Study on Integrated Command Platform for Emergency Rescue in Coal Mines Based on WebGIS

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Abstract—**Based on the actual needs of the Chinese national emergency rescue base in mining areas, and in order to effectively carry out emergency rescue in coal mine disasters, this article studies the response process of emergency rescue in coal mines, the analysis and calculation methods required in the relief work for mine disasters, the functional requirements of the integrated command platform and relationships between various subsystems. WebGIS is introduced to the mine rescue and combined with the response process of emergency rescue to develop the integrated command platform of emergency rescue in coal mines. At present, the system is successfully applied to the emergency rescue base in Kailuan (located in Tangshan, Hebei Province), and its operational results show that the system can effectively organize emergency rescue in mine disasters, and timely process the disaster data in order to provide technical supports for emergency rescue.**

Index Terms—**coal mine disaster, emergency rescue, decision technology for rescue, command platform, WebGIS**

I. INTRODUCTION

Information technology has been gradually applied in different majors concerning coal mines, and information and network has become the basis of coal mine informatization. It plays an important role in management and decision-making in coal mines. The emergency rescue capability in coal mines is a key to ensure the miners' safety and prevent the expansion of accidents.

When an accident occurs in coal mines, the emergency rescue information system needs to timely activate emergency plans, get the required information for rescue work, process the information and issue instructions during the entire rescue work. Meanwhile, a rescue decision supporting system is also very necessary: it can proceed with professional computation and relevant predictions and analysis according to the ventilation, gas, coal dust, water gushing and other information based on the scene of accidents and relevant areas; the prediction results will be in the form of three-dimensional graphics through GIS technology, and provide technical support for the decision-making of emergency rescue.

A lot of researches about WebGIS technology in emergency rescue on the ground have been made abroad [1-3],while the research about the emergency rescue in coal mine is less。The overseas information system of safety management in mining areas is more powerful, but its emphasis on the information management in open-pit mining conditions presents relatively weak functions concerning underground mining. In addition, due to the limitations of its data structures, drafting specifications, applicable standards, system functions, user interface, language and other aspects, foreign mining softwares in China are confined to a number of case studies in universities or research institutes instead of being used in daily information management of coal mines.The pure emergency plan system, the expert system for a certain profession, the information system for emergency rescue management, the command system for emergency rescue and so on have all been applied in China [4]. However, the processing system for the whole process of rescue relief work in coal mine disasters hasn't been studied or developed. Therefore, the development of integrated command platform for emergency rescue in coal mines which consists the information management system for emergency rescue and the decision-making supporting system for relief work is very necessary [5].

In this paper ,we introduce WebGIS technology into the mine rescue and combine emergency rescue response process ,finally develop the emergency rescue command platform in coal mine。The platform not only provides comprehensive emergency rescue, dynamic information, also provides technical assistance for the emergency rescue. Thus, incomprehensive and overdue emergency rescue information can be avoided, so can the shortcomings of the situation being commanded or decisions being made only by experts' experience [6].

The rest of this paper is organized as follows. We discuss the building goals and the system response processes of the integrated management command system of emergency rescue in the coal mine in the second part

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of our article (Section II). We describes the related ventilation simulation algorithm needed by the disaster relief in the third part, and in the fourth part introduces the related computer technology required by the system. System development process is introduced in the fifth section, the function of the system implementation in the sixth section and conclude in Section VIII.

II. Overview of System Construction

A. The General Target of System Construction

The integrated command system for emergency rescue as a platform is an integrated system with comprehensive management information, professional computation, dynamic simulation and analysis, and dynamic visual display. It is also an information system providing scientific emergency rescue. Therefore, the establishment of the system should be technologically advanced, user-friendly, stable and reliable in operation. Based on the management information system, the command system integrates real-time monitoring systems (which provide an interface to assemble information into a unified platform by using the software supplied by the company), management information systems, graphics systems, graphical drill systems, animated drills, training systems, virtual reality drill systems, training management systems and so on, in order to create system portals and achieve network connections with on-site rescue headquarters and upper management. Meanwhile, connections for remote video conference are also provided.

The emergency rescue system for coal mines based on GIS mainly adopts the combination of GIS and MIS technologies along with the application of relevant modern emergency rescue theories and technology, and it will provide scientific, comprehensive and graphical reference for coal mine emergency rescue.

