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Structuring and Recommendations for Research on the Construction of Intelligent Multi-Industry and Multihazard Emergency Planning Systems

Xiaolei Zhang [1,2], Kaigong Zhao [3,4,*], Changming Li [1,4] and Yansu Li [1]

1 School of Emergency Management and Safety Engineering, China University of Mining and Technology, Beijing 100083, China; zhangxl@chinasafety.ac.cn (X.Z.); 20038885@chnenergy.com.cn (C.L.); sqt2100803039@student.cumtb.edu.cn (Y.L.)
2 China Academy of Safety Science and Technology, Beijing 100012, China
3 School of Civil and Resource Engineering, University of Science and Technology Beijing, Beijing 100083, China
4 CHN Energy Investment Group Co., Beijing 100011, China
* Correspondence: zhaokaigong@ceic.com

Abstract: During production and operation, enterprises are faced with occurrences of production accidents. One of the prerequisites for enterprises to achieve sustainable development is building an intelligent emergency command platform. To establish a scientific and advanced emergency management information system and address the challenges related to managing emergency plans to ensure production safety, such as ambiguous roles and responsibilities, inefficient application processes, independent resources, and slow responses by enterprises with multiple types of operations and disasters, an intelligent emergency command platform was built for multiple types of operations and disasters, and this platform was extended to include rescue steps. The structure and digital management of emergency plans under multiple coupled disasters and multipoint cogeneration were determined. Similar emergency plans were automatically recommended by crawler technology and an SVM algorithm based on a public information data lake, and the effectiveness of the plans was evaluated via a fuzzy analytic hierarchy process to promote the preparation of more efficient and scientific emergency plans. Finally, the analysis of pipeline leakage and emergency drill scenarios proved that the system is scientific and reliable. The results are of great significance for improving the deep integration of modern emergency-related information technology and emergency management businesses, promoting institutional and mechanical innovation, to provide a reference for other multibusiness enterprises, wchih can also be integrated into methods for urban safety and rescue.

Keywords: sustainable development; emergency plan; energy companies; emergency command platform

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1. Introduction

Businesses need effective responses to risks and disasters. As an important aspect of management, emergency management plays a vital role in the sustainable development of enterprises. For example, large energy companies operate in high-risk sectors like coal and chemicals, where emergencies can have severe repercussions. Establishing effective emergency plans is crucial for minimizing these risks by unifying key elements such as emergency materials and command structures and leveraging the expertise of different departments [1–3]. However, human beings cannot avoid the evolution and development of emergencies, and the problem of connecting emergency plans among various departments is becoming more and more prominent. In order to better meet the need for comprehensive emergency management, systematic and flat emergency management systems can be built through the use of computer technology such as cloud computing and artificial intelligence. Through such systems, key elements such as emergency materials, emergency teams, and emergency command can be effectively coordinated. These systems improve the efficiency and capacity of the emergency response, provide more comprehensive and timely information support for emergency management, improve the ability to issue early warnings, and support decision making through intelligent means. They thus make the entire emergency management system more flexible and efficient, and protect the life and property of the public.

Currently, the academic community has made significant scientific advancements in the field of emergency planning. For instance, Grimaila has utilized technologies such as cloud computing and artificial intelligence to enable real-time access to emergency plans, template creation, and other functionalities. These innovations have enhanced the overall efficiency of emergency plan management [2–4]. Scholars regard emergency command systems as the only way to realize digital emergency plans. Computer technologies such as geographic information systems and artificial intelligence can help meet the need for the creation of emergency plans, generate visual displays of the emergency planning process, enable the real-time control of emergency resources, and establish an emergency database. They can additionally offer emergency prediction, early warnings of emergencies, and suggestions for emergency plans [5–8].

Despite the rapid developments in the field of emergency management, there are still three problems: (1) In emergency management, "plan is important, planning is not important", and "text is important, process is not important"; "Plan preparation" is often used to replace "emergency planning", where the operation and relevance of the resulting plans are poor and can only provide some "correct" but "empty" content [9–11]. (2) There are structural deficiencies in the emergency planning system. The classification of emergency plans is mostly based on the categories of events and the functions of centralized government departments, which tend to ignore the relevance of emergencies. Also, there is a lack of technical support modules in the operation process. A unified communication and information-sharing mechanism is needed in order to establish regional resource allocation and acquisition agreements, as well as for standardized emergency exercise planning and evaluation [12,13]. (3) The revision of plans is insufficient; the level of disclosure needs to be improved; the preparation of standard and dynamic management mechanisms of plans is lacking, as is the process of testing and evaluating plans [14].

