RESEARCH ON EMERGENCY RESPONSE SYSTEM OF DANGEROUS GOODS TRANSPORTATION VEHICLES

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ABSTRACT:

Due to the flammable, explosive, corrosive, radioactive and other characteristics of dangerous goods, if a traffic accident or leakage accident occurs during transportation, it will seriously endanger public safety and the safety of people's lives and property. It is of great significance for urban safety and stability to establish a risk early warning mechanism, ensure the safe transportation of dangerous goods, and formulate emergency rescue measures. In view of the problems that may occur during the transportation of dangerous goods, such as weak supervision, low efficiency in obtaining accident information, and difficulty in emergency treatment, this paper constructed a comprehensive perception and collaborative integration of urban emergency response system by integrating vehicle target intelligent monitoring platform and decision support platform. Under the support of target detection and tracking technology, PyQt5 is used to build an intelligent vehicle target monitoring platform based on satellite video data, which realizes the real-time tracking, monitoring and early warning functions for dangerous goods transport vehicles, and can quickly complete the location of emergencies and the statistics of environmental road information after an accident. With the support of database technology and ArcGIS Engine embedded component library, a decision support platform integrating statistics and spatial analysis is constructed. GIS technology is used to realize the spatial analysis of emergency points and basic information management functions. At the same time, the platform is based on the two basic starting points of fast response to emergency events and high scheduling efficiency, which realizes the rapid determination of the accident impact area and the planning of emergency rescue routes. Taking Chengdu as an example, the emergency response system constructed in this paper can monitor dangerous goods transport vehicles in the urban area in real time, and formulate emergency response measures in seconds. The system is conducive to reducing the damage and loss caused by emergencies and improving the informatization level of emergency related departments.

1. INTRODUCTION

With the rapid development of China's social economy and the increasing scale of the transport of dangerous goods, dangerous goods transportation attracts people and accumulates wealth but also gathers risks. Risk management in the transportation of dangerous commodities has become an issue that cannot be ignored and has been placed on the agenda. In order to avoid dangerous goods road transport accidents, deal with the accidents in a timely manner after the accidents, and minimize the harm of the accidents, it is necessary to conduct in-depth research on the emergency mechanism and security system of road transport of dangerous goods, and establish a sound safety supervision and emergency response system of dangerous goods transport.

In China, research on the transport safety of hazardous materials began rather late. With the continued development of GPS and GIS technologies, a number of domestic researchers have done pertinent studies on the movement of hazardous materials. Comprehensively utilizing intelligent transportation system, global satellite positioning system, geographic information system, and other means, (Zhao et al., 2008) constructed the framework of a road dangerous goods transportation management information system. However, the above research remains in the primary qualitative stage, lacks real data support, and it is difficult to provide information support for the effective management of road dangerous goods transportation. (Li et al., 2017) developed an ArcGIS-based road dangerous goods transport emergency response system to address the issue

of emergency rescue in road dangerous goods transport, thereby enhancing the effectiveness of emergency rescue. However, command and coordination of rescue forces are limited to their individual specialties and geographic domains, and there is no formal system for coordination and unification. (Xu et al., 1999) employed GIS/ES technology to carry out emergency management of risky commodities road transport, which considerably enhanced emergency management personnel's ability to respond swiftly to unforeseen accidents, but had limited capacity for systematic accident prevention. (Deng Ting, 2014, Lu Xiaojun, 2022) The dangerous goods transport vehicle management system developed based on GPS technology or deep learning technology has realized the whole road section monitoring of transport vehicles, effectively reducing the probability of safety accidents, but the absence of rapid response function after accidents has delayed rescue. In addition, missing trajectories caused by the loss of vehicle GNSS lock make it impossible to find non-cooperative targets, preventing the acquisition of environmental information surrounding the vehicle. What's more, the monitoring perspective and visual field are limited in the construction system based on the ground video. In conclusion, there are still some flaws in the current road transport management system of dangerous goods in China, which are manifested primarily as follows: on the one hand, the emergency competent department is unable to manage the vehicle operation effectively, making it difficult to effectively control the accident risk and reduce the frequency of accidents. On the other hand, due to the lack of accident information or the slow acquisition of accident information due to the traditional

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methods of on-site recording, the emergency competent department is unable to dispatch rescue forces in a targeted and scientific manner in order to reduce the loss caused by the dangerous goods transportation accident. In general, the lack of effective communication and integration between the hazardous goods transport vehicle management system and the decision support platform has posed greater challenges to the ability of urban emergency management services to share information in real-time and to coordinate the system as a whole.

