# AN OPEN URBAN EMERGENCY DECISION SUPPORT SYSTEM

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**ABSTRACT:**

Many contingencies, both natural and man-made, have taught people that well coordination of organizations involved in emergency is most critical for effective response, and decisions ought to be made on the foundation of a synthetical analysis of data from multiple sources. These lessons bring new requirements for emergency Decision Support System (DSS), which include the capability of integrating data from incident-related organizations in real time and performing a comprehensive analysis and model computations. In this paper, we present an open DSS for urban emergency - Eplan that is able to satisfy these requirements. The DSS is constructed on the basis of a Digital City Infrastructure Service Platform (CyberSIG) developed by us. Three systems of CyberSIG, spatial database management system, integrated simulation modeling system and CyberSIG service bus, and a decision support subsystem compose the DSS. Under the support of the three underlain systems, data from different organizations can be enrolled into or withdrawn from the DSS easily, and prediction models of incidents are able to be created or replaced quickly and with little difficulty. In fact, the DSS provides an emergency DSS framework capable of response to a variety of urban contingencies. The DSS is firstly introduced, and then questions on the system and the framework are discussed.

## 1. INTRODUCTION

The lessons from the past incidents, for example, the 9.11 terrorist attacks, the SARS outbreak, the Katrina hurricane, have clearly showed the critical importance of coordination of multiple organizations involving governmental agencies, the private sector and nongovernmental organizations for efficient and effective response to emergencies. The coordination depends on a series of measures, including well-organized response agencies with explicit responsibilities, handy communication system to support on-line information transmission, and decision support system to assist decision makers to issue appropriate response commands and help response operators to arrange activities reasonably. Among these measures, DSS plays a critical role, and essentially demands an integration of data from diverse organizations. While presently the DSSs created are almost deficiencies of the capability (Wallace and Balogh, 1985; Quaranta *et al.*, 2002), or only provide limited integration (Tufekci, 1995; Zerger and Smith, 2003; Bianconi *et al.*, 2004; Martin *et al.*, 2004; Alhajraf *et al.*, 2005). The reason is the lack of a framework capable of providing easy access to resources involving data and models widely dispersed in different organizations.

Digital City Infrastructure Service Platform (CyberSIG) (Lin et al., 2002; Li and Gan, 2005) that is developed by us as a underpinning system for digital city enables the sharing of resources of multiple organizations, and therefore provides a well framework described above for emergency DSS. In this paper, we present an emergency DSS named Eplan that is created based on CyberSIG. The underlain service platform brings the DSS to great capability of accommodating to response to different kinds of contingencies and diversified emergency situation. The architecture and segments of the DSS are described in section 2. A discussion on the system and relevant questions is given in section 3.

## 2. THE OPEN EMERGENCY DSS

### 2.1 System overview

The DSS is composed of a decision support subsystem and three systems of CyberSIG, spatial database management system (SDMS), CyberSIG service bus (CSB) and integrated simulation modeling system (Isim) (see Figure 1).

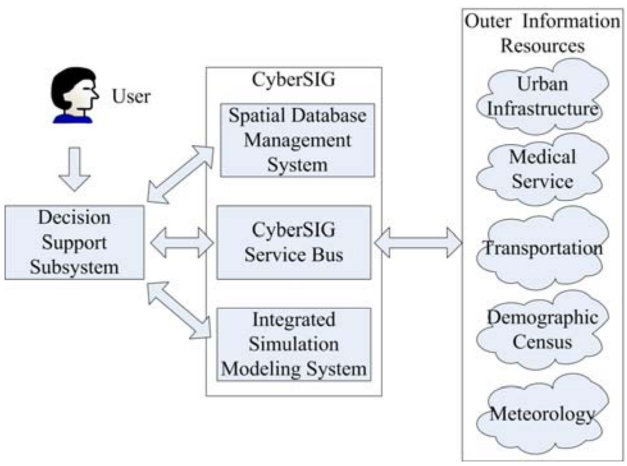


Figure 1. System architecture overview

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The three systems are independent of the DSS and each other, and the only way to utilize their functions is through the open access interfaces provided by them. On the contrary, the DSS must rely on the three systems, because they are able to provide a series of data and functions necessary for decision making analyses, for example, supplying surroundings-relevant data of an incident, modeling incident evolution and committing model computations. The decision support subsystem is the core of the DSS, which couples the other three systems together loosely to support decision makings. Outer data that commonly are hold by different organizations, such as urban transportation data, demographic census, meteorology etc., are able to be employed easily by the DSS in decision making analyses under the assistances of the underlain three systems.

