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Public Management Capacity of Chemical Dangerous Goods Accidents

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Accidents of chemical dangerous goods (CDG) are the typical public emergencies. In recent years, the accident rate has shown a clear upward trend. In order to prevent or reduce accidents, this paper carries out the study on the public management capability of CDG accidents. By taking Jinan City as an example, the fuzzy analytic hierarchy process (AHP) was used to evaluate the public management capacity of CDG accidents. Then, the ArcGIS-based public management capability decision support system of chemical dangerous goods was constructed, to simulate the ammonia leakage accident and analyse the emergency evacuation module. The research results show that: 75.3% of the experts believe that the public management capacity of CDG accidents in Jinan City is in a good or general state, and more attention has been paid to the crisis prevention and early warning ability before the accident; the system estimates the evacuation area, the evacuation personnel (38,792 people) and the best route for evacuation (1,536.84195458m long) after instantaneous rupture of 15t ammonia transport vehicle. This study has certain practical significance for preventing and reducing the casualties of people and property caused by CDG accidents.

1. Introduction

In recent years, public emergencies in China have occurred frequently, mainly in the fields of public health, natural disasters, accidents and disasters, especially, the incidence of chemical dangerous goods accidents has shown a clear upward trend, which has become a typical type of public emergency in China. Faced with such complex, sudden and violent public events as chemical dangerous goods, China's existing emergency management system lacks the risk analysis and assessment for such events, making it difficult to respond effectively (Harris et al., 2017) Therefore, in order to prevent or reduce the occurrence of chemical dangerous goods accidents and to ensure the safety of people's lives and property, it is urgent to conduct innovative research on the micro level of the public management system for the CDG. The public management of chemical dangerous goods (CDG) accidents includes two parts: crisis management and consequence management. Consequence management focuses on providing emergency rescue for sudden events, but in fact, public management of CDG accidents should not only stay in response and recovery from an accident, and it is more important to prevent and avoid accidents (Kourniotis et al., 2001). Therefore, the evaluation of government's CDG accident emergency response capability and the construction of emergency management capability support system are very important to improve the government's public management capabilities. In recent decades, there have been abundant research results of public management capabilities for emergencies in the world. The laws and regulations, white papers and related research reports on emergency management are also comprehensive (Ma, B, 2007), but most of them are compiled by the Federal Emergency Management Agency and related research institutes in United States, while the social sciences, operations research, and management science have also played a major role in public management (Igboamalu and Chirwa, 2018). Compared with foreign countries, China's public management research for emergencies is still in its infancy; it is focused on the theoretical and management system framework (Squire and Song, 2015), making it difficult to improve actual public management capabilities.
Based on the above analysis, by taking Jinan City as an example this paper establishes the public management capacity evaluation index system of CDG accidents in the expert valuation method. Then, the

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improved Delphi method was used to determine the importance matrix, the fuzzy analytic hierarchy process (AHP) was adopted to evaluate the public management ability of CDG accidents, the ArcGIS-based public management decision support system for chemical dangerous goods was constructed, and the overall structure of the system was analysed. Finally, the instantaneous rupture accident of 15t ammonia gas transport vehicle was simulated to analyse the system's emergency evacuation module of chemical dangerous goods accident, which verifies that the system can quickly and effectively determine the location of the accident, determine the evacuation area, the number of people who need to evacuate, and the best evacuation route.

2. Public management capacity evaluation of chemical dangerous goods accidents

The fuzzy analytic hierarchy process (AHP) decomposes the problem itself into layers to form a bottom-up hierarchical structure. It is a combined systematic analysis method of qualitative and quantitative analysis. The construction of the importance matrix is the key to fuzzy AHP.

