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Application of GIS technology in chemical emergency response

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Abstract: Responding to concerns raised by the Bhopal accident, more and more attention has been paid to local emergency, especially chemical emergency, prevention and planning worldwide, and many chemical emergency response systems for public response personnel have been built. With the successful application of geographical information system (GIS) technology in many fields, GIS can be an efficient tool for effective response to chemical emergencies. The purpose of this paper is to introduce the application of GIS technology in emergency response. Typical GIS technology is simply introduced and some of its existing applications to emergency, mainly natural disaster, response are summarized. Spatial data and spatial analysis requirements for chemical monitoring and emergency response are also discussed in detail. Finally a chemical monitoring and emergency response system under development by combining GIS and expert system for both chemical distribution centers and public response personnel is presented.

Key words: GIS; chemical emergency; emergency response; chemical management; expert system

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Introduction

Countless incidents involving hazardous chemicals have happened all over the world, and they are occurring or will occur everywhere. The most serious occurred in India in 1984. 50000 Pounds of methyl isocynate was released into the atmosphere in vapor and liquid form, because a safety valve at Union Carbon Plant in Bhopal, India, was opened. As a result, the plume of methyl isocyanate gas extended several miles to the southeast of the plant, killing at least 2000 people and injuring as many as 200000. Responding to concerns raised by the Bhopal accident and in order to prevent this kind of disasters from happening again, UNEP initiated a worldwide program, Awareness and Preparedness for Emergencies at Local Level (APELL), in 1988 (Jover, 1991). It is carried out not only in developed countries but also in some developing countries, such as China, Philippines and Thailand. Many information systems useful to emergency planners and responders have been developed (Vissr, 1991), such as CAMEO developed by National Safety Council, USA, CHEMSAFE of Germany, BATEX of France and AUSTOX of Australia (Ross, 1995). Some of them, especially CAMEO provide desired types of information about hazardous substances, air dispersion modeling, mapping, and emergency planning information and computational capabilities. In China, there is only a chemical emergency risk evaluation and prediction system developed by the military and is applied in some cities (Hu, 1995).

Some of the existing chemical emergency response systems have a mapping component. A plume calculated by an air dispersion model can be displayed on a local base map (Jover, 1991). This graphical illustration of an emergency is very helpful for rapid and effective response. But responders need to know much more geographical information right away, like the definite location of chemical facilities, nearby transportation routes, waterways, blocks, special public facilities with special population, and the spatial relationships among these geographical objects. If a system

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could provide graphical illustration of the affected area by an emergency, at different risk levels, automatically identify which and how much population must by evacuated urgently, which facilities and transportation routes must be closed or specially protected, through which way to reach emergency site is most convenient, it would be more helpful for responders to effectively and rapidly deal with emergencies. However, it is difficult to realize these functions in a pure expert system. Fortunately, they are easy to be realized by using a mature commercial Geographical Information System.

Almost all the existing systems are concerned with chemical accident prevention, emergency planning and response for a city or region at local level. They are appropriate for public emergency response personnel, such as police and firefighters, but not suitable to a specific chemical warehouse or plant. For such a given hazardous chemical distribution center as chemical warehouse or plant, it is still a problem to safely manage and operate its chemicals, automatically monitor chemicals and storehouse's status on real-time for emergency prediction and warning, and effectively respond to a potential emergency. It is therefore needed to develop a real-time chemical monitoring and emergency response system for chemical distribution centers.

Like local emergency response system, except chemical characteristic information, chemical emergency response knowledge and meteorological data, almost all the other necessary information in chemical monitoring and emergency response system is, to a gray extent, a kind of geographical information. And almost all response measures are related to specific chemical site and its circumstances. Therefore, it is very prospective to apply GIS to chemical monitoring and emergency response system for chemical distribution centers. In fact, GIS has been successfully applied to develop some natural disaster monitoring, evaluation and response systems (He, 1997; Liu, 1997; Tian, 1997, Tarr, 1993; Yin, 1996).

The purpose of this paper is to introduce the application of GIS technology to development of a chemical monitoring and emergency response system for both public response personnel and chemical distribution centers.

1 Typical GIS technology

GIS is a new computer technological system for managing, manipulating, synthesizing and analyzing geographical information. In a conceptual way, GIS is considered as a tool to deal with spatial data (Zhang, 1995; Yu, 1994; Jeffery, 1990; Liu, 1997). Since R. F. Tomlinson established the first GIS, Canadian Geographical Information System, in 1963, many GIS softwares have been produced. More than 20 of them can provide perfect functions (Yu, 1994). Arc/Info and GENASYS are two popular softwares in the world and available in China.