The DSS is constructed in client/server architecture. The server side consists of the decision support subsystem and the three underlain systems, which physically are distributed but logically form an integral system. The client side is composed of a web interface that acts as the user interface of the DSS and communicates with the decision support subsystem. This design makes all operations to the DSS be able to be completed in network. For example, inputting incident-related data and viewing incident evolution all can be done remotely.

The DSS is not designed for any specific kinds of emergencies. Essentially speak, it likely provides an emergency DSS framework that can by extended quickly and expediently to support decision makings of a great span of emergencies. The capability is obtained greatly owing to the underlain systems from CyberSIG.

In fact, the DSS is a typical application of digital city that presents and validates the capability of CyberSIG in the sharing of resources of different organizations. In the following, some detailed introductions to each segment of the DSS are given.

### 2.2 Spatial Database Management System

SDMS, as the core technique platform of Urban Spatial Data Infrastructure (USDI), is built upon Oracle database management system, and consists of a database, a metadata base and some function modules (Li et al., 2004) (see Figure 2).

The database stores a fundamental urban geospatial dataset that are utilized extensively in different applications. The elements of the dataset include image, DEM, vector map and traffic network of a city. The data layers of the vector map component involve river, road, administrative district, building, facility, organization and agency. These elements together constitute the urban geospatial framework data. Different data models, as well as spatial indexing approaches and data transmitting policies, are designed to manage these elements in the database for achieving high access speed and efficiency. The function modules offer dataset administrators the capability of managing the dataset and users the accessibility to the dataset. New data are able to be updated into the database quickly under the support of the data update module. Multiple image and geospatial data formats, such as Tiff, JPEG2000, shape files, mif, kml, gml, etc., are supported, which greatly improves the usability of SDMS. The management module is implemented on the ground of the metadata of the dataset that are recorded in the metadata base. Users employ the access module to query and abstract data needed from the database. For the convenience of remote access, three nuclear OGC services for data access, WFS, WMS and WCS, are developed and deployed within CSB.

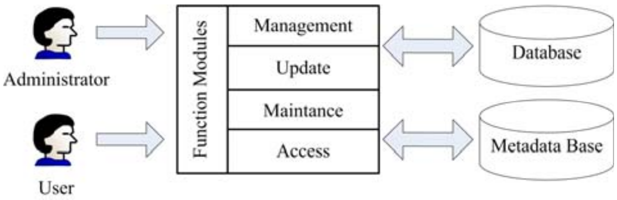


Figure 2. SDMS overview

In the DSS, the main function of SDMS is providing geospatial data that are related with an incident and relevant with decision making analyses. When an incident occurs, some data requests are to be generated by the decision support subsystem and submitted to SDMS. The contents involved in these requests have relationships with the type of the incident and are usually predefined in the decision support subsystem.

### 2.3 CyberSIG Service Bus

CSB, implementing a Service-Oriented Architecture (SOA), is a service management and invocation system for the purpose of resource sharing (Shi et al., 2006). Figure 3 gives a general illustration of the architecture of CSB. Resources of different organizations are required to be packaged as web services that may contain data, business operations or models. Services are registered into the resource catalogue that is constructed in terms of the UDDI (Universal Description, Discovery, and Integration) specification. The service management module provides fundamental functions for service providers and consumers, for instance, service register, lookup, invocation. The workflow engine gives support to cross-organization business processes that are defined as orchestrated web services. One organization can share its resources with other ones by registering specific web services into the resource catalogue, and at the same time it also is able to employ resources supplied by other organizations.