2.1 Applying the improved Delphi method to determine the importance matrix

1) The p selected experts separately estimate the importance between the evaluation index system. It's assumed that Formula (1) is the first estimate given by the k-th expert (Pinto et al., 2018):

$$X_1^k = \begin{pmatrix} x_{11}^{k1} & x_{11}^{k2} & \cdots & x_{1n}^{kn} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1}^{k1} & x_{n2}^{k2} & \cdots & x_{nn}^{k1} \end{pmatrix} \tag{1}$$

2) Calculate the mean and dispersion (Warren et al., 2013), submit the results of the p experts to the experts and then make re-evaluation based on the comprehensive results.

$$\text{Mean}: \overline{x_{ij}^1} = \frac{1}{p}\sum_{k=1}^{p} x_{ij}^{k1} \tag{2}$$

$$\text{Deviation}: d_{ij}^1 = \frac{1}{p}\sum_{k=1}^{p}\left| x_{ij}^{k1} - \overline{x_{ij}^1} \right| \tag{3}$$

3) Repeat the previous two steps until $d_{ij}^m \le \varepsilon$; ε is the pre-set standard, greater than 0, and d_{ij}^m is the dispersion of the m-th step. Submit x_{ij}^m and d_{ij}^m to all experts for re-estimating the value, and give their self-confidence degree e_{ij}^k estimated to x_{ij}^k, with the value e_{ij}^k[0-1].

4) After processing the matrix $\begin{pmatrix} x_{ij}^1 & x_{ij}^2 & \cdots & x_{ij}^p \\ e_{ij}^1 & e_{ij}^2 & \cdots & e_{ij}^p \end{pmatrix}$, the importance matrix is obtained.

$$X = \begin{pmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ \cdots & \cdots & \cdots & \cdots \\ X_{n1} & X_{n2} & \cdots & X_{nn} \end{pmatrix} \tag{4}$$

2.2 Determining the weight of management indicators

Table 1: Public ability assessment indicator system

Primary indicator	Secondary indicators
Pre-disaster crisis prevention and early warning capability	Law and plan preparation
	Monitoring and early warning
	Emergency management center and other regulatory agencies
	Training, exercises and education
Crisis response and disposal capacity during disasters	Hazard analysis hierarchy
	Field command, control and communication
	Professional team volunteer
	Planning and managing logistics
Post-disaster recovery and reconstruction capabilities	Post disposal
	Reply and reconstruction funding support

Taking Jinan City as an example, with reference to the public event emergency capability evaluation index given by Deng Yunfeng et al. and the US and Japan comprehensive management evaluation index (Beatty et al., 2006), this paper constructs the public capacity evaluation indicator system from three aspects: pre-

disaster, at the time of the disaster and post-disaster (Table 1). This system consists of 3 primary indicators and 10 secondary indicators.
According to the Delphi method and steps above, 25 experts were invited to evaluate the indicators and their importance, and then perform a summary calculation to obtain the following importance matrix.

$$X=\left(X_{ij}\right)_{10\times 10}=\begin{pmatrix} 0.5 & 0.678 & 0.755 & 0.564 & 0.631 & 0.766 & 0.351 & 0.488 & 0.578 & 0.732 \\ 0.341 & 0.501 & 0.744 & 0.471 & 0.494 & 0.675 & 0.277 & 0.433 & 0.489 & 0.647 \\ 0.244 & 0.256 & 0.501 & 0.189 & 0.334 & 0.443 & 0.024 & 0.165 & 0.354 & 0.386 \\ 0.445 & 0.53 & 0.529 & 0.811 & 0.517 & 0.62 & 0.312 & 0.469 & 0.579 & 0.591 \\ 0.356 & 0.506 & 0.678 & 0.483 & 0.49 & 0.593 & 0.278 & 0.438 & 0.492 & 0.562 \\ 0.246 & 0.326 & 0.567 & 0.378 & 0.407 & 0.501 & 0.167 & 0.341 & 0.387 & 0.489 \\ 0.652 & 0.733 & 0.976 & 0.688 & 0.720 & 0.831 & 0.498 & 0.643 & 0.693 & 0.811 \\ 0.502 & 0.577 & 0.833 & 0.531 & 0.562 & 0.659 & 0.357 & 0.502 & 0.538 & 0.656 \\ 0.414 & 0.513 & 0.646 & 0.423 & 0.51 & 0.613 & 0.307 & 0.462 & 0.5 & 0.603 \\ 0.278 & 0.361 & 0.612 & 0.407 & 0.438 & 0.513 & 0.192 & 0.344 & 0.397 & 0.501 \end{pmatrix} \tag{5}$$

According to the weight calculation formula $w_i=\frac{2}{n(n-1)}\sum_{k=1}^{n}x_{ik}-\frac{1}{n(n-1)}$, the weights of each indicator were calculated as W=(0.1512, 0.1008, 0.0537, 0.1082, 0.0973, 0.0735, 0.1227, 0.1158, 0.0987, 0.0786). By sorting, it can be seen that the law and plan preparation, field command, control and communication, and training, exercises and education are the top three indicators, indicating that the experts attach great importance to the pre-disaster crisis prevention and early warning capabilities.