Consequently, this paper integrates vehicle target intelligent monitoring and a decision support platform to construct a comprehensive perception and collaborative integration of a dangerous goods transport emergency response system to meet the actual needs of dangerous goods transport safety management. In light of the high frequency of accidents involving the transportation of dangerous goods, an intelligent monitoring platform is developed by integrating target detection and target tracking algorithms based on deep learning, utilizing video satellite data to monitor and track dangerous goods transportation vehicles, and determining the location of emergencies based on the operation status of the vehicles (Ali et al., 2019). It gives more detailed vehicle operation and environmental data than conventional GPS, while eliminating the issue of GPS traces going lost. Targeting the issues generated by the complex emergency response process, such as insufficient rescue efforts, arbitrary resource allocation, and excessive consumption of human and financial resources. This work develops an auxiliary decision-making platform based on ArcGIS Engine, establishes a database of emergency resources, and thoroughly comprehends emergency resources' pertinent information. Through spatial analysis of emergencies, the impact scope of accidents and suitable allocation of current resources are evaluated, and evacuation and rescue routes are designed (Yang et al., 2014). The system is able to monitor the running state of vehicles throughout the entire process, reduce the probability of risk accidents, quickly determine the location

of emergencies after accidents, shorten the response time to emergencies, provide emergency decision makers with a rapid decision-making basis, swiftly and scientifically formulate response measures to emergencies, and reduce the losses caused by accidents (Shen et al., 2006, Chen et al.,2019, Ye et al., 2008).

2. SYSTEM DESIGN

2.1 The Overall Structure

The system adopts the C/S technology framework, combines database technology, computer vision technology, ArcGIS Engine component development technology and system integration technology, and adopts the mode of function control flow and data flow cross organization to realize real-time monitoring of hazardous goods transport vehicles and the auxiliary decision-making function of emergency response on the basis of GIS spatial analysis (Zhu et al., 2009, Li et al.,2013). The system is developed and implemented with the idea of object-oriented design in a Windows environment, with consideration for the flexibility, ease of use, scalability, and security of the system, as well as the operability of users.

Based on detailed and accurate spatial geographic data, GIS technology is used as a spatial analysis tool, and computer vision technology is combined to construct a comprehensive perception and collaborative integration of urban emergency response systems to meet the needs of emergency response and assist command decision-making (Xu et al., 2019). Based on the principle of easy expansion and loose coupling, the system adopts the idea of hierarchical design. The overall architecture is composed of three layers, each of which is described below.

(1) The data layer. The data layer is an important foundation for the normal operation of the system. It is primarily utilized to store, access, and manage spatial and non-spatial data as well as provide data services for the application layer.
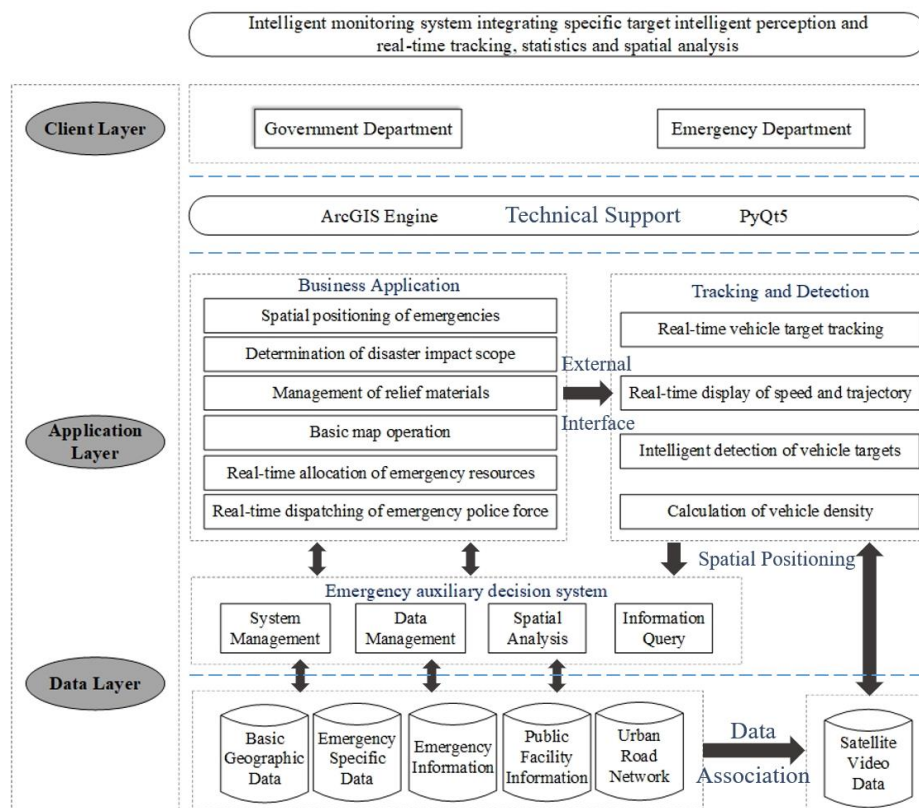