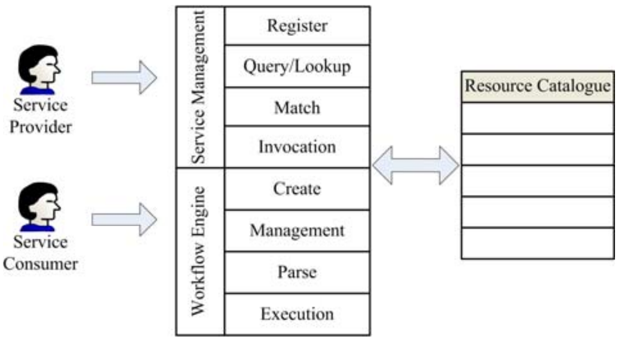


Figure 3. CSB overview

CSB satisfies the requirement of the DSS for data integration. During emergency preparation, organizations package their data as web services and enrolled them in the resource catalogue. When an emergency occurs, these data can be acquired in real time by calling to the registered services, and then are able to be used in prepared emergency models. Consequently, the results given by the models are guaranteed to be generated on the basis of the latest data and hence more dependable for decision makers.

### 2.4 Integrated Simulation Modeling System

Isim is an integrated modeling system developed for satisfying a spectrum of applications based on digital city. It adopts a component-based modeling approach, and at the same time designs an extensible plug-in framework for giving support to different modeling paradigms (see Figure 4). In Isim, models encapsulated as components are taken as "building blocks". By coupling these blocks, coarse-grain models are created and corresponding components for them are generated automatically. Three aspects of compatibility are checked when a coupling process is required, which are temporal compatibility, spatial compatibility and semantic compatibility, for the purpose of assuring the technical correctness and the actual significance of created models. In the system, models are managed on the basis of their metadata, and are able to be reused in different grains. Each model accepts two kinds of inputs: parameter and input variable. The first refers to the parameters of a model that need be specified only once during model execution. While the latter need to be set in each simulation step, and therefore are used to exchange data with other models.

The system is constructed in client/server architecture and tries to provide a maximum of simplicity for users. The client is composed of a complete graphical user interface that enables modelers to create a model by some operations of dragging and dropping components represented as icons and to simulate a model. The server consists of a model base, a metadata base, a plug-in library, and a series of function modules for sustaining user access, model management and simulation control. Using the client, modelers can drive the server remotely to generate or execute a generic model, and explore data transferred from the server in multiple manners supported by the client, such as image, table, statistical figure and report.

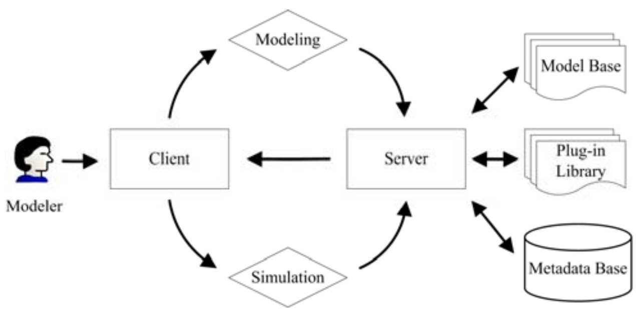


Figure 4. Isim overview

In the DSS, all emergency models are created and managed in Isim. At present, some models on prediction and evaluation of chemical incidents have been provided, and more emergency models are planned to develop.

On most occasions, CSB is called by the DSS to obtain necessary data as the input of specific models for an incident, which assures more accurate prediction of the evolution and evaluation of the effects of an incident. The associations between incidents and emergency models, as well as emergency models and data, are predefined and recorded in the decision support subsystem.

### 2.5 Decision support subsystem

The decision support subsystem acts as the control center of the DSS. It drives the other three systems to produce necessary data, and integrates them to form a general report for emergency decision makers, according to prepared emergency processes.