First, the emergency rescue information is acquired in an integrated way through MIS technology which ensures comprehensive and integrated information. Emergency rescue information mainly includes reserve plans for emergency response, emergency rescue experts, accident cases, relevant technology of emergency rescue, dynamic information of the accident scene, the technical data of the accident area, the supplies and rescue teams for emergency relief work, etc. The access to dynamic information on the accident site should be converged with the safety monitoring system, the equipment monitoring system, the personnel positioning system, the beam tube monitoring system, the video system, etc.

Second, appropriate professional computation through relevant information of the site of accident is processed, which provides scientific reference for emergency rescue. The professional computation mainly includes ventilation network computation, smoke diffusion computation, gas diffusion computation, flood submersion computation, explosion impact scope computation, etc.

Third, the aforementioned information is dynamically and intuitively displayed on the diagram of the emergency rescue system through GIS technology, which solves the problem that rescue command staff and experts have to expend great effort to fully understand the drawings of emergency rescue in mining areas at present.

B. System Response Process

The emergency rescue is the last key process to reduce casualties and property losses when an accident occurs. A quick response made by rescue teams and commanding agencies to accidents are the basis of emergency rescue work in mining areas. The response process of emergency rescue in coal mines is shown in Fig.1.

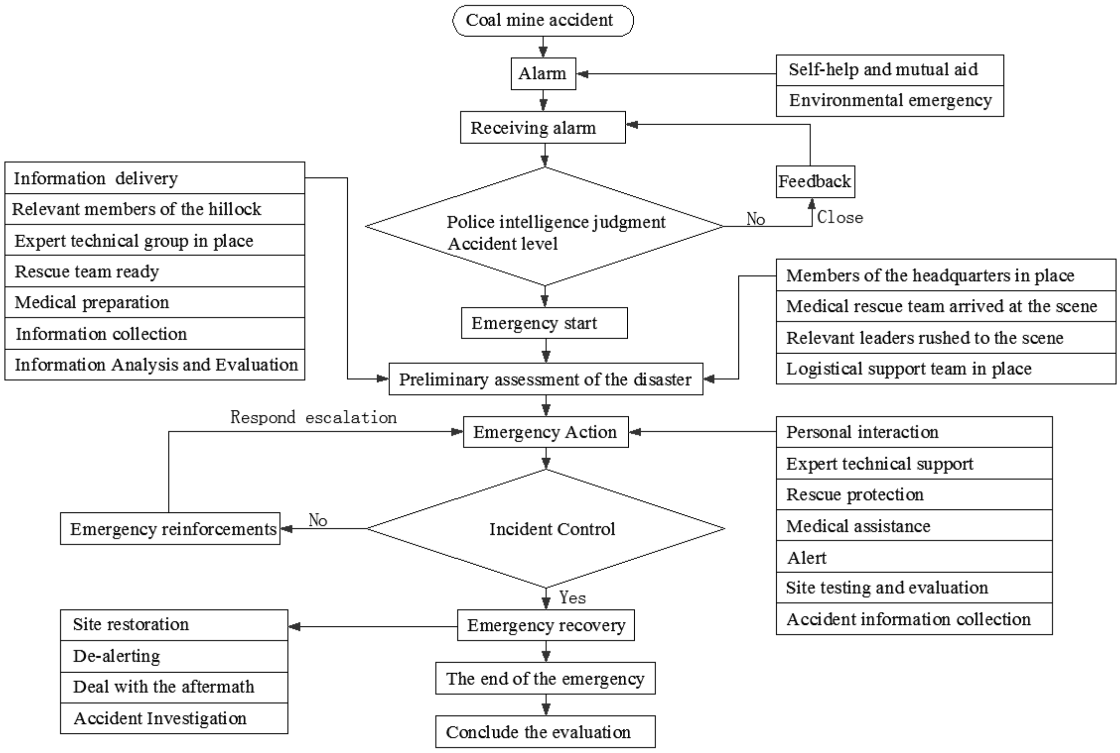

Fig.1 The flow chart of Emergency rescue response

III. Relief Decision-making Support

A quick and accurate analysis of the hazard data of mine ventilation networks and appropriate calculations and simulations to determine the impact scope of disasters play an important role in rescue decision-making when an accident occurs. The analytical procedures are different for various types of disasters, but simulation of underground fire smoke diffusion, simulation of mine gas accumulation and distribution, analysis of smoke diffusion, analysis of the explosiveness of disaster gas, analysis of gas accumulation, charting the best evacuation routes and so on all need mine ventilation simulation which is the basis of the decision-making in relief work. Therefore, this section focuses on the relevant algorithm about principles of the ventilation system simulation.