Given the above problems, we must use internet technology to digitize and structure emergency plans. Creating a structured emergency plans involves dividing the emergency plan into several independent modules and units according to emergency management logic and integrating these units into emergency procedures, with the goal of coordinating information flow, time flow, and incident response. A structured emergency plan is at the core of the digitalization of emergency management [15–19]. The structure of an emergency plan is used to form digital plan management, relying on the various levels of emergency plans and digital management to achieve rapid coordinated responses and to query statistics regarding accidents and disasters. In the field of emergency plan management, the construction of a corresponding emergency command and an emergency management system is one of the most effective means of unifying and coordinating various resources and enhancing the capacity for emergency response [20]. As for the emergency command system, there are many mature cases. For example, the Emergency Command System of the National Emergency Management System of the United States plays the role of the decision maker in emergency management and is an indispensable part of the emergency management system. The emergency command system established in Germany combines the emergency management network with the emergency management information system and expands on the modular design of the system. In terms of emergency command, China has built a national emergency platform system with vertical command and horizontal information sharing based on the emergency platform of The State Council [21–25].

Bearing this in mind, the objectives of this study were to achieve the comprehensive management and coordination of various operations and disasters, as well as to enhance information sharing and integration across governmental and corporate entities at all levels. To accomplish this, an emergency management system was developed, which incorporates functions such as information reception, research, analysis, decision support, and coordinated command. This system was designed on the principles of unified command, swift response, and hierarchical connectivity. By structuring the management of emergency plans and establishing a practical accident case database utilizing web crawlers and algorithms, a method of case reasoning was employed. This method enables the system to search for similar accident cases, apply accident structure models, and conduct similarity analyses to automatically recommend emergency plan templates. Consequently, this method enhances the scientific validity and reliability of emergency planning.

2. System Design

2.1. Overall Structure

Currently, the majority of emergency plans in China are stored, utilized, and managed in text format, with the limited use of information technology. This approach lacks effective integration and cohesion among plans, leading to various shortcomings in their practical application [26,27]. Large industrial energy conglomerates operate with diverse business models, spanning across regions and levels. They encounter a wide range of natural disasters and workplace accidents, totaling over 80 types, which pose significant challenges in terms of emergency coordination and comprehensive control [28–32].

Given the aforementioned challenges, establishing an emergency command system with a focus on "industrial integration, intelligent management, and data visualization" has become a necessary step. By enhancing the traditional emergency management system with additional emergency communication devices, an information-oriented emergency command system can be developed. This study employed a distributed and multlayer architecture, categorizing the emergency command system into a front-end display, business applications, application support, and data support layers. The system facilitates the transmission of emergency data through technologies such as emergency communication, the Internet of Things, and computer networks, resulting in the creation of a database, data lake, and data center. Leveraging big data and GIS technologies, emergency management is implemented in specific scenarios, with operations conducted through wartime emergency responses, peacetime activities, and mobile terminals. Visual display is achieved via devices such as PCs and large screens. Central to this approach is the emergency plan, supported by case-based reasoning using techniques like support vector machines to assist enterprises with managing, querying, and recommending similar plans, as illustrated in Figure 1.