An emergency process prescribes some basic elements and regulates an operation process for a kind of incidents. Generally, it answers a series of questions as follows:

*What data are needed to support decision makings of these incidents?*
*What models are required to support decision makings of these incidents?*
*What data are needed by each model?*
*How are these data obtained?*
*How is this process executed?*
*Where are the last results sent?*

When an incident happens, emergency managers can activate the decision support system by inputting incident-related data and call the decision support subsystem to execute a specific emergency process by the web interface. After that, three tasks will be executed sequentially to respond the emergency, which are data collection, model invocation and results integration (see Figure 5).

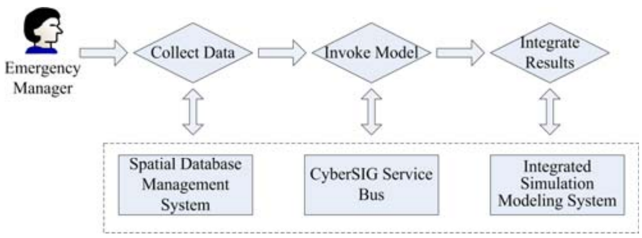


Figure 5. Decision support process overview

The first task collects necessary data for decision making analyses and incident prediction. Generally, in terms of source and content, these data can be categorized into three groups: incident-related, surroundings-relevant, and model-suited. The incident-related data are collected on the incident spot and inputted by emergency responders, which commonly describe the incident location, type, scale, risk level, primary effect region, and some other incident specific characters. The surroundings-relevant data are acquired from SDMS, and have same content as that of the fundamental urban spatial dataset described in section 2.1, but limited boundary. The data boundary is usually ascertained by the inputted incident type and effect region. The data that is necessary to model computations, except for the above two groups, constitute the model-suited data, for example, meteorology data, demographic census data. These data are obtained from other organizations under the support of CSB. The three groups of data are gathered and shape an incident-centric dataset.

The second task invokes Isim to run specific models that are defined in the emergency process to predict the evolution of an incident and evaluate its effects. The values of the parameters and the input variables of the models are obtained from the dataset generated by the first task. The results calculated that generally include the effect areas of an incident and potential risk at a given location and a specific time are returned to the decision support subsystem.

The last task performs some statistical analyses and evaluations, and generates some synthesized incident reports. On most occasions, many decisions are dependent on the statistical data that are drawn on the foundation of the effect areas and risk levels of an incident given by specific prediction and evaluation models. This is a case, for example, the number of the people in the high risk region in chemical contingencies, which is figured out based on demographic census data and risk levels, is critical for medical service agencies to arrange their rescue scale. Therefore, some common statistical computations are implemented in the decision support subsystem, and some ordinary integrated data involving effect region and population, emergency route system and evacuation scale are generated.

The last results given by the decision support subsystem provide well guides for emergency managers to issue task commands reasonably. On the other hand, these data also are an important basis to perform further decision making analyses for different emergency response agencies. For example, medical service agencies can establish detailed rescue plans on the basis of rescue scale, incident location and emergency route system.

## 3. DISCUSSION

A great span of organizations, including governmental agencies, the private sector and nongovernmental organizations, are always involved in emergency response. A centrally organized command center and a spectrum of distributed operation agencies are widely considered as an applicable organization framework to effectively respond to different kinds of emergencies (Turoff et al., 2004; Murray, 2007), and have been explicitly prescribed in many emergency plans (e.g., the National Emergency Response Program for Public Incidents of China and the National Response Framework of the U.S.A.). The most significant function of the command center is issuing orders that activate or deactivate specific response tasks, like evacuation, and coordinating activities of numerous operation agencies to accomplish the tasks, which are critical to successful emergency response. To achieve the function, many requirements, involving real-time situation perception of incidents and integrated analyses basing on collected multi-sources data, are usually indispensable. For satisfying these requirements, emergency DSS should not be constructed in a monolithic structure but an open architecture capable of integrating data from different organizations and adding needed resources as data and models easily.

The DSS - Eplan described in this paper gives such a design with an open architecture. It is built on three systems of the CyberSIG platform, and under their supports data and models from different organizations are able to be added into the DSS easily and participate in decision making analyses. The openness of the DSS mainly covers the following three aspects.

