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## The Need for Baseline Data Characteristics for GIS-based Disaster Management Systems

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### INTRODUCTION

An effective disaster management system requires collection of baseline data that is **comprehensive, accurate, timely, and accessible**. Without these four characteristics, an effective, economical, and task-oriented disaster management system cannot be achieved. One of the major problems faced by New York City during the September 11, 2001 rescue operations was the lack of readily available, integrated data indicative of the city's extensive and multi-layered infrastructure. Since a single repository containing above ground and subsurface information reflective of buildings, utility lines, and transportation networks was not available, data sets owned by various governmental and non-governmental organizations had to be collected prior to initiating any computer-based search and rescue operations (Flax et al. 2003, Huyck and Adams 2003). The enormity, complexity and temporal criticality of this task highlighted the acute and immediate deficits of currently available spatial information for disaster management.

An effective system must integrate data for all facets of disaster planning and management, including photographs, architectural and structural drawings, current Geographic Information System (GIS) maps and text descriptions of major building features (e.g. building location, structural system, condition). All relevant data must be affiliated with a single GIS-based disaster management system. The value of developing a layered, integrated, GIS system for disaster management has long been recognized (Goodchild 1996). Yet, the extensiveness, inter-relatedness, and distributed ownership of America's infrastructure directly taxes the limited resources of most communities to adequately maintain up-to-date and easily accessible knowledge of the most rudimentary aspects of their buildings, bridges, roads, and utilities. Beyond knowledge for maintenance, permitting, and zoning authorization, such information is

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essential for disaster management. To better track these substantial infrastructure needs, there is an ever-increasing reliance on computer tools and databases to better develop, use, and maintain computer systems. Specifically, infrastructure management information systems (IMISs) are being created with ever-greater rapidity, at all levels of the public and private sectors (Uddin and Engi 2002, Uddin et al. 2003).

An IMIS is not simply an extended set of GIS layers, a database, a master city map, or an electronic warehouse of construction details, but instead a powerful new spatial analysis tool for disaster management with strong potential to impact the areas of urban planning, earthquake engineering, homeland security, and risk analysis. The IMIS, being a tool for preventative measures and improved mitigation methods, has the potential to lessen the impact for natural and man-made disasters (Rozdilsky 2001). A highly functional IMIS can query information both tabularly and graphically by assigning extensive attribute data to the graphical representations of the infrastructure elements through a multi-phase oriented database (Fig 1). Thus, a spatial query is possible for various items, such as identification of all buildings built before 1920, within a sub-geographical area, possessing more than five stories, and having cast iron balconies. The resulting subset can then be accessed as a list or in a two- or three-dimensional (3D) view. To achieve such a system, the IMIS must be designed and developed for a baseline, locational referencing system so that data, including text, drawings, maps, and photographs, as well as typical attribute data (e.g. geometry, material properties) can be positioned within its framework.

### **Current Conditions**

GIS-based system can be used effectively to manage natural and man made disasters, and they are currently being used in the United States for a wide variety of governmental, disaster-related functions from predicting highway damage (Werner 2003) to monitoring seismic damage in water delivery systems (Liang 2003). When combined with a 3D, spatially-oriented database, rapid and detailed disaster assessments can be facilitated that were not previously possible, because of limitations of traditional tools. To fully benefit from such a system requires the regular contribution of data from a wide variety of sources.

Unfortunately, current IMISs do not facilitate such data sharing, because they are not connected to each other and are not connectable, as a direct consequence of hardware, software, and data incompatibilities. Increasingly, the data incompatibility obstacle is becoming recognized at both national

and international levels. Current examples of data standardization include the Technology Information, Forecasting and Assessment Council of India, where disaster information is being linked to improve disaster preparedness (Singh et al. 2003) and New Zealand's Lifelines Engineering program (Brunsdon et al. 2003). Unfortunately, the key to optimal data acquisition, storage, and usage is substantially more complicated than simply formatting.

