The Design and Implementation of a System for Epidemic Response in Urban Areas

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Abstract

The design of an emergency response system tailored to epidemics in urban areas include five main aspects: the assessment of requirements, data modeling, general system architecture, software architecture, and physical configurations. Geographic information system plays the central role in such a system because it is the best approach to realize the system objectives on epidemic emergency responses. The key functions of data collection, management, visualization, analysis, and information dissemination can be effectively implemented using a combination of GIS and state-of-the-art Web technology.

Introduction

In 2003, the SARS epidemic shocked China and the world. It exposed the severe problems in coordinating information from different agencies in the administrative hierarchy and across the geographic regions. The need for operational systems that can integrate information and assist decision support for health emergency situations became imminent. The Central government as well as some city governments funded several projects to develop computer systems for epidemic response. This paper is originated from one of these projects. We will focus our discussion on the design and implementation of the data model and the system architecture. Subsequent reports have four parts. Part one discusses the system requirements and objectives, followed by the data modeling in part two. Part three describes the system architectures from the general, software and hardware perspectives. Part four presents selected applications of the system in Hefei city.

System Requirement and Objectives

As the first step in developing the system, we identified the core requirements and objectives the system seeks to meet, which include four aspects: (1) Data collection and transmission; (2) Information integration and management; (3) Data visualization and analysis; (4) Information dissemination and operation management. These requirements and objects provide the basis for data modeling and system design.

The system should first be able to collect dynamic data through the urban public information network and the government management network. Typical categories of data to be collected include general epidemic situation, epidemic control and prevention, local epidemic situation, epidemic situations in other cities, and instructions from upper level management. Data from different sources should then be integrated for further analysis. Non-spatial data should be geo-coded so that they can be used together with spatial data. Metadata should be provided to facilitate efficient data integration. A combination of visualization and statistical analysis will be used to identify spatial and temporal patterns of the epidemic. Visualization tools required include thematic maps and statistical graphics such as box plot, stem-and-leaf plot, QQ plot, and conditional plots. In addition to traditional methods of point pattern analysis, such as quadrat analysis and nearest neighbor analysis, key users expressed strong desire to use newer methods based on spatial autocorrelation analysis and Poisson-based methods such as those developed by Besag, Newell, and Kulldorff. Results from these analyses will then transmitted to the decision makers through the dissemination system, who develop the operational instructions and send them out to the field officers.

Data Modeling

Object-oriented approach is adopted for data modeling. Use-case analysis is conducted to develop the application scenario which is subsequently used to identify the data objects and their relationships. As Geographic Information System has been recognized as the main framework for establishing the overall system, data modeling is also spatially oriented. Based on the use-case analysis, we identify the geographic features and associated attributes as well as the non-spatial data objects. The latter involves operational and management data which resulted in more than two hundred tables. Linkages for the two types of data objects are established through geocoding and key items (primary and friend keys). Operational rules and attribute domains are also specified using the UML modeling tool. After several rounds of user feedback, the data object diagram is translated into the data schema, serving as a consistent framework for data input and management.

Layer Names	Contents	Usage	Types	Main Attributes
Topography	1:10000 topography map	Background	Raster	None
Transportation	Urban transportation network	Background	Lines	FtrID,Name
Rivers	River system	Background	Lines	FtrID,Name
Lakes	Lakes and other areal water bodies	Background	Polygons	FtrID,Name
Administrative Regions	City, District (County), Sub-district (JieDao, Zhen), Quarantined Areas. Each as a separate layer	Analysis	Polygons	FtrID,Name,GISID,Code
Hospitals	All types of hospitals	Analysis	Points	FtrID,Name,GISID,Code
Inspection Teams	Locations of inspection teams	Analysis	Points	FtrID,Name,GISID,Code
Check Points	Health check points at bus stations, ports, airports, and train stations	Analysis	Points	FtrID,Name,GISID,Code
Schools	Locations of elementary and high schools	Analysis	Points	FtrID,Name,GISID,Code
Designated Locations	Locations required special attentions	Analysis	Points	FtrID,Name,GISID,Code
Public Activity Spaces	Such as parks and public squares	Analysis	Points	FtrID,Name,GISID,Code

Quarantined Locations	Separation zones	Analysis	Points	FtrID,Name,GISID,Code

Table 1. A brief description of the basic spatial data.

Table 1 is a brief description of the basic spatial data sets in the system. Except for the topography layer, all of the layers are vector data sets with four required attributes: Feature ID (FtrID), Name, GISID, and Code. The GISID is a unique ID for each feature and the Code stores the coding assigned to it.

A large number of the data sets are management and operation oriented. They are not collected with explicit spatial information. Examples include epidemic conditions, hospital resources, treatment data, health survey, resident / non-resident movement (in and out of the city) data, and records of operational commands. There are more two hundred tables. They are connected to the spatial data sets through geo-coding.