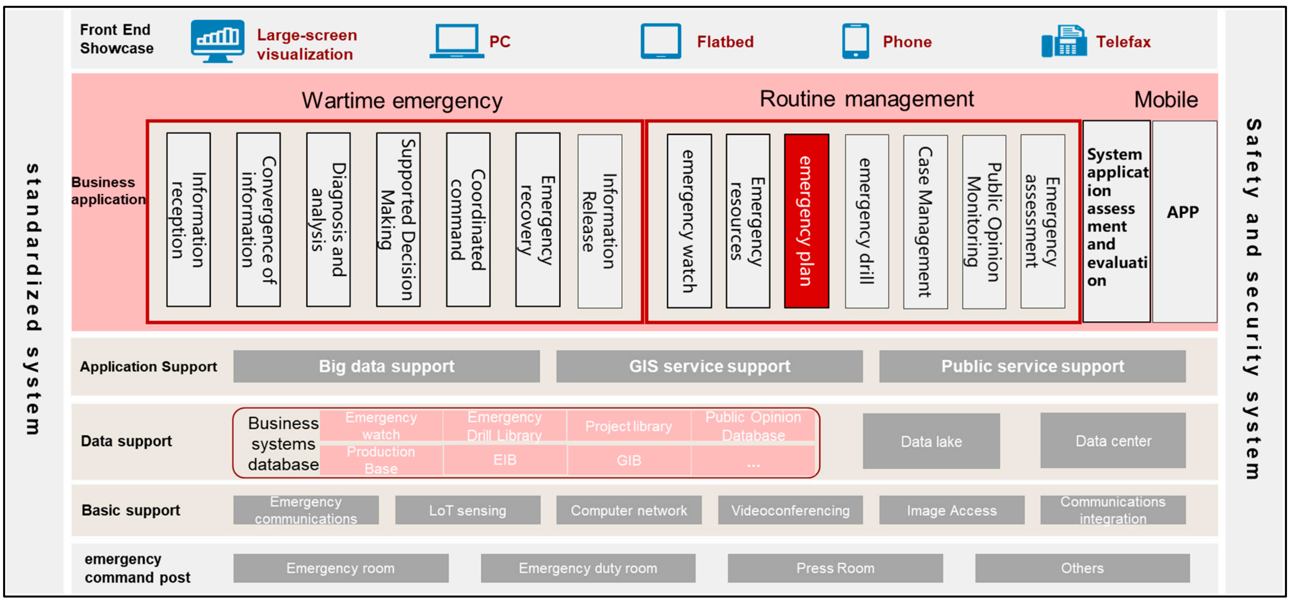

Figure 1. The overall architecture of the emergency command system.

2.2. Emergency Preparedness Management System Module

The key functions of the emergency plan module encompass comprehensive emergency plan management, plan structuring, evaluation system management, accident type system management, emergency response level management, monthly reporting, overview analysis, health analysis, report generation, and basic information management. To enhance work efficiency and ensure the consistency of data formats, predefined templates are provided for each subfunction within this module. For instance, under the emergency response section, the template comprises alarm reception, emergency reporting, accident processing, and other components, encompassing the entire emergency response process. The structure of emergency plan management is illustrated in Figure 2.

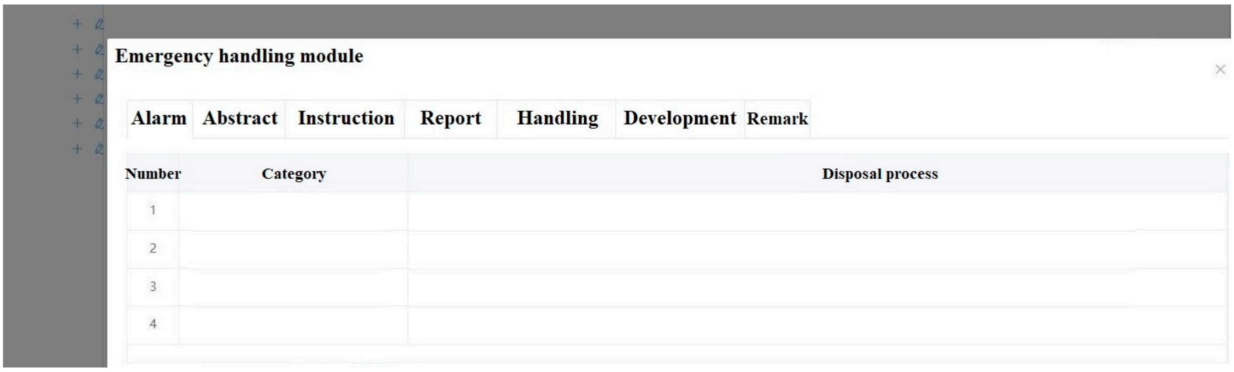

Figure 2. Emergency plan management interface.