When air flows in the ventilation system, it complies with the laws of mass balance and energy balance. These laws is applicable for any form of ventilation networks and any branch, and the air current in mines follows these equations [7-8]:

A. Conservation of Mass

In the network structure, the conservation of mass indicates that the algebraic sum of air mass that flows into and out of any node in a unit time is zero. The mathematic formula is:

$$\sum_{j=1}^{n} Q_j = 0 . \quad (1)$$

Where Q_j represents the air flow of j branch.

B Node wind Equilibrium

Node wind equilibrium law is a manifestation of the mass balance law. The sum of inflowing air flow of nodes in a ventilation network is equal to the sum of outflowing air flow of the same nodes.

The mathematical formula is:

$$\sum_{j=1}^{N} b_{ij} Q_j = 0, i = 1, ..., M-1 \quad (2)$$

In the form of a matrix :

$$BQ = 0 \quad (3)$$

Where B represents basic correlation matrix of branch nodes, b_{ij} represents the element in row i and column j of the basic correlation matrix; Q represents the wind column vector, and $Q^T = (q_1, q_2, ..., q_n)$ has the same order as B.

The wind network has M nodes, then the amount of independent air flow balance equations stands at M-1.Therefore, the value of i in the formula rangs from 1 to M-1.The vector Q is aligned as air quantityof cotree Q_Y stands upward and air quantity of branches Q_S stands downward, and it can be written as $Q^T = [Q_Y, Q_S]$. Accordingly, the Matrix B can be written as $B = [B_{11}, B_{12}]$, and therefore: $BQ^T = 0$

and then: $Q_S = -B_{12}^{-1} B_{11} Q_Y = C_{12}^T Q_Y$ (4)

Therefore , $Q = C^T Q_Y$ (5)

Where it represents the air quantity in the branch that complies with the node equilibrium equations, and only the air quantity in the cotree branches is independent.

C. Air Pressure Equilibrium Law

Loop equation is established on the basis that the algebraic sum of air pressure in various branches is zero when the air flows for a lap along any loop of the mine ventilation network, which obeys the law of conservation of energy. For the basic loop constituted of a spanning tree of the ventilation network, the air pressure equilibrium equations established in the loop are linearly unrelated and independent from each other with their quantity being N-M +1.Therefore, he air pressure balance equation for any loop can be expressed as:

$$\sum_{j=1}^{N} C_{ij} h_j - h_{ni} = 0, i = 1,...,(N - M + 1) \quad (6)$$

Which can be written in matrix form as

$$CH - H_n = 0 \quad (7)$$

Where c represents independent loop matrix in the ventilation network, H represents air pressure column vector, thus $H^T = (h_1, h_2, ..., h_n)$,and its branches sequencing is the same as c . c_{ij} represents the elements of Row i Column j in the independent loop matrix. h_{ni} represents i -th natural air pressure in independent loop matrix.

D. Basic Equations for Mine Ventilation

The basic equation of mine ventilation reflects the flowing characteristics of air flow in the underground tunnel. The underground air volume and pressure in turbulent state meet the ventilation resistance law. When the influence of local resistance from blowers' air pressure, ventilation conditioning and the like on ventilation is considered, the flow resistance of any ventilation network branch can be expressed as follows:

$$h_j = R_j \left| q_j \right| q_j + h_{rj} - h_{fj} \quad (8)$$

Where R_j represents the friction resistance in branch j , h_{rj} represents resistance caused by local air resistance of adjusting the windscreen and others in branch j , h_{fj} represents air pressure provided by a blower in branch j .

E. Airflow Correction Formula

The modified formula of air quantity is as follows:

$$\Delta q_{li}^k = \frac{\sum_{j=1}^{N} 2c_{ij}(R_j \mid q_j \mid q_j) - h_{fi} - h_{ni}}{\sum_{j=1}^{N} 2c_{ij}^2 R_j q_j^k - \frac{dh_{fi}}{dq_{li}}}, \quad i = 1,...,k \quad (9)$$

The "D•Scott—F•Hinsley" method based on meshes is adopted in numerical calculation of the ventilation network, which is also commonly used in the domestic ventilation network computation. The basic thinking of the method can be expressed in several steps. First, select a cotree to establish an independent loop equation, and use the Taylor series to unfold it as nonlinear equations, and then transform them into linear iterative equations by ignoring three and higher order terms; second, assign an initial value to the unknown air quantity, and use the modified formula to obtain the modified value, and then modify the air volume of each branch; Third, substitute the modified airflow value into the next iteration calculation. The calculation is not complete until the modified value meets the required accuracy.

