Design of risk assessment and decision support system for transportation of hazardous chemicals

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Abstract. According to the needs of risk assessment, path planning and emergency rescue of hazardous chemicals transportation, a risk assessment and decision support system of hazardous chemicals transportation was designed, including system structure, implementation process and main functions. The feasibility analysis of key technologies was carried out. This system took Geographic Information System (GIS) as the support platform, and integrated multi-source information such as hazardous chemicals, global positioning system (GPS), geographic environment, Meteorological information, etc. Based on classical pollution diffusion models and relevant domestic and foreign standards, the index system of transportation risk assessment was built. Then the quantitative index of risk assessment and the early warning sign could be given, and the hazard area of the chemical accident was determined. At last, this risk assessment and decision support system provided suggestions on route optimization for hazardous chemicals transport, which could be severed as scientific basis for emergency rescue and command decision.

1. Introduction

With the rapid economic growth, the transportation volume of hazardous chemicals has increased significantly. According to statistics, 80% of the hazardous chemicals in China are transported by road, and more than 95% of them need to be transported to other Cities every year. The annual road transportation volume of hazardous chemicals is about 300 million tons, accounting for 30% of the annual road transportation volume [1].

During the road transportation of hazardous chemicals, serious accidents such as leakage and explosion could cause harm to the human beings, animals, and environment. Generally speaking, these serious accidents have the characteristics of strong abruptness, great harm and wide range of pollution, which causes difficulties to our emergency rescue. For example, in 2012, the rear end collision of methanol tank cars in Shanxi Province caused a particularly serious accident, which caused 36 deaths. In 2014, the deflagration of an ethanol truck in Hunan province directly led to the death of 54 people [2, 3]. Therefore, High attention should be paid on the safety management of road transportation of hazardous chemicals, and advanced technologies should be applied to ensure the safety and provide guarantee for the road transportation of hazardous chemicals.

Recently, domestic and foreign researchers have paid attention to the risk assessment and decision support of road transportation of hazardous chemicals. X. Y. Chen has made statistical analysis on 562
accidents of hazardous chemical transportation in China from 2013 to 2014, which included the aspects of occurrence site, occurrence time, type of hazardous chemicals and accident cause [2]. X. Y. Kuang studied the risk of road transportation of dangerous goods for transportation planning and decision-making, and established the risk evaluation model according to the six risk indicators, which could give the optimization suggestions of dangerous goods transportation path [1]. The above research results show that the risk assessment and optimization analysis of road transportation can effectively reduce accident rate and accident hazard. However, due to the complexity of road transportation process and the lack of unified standards for risk assessment of hazardous chemicals accidents, many urgent problems need be solved, such as how to conduct risk assessment correctly, efficiently and quickly and give suggestions for emergency rescue of accidents.

2. System overall design
Risk assessment and decision support system for road transportation of hazardous chemicals is an intelligent system with human-computer interaction function. Based on GIS platform, we can select the supposition that includes hazardous chemicals type, road geographical environment, meteorological environment, population distribution, accident scenario and pollution diffusion model, etc. Then this system can identify the regional scope of hazardous chemicals accidents rapidly. Referring to the relevant standards and specifications, the risk assessment index system is constructed and provide scientific and reasonable decision support for the route planning of road transportation.

The system mainly includes the following modules:
(1) Hazardous chemicals information module
The module reads, accesses, stores, queries and manages the basic information of hazardous chemicals, including physical and chemical properties, toxicity, quantity, type, storage form, etc.
(2) GIS module
The module includes main traffic lines (road geographic information, road conditions, traffic flow, etc.), distribution of population and the sensitive areas (water resources, nature reserves, ecological reserves, scenic spots, bridges, tunnels, etc.) in China, so as to provide geographic information support services for other functional modules [4].
(3) GPS module
The module accesses, storages and distributes the satellite navigation data information of the road transport vehicles, and provides GPS information services for other functional modules.
(4) Meteorological information module
The module obtains the meteorological information of surrounding area of the accidents, including meteorological historical data, weather parameters and weather forecast products, and updates them time by time, so as to provide real and typical meteorological basic data and support for environmental impact assessment.
(5) Accident scenario module
The module analyses the historical accidents of road transportation of hazardous chemicals in the mission area, and gives the statistical parameters of sensitive elements such as accident sections, category of hazardous chemicals, cause factors and time periods of the accidents, etc.
(6) Environmental impact assessment module
The module integrates the GIS information and GPS information of hazardous chemicals road transportation. According to the accident scenario, based on the classical pollution diffusion model and relevant standards and specifications, it carries out environmental impact assessment, and gives drift direction and distance, toxic and harmful areas, dangerous classifications and early warning informations, etc.