In general, GIS is developed from two mature software technologies: data base management system (DBMS) and computer aided design (CAD)(Yu, 1994). But it is different from them. A common DBMS is often used for storing, managing and querying data, while there are two kinds of data in GIS, spatial data and attribute data. Spatial data include a geographical object's spatial location, circumstances, administrative region and so on. Attribute data of a geographical object include its name, characteristics, and other information on its features. GIS, as a spatial information system, not only deals with spatial data but also connects spatial data with attribute data. Spatial data sets can be linked with the spatial references. This linkage provides a powerful tool for study and integration of data sets from many different sources. And GIS not only can display spatial data in graphical form like CAD, but also has a unique strong ability to analyze graphics. That GIS can establish spatial topological relationships among geographical objects, like roads, rivers, administrative regions, pipeline networks, etc., makes such spatial modeling possible, as map topological overlay analysis, buffer analysis and network analysis.

In most GIS softwares, taking Arc/Info and GENASYS as typical examples, graphics are stored in special file form and dealt with by a specific module, and attribute data is managed by using a mature commercial DBMS (Huang, 1995).

2 Application of GIS to emergency response

GIS has been applied in many fields, including military management, resource and environmental monitoring and protection, land use, city planning, global change, disaster evaluation and response, and so on. In recent years, as more and more attention is paid to prediction, reduction and prevention of natural disasters and industrial accidents, GIS is paying a more and more important role in this field. Some information systems have been developed in China by using remote sensing and GIS techniques for monitoring and evaluation of serious natural disasters, including flood, drought, forest fire, snow disaster, earthquake, desertification and pine moth disaster. They have been successfully used for disaster monitoring and evaluation when extreme floods happened in the Boyang Lake area, Dongting Lake area and Liaohe River basin, with 3 provinces about 140000 km^2 involved, in summer of 1995, when a forest fire happened in Heilongjiang Province in 1995, and when a snow disaster in Naqu area, Tibet in 1995, and so on (He, 1997; Liu 1997; Ye, 1997). An integrated information system for urban disaster prevention is also being developed through combination of GIS, CAD and expert system in China (Tian, 1997). In United States, the Geodynamics Company also combined GIS with real-time remote sensing data to help California State put out a serious fire happened at Layuna Beach and make effective remediation plan. A data base is designed for urban seismic hazards studies (Tarr, 1993). Most emergency response systems are for oil spill on ocean. One of them was established in China, and is used as computer-aided emergency response decision-making system for oil spill control centers on ocean ships (Yin, 1996).

3 GIS: requirement for chemical monitoring and emergency response

Computerized expert systems can provide police and fire officials with tools for taking safe and effective actions (Huson, 1986). The ability of computerized expert systems to respond effectively to emergencies requires the utilization of many types of spatial data and analysis (Walker, 1985). It is the same for chemical monitoring and emergency response system for a given chemical distribution center.

For chemical monitoring for a given chemical distribution center, the spatial locations of chemicals and sensors, which are installed to automatically monitor the chemicals' status, and the relationships between them must be defined in the software system. Otherwise, when the monitoring unit gives out an alarm signal, the chemical managers or responders can not rapidly and exactly identify where the accident is happening and what chemicals are involved, so it is difficult for first responders to take effective response measures rapidly.

For emergency modeling and display, it is also necessary to know what chemicals are involved and where the accident is happening. Because different chemicals with different characteristics may cause different emergencies, in general, a suitable emergency model should be chosen according to the characteristics of the involved chemicals. For example, if a kind of combustible or explosive gas leaks out and encounters fire or spark, it will result in fire or explosion, in this case, relevant fireball model or explosion model not common dispersion model should be called to simulate the situation. In order to visually demonstrate the impacts of an emergency on the surrounding environment, the calculation results of the simulation model are displayed graphically on the local base map. In this process, a typical function of GIS called overlay analysis is needed. Through overlay analysis, a fire, explosion and dispersion fume of toxic gases could be easily related to the base map according to the spatial coordinate. Of course, much essential geographical information must be included in the base map, such as chemical facilities, nearby roads, streets, railways, waterways, and special populations. Through graphical demonstration, it is easy for managers or responders to rapidly identify the risk area at a glance, and also very helpful for making effective response decisions.

Computer aided expert system also needs a large amount of geographic information and spatial analysis. For instance, when a fire happens in a chemical warehouse, responders need to know not only which chemicals are involved, how much the firing area is and what are suitable fire-fighting measures, but also where fire hydrants are most closely located, which way is most convenient for fire fighters and equipment to reach the fire site, and which way is the quickest to get to special facilities and help special population evacuate. This kind of function can be accomplished by means of a typical spatial analysis of GIS network analysis. If the fire causes an accident of toxic gas dispersion in the atmosphere, it will be a harm to a very large area. In the process of making response decision, the surrounding circumstances of the accident site must be considered, e.g., how much the affected area at different risk levels is; which transportation routes, blocks, especially special facilities with special population must be closed and protected in the incident area, how many people must be evacuated rapidly, and how much population is involved. This information can help management effectively distribute fighting workers and equipment. Buffer analysis with GIS can rapidly and exactly provide the information based on the calculation results of a certain dispersion model and attribute data and spatial data of the surrounding circumstances of the accident site.