IV. Relevant Technology to Achieve the System

A. Selection of WebGIS Platform

WebGIS, also known as the world wide web GIS, is an Internet GIS based on B/S mode. It expands GIS application from the professional fields to the popularized service, and provides convenient and efficient ways for geographic information sharing [9]. Compared with the traditional GIS, WebGIS has the following advantages:

(1) Wide range of access;
(2) Independent client platforms;
(3) Low cost;
(4) Simple operation;
(5) Balanced and efficient computational load.

So far, many domestic and foreign companies have launched a series of WebGIS solutions, such as ArcIMS, MapGuide, MapXtreme, GeoMedia WebMap, GeoSurf, TopMap, etc. Through comparison and validation, Autodesk MapGuide is chosen as the development platform of integrated command system of emergency rescue[10].

B. MapGuide

MapGuide is a WebGIS map-releasing software launched by Autodesk. The software can enable users to use the browser to conveniently look into map data and quickly develop and deploy WebGIS applications and service, just like Google Map [11].

C. Map 3D

Autodesk Map 3D software is the leading platform for creating and editing spatial data. It provides practical mapping functions for engineers and geospatial professionals in order to integrate CAD (Computer Aided Design) and GIS (Geographic Information System) information. Autodesk Map 3D makes up for deficiencies of the existing GIS implementations and thus enables users to quickly access, efficiently edit, and easily manage various large-sized geospatial data sets [12].

D. ADO.NET Technology

ADO.NET, which is responsible for data access, is a class library collection in .NET platform. It can make any programming language on the .NET connect and access the sources of relational database and non-database data (such as XML, Excel and Word), and the independent category for processing application information [13].

E. ASP.NET MVC Model

The design model MVC separates the input, processing and output of web applications. MVC is the abbreviation of "Model, View and Controller". The aim of MVC model is to achieve function divisions of Web system. The model is shown in Fig. 2 [14].

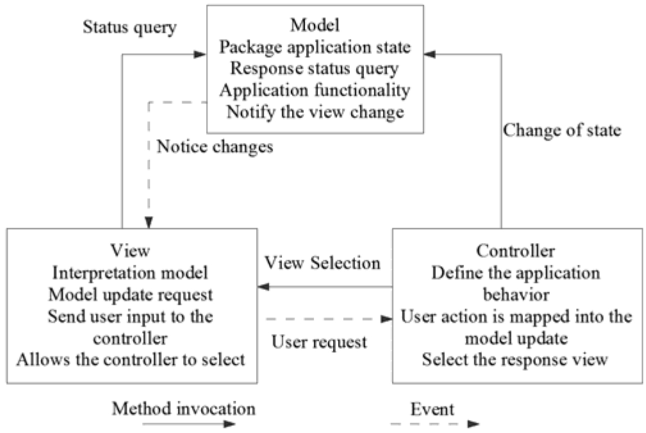

Fig..2 MVC model

F. The System Platform and Environment of Software and Hardware

The B/S structure design is applied to the system. All content of the system are directly achieved on the browser. Therefore, a stable, safe and reliable LAN of fine communication capability is required.

The server hardware requires GIS server, Web server and analog computation, and the database server. These three types of servers can be configured either on the same server or separately. High performance of the server is required as all functional calculations of the system are accomplished by the server. In order to facilitate its management, each server is recommended to be deployed independently.

As the system adopts B/S structure, the requirements of the client is slightly lower. The average PC can meet the requirements.

Software: The server adopts Windows 2008 server system, a database of SQL Server 2008 R2 version and an IE 8.0 browser; the testing client operating system is Windows 7 with an IE8 browser.

VI. System Development

A. Principles of System Software Design

According to the actual requirements of software development and characteristics of the software itself, the following principles are put forward:

(1)Advancement: the system design adopts the modular and standardized system integration technology to make the system open, compatible and extendable.

(2) Reliability: the reliability of the system platform and mobile information terminals.

(3) Utility: the operation of the entire system platform aims at convenience, concision and high efficiency.