The emergency plan management function encompasses comprehensive emergency plan management, special emergency plans, on-site disposal plans, and emergency disposal card management. With comprehensive emergency plan management, various emergency plans are collected, categorized, and indexed, enabling users to efficiently query and filter plans as needed. The special emergency plan section is dedicated to managing plans tailored for specific incidents, such as coal mine gas explosions and hazardous chemical leaks. The on-site disposal plan and emergency disposal card management segment centralize a wide array of on-site plans and cases, categorized by accident type for rapid access by managers. The system supports fuzzy search functionality based on plan names and types, allowing users to access existing emergency plans, upload new ones, and remove expired plans, thereby facilitating efficient information management.

The emergency command organization function oversees each emergency rescue group and enables professional groups to digitize the emergency response process according to their responsibilities outlined in the emergency plan. By clicking the "digitalize" button, users can access the emergency response page to input text, authorization orders, and unit positions. They can also edit, view, or delete this information, ultimately digitizing the emergency plan and enhancing its practical utility. The digitization process is illustrated in Figure 3. Upon the reporting of an accident and the initiation of the corresponding plan, the system automatically retrieves the digital result of the relevant emergency plan on the emergency command screen and the computer based on the business group and accident type specified by the user. It provides workflow guidance according to the plan as well as system research and judgment results, systematically organizes personnel to execute emergency actions, and effectively addresses the operational challenges related to the emergency plan. A visual display of an emergency plan is presented in Figure 4.

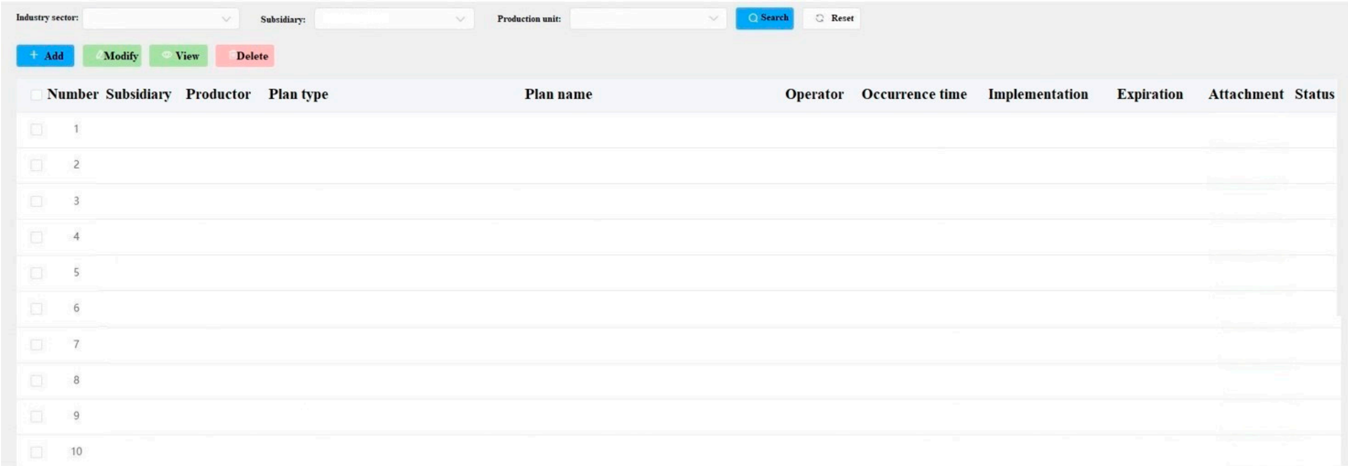

Figure 3. Digitization of emergency plans.

Figure 4. Emergency visualization screen.

2.3. *Principles of Reasoning Based on Support Vector Machine Cases*

To achieve the rapid identification and localization of emergency plans, this paper employed a support vector machine (SVM) classification and recommendation algorithm to construct a hierarchical-structured emergency plan generation model, specifically the "event-environment-emergency response-emergency action" model. The SVM algorithm maps data to a high-dimensional space, identifies a hyperplane within this space, and accomplishes classification by maximizing the margin between data points and the hyperplane. This process establishes a decision system based on the input characteristics of the database [33]. The algorithm possesses a solid theoretical foundation and basic framework, and has progressively evolved into an effective tool for addressing certain data mining challenges through optimization techniques. To some extent, the SVM algorithm is adept at managing traditional issues such as overfitting [34].

