meet the needs of users and decision-makers. Increasingly, SDIs are cyber-based information systems which evolve to adopt and use new technologies. The concepts of information infrastructures and spatial data infrastructures have been around for approximately 20 years. These concepts found their start in the convergence of computer and communication technology. This convergence of technologies has brought about today's vast and rapidly changing information infrastructure, one in which a single definition of terms is difficult. This may be true for information infrastructures in general, however since the late 1990s the geospatial community has moved toward a common understanding of the term spatial data infrastructure (SDI). A spatial data infrastructure can now be seen as the "dial tone" of the geospatial web. It is commonly defined as the means to assemble geographic information that describes the arrangement and attributes of features and phenomena on the Earth and includes the technology, policies, standards, delivery mechanisms, and financial and human resources necessary to acquire, process, store, distribute, and use geospatial data.

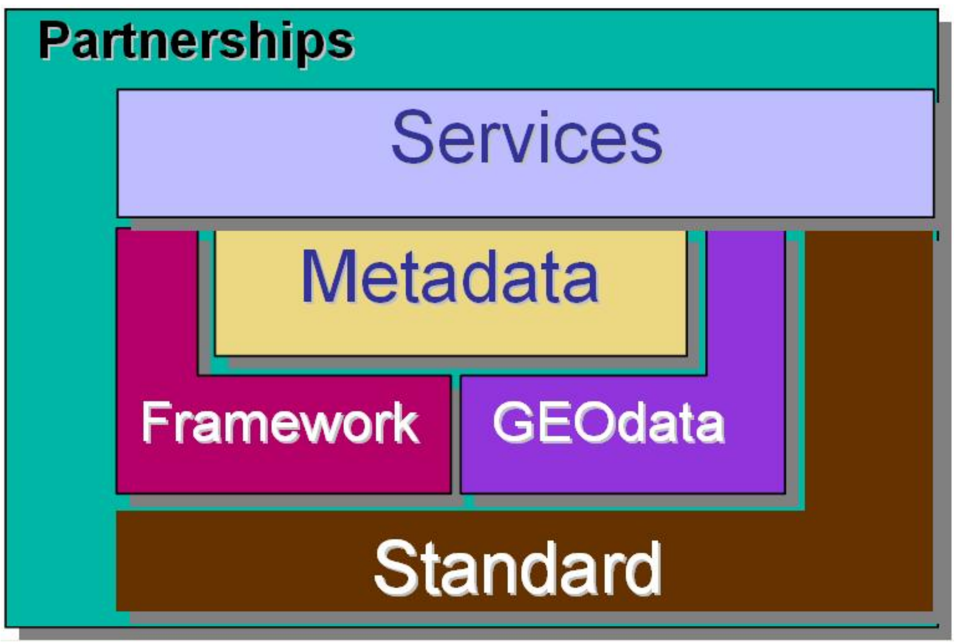



**Figure 1: The U.S. National Spatial Data Infrastructure Components (From FGDC Presentation www.fgdc.gov).**

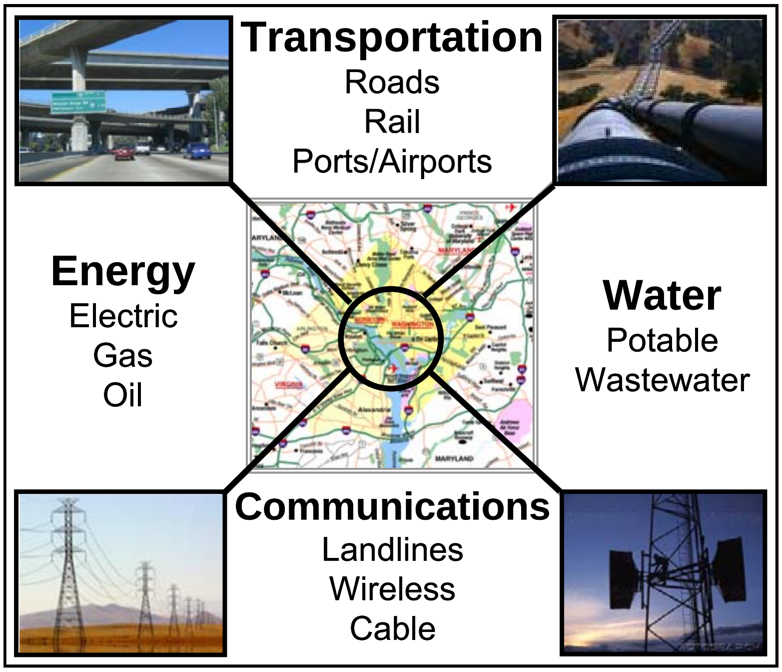
Here are some of the commonly accepted components or features of an SDI. How they are designed and implemented determines the potential effectiveness of the model. Whether or not the model gets broadly adopted and implemented determines its actual effectiveness.