(4)Expansibility: system information function modules can be expanded conveniently.

B. System Development Process

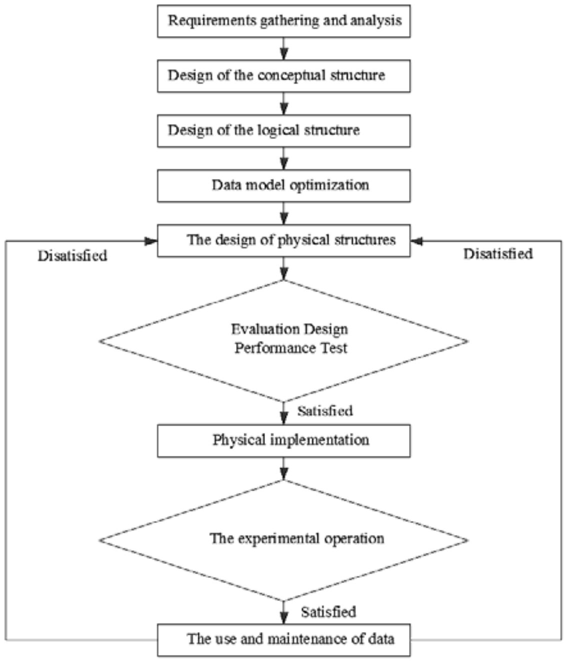

Fig. 3 Software development chart

The coalmine emergency rescue software also follows the general flow of software design and development. When the response process of coalmine emergency rescue is fully understood, the software development plan is formulated and each step of software design, code design, software testing and maintenance is clarified. The whole system is finally formed through the experience and feedback in running and testing the system [15]. The flow chart of the software development for the system is shown in Fig.3.

C. Selection and Design of Database

The choice of database

The massive data of emergency rescue information system of coalmine based on WEBGIS could hardly be handled by average structured database. Therefore, a stable commercial database should be adopted in such case. The Microsoft SQL server 2008 R2 with stable performance and good compatibility is chosen as the database after comparison [16].

Database design

Database design is the foundation of the whole safety information system for coal mines. A good database design guarantees the realization of the whole system functions. The entire database of emergency rescue system for coal mines is divided into two categories: object attribute data and spatial image data. These two types of data are interdependent and co-existent. The data displayed by graphical data attributes is provided by attribute database. The attribute data which is constantly renewed can be directly reflected on the graphics so as to be used effectively [17].

The attribute data of this system is mainly correlated to the management of emergency rescue security. The database design is well perfected in the E-R stuio at first to determine relationships between various database; then scripting languages are directly put into the database. The direct E-R relationship model of database is illustrated in Fig.4.