Although computer architecture related to an IMIS is not fundamentally difficult to achieve, how to populate the system is not necessarily evident, because of the need to select data for inclusion in a manner that is sufficiently broad to represent the physical environment without overpopulating the system with unnecessary details. Despite the fact that disasters are multi-factorial in their incarnations and their destructive abilities, it is postulated that there is a common subset of data related to the physical infrastructure that is needed for effective disaster management both temporally (before, during, and after) and irrespective of the specific disaster. Much of the required information for one disaster can be considered as common to all disasters, both because of general requirements of access and evacuation but also because a named disaster such as an earthquake may generate multiple hazards (e.g. collapsed buildings, fires, road blockage, and utility interruption).

### **Basic Needs**

To best achieve deployment and use of a disaster management system, it should be sharable across local, state, and federal jurisdictions, thereby reducing duplication of data collection efforts across organizational units. The development of data collection methods for pre- and post-disaster related activities using a multi-hazard approach is critical to this effort (Uddin and Engi 2002, Uddin et al. 2003). All of this, however, is predicated upon a strong consensus amongst the necessary players as to what data is to be collected, the collection mechanism, and its format. What is presently needed is guidance in the prototyping of a data collection system that is appropriate for urban planning, risk analysis, and disaster management. This paper outlines the requirements to prototype such a data subset and the general characteristics of the data beyond its mere content, specifically in the four areas of **comprehensiveness**, **accuracy**, **timeliness**, and **accessibility**. The applicability of each is shown through its application to a common data set.

## BACKGROUND

The multi-temporal nature of disaster management dictates that the success of any system is dependent upon capabilities in six related phases: *Identification, Prediction, Preparation, Mitigation, Response* and *Recovery* (Fig. 2). These various phases reflect areas of importance before, during, and after a disaster. An ideally designed disaster management system must address each temporally-based phase in a systematic way. Unfortunately, the focus of the main disaster systems [e.g. Hazards U.S. (HAZUS), Consequences Assessment Tool Set (CATS)] is on only a few of the six disaster phases (Pradhan et al. 2005). Consequently, for most communities, available data in its current configuration is of circumscribed use for analysis, response or planning (Huyck and Adams 2003).

To help rectify data applicability across the six phases, this paper focuses on baseline data collection, which can be defined as the scope and nature of the overall informational resources needed to prepare for and respond to a variety of disasters. What is presently required is a clear understanding of the characteristics of current informational resources, their functional capabilities, and their usefulness for disaster management.

## BASELINE CHARACTERISTICS

For an effective IMIS system, the following common data needs were identified as part of a National Science Foundation Workshop, in which over 30 members of North Carolina's emergency management community participated: (1) unique designators for infrastructure elements, (2) access routes, (3) safe congregation areas, (4) building egress points, (5) building structural support systems, and (6) high vulnerability elements. These six common needs are used to illustrate the concepts of **comprehensive**, **accurate**, **timely**, and **accessible**. The emphasis is on buildings, because in many ways they represent the greatest data collection challenge, because their ownership is more distributed than publicly financed projects, and because their construction exhibits an extraordinarily high level of variability in composition, geometry, and usage.

## **Comprehensive Data**

The term **comprehensive**, in relation to data collection, should not be misunderstood to signify everything that can be collected. If a community collected and electronically stored each detail of every constructed facility in all of its minutia, the likelihood that the system could be accessed quickly and efficiently for disaster response would be low – simply as a direct outgrowth of the magnitude of the data being stored. What is needed to adequately depict the multi-phase, multi-event nature of a disaster is a subset of the infrastructure data. Such data relates to road networks, utility systems, building layouts, and the relationships between all of these elements. Collection of such disparate data requires consensus as to both scope and format. Cities and municipalities cannot mandate data collection from facility owners and utilities without adequate knowledge of the *scope* and *format* in which to specify the collected data. The concepts are illustrated below using the above listed, six common data needs.