- Network
- Spatial Data
- Catalogues/Clearing Houses/Registries
- Web Services
- An Integrating Data Framework/Foundation
- Guidelines/Policies
- Standards
    - Metadata
    - Core/Base Data
    - Spatial Data
    - Services
- Institutional Capacity and Partnerships

A depiction of these components in the U.S. National Spatial Data Infrastructure (NSDI) is shown above in Figure 1.

**CRITICAL INFRASTRUCTURE DEPENDENCIES**

The importance of critical infrastructure protection and interconnectedness was highlighted in 1998 when the Presidential Commission on Critical Infrastructure Protection[3] 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




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

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 infrastructures 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 are proximity issues, arising when infrastructure components such as 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 marketplace on the Internet and other e-commerce systems, and the complicated links to financial markets, highlight the extent of cyber and logical interdependencies.

## GEOSPATIAL—A KEY TO UNDERSTANDING INTERDEPENDENCIES

Infrastructures can be spatially interdependent in several ways. Geospatial interdependency occurs when elements of multiple infrastructures are in close proximity. Given this proximity, events such as an explosion or fire could create correlated disruptions or changes in these geographically interdependent infrastructures. 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.

Other types of geospatial interdependencies are those relating to scale, time, and scope. When compared to a nation's size, a hurricane landfall usually has an intense impact over a relatively small area. Failure of local infrastructure (roads, bridges, water systems) has a large effect related to emergency response, yet occurs at the smallest geographic scale and its restoration will likely take the longest period of time. However, a local event may exhibit a broad zone of influence, damaging regional infrastructure in the local area, thus generating a threat of national significance. As the scope widens, time often becomes an important issue as greater numbers of people are dependent upon the affected infrastructure component, which prompts a faster recovery/repair period than that of the local infrastructure. In cases such as this, interdependencies of infrastructure include the corresponding interdependencies of scale and time and the way in which these impact individuals, communities, and the nation.

Geospatial interdependency also may take the form of a common need for or reliance on certain types of information and the ability to transmit or share information in a form in which it can be easily understood and used by others. Information about critical infrastructure comes from many sources and has potentially many uses. In the past, this information has been separate and not integrated. However, much of this information has a geospatial or place-based component to it and can be tied together through the use of a geographic framework. The use of information in a way that exploits geographic relationships can provide new ways of understanding critical infrastructure interdependencies and addressing both the opportunities and issues associated with these interdependencies. The ability to gain an understanding of infrastructure relationships and impacts is made possible by using data and information as a set of interdependent components rather than as independent elements. These interdependent components are often brought together most effectively in a mature spatial data infrastructure.

## Building Resilient and Sustainable Communities

The key to strong communities is for them to have a blend of economic, environmental, and social conditions that can be maintained over time and enable the community and its members to adapt to changing conditions and successfully address both opportunities and downturns in their fortunes. Sustainable and resilient communities are ones which provide a basis for future generations to enjoy a safe and decent quality of life. The development, operation, and management of critical infrastructure within and around a community are a big part of how sustainable that community is over time.

Proposed infrastructure investments, even when developed with environmental sustainability in mind, often come into conflict with competing issues. For example, reduction in road corridor widths to achieve densification may result in issues related to emergency response vehicle accessibility. Reducing environmental impacts of urban sprawl through increased urban density mean that more attention must be paid to other environmental issues, such as noise pollution.

According to Dr. Lewis J. Perelman, however, “green infrastructure investments can offer near-term, tangible returns from efficiencies in energy and resource use that just-in-case investments in hazard risk mitigation often do not.”[4] Incorporating the design features of both can often be identified, and resolved through the use of geospatial solutions. The likelihood of identifying these interdependencies as early as possible in the planning and design process is

[4] Infrastructure Risk and Renewal: The Clash of Blue and Green - Symposium Introduction, Dr. Lewis J. Perelman (2008)

directly related to the ease in which the corresponding information can be brought together. This reduction in ‘information friction’ is addressed through spatial data infrastructures.