Figure 1 is a data model for hospital emergency resources. It illustrates how the management and operational data sets are constructed.

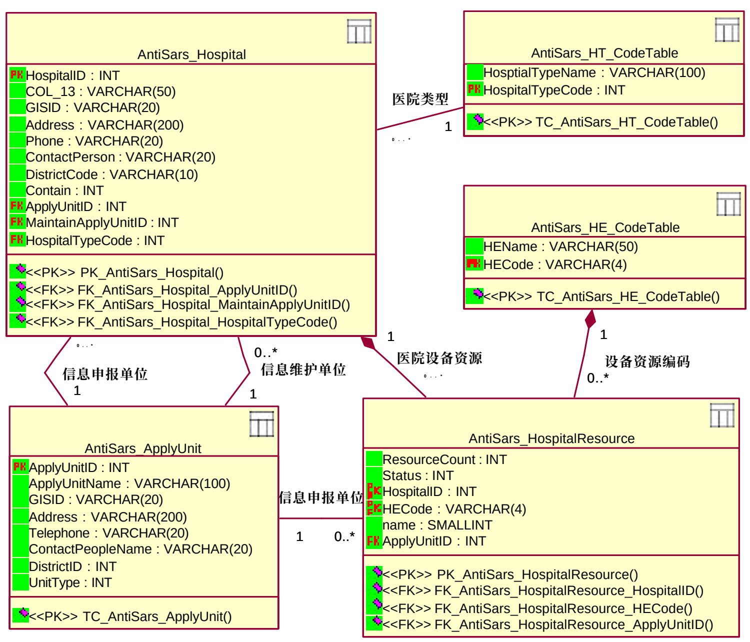

Figure 1. The data model for hospital emergency resources.

System Architecture

The health emergency response system includes five layers, corresponding with different groups of users. From the bottom to the top, they are the network communication layer, data collection layer, data management layer, decision support layer, and information dissemination layer. At the layers of network communication and data collection, information specialists and automatic surveillance devices collect data and transmit them to the data management layer. There database specialists perform data integration and such processing tasks as editing and geocoding. This is also where database administrators manage user accounts and usage rights. Once data are clean and ready, they are made available to decision support layer where high level analysts would conduct geoprocessing, statistical analysis, simulation, and process modeling. Thematic maps and statistical charts as well as reports will be generated and distributed to the proper user groups. Figure 2 illustrates the general architecture of this five layer system.

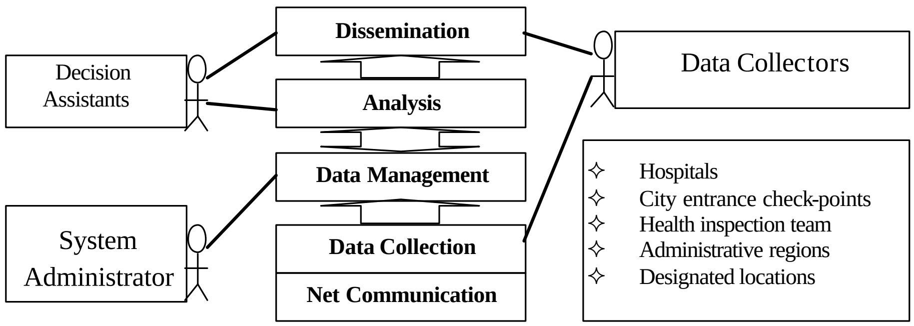

Figure 2. The general architectures of the emergency response system.

This complex system is inherently a distributed system. It is organized as three network subsystems, as depicted in figure 3: the digital government network, the decision support service network, and the digital city network. The government network connects various agencies that provide both data and services. The decision support service network mainly connects the elements for performing data integration and analysis. The city network is the main channel for collecting certain monitoring data and for dissemination of information to the general public.

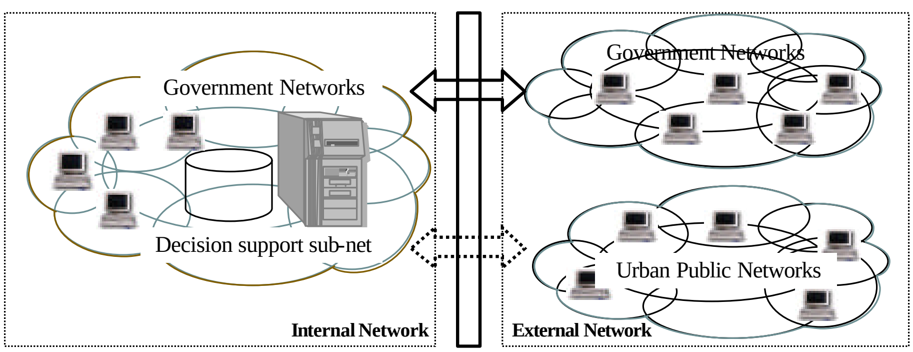

Figure 3. The physical configuration of the network systems. The internal and external networks are filter through a secured layer.