*Open access.* The client/server architecture and the loosely coupled structure make web-based access to the DSS available. The feature assures emergency managers and operators are able to employ the system expediently. When an incident occurs, first responders can input incident-related data collected on the spot through the web interface of the system. Similarly, decision makers are able to utilize the interface to perform model computations remotely. The results given by the system are organized in web pages and transferred back to decision makers.

*Open resources.* Resources from different organizations, for example, data and models, can be easily enrolled into or removed from the DSS. The adopted web service standard that is designed by W3C to achieve interoperability over a network gives great facility for organizations to package their resources as services demanded by the system, and the popular SOA architecture implemented by the system makes the register and the withdraw of services convenient. By some basic management functions provided by the web interface, organizations are able to manage their resources remotely.

*Open models.* The completely component-centric modeling approach brings powerful integrated modeling competency. Models developed by different organizations for specific emergencies can be integrated into the DSS as basic components. Emergency analyses and decision making models can be created in short time by coupling these basic or composed models residing in the system. When new models with higher precision are developed, the old ones can be replaced with little difficulty by uploading the new components to the server of Isim and making some modifications to the metadata of the old ones.

The open characteristic makes the DSS suitable for response to different incidents. In fact, the system provides a framework for emergency DSS, which consists of a series of ordinary elements of emergency DSS, for instance, incident-centric dataset, prediction and analysis models, and defines an approach that can compose these elements into an operation process. When extending to a new kind of emergency, most commonly, three steps are needed to create an emergency decision making process. First, organizations register their data that are required by decision making into the DSS. Second, emergency managers and specialists provide incident prediction and analysis models. Lastly, emergency managers create an analysis process for this kind of contingencies.

Emergency response usually involves a series of tasks that are selected to be executed due to the type and scale of an incident, for example, logistics, evacuation, and various rescues. Among these tasks, many decision makings are carried out, and accordingly some models that are able to assist these tasks are needed. Therefore, more models should be developed and integrated into the DSS besides the emergency prediction and analysis models. In general, at least three aspects of models are to be provided for constructing a perfect emergency DSS: incident prediction models, transportation optimization models for evacuation, logistics models. Incident prediction models, gas dispersion model for nuclear or chemical incidents (Chang et al., 1997; Alhajraf et al., 2005; Baklanov et al., 2006; Søensen et al., 2007) as an example, give the effect areas of an incident and evaluate its possible risk. Transportation optimization models yield an optimized arrangement of travel routes and destinations for evacuees under some specific objective functions and optimization formulas. Some typical optimization formulas include the shortest route(Campos *et al.*, 2000), the shortest evacuation time (Pursals and Garzón, In Press), the minimum cost (Yamada, 1996; Cova and Johnson, 2003), and the maximum traffic flow(Dunn and Newton, 1992). Logistics models (Bakuli and Smith, 1996; Fiedrich *et al.*, 2000; Yi and Őzdamar, 2007) produce an optimized resource allocation scheme aiming at maximizing the utilization of available resources. Except for the three categories, risk evaluation models (Lindell, 1995; Church and Cova, 2000) for emergency preparation are another important type, which evaluate emergency elements and give some high risk regions or traffic networks prone to occurring incidents or causing great damage.

## 4. CONCLUSION

As discussed, emergency DSS must be able to integrate needed data from multiple organizations involved in emergency. The urban emergency DSS presented in this paper achieves this capability through a way that takes CyberSIG – an infrastructure service platform for digital city as a basis to construct it. The open infrastructure makes resources from different organizations necessary to decision making, for example, data and models, are able to be integrated into the system easily. As a result, with little difficulty, the DSS can be extended to give supports to new emergencies.

On the other hand, a specific model base that comprises a series of models for decision makings in different processes of emergency management, for instance, emergency preparation and response, is required. In general, incident prediction models, transportation optimization models, logistics models and risk evaluation models are typically involved in emergency management. At present, besides some incident prediction models, a number of basic transportation optimization models are under development in the digital city laboratory of Peking University.

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