Figure 1. Overall framework of the system.

(2) The application layer. On the basis of the data layer and the technical support framework, the application layer implements the business management, decision support, information service, intelligent monitoring, and other application services required for emergency response by relevant collaboration departments.

(3) The client layer. The client layer mainly describes the objects for which the system is oriented. Government departments and emergency departments are the principal service objectives of the system and have management rights.

The data layer includes the emergency comprehensive geographic database and the business database. The geographic database is managed by GIS Geodatabase, and the business database is managed by Access2016. The emergency comprehensive geographic database is separated into four categories: fundamental geographic data; emergency-specific data; data on public facilities; and information on urban road networks. Emergency information mainly depends on the detection and tracking of vehicle targets in satellite videos, which is the medium of data sharing between the two platforms and the key to the spatial location of emergencies.

As the core of the auxiliary decision-making system, the application layer comprises of a detection and tracking platform and a business application platform. The integration of the two platforms enables the management, gathering, and update of emergency information, emergency resources, and other data, as well as decision-making GIS services. The business application must establish a connection with the detection and tracking platform by invoking the external system interface, and the detection and tracking platform can provide data information to the business application platform in order to facilitate data sharing between the two platforms. The overall framework of the system is shown in Figure 1.

2.2 The Business Capabilities

The purpose of the emergency response information system is to solve problems associated with the management of dangerous goods transportation vehicles and emergency response in order to ensure the safe transportation of such vehicles and provide information for emergency decision-making in the event that they cause an emergency. The system is primarily composed of three functional groups and seven functional modules, including the satellite video surveillance function group, the data management function group, and the decision-making function group. As depicted in Figure 2, two functional modules comprise the satellite video surveillance function group: vehicle operation tracking and data statistics. The data management function group is comprised of three modules: user management, basic data management, and emergency management. The auxiliary decision-making function group has two functional modules: disaster area analysis and resource allocation analysis.
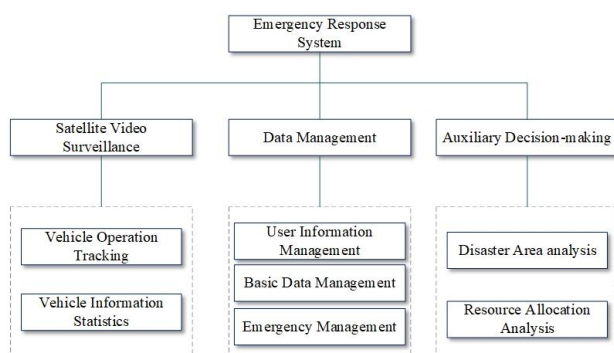
(1) Vehicle tracking module: Track the target vehicle in real time, record and update the vehicle's position, speed, and route information in real time.

(2) Data statistics module: Counting the number and density of other vehicles within a given range of dangerous goods transportation vehicles based on the results of target detection.

(3) User information management module: Implement user authentication and registration functionality.

(4) Basic data management module: This module primarily provides the data management capabilities of adding, deleting, modifying, and verifying auxiliary data (spatial data and attribute data) of disaster emergency response, such as traffic network, emergency rescue organization, emergency relief materials, and open land.

(5) Emergency information management module: It mainly provides the data administration capabilities of adding, modifying, querying and deleting emergency points.

(6) Disaster area analysis module: It realizes the function of calculating the impact range of emergencies, visually displaying the impact range, and counting the number of affected vehicles and environmentally sensitive areas.

