Design of hazardous materials transportation safety management system under the vehicle-infrastructure connected environment

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Abstract

Purpose – For the purpose of reducing the incidence of hazardous materials transport accident, eliminating the potential threats and ensuring their safety, aiming at the shortcomings in the process of current hazardous materials transportation management, this paper aims to construct the framework of hazardous materials transportation safety management system under the vehicle-infrastructure connected environment.

Design/methodology/approach – The system takes the intelligent connected vehicle as the main supporter, integrating GIS, GPS, eye location, GSM, networks and database technology.

Findings – By analyzing the transportation characteristics of hazardous materials, this system consists of five subsystems, which are vehicle and driver management subsystem, dangerous sources and hazardous materials management subsystem, route analysis and optimization subsystem, early warning and emergency rescue management subsystem, and basic information query subsystem.

Originality/value – Hazardous materials transportation safety management system includes omnibearing real-time monitoring, timely updating of system database, real-time generation and optimization of emergency rescue route. The system can reduce the transportation cost and improve the ability of accident prevention and emergency rescue of hazardous materials.

Keywords Hazardous materials, Transportation safety, Management system, G IS, Route optimization, Intelligent connected

Paper type Research paper

1. Introduction

With the rapid development of the economy and the accelerating process of industrialization, the demand for hazardous materials has been increasing year by year, resulting in a significant increase of traffic volume. Various types of vicious accidents have frequently occurred; therefore, all sectors of society have paid great attention to the safe transportation of hazardous materials. The special physical and chemical properties of hazardous materials can easily lead to secondary accidents when the accident occurred, resulting in dangerous goods leakage, explosion, poisoning and so on. According to statistics, in China, there are hundreds of security accidents caused by hazardous materials transportation every year (Lu, 2018). It has caused great losses and potential threats to the lives and property safety of the state and the people.

In August 1925, an electronic engineer of the United States Army Francis P. Houdina developed the first driverless car controlled by radio waves, which was officially unveiled in the USA. After that, intelligent connected technology has been rapidly developed worldwide, mainly used in the intelligent and networking of intelligent connected vehicle (ICV). In China, in the interpretation of "Made in China 2025" by the Ministry of Industry and Information Technology in 2015, the concept of ICV was first put forward, and the development goal was defined. ICV refers to the organic combination of vehicle

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Journal of Intelligent and Connected Vehicles
2/1 (2019) 14–24
Emerald Publishing Limited [ISSN 2399-9802]
[DOI 10.1108/JICV-11-2018-0012]

This study is supported by the Natural Science Foundation of China (No.71861023), the Program of Humanities and Social Science of Education Ministry of China (No. 18YJC630118, 15XJAZH002), the Natural Science Foundation of Shandong Province of China (No. ZR2016EEM14), the Natural Science Foundation of Gansu Province (No. 1506RJZA083), and Foundation of A Hundred Youth Talents Training Program of Lanzhou Jiaotong University.

Received 13 November 2018
Revised 25 January 2019
17 April 2019
Accepted 24 June 2019

networking and intelligent vehicle. It is equipped with advanced vehicle sensors, controllers, actuators and other devices, and integrates modern communication and network technology. They can realize intelligent information exchange, sharing and behavior coordination of cars and people, cars, roads, and backstage, and provide support for the driver's driving behavior, so as to achieve a multi-vehicle system with safe, orderly and efficient running.

To regulate the transportation of hazardous materials, a number of laws and regulations have been issued on the safety management of hazardous materials transportation. However, there are still some problems, such as the lack of management techniques and the imperfect management system, etc. (Aini *et al.*, 2001). For the transportation of hazardous materials, shippers and government departments lack a relatively complete transport safety and information management system, and the laws and regulations concerning the safety of hazardous materials transportation still need to be improved.

Since 1990s, many experts and scholars have carried out more systematic and in-depth study on the issues of. Information technology, risk assessment, mathematical statistics and optimization method have been widely used in the field of hazardous materials transportation safety management. Julian (1993) introduced the type of traffic and communication system established on the basis of the consensus by the European Energy Commission, he also described the European freight management department's regulatory methods for the hazardous materials transportation. Fabiano *et al.* (2002) studied the framework for risk assessment and decision-making of hazardous materials transportation. Daniels and Daniels (2002) put forward the "integrated emergency management", namely, "full risk, whole process" emergency management system. Subsequently, Emergency Management Institute (2003) has studied some problems of the integrated emergency management, such as all-hazards approach, integrated management system, life cycle management and unified allocation of materials. Kara and Verter (2004) theoretically designed the hazardous materials transportation network in Canada. Pasquale *et al.* (2005) proposed a remote real-time monitoring system for hazardous materials transportation. The system can diagnose the vehicle's technical condition, operation risk and cargo defect in advance. From analyzing the causes of hazardous materials transportation accidents, Lian and Liu (2006) put forward an intelligent whole course transportation monitoring system based on GPS positioning. Tang and Yang (2007) analyzed the advantages and disadvantages of the hazardous materials transportation environment and Radio Frequency Identification (RFID) technologies, applied RFID to the hazardous materials transportation. Tao *et al.* (2007), from the hazardous materials road transportation emergency management status quo, built the overall framework of emergency transportation system of hazardous materials transportation. In accordance with the relevant steps of Intelligent Transport System (ITS) framework in China, Zhao *et al.* (2008) have designed the system framework of road hazardous materials transportation management information system based on ITS. Pietro *et al.* (2008) study the application of the problem framework approach to simulating the demand for hazardous materials transportation monitoring system. Fabio *et al.* (2009) proposed a real-time monitoring system of hazardous materials transport vehicles based on the wireless sensor networks, the system can synchronously check the position of the vehicle, the mechanical condition and cargo status. Romano and Romano (2009) developed a decision support system which can quantify the risk of hazardous materials transportation, it effectively reducing transportation risk, and providing reference for land planning and emergency management of relevant departments. Liu (2011) used system theory and system engineering methods combined with scenario construction to conceptualize the emergency plan system and discusses its overall structure, concept classification, and functional composition. Li (2013) established a theoretical framework for emergency preparedness planning based on targeting the ability to promote, and put forward the construction methods of unconventional emergency situations, emergency general task lists, and the list of target capabilities to deal with typical scenarios of unconventional emergencies. Shi (2014) established a comprehensive management system for road transportation safety of hazardous materials. The system can not only query and manage all laws, regulations, and standards related to road transportation of hazardous materials, but also search for hazardous materials list, as well as query and manage emergency rescue measures and typical accidents cases. Combined with the typical accident of hazardous materials road transportation, Wu (2015) analyzed the main problems existing in the supervision mechanism and emergency rescue system of hazardous materials road transportation in China, and put forward some countermeasures for constructing the basic information system of hazardous materials transportation safety supervision and perfecting the emergency rescue equipment system of hazardous materials road transportation. Ma *et al.* (2018) established a comprehensive risk assessment model based on accident probability and accident consequences to evaluate the risk of urban road hazardous materials transportation, which providing a basis for the adoption of prevention and control measures, reducing the probability of urban road hazardous materials transportation accidents and the loss caused by accidents. By summing up the current situation of hazardous materials transportation management in China, Huang (2018) put forward and established the standard system framework of road transport regulations for hazardous materials.