2.3 Public management capability evaluation

Table 2 lists the evaluation results of the public management capacity indicators by the 60 invited experts.

Table 2: Public ability index evaluation result

Index \ Evaluation level	Good	Better	General	Poor	Very poor
Law and plan preparation	5	48	16	0	0
Monitoring and early warning	0	0	16	44	0
Emergency management center and other regulatory agencies	0	24	22	14	0
Training, exercises and education	0	0	13	47	0
Hazard analysis hierarchy	0	19	32	9	0
Field command, control and communication	0	0	54	6	0
Professional team volunteer	6	31	23	0	0
Planning and managing logistics	0	25	29	0	0
Post disposal	0	38	22	0	0
Reply and reconstruction funding support	9	41	10	0	0

The vector of membership degree $R_i=(R_{i1}, R_{i2}, R_{i4}, R_{i5})$ is used to represent each evaluation level U_i, and the public management capacity evaluation matrix R is obtained.

$$R=\begin{pmatrix} 0.083 & 0.8 & 0.267 & 0 & 0 \\ 0 & 0 & 0.267 & 0.733 & 0 \\ 0 & 0.4 & 0.367 & 0.233 & 0 \\ 0 & 0 & 0.217 & 0.783 & 0 \\ 0 & 0.317 & 0.533 & 0.15 & 0 \\ 0 & 0 & 0.9 & 0.1 & 0 \\ 0.1 & 0.517 & 0.383 & 0 & 0 \\ 0 & 0.417 & 0.483 & 0 & 0 \\ 0 & 0 & 0.633 & 0.367 & 0 \\ 0.15 & 0.683 & 0.167 & 0 & 0 \end{pmatrix} \tag{6}$$

Its public management capacity is calculated as:

$$C=W\bullet R=(0.037, 0.372, 0.381, 0.21, 0) \tag{7}$$

Figure 1 shows the evaluation results of the public management capacity for CDG accidents in Jinan City. It can be seen from the figure, most experts believe that the current public management capacity of CDG accidents in Jinan is in a better or general state, only 3.8. % thinks it is good; also, exercises and education as well as the monitoring and early warning scores are low, indicating that the corresponding management should be strengthened.

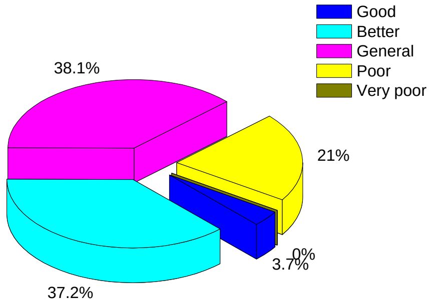

Figure 1: Public management capacity assessment results

3. Decision support system of public management ability

3.1 System overview

ArcGIS integrates mainstream technologies such as GIS and network technology, artificial intelligence, and database etc. It has powerful data processing capabilities and can improve the integrated and complete integrated environment. Thus, this paper designs one ArcGIS-based public management capability decision support system of CDG.