### *Scope*

Although the topic of urban disasters is broad in subject area, it is limited in its geography. As such, most urban disasters can be seen to have a large common data set. The scope of such data can, thus, be fairly clearly specified. As an example, unique designators for infrastructure elements would consist of street addresses (or cross-streets) and GPS positions. Access routes between points of interest for emergency vehicles require information on the transportation grid of roads, tunnels, and bridges, especially height, width, and weight restrictions due to the potential need to transport heavy rescue and recovery equipment. Information for safe congregation areas must extend beyond knowledge of street layouts and fire hydrant locations. For staging temporary medical treatment areas and creating post-evacuation meeting points, parking lots, wide sidewalks, and other unobstructed areas should be identifiable, as well as information about their proximity to water and electricity. To facilitate search and rescue, immediate identification of all above-ground and subsurface egress points should be known for all multiple-occupancy and public assembly structures. Building floor plans and elevations are needed to identify doors, windows, and stairwells. Subsurface transportation routes and large-diameter, utility line layouts are also required.

The structural aspects of buildings impacted by disasters also need to be known for potential damage assessment, as well as for risk evaluation of adjacent structures. The type and layout of the

structural support system (e.g. unreinforced masonry, steel skeleton, prefabricated concrete) and its key features must be known, along with all high vulnerability elements (e.g. glazing and glass cladding) via plans and section drawings. A full set of structural drawings is ideal to secure this knowledge but may not be reasonable due to data storage requirements. Furthermore, post-disaster building inspectors could preview each building's structural system and cladding details just prior to its post-disaster, field inspection for improved accuracy and safety. As personal digital assistant systems continue to evolve in their applicability to disaster management (Deaton and Frost 2001), the value of such information to on-site rescue and recovery personnel will continue to increase (Huyck and Adams 2003). The scope of the available data in an IMIS system should be reflected in a detailed catalogue viewable by entity, quantity, source, and format.

#### *Formats*

A major impediment to an effective IMIS is finding existing data in a format that can be stored and retrieved in a rapid and understandable manner. Data formatting is especially important as it may restrict or promote cross-format sharing and ultimately usability. For example, the data harvesting and integration efforts in New York after September 11 were severely hampered by the wide variety of data types and formats collected by each of the contributing entities (Huyck and Adams 2003). As a result, only the most rudimentary conversions and connections were made between the data (Flax et al. 2002). To facilitate ease of use for both data entry and retrieval, there should be a predefined set of data categories available for each database field, in addition to open querying.

Presently, data may be in the form of a spatial representation (where a structure or element is physically located, as in the case of access routes and safe congregation areas), an attribute (e.g. sizing, material characteristics, age for high vulnerability elements and unique designators for infrastructure elements), or a graphical depiction (photographs, videos, or drawings of building egress points and building structural support systems). Of particular interest are the spatial and geometric features of the total infrastructure and of specific building geometries, structural systems, and cladding materials. Relevant information should appear in a relational database so that it can be queried. The information should also appear in 3D, GIS manifestations.

In many GIS software packages, both spatial data and attribute information are stored in proprietary file formats (e.g. ESRI shapefile, ESRI coverage, AutoCAD dxf). Proprietary file formats are not based on standards, thus integration is hindered. International geospatial standards for GIS minimize the number of geospatial data formats in the marketplace, with the goal of reducing duplication, optimizing resource expenditure, and facilitating information exchange (Clément and Larouche 2000). Recently developed standards by both governmental and non-governmental organizations promote data sharing and integration. Among the most useful standards (in terms of completeness, flexibility, and life expectancy) are the Simple Features Specification and the Spatial Data Transfer Standard (SDTS 1997). The Open GIS Consortium (OGC) organization, was established by the United States Geological Survey USGS for standardized data exchange (OGC 2003). These standards aid data digitization, modeling, and storage (SDTS 1997).

### **Accurate**

Accuracy is the second key characteristic for baseline data. Broadly speaking, data errors emerge from two sources: (1) new data entry and (2) errors in existing records. The second scenario is complicated by the fact that the data is retrieved from disparate sources (because of incomplete existing records), which may themselves contain inaccuracies. For older cities, where buildings may date as far back as the eighteenth century, much of the data may not be available in any format. Even important landmark buildings may be without known as-built drawings, as was the case with Carnegie Hall until late, twentieth century renovations (Laefer et al. 2002). In reference to egress points, structural support systems, and high vulnerability elements, the lack of as-built drawings poses a substantial impediment. Accurate as-built drawings hold within them the data that empowers the base IMIS and all supplementary pre- and post-disaster analyses. Much of this data is available from existing sources.