To avoid the occurrence of hazardous materials transportation accident as much as possible, to minimize the heavy losses caused by the hazardous materials transportation to the state and people. With the full cooperation of government departments, further improve the relevant laws and regulations, strengthen the supervision of hazardous materials transportation safety. Most of the existing research results are based on a certain angle of hazardous materials transportation and research. Some scholars have chosen different methods to build models to calculate and analyze certain indicators of hazardous materials transportation, such as risk assessment models and path optimization models. There are also scholars who study how to improve the safety of transportation or how to manage hazardous materials transportation information more efficiently. At present, most of the design for hazardous materials transportation management system was only a systematic research and design of one aspect of hazardous materials or hazardous materials transportation. For example, hazardous materials information management system, hazardous materials transportation path optimization system, hazardous materials emergency rescue management system, etc. Therefore, based on the analysis of the existing hazardous materials transportation management system, combining intelligent connected technology, a comprehensive hazardous materials transportation safety management system under the vehicle-infrastructure connected environment is designed. ICV is closely related to vehicle networking and intelligent transportation system. The common progress and development of these technologies will greatly improve traffic safety. In addition to the basic information management, the system also integrates early warning and emergency rescue function modules and path optimization. The purpose is to provide more efficient management means for the hazardous materials transportation, and optimize the process of hazardous materials transportation management. At the same time, the system strengthening the dynamic monitoring of the link in the transportation process, effectively improving transportation safety management level, and promoting road hazardous materials transportation safety management mode from "passive processing" to "active prevention" (Ma *et al.*, 2015).

From three aspects, system design, subsystem function design and introduction and conclusion and outlook, this paper describes the framework of hazardous materials transportation safety management system under the vehicle-infrastructure connected environment.

2. System design

Based the background of ICV technology, this paper designed a hazardous materials transportation safety management system under the vehicle-infrastructure connected environment. The core technologies of ICV include vehicle overall sensing technology, wireless communication technology, vehicle *ad hoc* network (VANET) technology, safety assistant driving technology, information fusion technology and data processing technology. The system uses C# as the development language, based on the Microsoft Visual Studio 2010 platform to introduce ArcGIS Engine, SQL Server 2008, and GPS plug-in development. Using the hierarchical design as shown in Table I, the system has the characteristics of high maintainability, easy code reuse and flexible expansion. Based on SQL Server 2008 + C# platform, the database management function of hazardous materials transportation route optimization system is developed, and the information management of drivers, vehicles, hazardous materials, transportation records and emergency plans is realized.

The hazardous materials transportation safety management system designed in this paper, through the analysis of hazardous materials and its transportation characteristics, and made further refinement and perfection on the basis of the existing hazardous materials transportation management system. This system learn the prominent and mature functional modules from existing systems, making up for the shortcomings of the existing hazardous materials transportation safety management system is not comprehensive, setting up a relatively perfect transportation safety management system in

Table I Hierarchical design table

Hierarchy	Content
Data interface layer	Pay attention to the logical relationship between data, according to the design principle of synthetic reuse, interface programming for hierarchical and partitioned data structure
Logical service layer	It encapsulates the map operation class, database query class, GPS class and so on. At the same time, it realizes the operation class of each service to the underlying data
User view layer	From the functional modules and user needs to consider design documents, map browsing, information inquiry, path query, information management, GPS monitoring and other major functional menu

the background of the geographic information system. The system consists of five subsystems, and the detailed functional modules are shown in Figure 1.

3. Subsystem function design and introduction

3.1 Vehicle and driver management subsystem

The vehicle and driver management subsystem mainly realizes the monitoring and scheduling of vehicles, fatigue monitoring of drivers (Ma *et al.*, 2015), vehicle communication system and alarm system. This subsystem combines the vehicle overall sensing technology, wireless communication technology, vehicle *ad hoc* network technology, safety assistant driving technology of ICV. It can better monitor and judge the vehicles and the traffic environment around them, as well as timely and continuous updating and interaction of information.

3.1.1 Vehicle monitoring and scheduling

In the process of hazardous materials transportation, the real-time state of the carrier is very important. This module uses GPS, GIS, wireless communication network, RFID technology, sensor technology, multimedia and other related techniques for basic positioning and monitoring of all controlled vehicle, and real-time continuously display the vehicle state information and scheduling information, such as vehicle operating speed, acceleration, vehicle routes, continuous driving time, braking pressure and related security information. In addition, the real-time safety monitoring of the vehicle operating state, acquisition of the related data in the vehicle operating process. The data can be saved to the vehicle information database, its working principle as shown in Figure 2.

3.1.2 Driver fatigue monitoring

The main function is to analyze the driver's eyes movement video transmitted by the vehicle monitoring system through the vehicle alarm system, and then calculate the fatigue index of the driver.