The basic idea of SVM is finding the separation hyperplane with the largest geometric interval while correctly dividing the dataset. In Figure 5, $w^*b = 0$ is the separation hyperplane to be found, and there is often only one geometrically maximized separation hyperplane in the same dataset.

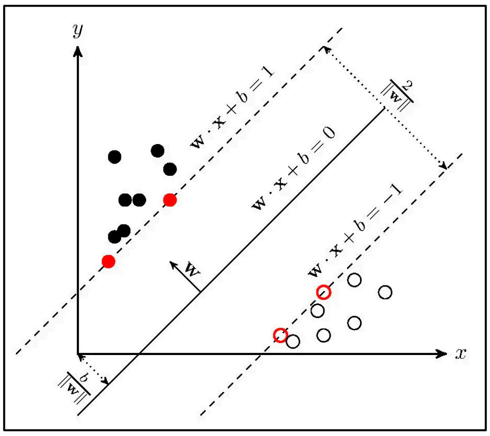

Figure 5. SVM schematic.

The SVM solving steps are as follows:

(1) Input the training dataset:

$$T = \{(x_1, y_1), (x_2, y_2), \cdots, (x_N, y_N),\} \quad (1)$$

$$x_i \in R^n, y_i \in \{+1, -1\}, i = 1, 2, \cdots, N \quad (2)$$

(2) Output the separating hyperplane and classification decision functions:

Choose the penalty parameter C > 0, then construct and solve the convex quadratic programming problem:

$$\min_{\alpha} \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \alpha_i \alpha_j y_i y_j (x_i * x_j) - \sum_{i=1}^{N} \alpha_i \quad (3)$$

$$\alpha^* = (\alpha_1^*, \alpha_2^*, \cdots, \alpha_N^*,)^T \quad (4)$$

$$w^* = \sum_{i=1}^{N} \alpha_i^* x_i y_i \quad (5)$$

$$b^* = y_i - \sum_{i=1}^{N} \alpha_i^* x_i x_j \quad (6)$$

(3) Find the hyperplane:

$$w^* * x + b^* = 0 \quad (7)$$

The classification decision function is

$$f(x) = \text{sign}(w^* * x + b^*) \quad (8)$$

The model devised in this study comprehensively captures the process of emergency plan generation, the progression of event development, and the measures and countermeasures implemented under specific environmental conditions. Leveraging early warning indicators, the analysis of accident risks is conducted, leading to the establishment of upper and lower thresholds for early warning within an alarm system. Subsequently, the pertinent alarm conditions are input into the preplan database for case reasoning. The outcomes derived from the preplan database are then fed into the command system, facilitating on-site response and management through this system. During the on-site response phase, feedback on the preplanned actions is continuously gathered, serving to refine and revise the preplan. The overarching concept is illustrated in Figure 6. In the identification of an emergency plan based on the support vector machine algorithm, the classification basis of the emergency plan is obtained through "text information structured processing–feature selection–feature mapping–hyperplane computation–sample classification". The main steps are described below, and the flow chart is shown in Figure 7.

