The Use of Geographic Data in Emergency Response Decision Making System

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THE USE OF GEOGRAPHIC DATA IN EMERGENCY RESPONSE DECISION MAKING SYSTEM

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SUMMARY

Geographic data have a number of key roles in emergency response systems focused on releases of hazardous material to the environment. Maps are a key element in allowing emergency response personnel to become oriented during a response and in presenting status information effectively to these personnel. Geographic data are essential for modeling to predict dispersal patterns during a release. It is also necessary to integrate model and measurement data with demographic information in order to assess the consequences of a release. Appropriate support for such capabilities is based on a number of evolving technologies including fast computers, large databases, network technology, remote sensing and geographic information systems.

I. INTRODUCTION

Effective decision making in a wide range of problems is facilitated by presentation and analysis of the relevant information in a geographic context. While certain presentation requirements can be met with traditional capabilities such as paper maps, the requirements of most emergencies are too stringent to generally rely on manual techniques. Thus, geographic data, as utilized in computer applications, are an essential component in dealing with many kinds of emergencies. Of particular interest here are those events associated with the release of hazardous material into the environment and the systems needed to support informed decisions in handling the response to them.

There are many applications of geographic data in emergency response decision support systems that, for the purposes of the discussion here, are grouped into three general areas that have distinct characteristics. First, orientation to complex problems that are spatially extensive is greatly facilitated by the use of maps in both paper and digital forms. In the following discussion such capabilities will be termed mapping applications. Second, in many cases an important component of a response is modeling of hazardous material dispersal to predict the spatial extent of the problem. The more sophisticated process models of such phenomena are sensitive to geographic variation in a number of variables and so detailed modeling requires geographic data to represent this variation. These capabilities are termed modeling applications. Lastly, assessment of the consequences of an emergency must incorporate information about the distributions of people and other characteristics that can have a direct effect on people. That is, such data are used to analyze the effects of an event, consequently such procedures are termed analysis applications.

An emergency response environment places severe constraints on the use of geographic information. These constraints are associated with the needs for speed and reliability during a response. In addition, for systems that respond to a range of possible release scenarios at arbitrary locations, referred to here as full-function emergency response systems, the need for general readiness implies a large requirement for geographic data. The challenge of meeting these requirements is being facilitated by the rapid evolution of a number of technologies. These areas include both general capabilities, such as the increase in disk capacity, as well as more specific technologies, such as geographic information systems (GIS). The remainder of this paper will elaborate on these basic ideas, with section II focusing on the different categories of geographic data applications. Section III covers the challenges that must be met for geographic data use in emergency response applications and Section IV discusses the potential of new technologies to help meet these challenges. Section V offers a brief conclusion.

II. GEOGRAPHIC DATA APPLICATIONS

A. Mapping Applications

Essentially all emergency response applications can benefit from the display of relevant information in a geographic context. For example, presenting the location of fires, traffic accidents and other similar emergencies on a map, in combination with the location of relevant response assets, is of clear value. In the context of the response to releases of hazardous material to the environment, mapping is also very important. The underpinning of any mapping application is the ability to create an appropriate base map. A base map is a map or image that serves as a representation of a region in order to provide users with a general geographic orientation to the region as a background for other specific information or for general reference.
There are two general approaches to the representation of base maps. One is to use vector representations of individual geographic features, i.e., linear features such as roads are represented geographically by a series of locations that describe the path of the feature. The boundaries of area features, such as lakes, are represented in similar fashion and point features such as meteorological observation stations are represented by a single location. That is, discrete objects are represented. Also note, that the distinction between point and area features, as well as line and area features, is a matter of scale. For example, on maps of a reasonably large city, an individual building is likely to be a point feature, while on maps covering a typical nuclear power plant, buildings will be considered area features. In contrast to vector maps, raster representations are composed of grids of pixels that represent an image. In applications to base mapping, these images can be images of paper maps, typically map series such as the U.S. Geological Survey 1:24,000 topographic maps, or they can be images of the area developed from aerial photographs or satellite imagery. Note that, in the case of photographs or images, the original information must be transformed to a map coordinate system.

Both vector and raster base maps have strengths and weaknesses. Vector information can be filtered on a feature-by-feature basis or on the basis of feature category to produce a parsimonious representation of the base map that can have the virtue of controlling clutter, thus avoiding distractions from the primary information contained in the map. When such maps are being transferred electronically, this compactness can be important. In addition, simple line maps can be transferred via facsimile machines, as well as being displayed on inexpensive printers with reasonable quality. The focus of vector maps on geographic features facilitates query capabilities associated with attributes of each feature, e.g., its name. An additional advantage of vector maps is that they can be transformed to different projections without loss of information. Map scale can also be changed by just replotting the data, using a different window, although significant scale change involves the difficult problem of automated map generalization.