The software system that supports the operations is also highly complex. There are five main groups: DBMS, GIS, statistical analysis system, ontology server, and system software. In addition to the general tasks for managing and analyzing data using DBMS, GIS, and statistical system, we need the ontology server to integrate data from different sources and we need system software such as application server (TomCat), XML packages, and the .NET framework to enable the system. Further, special functions for analyzing spatial patterns and performing surveillance are incorporated to the system as key elements for decision support.

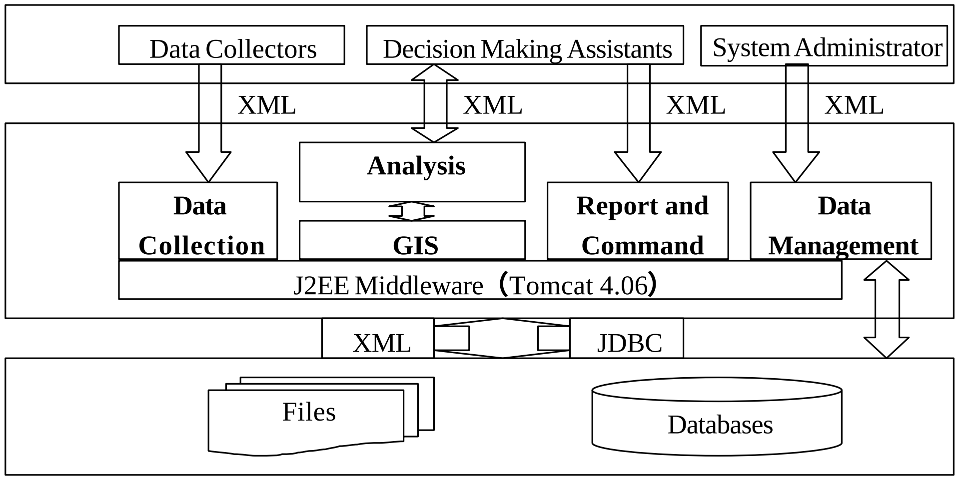

Figure 4. The software architecture for the emergency response system.

Applications

The SARS Emergency Response System was developed for Hefei City, Anhui Province. The aforementioned software system was developed through intensive application programming using ESRI's GIS software in combination with a number of Web development tools such as Tomcat and JavaScript. Figure 5 is a screen capture showing how the inspection and tracing data can be dynamically display on the Web browser. Likewise, Figure 6 shows also real time information on resident movements into and out of the city. Similarly, the number of patients under treatment and the corresponding hospital information can be displayed readily, as shown in figure 7.

Figure 5. Dynamic mapping of health investigation and tracing.

Figure 6. The number of people going through each check point are shown on the map.

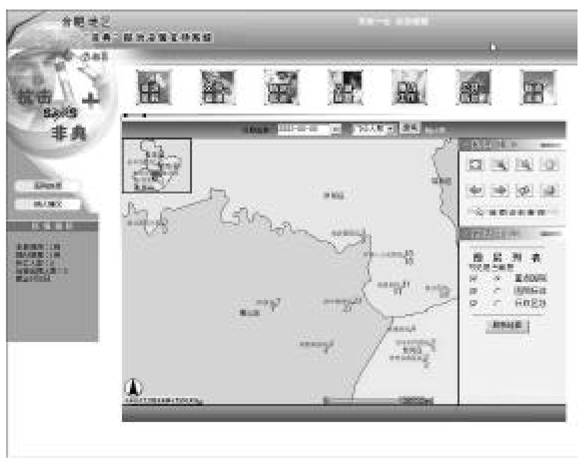

Figure 7. The number of patients currently under treatment is shown on the map. Corresponding information about hospital resources can be retrieved and utilization can be analyzed.

Summary

We briefly reported the design and implementation of an urban epidemic response system. The core philosophy is GIS-centric. Geographic information system plays the central role in data collection, management, analysis, and information dissemination. Although a large amount of data were collected without explicit spatial information, the inherent spatial attributes of the majority of data make it possible to integrate them with spatial data through geocoding. The pilot system developed for Heifei city was effective and well received by decision makers as well as urban residents. People seemed to be satisfied even with simple map displays of real time data. Much of the potential of spatial statistical analysis has yet to be realized. One of the major problem in implementing such the system in Chinese is geo-coding, as there is no common address reference framework in place, resulting in ad-hoc solutions, which are expensive and difficult to update.

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