### *Existing Data*

Existing data sources may include Sanborn maps (ProQuest UMI 2003), local colleges, design offices, government agencies, architectural organizations, historical societies, older community residents, and Internet sources. Unique designators, and access route information may be available from governmental

records, and maps (both digital and non-digital). Identification of safe congregations areas requires those above-listed elements, as well as building typology data and capacity, not dissimilar to the base information needed for egress points, structural support systems, and high vulnerability elements. The focus is the building's geometry and nature and how it is assembled. Critical data should be verified via multiple, published and web-based sources to minimize new errors and to prevent further propagation of old ones.

#### *New data*

To reflect the evolving nature of a community, new data must be collected continuously. The occurrence of events (both disaster and non-disaster related), from flooding to new road construction must be documented promptly and accurately to exploit the full potential of the IMIS. This new data must be combined and integrated with the existing data within the IMIS. Each update establishes a new baseline condition (Lim et al. 2001).

#### **Timely**

The third criterion is timeliness. With existing and new data constantly being added, a baseline system must provide efficient data storage, because of the need to obtain real-time data as a disaster is occurring. Decision makers, incident commanders, emergency responders, and city managers simultaneously need time-sensitive, spatial information. Since timing is critical for evacuation, search and rescue, and prioritization of utility service restoration, all required data sets must be pre-stored in a centralized repository system. Such pre-emptive activity ensures that mission-critical data can be retrieved and disseminated amongst the necessary personnel and agencies for timely analysis.

A few communities currently require certain classes of buildings to be inspected on a periodic basis for public safety [e.g. New York City's Local Law 11 related to façade inspections (NYC DOB 1998)]. Where available, damage information from such reports should be incorporated into all relevant portions of the IMIS (i.e. CAD, photos, relational database), with an indication as to the date of observation and the severity of the observed damage. Additionally, all images must be date stamped, and data must be entered into the system contemporaneously with any changes that occur. The building permitting process provides a likely venue for this. Currently, construction information is submitted to the local building

authorities as the basis for permitting and inspections. Depending upon building usage, different levels of documentation are required for framing, general layout, foundations, and utilities.

Once a permit is issued, many accuracy-related problems may arise. Plans may change after the permit is issued, either because of differing site conditions or the owner's evolving needs, all while the information on file remains unchanged. The accuracy of as-built drawings is a regular problem in the construction industry, even for non-digitized drawings required by contract at the end of a project.

A fully functioning IMIS requires a high degree of compliance in the submission of accurate, as-built drawings to the permitting agency. This will require a change in culture, as well as procedure. The current manual method still used by most communities is dated and inefficient, resulting in delays and higher costs from unnecessarily slow processing time. As documents wait for approval, so does the construction. Manual data entry offers few benefits and requires enormous resources from both owners and public officials. Consequently, data is often simply not updated, limiting the usefulness of the file records. Keeping the system updated, however, is a major task, which requires constant inputting of new and changed data, as well as regular error checking. Structures and sites are dynamic. Thus, record systems must reflect these changes, whether this is a modification to access routes in the road network or alterations of egress points in a school building, or the unique designators of major infrastructure elements due to bridge widening.

The permitting process has the potential to become highly automated and entirely electronic. The permit issuer could connect to the IMIS, allowing for an immediate updating of proposed changes for local structures (both existing and new), with electronic copies of plans and specifications attached for ease of retrieval. The IMIS could be internet-enabled and accessible on a limited basis via a username and password. This would allow secure access at virtually any internet-enabled location. Automation of the permitting process has the dual benefit of ameliorating the aforementioned accuracy issues and keeping the IMIS updated. As part of the attribute data, drawings and photos can be archived to reflect the evolution of a building or site, potentially providing long-term planning benefits for disaster and non-disaster scenarios. Changes in the building's structural support systems, and high vulnerability elements aspects need to be accurately reflected, especially in the aftermath of a crisis, when a multitude of changes may need to be documented. Instead of being overwritten, the data can be archived in the same manner as the drawings

and photos are, allowing the user to see both a visual and text oriented timeline of the evolution of the building, including any disasters that have damaged the building and any subsequent repairs.