(7) Resource allocation analysis module: When combined with road network information and emergency resource distribution information, this module provides supplementary data for emergency rescue decision-making, such as emergency rescue path planning, emergency rescue organization allocation, and emergency rescue material allocation.

2.3 The Design of Database

Data is the indispensable content of system construction and the basis of supporting the system's normal operation. Basic geographic information service, resource information query service, path planning service, and decision support service are required for the urban emergency response system. In order to meet the requirements of system construction, the data is separated into three categories: geographic data, thematic data and emergency information. The geographic data came from the National Geographic Information Open Website, and the thematic data came from the Amap API, with a total of more than 1800 items of emergency thematic object location and attribute information. The emergency information is gathered by detecting and tracking satellite video data via the system's external interface, and then correlating it with the system.

The system database uses GIS Geodatabase for spatial data management and Access 2016 for user data management. The data involved in the system is abstracted into entities according to the data type and system functionality requirements. Entity is a relatively independent real-world phenomenon that cannot be subdivided into the same phenomenon. All entities have some form of interaction or relationship, with other entities (Li, 2009). Table 1 displays the entities present in this system and their corresponding Geodatabase element types.

Figure 2. Functional structure of the system.

Logical Group	Entity	Related Entities	Space Type	Geodatabase Element Type
Geographic Data	administrative division	—	area	area element
	building outline	—	area	area element
	river system	—	line	line element
	road network	—	network dataset	network dataset element
	emergency	—	point	point element
Emergency Information	vehicle	emergency	object	object element
	road environment	emergency	object	object element
	accident impact	emergency	object	object element
	environmentally sensitive area	accident impact	object	object element
	rescue plan	emergency	object	object element
	Emergency rescue organization	rescue plan	object	object element
	emergency rescue material	rescue plan	object	object element
	vehicle trajectory	vehicle	object	object element
	dangerous goods	vehicle	object	object element
Thematic Data	hospital	emergency rescue organization	point	point element
	fire brigade	emergency rescue organization	point	point element
	public security organization	emergency rescue organization	point	point element
	rescue material	emergency rescue material	point	point element
	forest park	environmentally sensitive area	point	point element
	famous scenery	environmentally sensitive area	point	point element
	cultural relics	environmentally sensitive area	point	point element
	public greenbelt	environmentally sensitive area	point	point element
	college and university	environmentally sensitive area	point	point element
	metro station	environmentally sensitive area	point	point element
	government organ	environmentally sensitive area	point	point element

Table 1. Entity and its element type match.

The structure of the data tables is based on the master-slave table method. The master table stores emergency attribute information and road traffic attribute information that must be queried and counted in relation to emergencies. The slave table stores information regarding the vehicles involved in the accident, the road environment, and the accident's consequences. Through keywords, the master and slave data tables establish the connection between distinct entities. In addition, for attribute information in the main table and slave table data items, the reference table method can standardize the attribute data definition on the one hand, effectively reduce the storage space of emergency information on the other hand, and effectively provide system processing speed. The logical relationship between primary data tables is depicted in Figure 3.

Figure 3. Main logical structure of data table.

2.4 System Development

Based on the requirements of the urban emergency system's overall framework design, functional module design, and decision support, the system is divided into vehicle target detection and tracking platform and spatial analysis platform. The vehicle target detection and tracking platform primarily carries out the functions of intelligent monitoring and provides statistical data to the spatial analysis platform. The spatial analysis platform provides the function of spatial analysis of emergencies to meet the decision-making and command requirements of managers. The sharing of data between the two platforms can improve rescue efficiency and system adaptability. The vehicle target identification and tracking platform uses PyQt5 to finish the interface design and incorporates a deep learning-based mechanism for target detection and target tracking. During operation, the identified target information is saved to a file in order to monitor and acquire information on vehicle targets. The geographical analytic platform is implemented using C#, Arc Objects, and object-oriented component development technology in conjunction with ArcEngine 10.2. In the development process, Geodatabase is utilized to realize the table structure design, table relationship establishment, and data entry of geographic data, thematic data, and emergency information, while Access2016 database software is utilized to realize the table structure design and table relationship establishment of user information.