## SPATIAL DATA INFRASTRUCTURES

Geospatial information has long been recognized for its ability to provide visual clarity and representation of natural or man-made objects on the ground. Now more than ever before, geospatial information and technology have taken on new meaning and roles in the networked information technology arena. Because more and more people and organizations recognize that “everything is somewhere” and that much of our information has a geospatial component, we are experiencing new opportunities for the use of geospatial information and technology. Geospatial or place-based information provides a common link for almost all other data and offers a way of organizing information to connect and understand relationships among people, things and activities. The “where” component is vital in business, natural resources and the environment, defense and intelligence, and critical infrastructure protection.

Consumer oriented tools such as imagery Web browsers, in-car navigation systems, Internet direction finders, and cell-phone applications are fostering an explosion of applications that are useful to most citizens. The recent geospatial technology revolution has also enabled the use of geospatial information by virtually everyone, not just skilled disciplines such as cartographers, remote sensing specialists, imagery scientists, and GIS specialists.

Geospatial information and technology gives a new ability to operate both locally and globally at the same time and understand the interactions between what you see and what others see. This geospatial dimension is the element that enables users and decision-makers to connect the pieces and better understand how the different critical infrastructure elements relate. “Everything is somewhere” certainly applies to current and future geospatial capabilities.

As with any complex endeavor, the critical infrastructure community is faced with many different and sometimes competing or conflicting forces. One infrastructure sector may have assets, which overlap a competitor or with assets from another infrastructure sector. A business domain in one part of the same infrastructure sector may collect information for a purpose, which is the same but defined differently in another part of the community. All businesses, as well as governmental organizations, have certain information that they wish to protect for business or national security reasons. Thus collaboration and sharing in this web of loosely connected but interdependent components is difficult.

The common element in all of the critical infrastructure elements is the geospatial element. By using the paradigm of place as a common link to connect and understand the relationship of multiple sources, we have the greatest opportunity ever in fusing data and information for current and future applications.

Over the past 20 years the geospatial community has been maturing its ability to organize, discover, share and use information with a geospatial component. Efforts to do this exist in many locations around the world. A majority of these efforts are implementing the concepts of a spatial data infrastructure (SDI).

### SDI Explained

A spatial data infrastructure is generally seen as the technologies, policies, resources, practices, and institutional arrangements that facilitate the availability of, access to, and use of geospatial information and technology.

One of the recent pivotal developments to come out of geospatial coordination efforts in the U.S. is the establishment and implementation of the National Spatial Data Infrastructure (NSDI). In 1993, the National Research Council, Mapping Science Committee (MSC) issued a report titled "Toward a Coordinated Spatial Data Infrastructure for the Nation." The report identified that an *ad hoc* national spatial data infrastructure existed and recommended a series of actions to strengthen the NSDI and make it more robust. Subsequent reports provided more recommendations for the development and implementation of the NSDI. In the eyes of the MSC, the NSDI should be the means to assemble geographic information that describes the arrangement and attributes of features and phenomena on the Earth. It also identified four principles to guide its development. These principles were: data should be widely available; accessing spatial data should be easy; the NSDI should be flexible and not dependent on current technology; and data or organizational structures and the infrastructure should be a foundation to foster new applications, services, and industries.

The NSDI concept was formalized in 1994 with the issuance of Executive Order 12906, which established the U.S. National Spatial Data Infrastructure. The EO defined the NSDI as ‘the technology, policies, standards, and human resources necessary to acquire, process, store, distribute, and improve utilization of geospatial data” and designated the FGDC to coordinate the Federal Government’s activities and to engage the non-federal sectors in implementation of the objectives of the NSDI.

The U.S. was not the only nation exploring the potential for establishing new mechanisms for use of geospatial information and technology and its actions in concert with other countries and the private sector began to accelerate a wave of innovation and interoperability. Across the globe many other nations are implementing standards-based spatial data infrastructures to better enable them to access, integrate, and use spatial data from disparate sources in decision-making. With the framework of standards that have been developed and can be used for data, technology and services integration, common approaches for geospatial enterprise architectures are coming into place with the most mature of them using a common solid framework of consensus standards for interoperability. Spatial data infrastructures being developed and implemented to meet many different missions and to serve the needs of societies around the world are dissimilar in several respects. They are driven by different cultural and economic requirements; they have different sets of legal requirements; and frequently have different access and privacy rules.