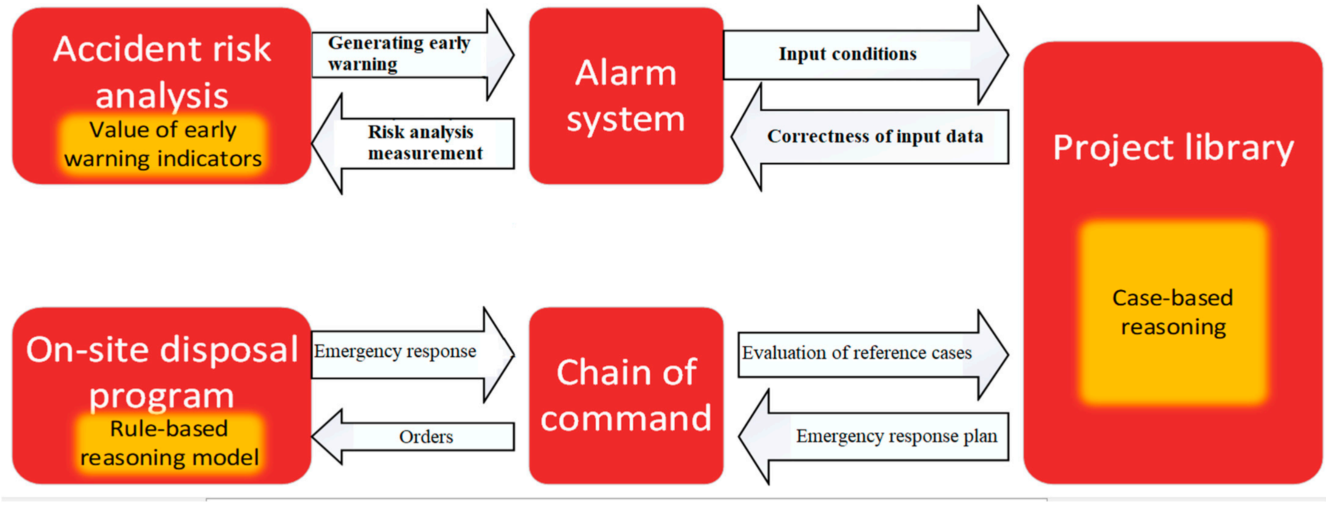

Figure 6. General idea.

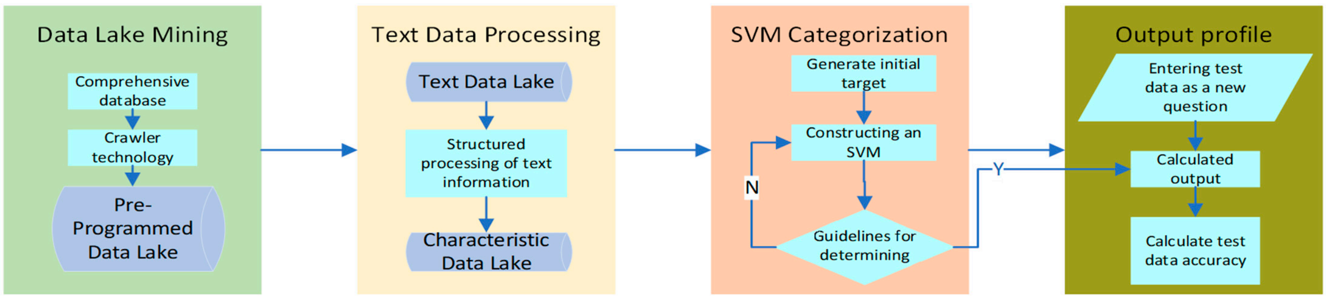

Figure 7. SVM case inference process.

(1) Text information structuring: Assuming that there is a data lake, the main steps are $DL = \{e_1, e_2, e_3, \ldots, e_n\}$, using network crawler technology to collect and organize data from the data lake to obtain a large amount of basic data. The artificial intelligence in the lexical technology processes the data after automatic structured storage. After storage, the data can be indexed by the feature value.

(2) Feature selection: This study adopted the Pearson correlation coefficient evaluation index to assess the relationship between each feature and the target variable, and its calculation formula is shown below:

$$P(s_i, s_j) = \frac{\mathrm{cov}(s_i, s_j)}{\sqrt{\mathrm{var}(s_i)\mathrm{var}(s_{j,})}} \quad (9)$$

where s_i, s_j denotes the feature vector of the sample, i and j denote the feature attributes, $\mathrm{cov}(s_i,s_j)$ denotes the covariance between s_i and s_j, and $\mathrm{var}(s_i)$, $\mathrm{var}(s_j)$ denote the variance of s_i and s_j.

We used the Pearson correlation coefficient evaluation index to calculate the correlation of all the features; the value range was set to 0~1. We selected a subset of features as the feature subset after ranking them from high to low, we obtained the final set of feature selection by training on these subsets $F = \{s_1, s_2, \ldots, s_i, \ldots, s_j, \ldots, s_m\}^T$, and we verified the final results.