### **Accessible**

Easily accessed data capable of being shared across federal, state, and local jurisdictions is fundamental to the decision-making capability of those charged with community protection, as there are many infrastructure elements that are not wholly controlled by local building authorities. These range from the obvious (e.g. state highways), to high profile targets such as federal buildings. Yet, without the real-time capacity to visualize activity patterns, maps, locations, and major features, disaster management will not be effectively achieved (FGDC, 2002). Rapid access to and application of accurate geospatial data is critical to these activities. Similar to the electronic permitting process, during a crisis a community may find it highly beneficial for the IMIS or portions of it to be accessible via the Internet, such as access routes, safe congregation areas, and high vulnerability elements. Each community must individually assess security concerns related to having such information on an externally-accessible network, as security breaches are a potential downside to easy access. Additionally, issues of large-scale web accessibility do not address a wide variety of computer processing concerns related to concurrent data entry, data conflict resolution, and redundancy (Pradhan 2003).

Finally, an in-depth understanding of images must be established as to an appropriate subset of data so that content can be readily archived in a manner that is meaningfully catalogued and available for retrieval, analysis, and display. A methodology of pictorial collection standardization is a critical component for a fully functioning IMIS. More difficult than culling visual components for textual entry into the relational database is having the capacity to query graphical elements in a highly exact manner. There must be a visual marking and querying system based on both a point and click system and with a textual tagging component. To date such a system is not yet available.

### **CONCLUSION**

By embracing the four key characteristics of **comprehensiveness**, **accuracy**, **timeliness** and **accessibility** for baseline data collection, an IMIS can fully accommodate the wide range of information

necessary to address the multi-phase nature of disaster management and provide capabilities to store, analyze, query, and visualize critical disaster information across many organizations. In addition, such a system can promote the future safety and well-being of the public in urban areas by its applicability to disaster management irrespective of the scope and nature of the disaster. All of the advantages of an integrated, spatially adaptable IMIS are hard to envision in its potential to revolutionize disaster management. With proper selection of input data and timely and rigorous system updating, large amounts of additional analysis for direct intervention and planning can be incorporated with respect to utility protection and redundancy, critical infrastructure assessment, structural evaluation and intervention, and hazard reduction. Such needs mandate the implementation of specific baseline data characteristics for all proposed disaster management IMISs.

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Figure 1.