3. SYSTEM FUNCTION REALIZATION

3.1 Vehicle Target Monitoring

Target tracking technology is used to record and transmit the location, route, and speed of transport vehicles in real time to detect whether the vehicles exceed the speed limit or deviate from the route, and simultaneously count vehicle information, thereby achieving positioning, monitoring, recording, statistics, as well as other comprehensive functions.
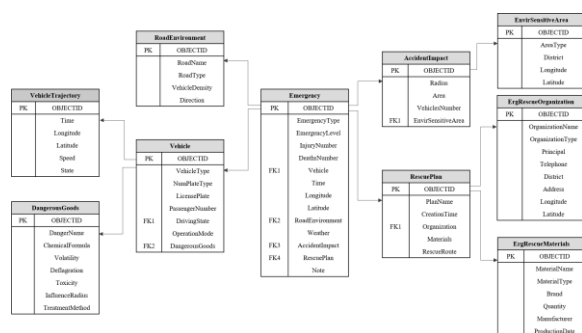
3.1.1 View the Driving Route of the Vehicle：The driving path of the vehicle should be evaluated based on actual requirements when the vehicle is in motion. The trajectory line is a record of the actual location of the vehicle, and monitoring workers can assess if the driving trajectory conforms to the predetermined plan in order to check for an anomalous transport status.

3.1.2 Vehicle Speed Detection：Excessive speed is one of the most common negative aspects of vehicle operation. Excessive speed may result in product deviation or a change in the position of the centroid when performing an emergency stop or turn, which has a direct impact on the transport of hazardous materials and may potentially cause accidents. According to The Measures for The Safety Management of Road Transport of Dangerous Materials of the People's Republic of China, and taking into account that the subject of this article is urban roads, the system sets the speed limit at 60km/h. When the vehicle speed surpasses this threshold, appropriate agencies will receive alert messages.

3.1.3 Vehicle Position Monitoring : The vehicle being tracked is spatially positioned, its location is clearly displayed on the map for monitoring, and the information regarding the vehicle's location is updated in real time in conjunction with the vehicle's movement. In the event that the vehicle is involved in an accident, the emergency points can be directly added to the emergency data table based on the location information obtained from the monitoring. This allow for the provision of spatial information for the response in the event of emergencies.

3.1.4 Statistics of Vehicle Density：The detection results of moving objects. According to the detection results of moving targets, statistical information such as the number and density of vehicles within a certain range around the dangerous goods transport vehicle can be obtained, providing information support for the subsequent spatial analysis-based determination of the impact range of disasters and emergency response.

3.2 Basic Data Management

The basic data operation module focuses primarily on the creation and implementation of relevant basic operation features, such as user authentication, emergency management, and rescue resource management.

3.2.1 User Information Management：It largely satisfies the required system authority management design requirements. The system verifies the password by accessing the user database and querying the user's specific information in order to implement the user's custom account name and password for login verification. Moreover, the system enables user administration functions, such as the creation of users and the modification of user passwords, by updating user tables.

3.2.2 Emergency Management：The emergencies targeted by the system are accidents and disasters that may cause severe social suffering due to natural or man-made causes during the operation of risky goods transport vehicles, and emergency measures are required to address them. Emergency points can be automatically added to the system after an accident through the monitoring location in the vehicle operation tracking module, and this module allows users to performs update operations such as adding, modifying, deleting, and querying emergency points.

3.2.3 Rescue Resource Management：Emergency resource management refers to the centralized management of current emergency rescue resources, including the administration of emergency organizations and emergency supplies. The emergency organization management module primarily realizes the centralized management of relevant emergency units and competent departments, including hospitals, fire brigades, traffic police forces, police stations, and other rescue agencies; the emergency material management module primarily realizes the centralized management of the necessary material support throughout the entire process of responding to public emergencies. This module enables the management of spatial data, including the addition, modification, querying, and deletion of emergency rescue organizations and supplies.

3.3 Auxiliary Decision-making

In order to address the issue of the high destructive force and random location of emergencies, it is necessary that rapid scientific and effective emergency rescue judgments can be made to mitigate the harmful consequences of catastrophes. This system utilizes GIS spatial analysis technologies to rapidly identify the disaster-affected area and aid in the design of rescue routes and resource allocation. The system as a whole accomplishes the comprehensive management of emergencies and the coordination and deployment of emergency resources, so that each emergency department is accountable for linked occurrences based on their classification and classification.