In a word, it requires close combination of expert system and GIS to build a chemical monitoring and emergency response system.

4 System under development

There are more than 1000 middle and large sized chemical warehouses and a lot of chemical plants in China, where chemical emergencies occur now and then. But up to now, no chemical monitoring and emergency response system has been built and installed in any one of them. Because of the obvious need, a chemical monitoring and emergency response system is under development by combining GIS and expert system. The system framework is shown in Fig. 1. It consists of three main parts which are independent but closely connected: GIS, expert system and real-time monitoring system. It also contains a user interface that helps the user make routine management of chemicals stored in a specific center, queries for site-specific and accident information and delivers the best possible response. There is also an optional module, natural language processor, which provides an approach for user to communicate with the system using natural language. In the GIS part, site-specific geographical information and other information required for spatial analysis including meteorological data are stored and managed, and spatial analysis functions are provided.

The expert system is composed of a chemical database of some 3000 chemicals describing chemical characteristics, operation cautions and emergency response measures; a warning and prediction knowledge base; a risk evaluation knowledge base; emergency response decision-making knowledge base; about 12 emergency simulation models on passive dispersion of toxic release, heavier-than-air gas dispersion, continuous and instantaneous liquid release, vertical jet emission, fire, explosion etc.; and an inference engine. The real-time monitoring system consists of some groups of sensors including temperature, pressure, smog and photoelectric sensors and particular chemical sensors like alcohol and benzene sensors.

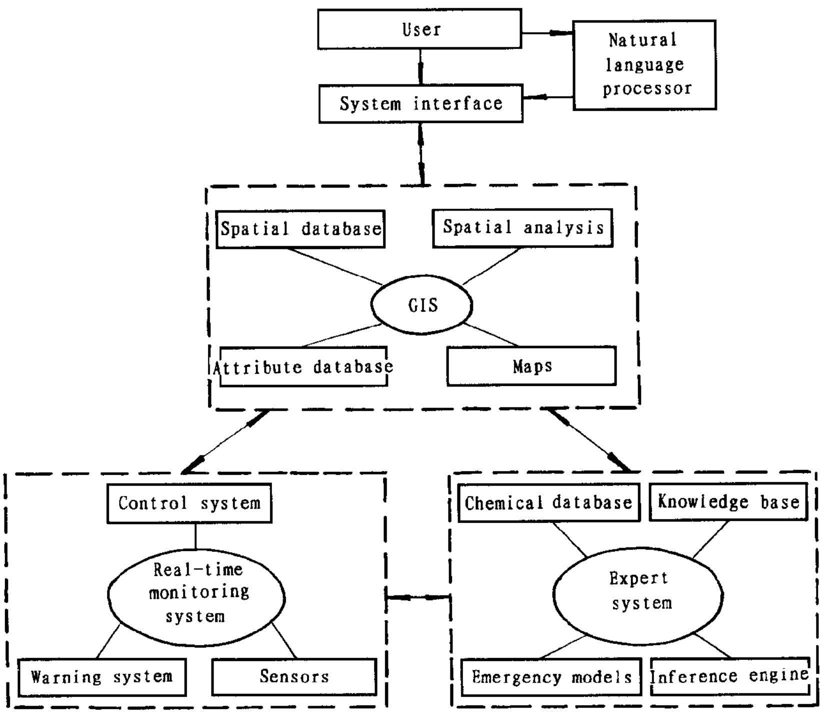

Fig. 1 Chemical monitoring and emergency response system

The system has two major functions: computer-aided daily management for chemical center managers and emergency response decision-support for managers and responders. For routine management, managers can check, query and date the storage information about chemicals on any controlled site, such as storage location, amount, characteristics, iteration cautions and emergency response measures, and information about the status of the monitored locations such as temperature, pressure, smog and chemical concentration. When an observed value contained in the monitored indices is beyond its warning threshold, the monitoring system will automatically give out warning signals. At the same time, the system is ready for emergency response. It will present the information on the incident, what chemicals are involved; whether the trouble can be prevented by managers through simple common measures; if not, it should immediately inform public response organizations and deliver most appropriate response decisions about the critical affected area or route, the best extinguishing materials, protection equipment for responders, population evacuation, and so on. In addition, the system has the ability to automatically create and send emergency report to relevant organizations in which enclosed are the accident causes, status and approximate loss of the emergency, response measures taken and possible restoration measures.

The objective of the work is to design a hardware system for chemical monitoring and warning and a software system that can be operated on a commonly available 586 personal computer. Now, individual modules of the system are almost completed and integration is ongoing. A prototype of the integrated system for testing is expected by early, 1999. It is hoped that such a system will be available commercially shortly thereafter.

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