Raster maps often provide a more detailed representation of the region. Image maps provide a realistic presentation of the region and, given appropriate interpretation, can be used to extract a wide range of information about the area. Raster maps based on images of paper maps are useful in providing a familiar background at a standard scale, which can be helpful in orienting people to a problem. Changing projections of a raster map involves some loss of information, which could limit the usefulness of these maps for certain applications. Both vector and raster base maps have important applications and a full-function emergency response system should support both capabilities.

Given the availability of appropriate base maps for an area, numerous additional applications beyond the simple display of these maps are also of interest. Displaying the location of the source of a release of hazardous material is an important first step in acquiring an orientation to the problem and getting a sense of what the potential consequences might be. Displaying the location of available resources that are relevant to a response, such as schools, hospitals and airports, is clearly useful. Mapping the location of emergency response teams is important in coordinating a response and mapping the location and values of measurements is essential to the interpretation of the data.

- Note that the absolute accuracy requirements for maps that focus on this type of point positioning information is extremely high. For example, if a release location is mispositioned with respect to the base map information by a few tens of meters, the release may not have the correct relationship with the nearby features, i.e., it may be represented on the wrong side of a road or river. Even if the other information being presented, e.g., modeling or analysis results, is not particularly sensitive to such relatively small positioning errors, an error of this type is liable to leave people with local geographic knowledge with an impression of shoddiness in the results.

As described here, mapping applications are restricted to the presentation of base maps and other information that is not based on modeling or analysis. Thus, the focus is mainly on the display of information in an effective manner. These same considerations apply to modeling and analysis applications, partly because the results of modeling and analysis are generally presented in map form over the same base maps. However, consideration must be given to the additional complexities these applications introduce.

B. Modeling Applications

An important component of an emergency response decision support system for environmental releases of hazardous material is an ability to predict the dispersal of the material over time. While many of the issues regarding the use of geographic data apply to modeling of contaminant dispersal by surface and subsurface hydrology, the comments here will focus on atmospheric modeling as it is applied to such applications. Dispersion models cover a range of sophistication from simple Gaussian models, that can be run on programmable calculators, to numerical mesoscale weather prediction models (the mesoscale is associated with domains ranging from ~2 to 2000 km), that calculate dispersion directly or are coupled with a particle model that produces the dispersion predictions based on the meteorological fields provided by the mesoscale model.

The requirement for geographic data in such models parallels the complexity of the model, i.e., the simplest Gaussian models ignore geographic effects: models of intermediate complexity incorporate the effects of terrain on the winds along with spatial variation in certain surface turbulence parameters, such as roughness height. The most sophisticated mesoscale models include full surface energy modeling, which requires a detailed representation of a number of land surface characteristics.
Sophisticated modeling applications require geographic data that have somewhat different characteristics from the data used primarily for mapping applications. Instead of focusing on geographic objects, as in mapping applications, models generally require representations of fields, i.e., quantities or characteristics that vary continuously over the earth's surface, such as elevation. Since mesoscale atmospheric models are gridded, the geographic data used by such models are also represented as a grid, thus the focus of these applications is on raster data. A processing step is generally required to transform the geographic data grid to the map projection and grid of the atmospheric model; such a step can be termed data assimilation.

In contrast with raster data used in mapping applications, which is generally an image that convolves information from a number of variables, data used in modeling represent a particular aspect of the land surface. A land surface model, used to model the energy exchange at the surface that can drive important near-surface atmospheric behavior, will require a number variables that vary geographically. In general, these variables are not those found in geographic databases. As a result, an additional transformation process is needed to derive the model variables from the available geographic data, as part of data assimilation. In general, modeling applications are not as sensitive to precise positioning as mapping applications, due to the various inaccuracies associated with measuring and interpreting most kinds of environmental information. Also note that for a modeling application to be useful in emergency response situations, the results must be presented in map form over an appropriate base map. That is, model applications must be integrated with mapping applications.

C. Analysis Applications

In contrast to model applications that focus on physical processes that affect the nature and evolution of an emergency, analysis applications focus on the effects the emergency may have on people and society. The information needed for such applications will obviously include population data and, depending on the specific problem, will require a range of other information, such as agricultural censuses or detailed information on road networks. For example, estimating the chronic health effects of an atmospheric release of hazardous material would also require population density and journey-to-work data, as well as agricultural censuses and sheltering characteristics of housing and buildings. Such information would be combined with predicted or measured values of material concentration to estimate health effects. The results of such an analysis would generally be presented as a map. Thus, a complete analysis is likely to be a synthesis of analysis, modeling and mapping applications.