Fatigue index is the function of the driver's eyes closing time. Setting a threshold which corresponding to the driver's eyes closing time. Once exceeded this threshold (time), the driver is determined to be fatigue driving. The alarm system will receive the alarm information from the vehicle monitoring system,

Figure 1 Framework of system function design

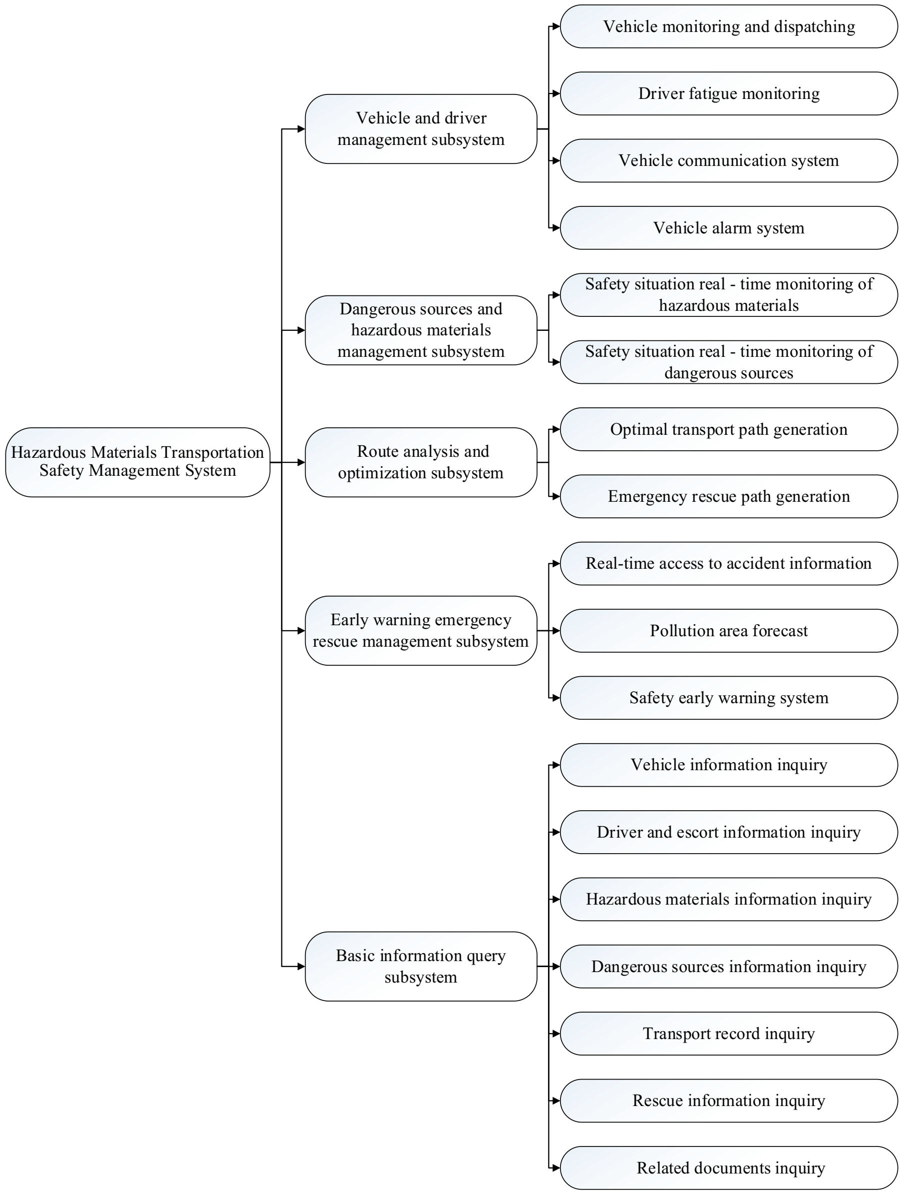
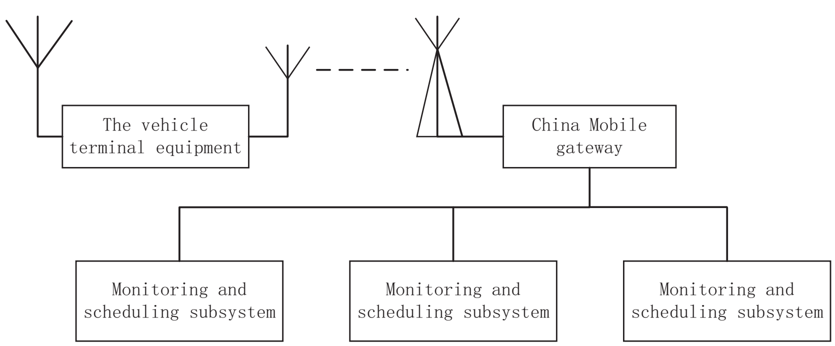


Figure 2 Principle of vehicle monitoring and dispatching



and the alarm information will also be alarm to the driver through the vehicle monitoring system, which can reduce the potential risk of fatigue driving. Here we set the threshold of fatigue index is 10 (corresponding to 4 s eyes closing). If the driver's eyes closing time is more than 4 s, that is the fatigue index is more than 10, the driver is judged to be fatigue driving (Ma *et al.*, 2015).

3.1.3 Vehicular communication system

The system uses the Socket communication technology to realize the real-time communication between the monitoring system and the GPS terminal, the design process is shown in Figure 3. This system realizes the real-time communication of a monitoring center and multi GPS; data transmission is so stable and efficient that can be a variety of information transmission like speech and action; cross platform data transmission and rapid mobilization of emergency rescue force after the accident.