The overall flow chart of the system is as follows:
3. Key technology design

3.1. Hazardous Chemical Accident Scenario
According to physical and chemical characteristics of hazardous chemicals and severity of accidents, they are divided into the following grades [5]:

1) Minor level: dangerous chemicals leak into the environment in gaseous state, which will endanger human health after excessive inhalation;

2) Serious level: dangerous chemicals entering the environment in gaseous or liquid state, if the people inhale the air in the polluted area, the toxic effect is obvious and they need to evacuate from the dangerous area.

3) Major level: the leaked hazardous chemicals may cause rapid death, so it is necessary to evacuate the contaminated area immediately.

4) Extra large: the leaked hazardous chemicals can cause rapid death. The pollution area is huge and the population in the pollution area is concentrated.

3.2. Pollution Diffusion Model Selection
In order to get the concentration of toxic and hazardous chemicals in the air and predict their propagation process, it is necessary to master the diffusion law of hazardous chemicals in the air. The commonly used diffusion models include Gaussian model, Lagrange Model and Euler model [6].

Among them, Gaussian model is mainly based on semi-empirical formula, assuming that the diffusion of hazardous chemicals conforms to Gaussian distribution in horizontal and vertical directions [7]. Gauss model is a simple calculation method with few input parameters. At present, it is more mature than others, including Gauss plume model and Gauss puff model. Many software systems based on Gauss model have been developed at home and abroad. The principle of Lagrange model is to release and track a large number of virtual chemical particles to simulate the migration and distribution in the atmospheric environment [8]. Lagrange method can simulate the distribution of hazardous chemicals in time-varying atmospheric environment, but it needs more input parameters, more complex functional equations and longer time. Euler model is based on gradient transport theory [9], which need input atmospheric environmental data, solve the fluid dynamics conservation equations, and calculate the change of concentration of hazardous chemicals in the grid. Euler model is more convenient to deal with the changing pollution sources and meteorological conditions, but it is difficult to solve the closure problem of the equation and the numerical diffusion problem in the difference scheme.

In engineering reality, for different accident scenarios, we should select an appropriate model to simulate the diffusion of hazardous chemicals, considering the model stability, calculation time,
meteorological conditions, calculation complexity and the nature of dangerous goods. In contrast, Gaussian model is relatively simple, fast and easy to program and calculate with few input parameters. For example, Gaussian plume model is more suitable when long-time continuous leakage occurs and dangerous chemicals are neutral gas with density close to air. On the contrary, the diffusion of short-time leakage (such as sudden leakage) needs to focus on time-varying effect, then Gaussian puff model can be used. Figure 2 is a typical case of leakage and diffusion simulation of hazardous chemicals in sudden accidents using Gaussian puff model.

![Figure 2. Diffusion of hazardous chemicals in sudden accidents.](image)

3.3. Meteorological Information Acquisition
As the main input parameters of diffusion model, meteorological information has an important impact on the results of hazard assessment. Meteorological data includes observation data and numerical weather forecast products. Generally speaking, the observation data of weather stations are distributed in discrete points, and cannot be used directly in the diffusion model. In recent years, with the improvement of science and technology, numerical weather forecast products have been widely used. Compared with observation data, the numerical weather forecast products are grided data, which is more convenience to input diffusion models. Some diffusion models have provided data interfaces for meteorological forecast products.

At present, the commonly used forecast products include: Chinese T639 products, European EC products and American GFS products, etc. these products include not only short-term forecast (3-6 hours), but also medium and long-term forecast (12-240 hours). The horizontal resolution can be 0.125°, including wind, temperature, cloud, precipitation and other parameters. Figure 3 shows the forecast results of surface wind field of the severe convective weather process in Shanghai at 08:00 on April 12, 2020 given by GFS product.
3.4. Environmental Impact Assessment Technology

The main functions of hazard assessment module are: Based on the accident scenario of hazardous chemicals, we can obtain the basic geographic and meteorological information data. Then run the software for hazard assessment of hazardous chemicals, and get the distribution and concentration of hazardous chemicals in the area of concern [10]. Referring to the relevant standards, specifications and threshold settings, the system gives different levels of hazardous areas (The calculation example is shown in Figure 4). Coupling the population and road conditions in the dangerous area, the quantitative analysis methods such as Analytic Hierarchy Process (AHP) and decision tree are adopted to quantitatively determine the hazard level of different areas, and generate accident assessment report to provide reference for emergency rescue.

4. Conclusion

It is a complex process to carry out risk assessment of road transportation of hazardous chemicals, which urgently needs auxiliary decision support, so as to shorten the response time of emergency rescue, improve the effectiveness and reliability of rescue, reduce casualties as much as possible, and minimize the accident hazards. Therefore, this risk assessment and decision support system has a good application prospect, which needs the cooperation of multi-disciplinary researchers.

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