(3) Hyperplane computation: Feature sets can uniquely represent the text information's structured processing that was obtained by the preprogramming AI. For the preprogramming

of the main attribute features, each attribute's value in the classification of is different. The weights obtained are different, so we need to weight the feature vector F_i $P_i = \{p_1, p_2, ..., p_m\}$ to obtain the set of points distributed in hyperspace X. For datasets consisting of multiple sample pairs $\{X_i, Y_i\}$, $X_i \in R^m$, $Y_i \in \{-1, +1\}$, searching for a hyperplane $W^T X + b = 0$ maximizes the spacing between categories and minimizes the classification error, as shown in the following equation:

$$\begin{cases} \min E(W) = \frac{1}{2}||W||^2 + \theta \\ y_i \geq 1 - \epsilon \end{cases} \quad (10)$$

where W is the weight coefficient of the hyperplane, θ is the penalty parameter, and ϵ is the slack variable.

(4) Sample classification: Input the feature vector of the accident. After hyperplane processing, $W^T X + b \geq 0$ is recorded as 1; otherwise, it is recorded as 0. The final output vector a = (0, 1, 0, ..., 1, 0, 1), which is the output of the corresponding scenarios, is found based on the results.

2.4. Application of Case-Based Reasoning Using Support Vector Machine Algorithm

In emergency plan reasoning, the support vector machine algorithm essentially partitions the cases within the data lake into training sets and test sets, subsequently deriving optimal classification parameters through iterative processes. By inputting the emergency scenario into the model for analysis, the most appropriate emergency plan is obtained. The analysis of emergency cases reveals that accidents exhibit key characteristics such as specific accident types, scales, impacts, temporal and spatial features, environmental conditions, and resource requirements. The key features extracted from data lake statistics are denoted as source features *O*i, while those derived from emergency accidents not included in the data lake are denoted as derived data *D*i. An expert assigns a value within the range of [0,10] to each feature datum and provides the corresponding feature weight, as illustrated in Table 1. Ultimately, the accident feature vector is substituted into the hyperplane model, yielding the most suitable emergency plan as the output result.

Table 1. Feature collection for a plan.

Serial Number	Feature	Feature Attribute	Data Source	Assignment	Weighting
1	Type of accident	Natural disasters, accidents, and calamities	Source data	8	0.2857
2	Time specificity	Specific time and duration of the accident	Derived data	3	0.1071
3	Spatial features	The specific location of the accident, topography	Derived data	4	0.1429
4	Scale of the accident	The extent of impact, the extent of damage, number of people involved in the disaster	Source/derived data	5	0.1786
5	Impact of accidents	Impact on life, property, environment	Source/derived data	3	0.1071
6	Environmental conditions	Climate, temperature, humidity environmental factors	Source/derived data	3	0.1071
7	Resource requirements	Materials, technology, and other resources needed for incident response and rescue	Source data	2	0.0714

2.5. Case Reasoning Assessment

The fuzzy analytic hierarchy process is used to evaluate the effectiveness of a plan. The effectiveness V of the plan is calculated using the following formula:

$$V = (a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8) \times \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \\ \beta_6 \\ \beta_7 \\ \beta_8 \end{pmatrix} \tag{11}$$

According to the data in Table 1, the validity matrix of the current plan can be calculated as (2.2856, 0.3213, 0.5716, 0.893, 0.3213, 0.1428). In accordance with the principle of maximum membership degree, the evaluation result of the plan is deemed excellent, indicating that the indicators generated by the SVM exhibit a satisfactory fitting effect, which is largely congruent with the actual circumstances. This signifies that the application of SVM to the training of contingency plans yields favorable outcomes, enhancing the efficiency and scientific rigor of emergency plan preparation.

3. Practical Example

To assess the practicality of the system, an emergency drill was conducted, simulating a natural gas transportation pipeline leakage and a subsequent fire accident within a city, utilizing the emergency command system. During the drill, central control personnel detected abnormal pressure in a section of the gas pipeline, which was subsequently confirmed as a leakage and a fire through on-site investigation. Consequently, the emergency system employed in this study promptly reported the incident to the company, facilitating the initiation of the emergency plan, structured plan implementation, research, and judgment, ultimately achieving successful outcomes during the drill.