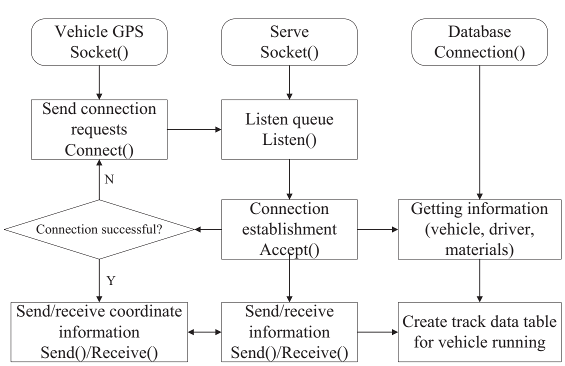
Vehicle communication system includes a GPRS module, sent the location information and system control signal to the server through the communication network of China Mobile Company. At the same time, the system control information sent by the server is received, and the data communication among subsystems is completed. The real-time communication between the vehicle terminal and the server is carried out through the China Mobile GPRS network, and the real-time communication between the clients of the command center is carried out through the internal local area network or internet.

The system also includes the function of the car phone, mainly through the voice processing module to complete the voice communication between the command center and the vehicle terminal equipment.

3.1.4 Vehicle alarm system

Vehicle alarm system is divided into vehicle automatic alarm and driver active alarm. Vehicle automatic alarm is a series of alarm behavior which is real-time monitoring by the vehicle monitoring system to the controlled vehicle, such as over speed alarm and vehicle abnormal alarm. The alarm information will be real-time response to the driver, but also time back to the server. After that, the driver immediately handles the emergency and waits for the server to release the relevant decision, meanwhile execute the received instructions in time. The driver's active alarm is usually in the case of traffic accident or the vehicle terminal system is damaged, moreover cannot communicate with the server in time. Therefore, the driver takes the initiative alarm to obtain the corresponding rescue.

Figure 3 Network communication process



3.2 Dangerous sources and hazardous materials management subsystem

The safety of dangerous sources and hazardous materials is the most important thing in the hazardous materials transportation. Hazardous materials have certain harmfulness, and will produce new potential hazards in transportation. Once an accident occurs, it will cause huge casualties and economic losses to the society.

In the process of hazardous materials transportation, a series of sensors, such as temperature, pressure and fireworks, are used to track and monitor the dynamic information of temperature, pressure and leakage of hazardous materials. The subsystem in addition to the real-time monitoring for the safety situation of hazardous materials in the transportation process, it monitors the safety status in real time of dangerous sources in relatively static existence. To reduce the losses of society, the corresponding remedial measures should be taken as soon as possible in the case of hazardous materials leakage, explosion or transportation accident.

3.3 Path analysis and optimization subsystem

Based on the analysis of hazardous materials road transportation characteristics, using ArcGIS to fuse the 6 kinds of multi-source information involved in the route optimization of hazardous materials transportation, selecting effective sections suitable for hazardous materials transportation. Then, the paper selects the three factors, including road transportation risk, sensitive target population and transportation time, and designs a hybrid algorithm to solve the optimal transportation path of hazardous materials. With the help of ArcGIS Engine + C# platform, database technology and Socket network technology to develop the of hazardous materials transportation route optimization system. The hazardous materials transport vehicles from the transport path optimization to the monitoring during the transportation, and emergency rescue path planning and comprehensive management after the accident occurred are realized.

3.3.1 Generation of optimal transportation path

3.3.1.1 Multi source information fusion. There are six kinds of multi-source information in the subsystem, including vector geographic information, key protected place information, population distribution information, vehicle location information, emergency resource information and road interruption information. With the strong data storage, data fusion and visualization functions of GIS, the subsystem comprehensive use of ArcGIS, Google Earth and database technology, storing the multi-source information in the form of attribute fields in the background. Then the road transportation were screened to determine the effective road for the hazardous materials transportation, they will provides a powerful data support for the path optimization.

3.3.1.2 The generation of optimal transportation path. There are four characteristics in road transportation of hazardous materials: first, hazardous materials have different transportation risks in different sections; second, hazardous materials in transit are dangerous sources of flow, and it is necessary to serve the destination as soon as possible; third, hazardous materials transportation accident may have a significant impact on the surrounding personnel and the natural environment, especially the leakage of toxic gases, the explosion of flammable and explosive products; fourth, hazardous materials transportation accident has the characteristics of sudden, delay, long-term and social, even some accidents easily lead to a certain degree of panic.

Comprehensively considering the characteristics of the hazardous materials transportation, the hazardous materials transportation risk, sensitive target population and transportation time are selected as the attribute elements of effective sections, the calibration methods of each element are as follows.

1 Road transportation risk

Using the traditional transportation risk definition model, as shown in formula (1) (R. Bubbico *et al.*, 2004).

$$R_{ij}^{k} = l_{ij} \cdot p_{ij}^{k} \cdot M^{k} \tag{1}$$

where:

R_{ij}^{k} = risk value produced by the dangerous goods K passing through the road section ij;
l_{ij} = length of the road section ij;
p_{ij}^{k} = probability produced by the accident of hazardous materials K passing through the road section ij; and
M^{k} = loss caused by the accident of hazardous materials K.

2 The number of sensitive target population

Buffer analysis in GIS has powerful functions of map information space retrieval and comprehensive processing of information. It can accurately and visually measure the population distribution around the hazardous materials transportation section. Take hazardous materials transportation section as the essential factor, take hazardous materials leakage or explosion impact radius as a buffer zone to establish buffer. Computing the total population of facilities covered by the buffer (schools, hospitals, hotels, scenic spots), it is defined as the sensitive target population. Calculate the number of sensitive target population according to formula (2).

$$Q_{ij}^{k} = \sum m_r \cdot pop_r \tag{2}$$

where:

Q_{ij}^{k} = sensitive target population of dangerous goods K through the road section ij;
mr = total number of the place r in the buffer field; and
$popr$ = number of people at the place r.

The subsystem takes the road network of Lanzhou city as an example, on the influence radius d_k = $0.1km$ of hazardous materials transportation risk as the benchmark. It using ArcGIS on the road buffer analysis, demographic results of sensitive targets are obtained. Its spatial distribution is shown in Figure 4.