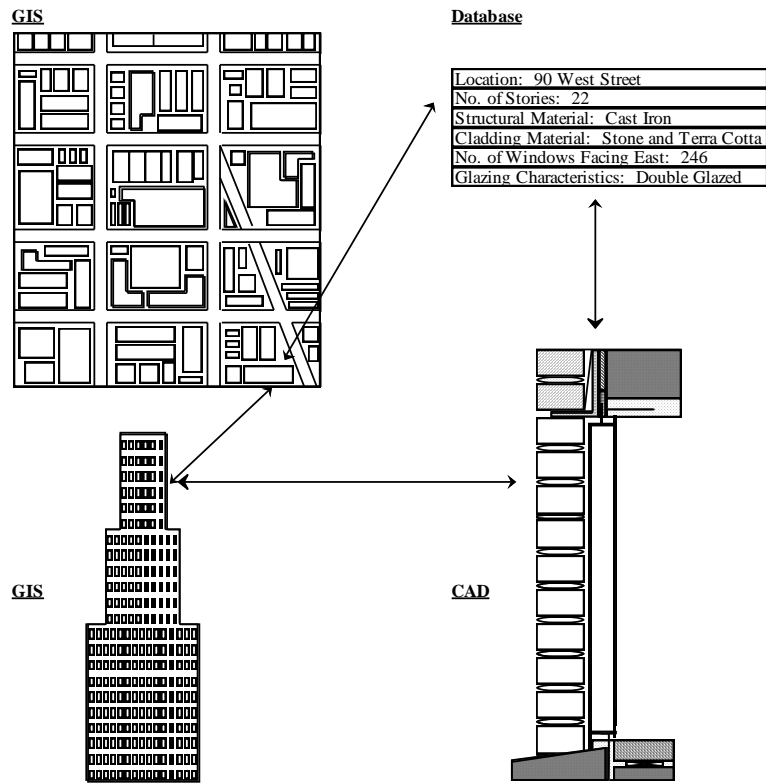
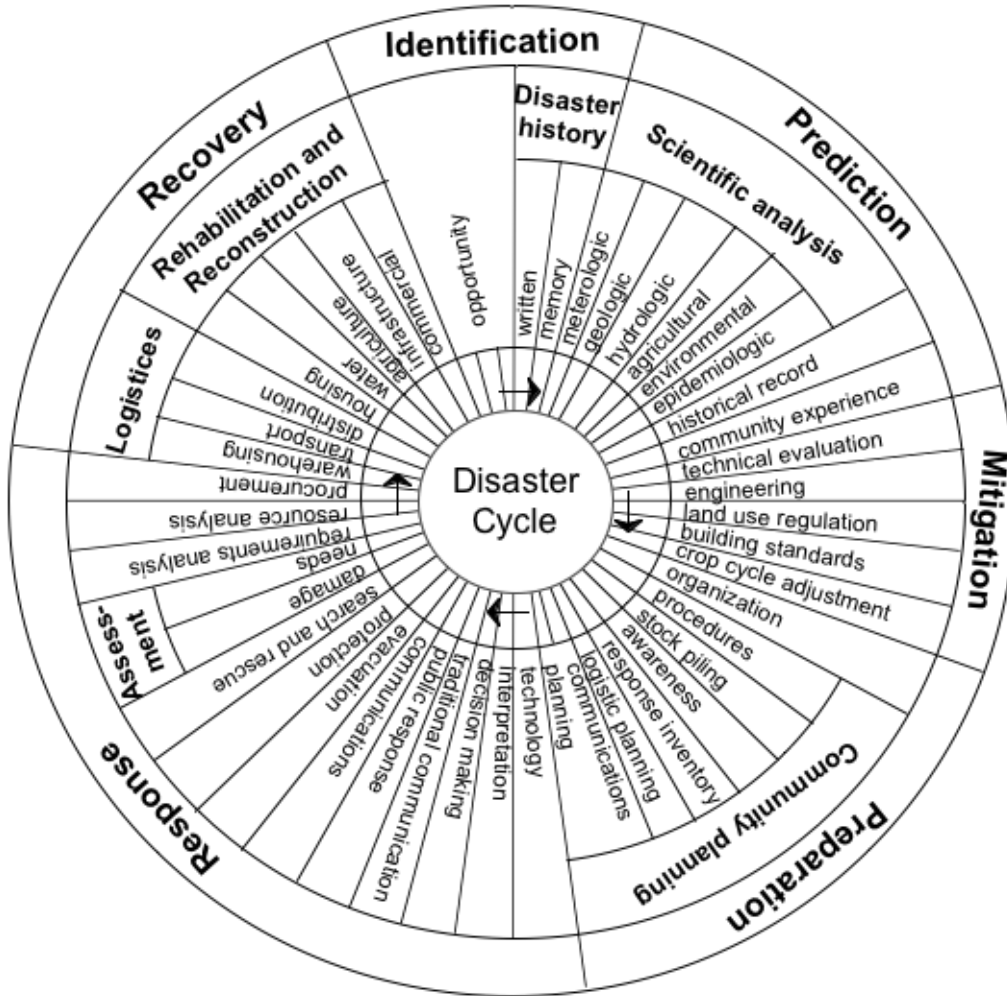


Figure 2.



**FIGURE CAPTIONS:**

Figure 1. GIS-based IMIS with Relational Database and Support of Multiple Data Formats

Figure 2. Multi-phase Disaster Management Needs (adapted from Johnson 2003 and USDFA 2003)

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