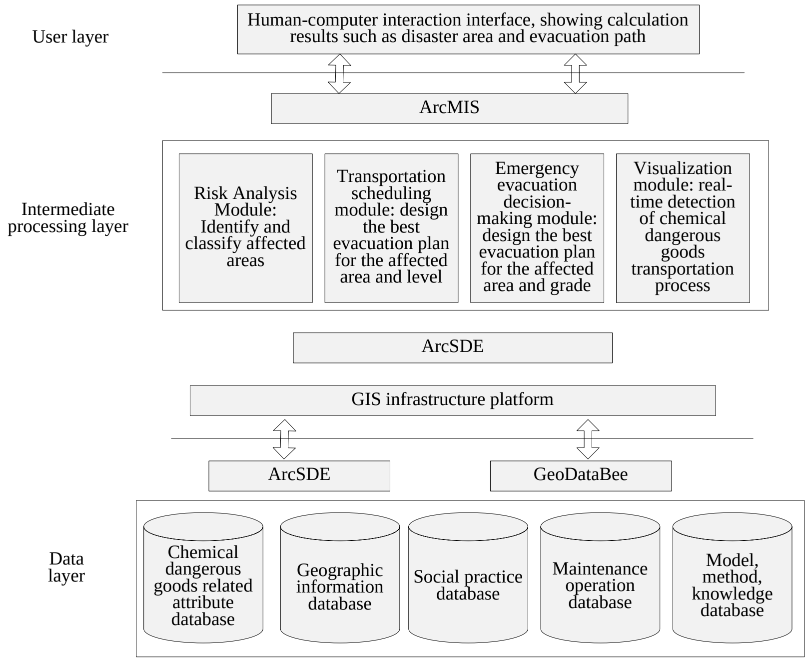

Figure 2: System overall framework

Figure 2 shows the overall architecture of the system. The system consists of the user layer, the intermediate processing layer and the data layer (Alamdar et al., 2016). The user layer provides a human-computer interaction interface, displaying the calculation results of the disaster area and evacuation path etc.; the intermediate processing layer includes four modules: risk analysis, transportation scheduling, emergency evacuation and decision making, and visualization (Jang et al., 2009), so it is the core functional module of the system implementation function; the data layer is the underlying data design, covering the data such as hazardous chemicals and geographic information etc. required for the intermediate processing layer.

3.2 System function design

According to the four-stage model of public emergency management of CDG accidents, this paper divides the system into four modules: risk analysis, transportation scheduling, emergency evacuation and decision-making, and visualization. Due to limited space, this paper focuses on the emergency evacuation module for chemical dangerous goods accidents.

3.2.1 All-round geographical environment display

The familiarity and understanding of the city's basic geographical environment are the basis for the organization of emergency evacuation. The system can provide decision makers with spatial basis data of different scales, making it convenient for decision makers to understand the basic geographic information of the whole city, as shown in Figure 3 and 4.

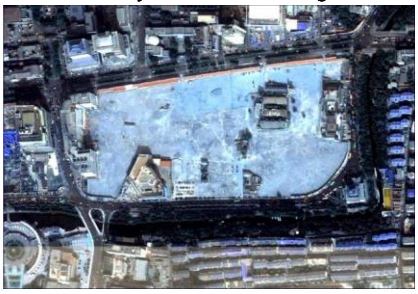

Figure 3: Jinan City remote sensing image map

Figure 4: Jinan City 1:5000 urban area map

3.2.2 Evacuation area determination

In this paper, based on the existing evacuation model, it's assumed that the 15t ammonia transport vehicle instantaneously ruptures under the wind speed of 5.5m/s. According to the dynamic grid calculation method, the envelope diagrams/maps of the lethal circle, the semi-lethal circle and the wounding circle are determined (Figure 5).

3.2.3 Evacuation personnel estimation and emergency evacuation route selection

In order to reduce the post-disaster casualties, the number of people who need to evacuate the surrounding buildings and roadsides should be quickly estimated. Figure 6 shows that the estimated number of evacuated personnel is 38,792.

Figure 5: Envelope map of different affected areas

Figure 6: Total number of evacuated population

3.2.4. Emergency evacuation route selection

Figure 7: Evacuation path

The emergency evacuation route should be selected by fully considering the road grade and the actual traffic information, to ensure that the people can be evacuated outside the dangerous area in the shortest time. Figure 7 shows some emergency evacuation paths calculated by the system based on the A* algorithm and the equivalent distance.

4. Conclusions

Chemical dangerous goods accident is the typical public emergency, which can cause huge losses to people's lives and property. It is a huge test for the public management capacity of emergencies in China. Therefore, this paper carries out the study on the public management capacity of CDG accidents. The specific conclusions are as follows:

(1) Taking Jinan City as an example, the public management capacity evaluation index system of CDG accidents was constructed, the importance matrix was determined by Delphi method, and the weight of indicators was determined by fuzzy AHP. It's concluded that the public management capacity of CDG accidents in Jinan is at a good level;

(2) The ArcGIS-based public management capability decision support system of CDG was constructed, and the main architecture and function of the system were also analysed;

(3) Taking the emergency evacuation module of chemical dangerous goods accident as an example, the CDG accident of the 15t ammonia gas transport vehicle was simulated to calculate the number of evacuated personnel and the best evacuation route, and verify the system effectiveness.

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