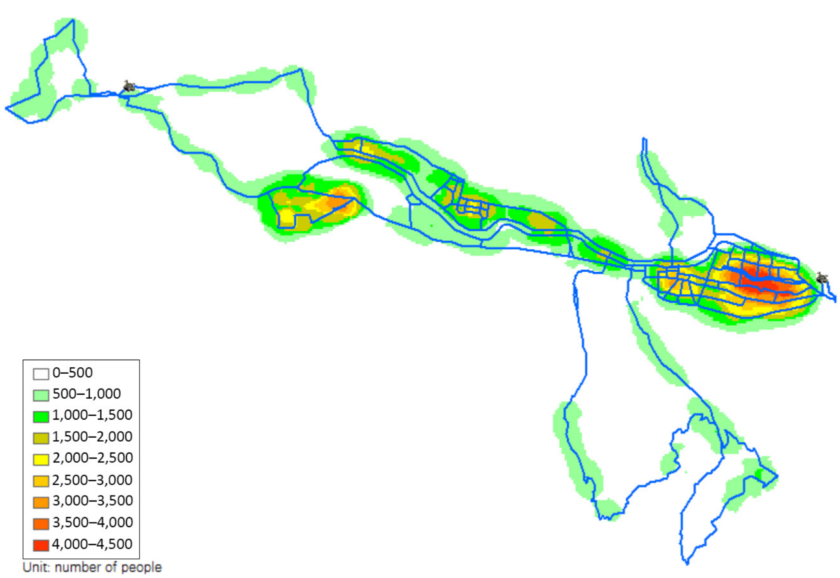
3 Transportation time

The transportation time can be calibrated according to the historical record returned by the GPS for installation of hazardous materials transportation vehicles. The traffic information center can also collect the road network and vehicle data through the road infrastructure, and deal with the relevant data in the environment of vehicle networking. Traffic flow data of each monitoring point and road network are obtained, and then the road transport time is calibrated by using the United States Federal Highway Administration function (BPR function).

$$t_{ij} = t_{oij}\left[1 + \alpha\left(\frac{x_{ij}}{U_{ij}}\right)^{\beta}\right] \tag{3}$$

where, t_{ij} is the impedance of the road section ij; t_{oij} is the zero flow impedance of the road section ij; u_{ij} is the traffic capacity of the road section ij; x_{ij} is the road traffic flow; and α and β are the blocking coefficients. Wang Shusheng,

Figure 4 Spatial distribution map of sensitive target population in each section of Lanzhou



Huang Wei and other scholars combined with China's national conditions to improve the BPR function, improved coefficient $\alpha = 0.5668$, $\beta = 1.443$.

4 A hybrid algorithm for optimal transportation routing
Based on the combination of the above six kinds of information and the effective transportation section is determined, comprehensively considering the three elements of transportation risk, sensitive target population and transportation time. First, entropy method is used for information fusion. And then, the comprehensive impedance of road section is obtained. Finally, the Dijkstra algorithm is used to get the optimal transportation path. The algorithm flow chart is shown in Figure 5.

The specific operation process of solving the optimal transportation path is explained below:

- *Step1*: using the ArcMap + Googel vector map, the multi-source information is stored in the form of attribute table, and carrying out the information fusion.
- *Step2*: after multi-source information fusion, take the road section as the factor and the hazardous materials influence scope as the bandwidth, uses the ArcGIS to make the buffer analysis.
- *Step3*: whether the buffer zone contains key protection sites (water, chemical plants, power facilities, military control areas), if included, determined road as invalid section, road impedance set to be infinite; otherwise, Step4.
- *Step4*: determine the road as effective section, and respectively calculate its transportation risk, sensitive target population, transportation time.
- *Step5*: using entropy method to fuse information and solve the impedance of road section;
- *Step6*: using Dijkstra algorithm to solve the optimal transportation path.

3.3.1.3 Path visualization. ArcGIS Engine is a GIS control based on component object model (COM) technology launched by Environmental Systems Research Institute Company after ArcGIS 9, it can realize the map browsing and editing function, spatial information query and data analysis and rendering functions. The system uses the ArcGIS Engine + C# component type two development platform to realize the visualization of the hazardous materials optimal transportation path.

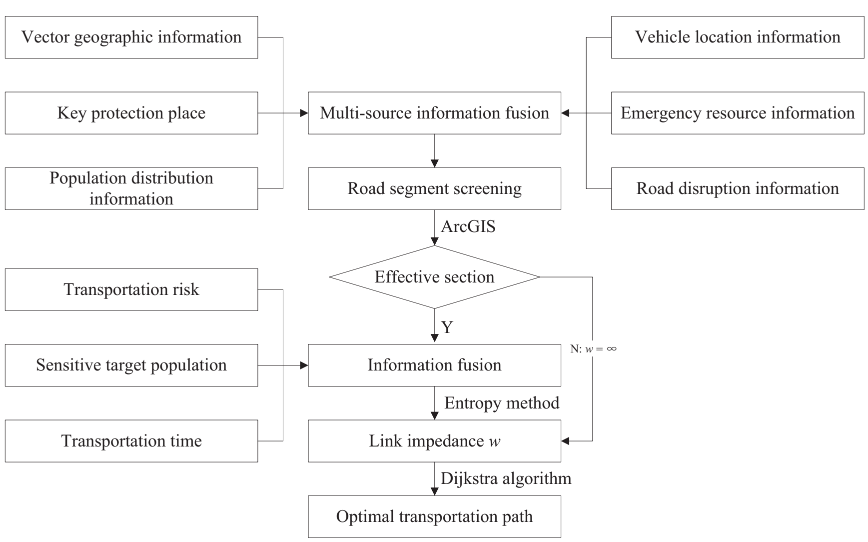
3.3.2 Generation of emergency rescue path
The rescue of hazardous materials transportation often requires multi agency cooperation. After the accident, first, querying the types of hazardous materials through the basic information query subsystem. And then, selecting the emergency rescue plan through early warning and emergency rescue management subsystem, searching the corresponding rescue agencies, and providing emergency rescue path.