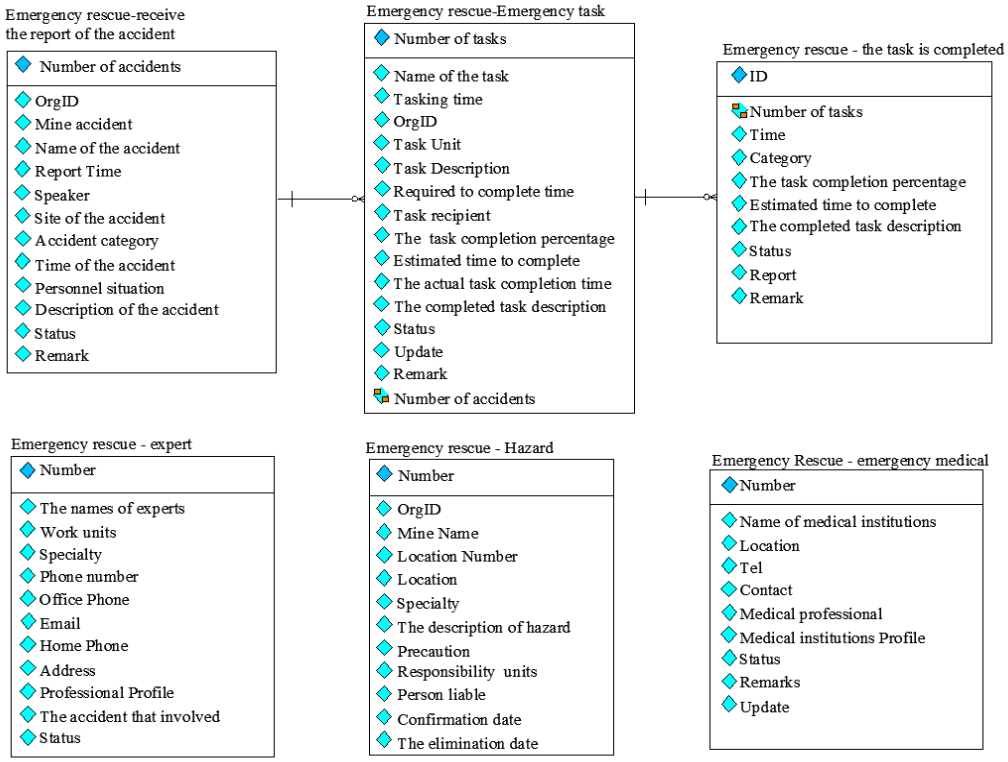

Fig. 4 E-R map

VII. The Introduction of the System Functions

The integrated command platform of mine emergency rescue can achieve dynamic access to disasters information, analysis and computation of disaster data, scientific formulation of emergency rescue plan, prompt delivery of emergency rescue decisions and prompt access to the information of decision-execution for emergency rescue through the joint application of computer technology, network technology, communication technology, GIS and GPS technology. Therefore, the emergency rescue is fully supported. The means of communication is adopted to timely report the disaster. Emergency plans are immediately launched through management system. According to the setting of the management system, relevant personnel and teams are notified to reach the site through the communication system. The command center makes decisions through the management system and decision support system [18]. When decisions are made, tasks will be assigned and rescue force will be mobilized through the communication system. Ultimately the linkage of the command of emergency rescue, decision-making, rescue and so on for coal mine accidents will be achieved.