This focus on integration and the subsequent analysis of geographic data sets is the core capability of geographic information systems. Thus, analysis applications are most effectively implemented using GIS. Mapping applications can also be developed using GIS, although this can impose certain limitations on very rapid response that can make other implementation options attractive. Simple modeling applications can also be integrated within a GIS. However, the more sophisticated models generally require complex, special purpose support systems that do not lend themselves to being sub-components of a GIS. Thus, while GIS is an essential component of any full-function emergency response system, there is a variety of options for integration of mapping and modeling capabilities with GIS.

III. EMERGENCY RESPONSE REQUIREMENTS

Developing complex modeling and analysis systems that rely on geographic data is challenging in any case. Any inherent difficulties are greatly magnified by the constraints imposed by emergency response applications. Obvious characteristics are the need for speed and robustness in emergency response systems. The need for speed differentiates these applications from many common applications of GIS, where several months might be spent gathering data for an analysis and days or weeks spent on developing a final map product. In emergency response, basic maps are needed within seconds or minutes and finished products within hours. In addition, emergency response requires reliable systems that also can function with the limited information that is typically available early in an emergency response.

A full-function emergency response system must also be able to handle events that affect a full range of spatial scales and that can occur at any location. As a result, geographic data for all three types of applications should be available globally at a range of scales that support local responses as well as global responses. While data availability is improving rapidly, the full range of requirements indicated cannot be met with existing data sets. This has two implications. One is that the system must be able to function adequately with a reduced level of geographic data support for an area. The second is that geographic data handling systems for emergency response must be able to easily incorporate new geographic data, both site-specific information, which might become available during a response, as well as new databases that are becoming available at an increasingly rapid rate.

In the same vein, emergency response systems must be able to generate maps at several levels of quality. While high quality, large format maps are important for the presentation of information to high level personnel and the media, small format, vector maps are often very useful since they are quickly, easily and cheaply reproduced. Generally, the nature of emergency response magnifies the requirements for a complete system.

IV. NEW TECHNOLOGIES

While the previous discussion highlights the difficulties of developing comprehensive decision support systems for
emergency response, there are developments in a number of technologies that bear directly on such systems and provide a basis for rapidly improving them. In general, the rapid increases in the speed of computers, the capacity of storage devices and the bandwidth of networks, combined with decreasing costs per unit of capability, are allowing many traditional functions to be done much faster, while permitting new capabilities to be utilized in emergency response systems. For example, it is becoming possible to execute mesoscale prognostic models on workstations quickly enough that the results can be applied in some emergency response situations.

Beyond these basic changes in technology, a number of specialized technologies are contributing to improvements in emergency response systems. For example, the Global Positioning System (GPS) is greatly increasing the ease of accurate point positioning and of acquiring needed map information in emergencies. Network technologies such as the World Wide Web are increasingly improving the availability of geographic data. Much of the development in this area is ad hoc; however, the U.S. government, as well as state and local governments, are focusing on the development of a National Spatial Data Infrastructure (http://www.fgdc.gov/nsdi2.html), with the goal of using Web technology to support more effective use of data resources in government. Ideally, an outcome of this effort would be the ability to gain access to a local government’s maps for use by emergency response groups. Thus, access to the most detailed geographic information would exist for emergency response organizations, without the need for each such organization to develop its own detailed databases. This distributed approach to high-resolution geographic data access has the potential to greatly increase the quality of emergency response systems at modest cost.

Remote sensing is another important growth area that has seen application in emergency response. The number of satellite-based data sets is increasing rapidly. At present, the size of these data holdings and issues of cost recovery have limited the application of this information. Given the rapid growth of technology in this and related areas, there may be changes in how this data is distributed that will overcome some of the past limitations to general use. Certainly the applicability of up-to-date satellite imagery to emergency response situations is undeniable.

The last technology mentioned here is GIS, which can be considered the core technology in this area. Growth in GIS has focused much of the development in geographic data handling and created a substantial market for geographic data products. Emergency response systems clearly benefit from the new data sets and software that are becoming available as a result of this market. As suggested above, GIS has a key role in any full-function emergency response system. The evolution of GIS is integral to the improvement of such systems and is tied to the advances being made in the various technologies mentioned above. As the capabilities of GIS continue to increase, their ability to contribute to emergency response applications will also increase.

V. CONCLUSIONS

Geographic data play an essential role in many aspects of decision support systems for emergency response. Effective use of geographic data, particularly in emergency response applications, is contingent on increasingly high levels of technology. The rapid growth in the related areas of technology provides the promise of increasing capabilities for effective response to emergency situations, while also challenging system developers to create systems that harness this potential and that can adapt in a cost effective way to future technological advances.

REFERENCES


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