3.3.1 Analysis of Disaster Areas : The magnitude of an accident is a crucial component in determining its effects. The area that may be affected or affected by dangerous products in the event of a transportation accident is referred to as the area of influence of the accident. A semicircle, a circle, a rectangle, and a Gaussian plume model are the four typical geometric forms used to mimic the accident impact region, according to domestic and international research. This study employs a circular graph to simulate the accident influence range of crises, where the accident influence radius is calculated by the evacuation distance, since the circular model is suited for the majority of emergencies. According to the Emergency Response Guide of the US Department of Transportation, the evacuation distance is determined by the evacuation distance standard for various hazardous materials recommended in Table 2.

Type	Radius (km)
Radius (km)	1.6
Inflammable Compressed Gas	0.8
Flammable Liquid	0.8
Flammable Solid	0.8
Oxidizing Substances	0.8
Toxic Substances	8.0
Corrosive Substances	0.8

Table 2. Evacuation distance of different types of dangerous goods.

In the aftermath of the accident, it is essential to evaluate the damage caused by the abrupt accident of the risky goods transport vehicle to other vehicles in the affected area and to evacuate the affected vehicles in a timely manner. The area of the accident disaster zone is determined by the accident scope model described previously, while the density of affected vehicles are determined by the intelligent monitoring platform's statistics. Multiplying the two quantities yields the number of affected vehicles. Accidents involving dangerous items may also cause harm to the social and ecological environments. Through overlay analysis and statistics of environmentally

sensitive areas in the disaster area, such as schools, hospitals, subway stations, scenic spots, etc., decision-makers can gain a thorough understanding of the accident site in order to organize personnel evacuation or take other precautions to protect personnel in the disaster area.

3.3.2   Analysis of Resource Allocation： After an accident, the emergency decision-making department must gather the necessary personnel to carry out site supervision, emergency repairs, and rescue. Therefore, it is essential to comprehend the details around the accident's resource allocation, including personnel and resources. Based on the relevant needs of emergency rescue auxiliary decision-making, with the support of traffic road network data, emergency rescue organization and emergency resource distribution data in the study area, development and implementation of emergency rescue path analysis, emergency rescue organization query, emergency rescue material distribution, and other related auxiliary decision-support functions to provide a solid foundation for decision-makers to organize rescue operations.

There are numerous emergency rescue units in the city, and their distances from the accident site vary. At offer rescue services to the emergency location in the shortest amount of time, it is required to develop the optimal rescue organization and warehouse for rescue materials. After an emergency occurs, the emergency rescue organization query function can quickly locate the addresses, phone numbers, and other pertinent information of the closest emergency rescue organizations, such as public safety, fire, medical, and traffic police. The emergency rescue resource query function provides various rescue materials appropriate distribution. This serves as a resource for enhancing the efficacy of emergency rescue and minimizing the cost of emergency resource scheduling in the emergency rescue of hazardous goods incidents.

After an emergency has occurred, the commander must not only know the location of the rescue resources, but also organize and dispatch them rationally. After determining the rescue organization and the rescue material warehouse, the emergency rescue route analysis can quickly plan the best route from the departure point to the incident location, aid the commander in arranging rescue personnel and dispatching rescue materials to the disaster area, shorten the emergency response time, and reduce the accident hazard.

4. SYSTEM TSET

On the basis of the above system model, this paper selects Chengdu as the simulation research area to analyse the feasibility of the system. By collecting relevant data and materials, including basic geospatial data, emergency resource data and satellite video data in the region, the emergency response system of dangerous goods transport vehicles in Chengdu was established. Due to the lack of satellite video data in Chengdu, satellite video data without geographical coordinates in other regions are used to test the system by simulating events after they are given geographical coordinates in Chengdu.

4.1   Functional Testing

The system carries on the real-time monitoring to the vehicle running process. Figure 4 shows the results of real-time monitoring of the location, speed and driving route of the designated dangerous goods transport vehicles, and counting the number and density of vehicles in the area where the vehicles are located.
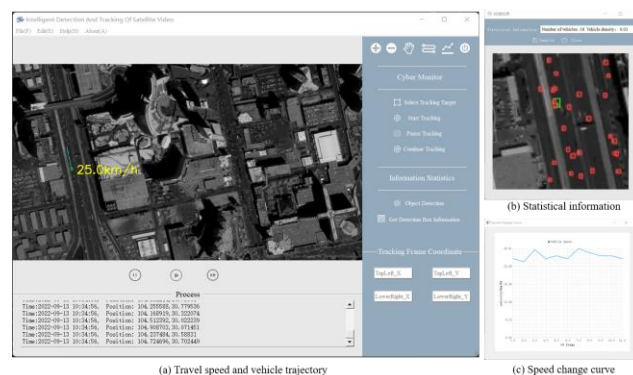

Figure 4. Vehicle monitoring platform information.