The generation of emergency rescue path, which is taking the transportation time as the road impedance, using Dijkstra algorithm to solve it. Through the interface programming of the map layer, the emergency rescue path is visualized, and the emergency rescue route navigation map is released to the rescue agency, achieving rapid rescue and minimizing the loss.

3.4 Early warning and emergency rescue management subsystem

Hazardous materials should not be underestimated whether in transportation or in static state. To minimize the serious consequences caused by hazardous materials, the emergency rescue management subsystem accordingly carries out the emergency rescue management of hazardous materials as an independent module. This subsystem combines the information fusion technology and data processing technology of the ICV. It can obtain the first-time data quickly and timely, under certain criteria, using computer technology to analyze and synthesize the multi-source information, accordingly produce complete, accurate and effective comprehensive information.

Figure 5 Flow chart of hybrid algorithm for solving optimal transportation path



3.4.1 Real-time access to accident information

Facing the hazardous materials such a special type of freight transportation, we must always grasp the hazardous materials transportation status or the safety of dangerous sources. Real time acquisition of accident information is the real-time acquisition and transmission of information through the vehicle and driver management subsystem and dangerous sources and hazardous materials management subsystem. The vehicle and driver management subsystem real-time reflects the accident information to the server through real-time monitoring and alarm system, such as real-time vehicle location, vehicle status, driver status, etc.; the dangerous sources and hazardous materials subsystem can quickly and accurately return the current safety situation of hazardous materials through the real-time monitoring of hazardous materials.

3.4.2 Pollution area forecast

There are many kinds of hazardous materials, and most of them have different degrees of pollution. After the dangerous source accident or hazardous materials transportation accident, it is bound to cause serious destruction and pollution to the surrounding residents, environment and public facilities within the scope of the accident point as the center. Therefore, the pollution area forecast after the accident is also a key point to take effective rescue measures.

The influence area of hazardous materials transportation accident depends on the nature of the hazardous materials, environmental characteristics, weather, wind speed and so on. In this paper, Gauss plume model is used to simulate the contaminated area, the model formula (4) is:

$$X(x,y,z,t,H) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\frac{y^2}{\sigma_z^2}\right) \times \left[\exp\left(-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right) + \exp\left(-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right)\right] \quad (4)$$

where X is the value of pollutant concentration ($\mu g/m^2$); x is the distance to the wind direction (m); y is the crosswind distance (m); z is the target elevation (m); t is the time after the hazardous materials leaks (s); H is the pollution source altitude (m); Q is the release rate of hazardous materials (g/s); u is the wind speed (m/s); σ_y and σ_z are the diffusion parameters of Y direction and Z direction respectively (m).

Based on this model, early warning and emergency rescue management subsystem can generate pollution area maps with different concentration levels based on the leakage source of hazardous materials, command centers and rescue forces can be targeted to evacuate people in the forecast area, thereby reducing and avoiding casualties.

3.4.3 Security early warning system

Based on the analysis of hazardous materials transportation vehicles safety monitoring, a safety warning module of hazardous materials transportation vehicle is designed by using sensor technology, communication technology, global positioning system and hardware in the loop simulation technology. Real time monitoring of hazardous materials transport vehicles safety parameters by vehicle monitoring system, such as the tank temperature, pressure, liquid level, vehicle speed and vehicle distance. The monitoring data are sent back to the existing Tianxingjian platform of transit vehicle management system, to realize data sharing and monitoring. Before the accident occurs, the safety parameters of the hazardous materials transportation vehicle can be perceived. When the accident occurs, the system sent out alarm in advance to remind the driver taking immediate measures to avoid the accident. At the same time, the Tianxingjian monitoring platform can also real-time query the vehicle's driving state, including the location, speed information. Even if an accident occurs, it can also locate in time to carry out rescue and minimize the accident loss. This module's innovation are effectively monitor the security risks of hazardous materials transportation vehicle's inside and outside, automatic test a large amount of given data and effective simulation of tank cars road running.

According to the characteristics of different hazardous materials, different transportation vehicles and different transportation routes, the emergency rescue plan for all kinds of hazardous materials accidents is stored beforehand in the system database. According to the real-time accident information obtained by this module and the predicted pollution area size, the best emergency rescue plan is screened and implemented. In the specific implementation of the rescue process, the system will receive important rescue instructions from the command department at the server side. After the implementation, the system will improve the corresponding emergency rescue plan, to provide more rapid and efficient implementation of the rescue.

3.5 Basic information inquiry subsystem

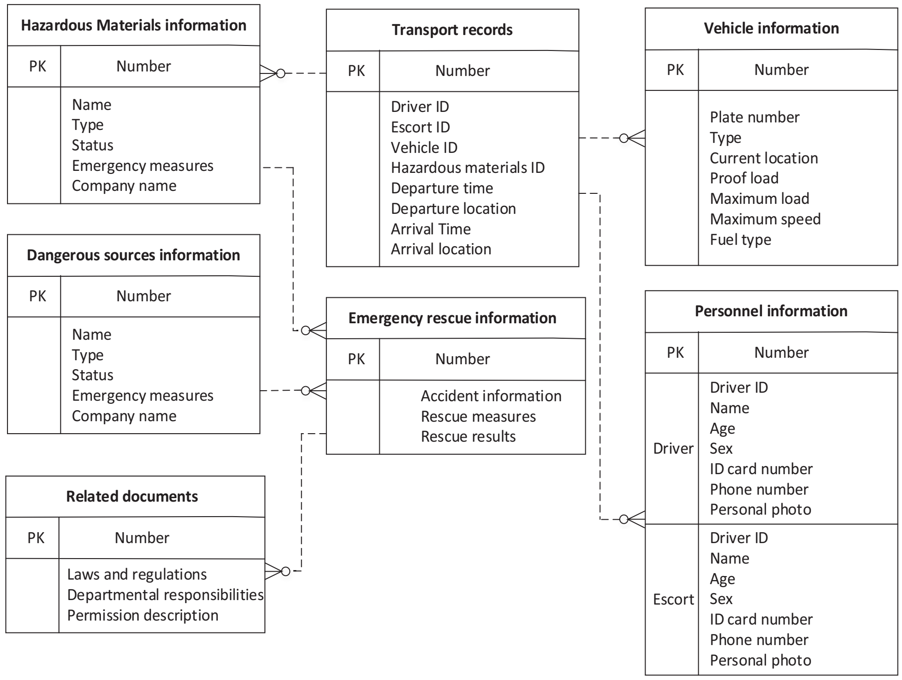
The subsystem provides a series of information query interfaces for different users, and each subsystem stores the basic attribute information or records in the corresponding database while working. The transportation enterprise of hazardous materials, shipper, individual departments and driver families by verifying the validity and legitimacy, they can query the vehicle information, driver and escorts information, dangerous source and hazardous materials information, record information, rescue information and related documents in the scope of authority from the monitoring center database.