However, more importantly than the differences, most of the SDI initiatives have, to one degree or another, a number of common characteristics:

- Involvement of Interested Parties
- Collaboration and Communication with other Organizations
- Education and Research

- Standards
- Sharing of Value and Benefits
- Common Core Components – in order to find, access, share, and use data among local, national, and global levels and across organizational and jurisdictional lines, spatial data infrastructures generally include the following core components:
    - Metadata – standards are now in place for geospatial metadata.
    - Core/Base Data and Other Geospatial Data – includes basic sets of commonly used data as well as other geospatial data resources.
    - Clearinghouse/Data Portal Network – distributed networks that contain collections of metadata and data which can be searched through common, standards based user interfaces.
    - Policies/Legal Frameworks – guidelines and rules by which a particular SDI and its resources are administered. Policies and legal frameworks differ greatly around the world. Critical policies include those for privacy, security, and public access.
    - Partnerships – organizational and other working relationships for communication, coordination and collaboration to include activities to reduce duplication, share skills, leverage technology and data investments, and conduct joint projects.
    - Web Services – standards-based Web applications for exchanging data or performing other functions ranging from simple transactions to complex business processes.

      (From Global Spatial Data Infrastructure – Are the Vision and Concepts Still Relevant? Paper Moeller 2006)

### SDI: A Tool for Better Understanding of Infrastructure Interdependencies

The use of spatial data infrastructures as a tool for an organization has the potential to be extremely powerful. It provides new ways of organizing and understanding information about people, things and places and offers new perspectives on potential decisions that can have profound effects on economic, social, and environmental issues for business, communities, and the nation.

However, perhaps the most important potential of the new, cyber networked IT environment is the opportunity for organizations to develop spatial data infrastructures within their organization that will be able to interact with larger SDIs. There is a well-established economic case for stable, self-correcting data infrastructures within organizations. Sometimes called master data management and sometimes called by other names, data infrastructures are increasingly recognized as critical enterprise assets. With increasing interoperability and the implementation of common geospatial architectures, communities of interest as well as communities of place are now able to engage in efforts to share data and collaboratively address issues of importance to them. As information systems mature, these enterprise spatial information infrastructures are able to evolve to be part of spatial data infrastructures that have regional, industry, national or even global relevance.

Well-integrated geospatial technology and data can add specific value to enterprise information in a number of ways. In addition to the ability to visualize critical infrastructure, some of the ways in which geospatial capabilities can improve how critical infrastructure information is integrated and used are:

- Location along with time are fundamental ways that we order our lives. In an information system, location provides a useful context that makes other data more meaningful.
- Geospatial data and technology add unique spatial characteristics like distance and physical relationships between objects. These characteristics enable a broad range of unique quantification, measurement, and analysis capabilities.
- Reference data are used to group, cluster, or categorize other data found in a database or for relating data in a database to information beyond the boundaries of the enterprise. Example: State or local government abbreviation tables or transportation district boundary files.
- Location provides a useful framework for organizing and enhancing collaboration among individuals and social groups. Location-enhanced collaboration can also extend to self-correcting mechanisms for workflows and processes.
- Querying the spatial characteristics of information often provides the most intuitive and effective approach to finding information and relating it with other information. New search technology is increasingly making search and discovery a viable option for some integration. Discovery also facilitates data access when users can locate appropriate data.

## SUMMARY AND CONCLUSION

The GITA message is simple: geospatial information is now an integral part of broad information networks. Cyber infrastructures including spatial data infrastructures are key components to ensuring that critical infrastructure assets and investments serve to make our communities and nation stronger and more sustainable. To be successful in understanding and integrating the complex interdependencies of critical infrastructure, individuals and their organizations must recognize the influencing factors and requirements that reach beyond their own perspective and must seek to synthesize and balance their needs with those which are the common needs of the enterprise. Geospatial capabilities can be valuable not only across an organization but more importantly with other organizations. Geospatial information about critical infrastructure is an important corporate/organizational asset which becomes an even more important community and national asset when shared and used appropriately to deal with the opportunities and issues of critical infrastructure planning and operations and the associated interdependencies.

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Any opinions, findings, conclusions, and recommendations expressed in this material are those of the authors and do not necessarily reflect those of the Geospatial Information & Technology Association.


## *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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