After discovering through monitoring that a dangerous goods transport vehicle has been involved in an accident, the management department can examine the impact scope of the emergency event by adding the pertinent parameters into the emergency rescue platform. Figure 5 depicts the results of the simulation's influence range calculation as well as the statistical results of the number of affected cars and ecologically sensitive areas.
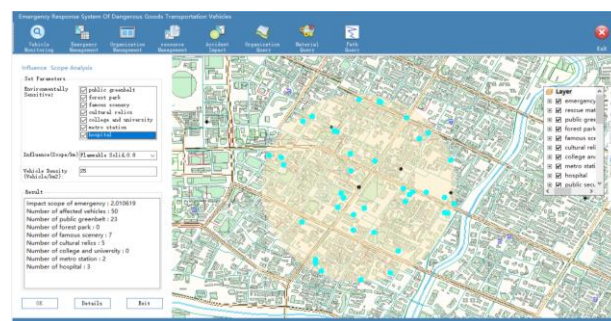

Figure 5. Disaster area analysis results.

In conjunction with the rescue force information stored in the database, the corresponding parameters were entered into the emergency rescue platform to locate the geographical location and contact information of the traffic police, fire protection, medical, and other departments closest to the location of the emergency, and the distribution of rescue materials was made in a reasonable manner. When some stretches of road are impassable due to accidents, obstacle points are marked on the map and the ideal route is suggested depending on the real circumstances for rescue reference. Figure 6 displays the query results and route planning outcomes for the nearest medical department to the emergency spot.
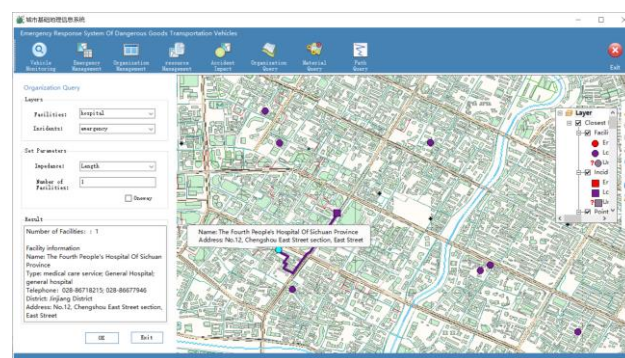

Figure 6. Rescue organization allocation results.

4.2 Test Analysis

In the simulation test of the emergency response system of dangerous goods transport vehicles, each subsystem has a clear division of labor, effectively and comprehensively realized its own functions, and has a high use value, which proves the practicability and scientific rationality of the system.

5. CONCLUSION

Based on computer vision and GIS technologies, this research develops an emergency decision support system that combines intelligent surveillance of vehicle targets and spatial analysis. On the basis of the PyQt5 interface design engine, an intelligent monitoring platform for vehicles is created initially. By integrating the target detection and target tracking algorithms into the platform, the vehicle tracking and detection results are visually displayed, the running track of the tracked vehicle is drawn, the vehicle speed is monitored in real time, the prediction and early warning are generated, and the number and density information of other vehicles around the abnormal vehicle is counted to serve as a reference for emergency evacuation command. Second, the spatial analysis platform is developed using ArcGIS Engine component development technology in order to show and operate maps. Intuitively display the incident's location and the distribution of emergency rescue sites, and vividly and graphically convey emergency information, the utilization of resources and data, as well as a new method of management. It has fulfilled the functions of public security fire emergency auxiliary decision-making, rescue path planning, and warning space analysis, enabling the design of emergency rescue strategy scientific and accurate.

Through the research presented in this paper, it is anticipated that the system will be able to realize emergency rescue beyond the limitations of time, space, and departmental separation in the future, provide an orderly, rapid, and effective response to emergencies, and increase the level of informatization of departments involved in emergency response. Simultaneously, we will provide society with comprehensive, high-quality, standardized, and transparent emergency management and services, enhance the government's ability to ensure public safety and respond to public emergencies, promote the maintenance of social stability, and steer the development of smart city construction in a coordinated, sustainable manner.

ACKNOWLEDGEMENTS

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