Interface programming of each data table in the hazardous materials transportation basic information management database according to the design principles of composite multiplexing. Taking the transportation record table as the core, the following table relations are connected with the personnel information table, the vehicle information table, the hazardous materials information table, the dangerous sources information table, the rescue information table and the related documents information table. The information increase, delete, change and check are realized through the encapsulation database operation class. The relationship between the data tables is shown in Figure 6.

3.5.1 Vehicle information query

One part of the vehicle information comes from the original database input to the basic information of the vehicle, another part is the real-time updating of the vehicle information in the database when the vehicle and driver management subsystem

Figure 6 Data tables relation diagram



operates. The users who are allowed to query the information can query the vehicle type, brand, load, whether to get out of the car for transportation tasks, the current position and other relevant information.

3.5.2 Drivers and escorts information query

One part of the driver information from the basic information input of the original database, another part from the real-time update information on the driver vehicle and driver management subsystem, such as whether the driver is driving, physical status and other real-time information. The users who are allowed to query the driver's information can query the driver's name, sex, age, number, length of service, affiliation, contact, and whether to carry out transportation tasks and other relevant information. They can query escort related basic information like the driver's.

3.5.3 Hazardous materials information inquiry

One part of the hazardous materials information from the basic information input of the original database, such as type, name, number of hazardous materials, and whether to participate in transportation operations, another part comes from the dangerous sources and hazardous materials management subsystem to update the real time condition of hazardous materials, such as the increase and decrease of the quantity, the change of the hazardous materials status, etc. The users who are allowed to inquire the information can inquire about the latest situation of hazardous materials.

3.5.4 Dangerous sources information inquiry

The basic information of the dangerous sources include the name, type, nature, protection method, emergency treatment method and so on. All of this basic information is stored in the initial database. In addition, through the real-time monitoring of the dangerous sources and hazardous materials management subsystem, the real-time information of the dangerous sources will be updated, such as the change of the inventory of hazardous materials before and after the transportation task. According to the specific requirements of the relevant departments, the dangerous sources information open query permissions only for some users.

3.5.5 Transportation records query

Transportation records occurred after the transport operation, mainly include transport path generation in path analysis and optimization subsystem, real-time generation of transport paths and vehicle trajectory images by the vehicle monitoring and scheduling module in vehicle and driver management subsystem. Besides, transportation records include the relevant information of vehicles, drivers, escorts and hazardous materials in a transport operation. The users who are allowed to query this information can query transportation records or replay the vehicle running tracks and images.

3.5.6 Rescue information query

Rescue information is generated after the implementation of rescue operations, they are divided into three aspects: before the rescue, during the rescue and after the rescue. Rescue information includes historical accident information, specific rescue measures and the results after rescue. The users, who are allowed to query the information, can retrieve the corresponding rescue information for verification or analysis as needed.

3.5.7 Related documents query

Related documents include the relevant laws and regulations on hazardous materials transportation, the responsibility of hazardous materials supervision department, the system use and query permissions description etc. The users who are allowed to query the information can inquire about the relevant laws and regulations.

4. Conclusions and prospect

4.1 Conclusions

The combination of hazardous materials transportation safety management system under the vehicle-infrastructure connected environment and ICV technology, which can improve the efficiency and safety of hazardous materials transportation to a greater extent. The design of hazardous materials transportation safety management system is discussed in this paper, revolves around strengthening the management of hazardous materials transportation on roads, integrates information management, emergency rescue management, path optimization and other functional modules on the basis of predecessors. A dynamic route optimization model and geographic information system are integrated to build a more comprehensive safety management system for hazardous materials transportation. It not only includes the management of basic information such as goods, vehicles and drivers in the transportation of hazardous materials, but also strengthens the safety and efficiency of transportation. The system expanding the range of users for hazardous materials transportation management system, breaking the situation that the government or the owner of the goods company is supervised independently, realizing the mutual supervision between government and individual, and the information communication among different regions, departments and enterprises, making the transportation process of hazardous materials transparent. Before the accident, the monitoring system and the early warning system can provide timely warning information, and relevant departments or personnel take effective measures to avoid accidents. At the moment of the accident, the power and responsibility can be clearly defined, and the further development of the accident can be controlled at the first time, the occurrence of secondary accidents can be avoided. The path optimization system not only optimizes the normal transportation path, but also provides the emergency rescue path, which effectively improves the safety and efficiency of the hazardous materials transportation.

This paper theoretically perfects the incomplete areas of existing hazardous materials transportation management system, but also has some shortcomings. In addition to the subsystem involved in the paper, there are some basic functional modules not discussed in detail, such as vehicle navigation, vehicle registration, accident processing flow, etc.