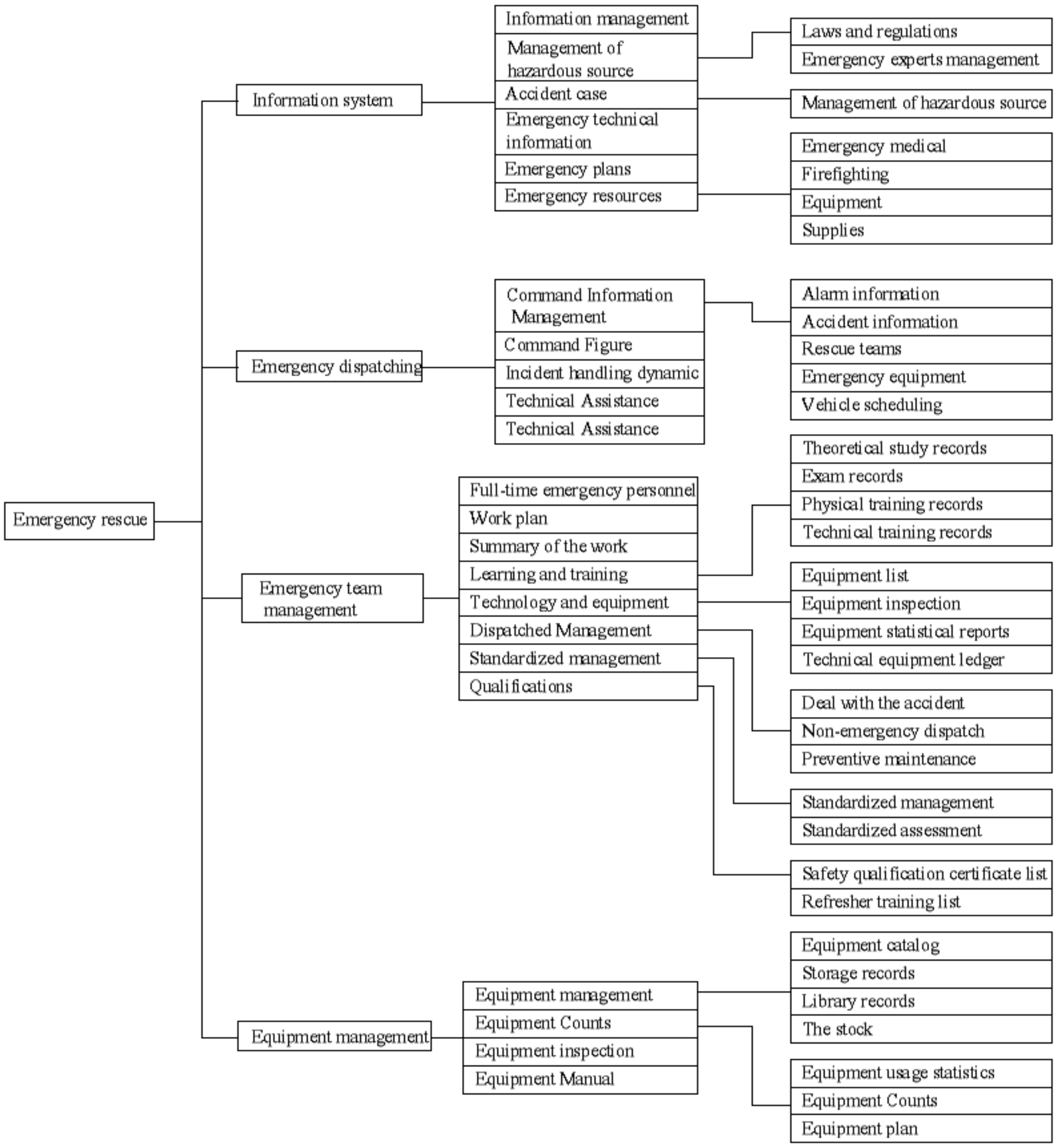

Fig.5 The diagram of the system structure

The integrated command system of emergency rescue in coal mines mainly includes four parts: the information system, the dispatching and command system, the rescue team management and equipment management for emergency rescue (shown in Fig. 5).

The information system of emergency rescue: the main goal of this part is to achieve information management of relevant resource and technology of emergency rescue in coal mines. It mainly contains: information management, dangerous source management, accident cases, materials for emergency technology, emergency plan and resource.

The dispatching and command system of emergency rescue: this part is mainly an integrated information platform to achieve on-site emergency rescue and command, and also is the core of this command platform. It can process informations and issue commands for the entire rescue process, and provide rescue experts with technical assistance, including analysis of the fire smoke diffusion, hazardous gas explosiveness, gas accumulation, etc.

The management of emergency rescue team: It is significant to strengthen the management of emergency rescue team for coalmine accidents, enhance drill and training for major disasters in coal mines with the purpose of improving emergency rescue capability. It mainly includes the enhancement of the commanders' decision-making, training for rescue teams to improve their capability, and the learning of rescue knowledge for coal miners.

The equipment management for emergency rescue mainly includes: equipment management, equipment statistics, equipment checking and equipment instruction manuals.

VIII. Conclusion and Future Work

The integrated platform of emergency rescue in mining areas introduces information technology into the emergency rescue work, making the emergency rescue process-oriented. The emergency rescue is carried out rapidly and orderly through management modules of command information and emergency dispatching. The speed and efficiency of emergency response are both increased greatly. Meanwhile, the system provides not only management of various information and technical support required by on-site rescue, but also training and daily management of equipment for rescue teams, groups and companies, leaders at all levels of the coal mine management, training for general staff and daily management of equipment.

The strong ability of information integration of the system can apply the data of real-time monitoring to analysis and decision-making. The data is calculated and analyzed through auxiliary means, and the observable results will be eventually displayed on the GIS graphic layers. Then the spatial locations and attribute data of the mines' environment information are integrated in a dynamic way, which promotes the timely and accurate decision-making of rescue members, and improves the ability of emergency rescue for coal mine accidents. At present, the system has been on actual operation in Kailuan emergency rescue base. The results show that the system is able to handle large amounts of field data analysis, providing a guarantee for the effective implementation of the emergency rescue.

The integrated platform system of emergency rescue in coal mines based on WEBGIS adopts B/S mode in designing and developing. It overcomes the shortcomings of short system lifecycle, difficult transplantation and high cost in traditional C/S mode.

The system is simple and easy to use. It adopts modular design and component-based development with good expansibility. Hence, it can not only conveniently modify existing features, but also easily extend the capabilities for future system functions.

WebGIS platform has a powerful spatial data and strong capability of processing basic data. The system studied in this paper only applies part of it. There are many other powerful functions worth exploiting and utilizing in order to better serve the emergency rescue work in mining areas.

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1 Bing Wu, Xu Liu, Kai Wang, the reliability test of mine ventilation network data. Journal of Safety Science and Technology.2010

2 Bing Wu, Yihua Zhen ,Security Realization of Linux-based Coalmine Safety Information Management System. Journal of Safety Science and Technology.2005.

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