4.2 Prospect

The particularity of hazardous materials transportation is unavoidable. Therefore, while designing and developing a perfect transportation management system, it is necessary to enhance the transportation safety capability of transport equipment. Nowadays, the intelligent driving assistant system, which is widely promoted in China, integrates location-aware technology. If it can be combined with hazardous materials transportation in the future, in addition to better coordinated vehicle-infrastructure control, unmanned driving is also a great breakthrough for the hazardous materials transportation. Integration of intelligent transportation and vehicle-borne information products is a better development direction for hazardous materials transportation industry. Intelligent connected has become an internationally recognized future development direction, which will greatly promote the development of hazardous materials transportation and the improvement of transport safety. To develop hazardous materials industry more safe and efficient, we should strive to establish a scientific, effective and well operated dynamic safety management system for hazardous materials road transportation. Combining the ICV technology, it can realize the efficient management of all kinds of information, dynamic and real-time supervision of the whole process of hazardous materials transportation. Furthermore, to strengthen the construction of emergency rescue management system, and provide effective cross departmental and trans regional supervision mode. To further optimize and perfect, the corresponding data should be obtained to evaluate the system on this basis. At the same time, the governments departments need to improve the relevant institution, strongly cooperate with enterprises to carry out safety management of hazardous materials transportation. Enterprises should also strengthen the training on all aspects of personnel quality, and actively promote the safety management of hazardous materials transportation, to provide more reliable security for the country and people.

References

Aini, M.S., Fakhru'l-Razi, A., Daud, M., Ibrahim, W.M.N. and Tangavelu, S.K. (2001), "Study on emergency response preparedness of hazardous materials transportation", *Disaster Prevention and Management: An International Journal*, Vol. 10 No. 3, pp. 183-188.

Bubbico, R., Cave, S.D. and Mazzarotta, B. (2004), "Risk analysis for road and rail transport of hazardous materials: a GIS approach", *Journal of Loss Prevention in the Process Industries*, Vol. 17 No. 6, pp. 483-488.

Daniels, R.S. and Daniels, C.L.C. (2002), *Transforming Government: The Renewal and Revitalization of the Federal Emergency Management Agency*, Nova Science Publishers, New York, NY.

Emergency Management Institute (2003), *Principles of Emergency Management*, Independent Study IS-230.

Fabiano, B., Curro, F., Palazzi, E., *et al.*, (2002), "A framework for risk assessment and decision-making strategies in dangerous good transportation", *Journal of Hazardous Materials*, Vol. 93 No. 1, pp. 1-15.

Fabio, V., Giammarco, Z., Piefrancesco, L. and Pietro, C. (2009), "A telecommunications framework for real-time monitoring of hazardous materials transportation", *2009 9th International Conference on Intelligent Transport Systems Telecommunications, ITST 2009*, pp. 13-18.

Huang, P. (2018), *Development of Management Information System for Hazardous Materials Road Transportation*, Chang'an University, Beilin.

Julian, (1993), "Management of hazardous materials transportation: the European approach", *Proceedings of the*

IEEE-IEE Vehicle Navigation and Informations Systems Conferenee, pp. 674-678.

Kara, B.Y. and Verter, V. (2004), "Designing a road network for hazardous materials transportation", *Transportation Science*, Vol. 38 No. 2, pp. 188-196.

Li, H.S. (2013), *The Constitution of Unconventional Emergency Preparedness System and Study of Evaluation Theories and Methods*, China Emergency Management, China, Vol. 8, pp. 13-21.

Lian, B.K. and Liu, J.Q. (2006), "Analysis of GPS transportation monitoring technology for hazardous materials", *Journal of Safety and Environment*, Vol. 6, pp. 173-175.

Liu, T.M. (2011), "Research on conceptual design of emergency plan system for emergencies", *China Safe Production Science and Technology*, Vol. 8, pp. 5-13.

Lu, Y.D. (2018), *Research on Real-Time Risk Early Warning Method for Road Hazardous Materials Transport Vehicles*, China University of Geosciences, Beijing.

Ma, X.L., Liu, Y.J. and Lu, Y. (2018), "Risk assessment of urban road hazardous materials transportation", *Chinese Journal of Safety Science*, Vol. 28 No. 5, pp. 179-184.

Ma, Q.Y., Wang, C., Lu, J. and Gao, T.T. (2015), "Development of comprehensive emergency management system for road transportation of hazardous materials", *Safety and Environmental Engineering*, Vol. 22 No. 5, pp. 107-112.

Pasquale, A., Giuseppe, L. and Antonio, Z. (2005), "Multi-agent remote predictive diagnosis of hazardous materials transportation", *Conference Record-IEEE Instrumentation and Measurement Technology Conference*, Vol. 3, pp. 685-690.

Pietro, C., Vieri, D.B. and Luigi, L. (2008), "Using problem frames to model the requirements of a system for monitoring hazardous materials transportation", *Proceedings International Conference on Software Engineering*, pp. 60-66.

Romano, A. and Romano, G. (2009), "A decisional support to quantify risk due to the transportation of dangerous substances", *WIT Transactions on the Built Environment*, Vol. 108, pp. 565-573.

Shi, L. (2014), "Statistical analysis of hazardous materials road transportation accidents and establishment of comprehensive management system", *Chang'an University*, Vol. 3 No. 65.

Tang, X.L. and Yang, Y.M. (2007), "About the application of radio frequency technology in the transportation of hazardous materials", *Safety Science and Technology*, Vol. 5, pp. 5-6.

Tao, C.X., Yan, X.P. and Liu, Q. (2007), "Research on early warning and emergency linkage mechanism of hazardous materials transportation", *Journal of Wuhan University of Technology*, Vol. 31 No. 6, pp. 980-983.

Wu, J.Z. (2015), "Analysis and countermeasure research on the safety supervision system of hazardous materials road transport", *Road Traffic Technology*, Vol. 32 No. 12, pp. 15-23.

Zhao, J.Y., Liu, D.X. and Sun, W. (2008), "Framework design of road hazardous materials transportation management information system", *Journal of Chang' an University*, Vol. 28 No. 2, pp. 75-79.

Further reading

Yu, M.Y., Li, S.W., Xie, X.L. and Yang, S.Q. (2010), "Analysis and countermeasure research on the supervision process of road hazardous materials transportation", *Highway Traffic Science and Technology*, Vol. 27 No. 8, pp. 155-158.

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