The emergency drill process is structured into four distinct stages. The initial stage pertains to the team's emergency response, where the team promptly addresses the scene following the accident and initiates a regional emergency plan. The second stage involves regional emergency response and management, wherein the regional director assesses the fire situation, reports to dispatch, activates the regional emergency plan, and submits a report to the company via the designated system. The third stage encompasses company-level emergency response and management, as the company is notified by the system, prompting the initiation of the company-level emergency response. Subsequently, company-level emergency teams arrive at the accident scene to execute rescue operations. The fourth stage focuses on group-level emergency response and decision making, where the group formulates emergency decisions based on the emergency plan displayed on the large emergency command screen. The group proceeds with rapid deployment and emergency decision making in accordance with flow-based guidelines. Throughout the accident management process, the emergency command system primarily accomplishes the following functions:

(1) Guidance for the emergency plan process: Upon receiving accident information uploaded by the company, the system promptly notifies members of the emergency command team to quickly proceed to the emergency command room for immediate handling. Command personnel can access relevant information and monitor the progress of accident resolution through a large emergency command screen, enabling them to respond according to the emergency plan displayed by the system. Adhering to the workflow indicated on the command screen, they execute a series of duties such as alarm response, authorization, emergency reporting, issuance of emergency instructions, etc.; swiftly assign tasks to each department; and ensure that each team takes appropriate actions in accordance with the

structured plan. Figure 8 illustrates the actual emergency drill conducted during a natural gas pipeline leakage accident, while Figure 9 showcases the visual platform system used for emergency rescue operations.

Figure 8. Field emergency drill photographs.

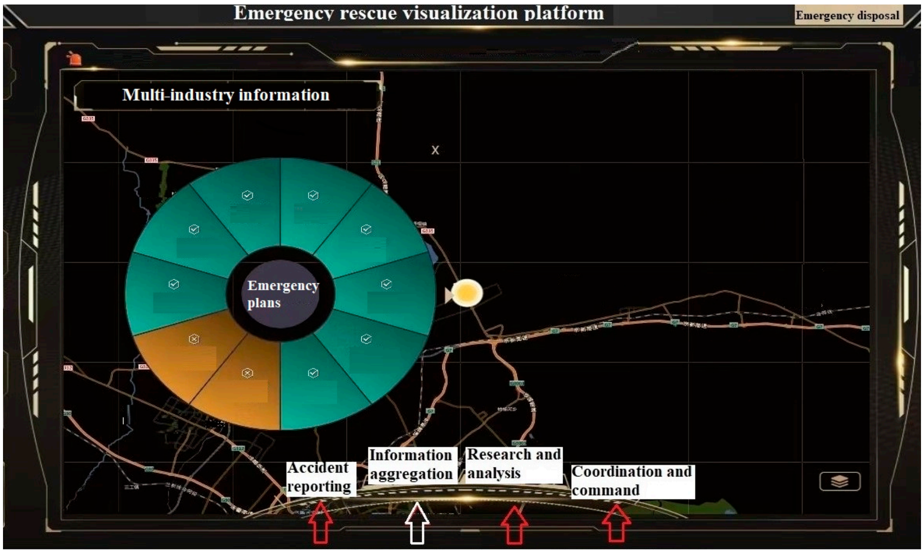

Figure 9. Emergency rescue visualization platform.

(2) Automatic recommendation and evaluation of emergency plans: Upon the aggregation of system information, accident drill data are automatically compiled, and the emergency command system automatically searches for similar cases and their corresponding structured processes based on various types of information. A fuzzy hierarchical evaluation method is employed to automatically assess the recommended plan, which is then presented to the decision maker as a basis for emergency command decisions. Table 2 compares the traditional rescue response time with the system rescue response time in a natural gas pipeline leakage fire accident. It is evident that the emergency rescue response platform developed in this study significantly reduces reaction time in all aspects of emergency response and enhances the efficiency of emergency mitigation.

Table 2. Emergency response time of natural gas pipeline leakage fire accident.

Serial Number	Emergency Response Link	Emergency Handling Node	Traditional Method/min	Time in the System Platform/min
1	Emergency watch	Sub-subsidiary warning	0	0
2		Sub-subsidiary responding	2	0
3		Sub-subsidiary reporting	10	0
4		Subsidiary warning	5	0
5		Subsidiary responding	10	0
6		Subsidiary reporting	15	0
7		Parent company warning	18	0
8		Parent company responding	20	0
9		Parent company reporting	60	0
10	Emergency team	Emergency team operation	2	2
11		Regional team collaboration	30	10
12	Emergency supplies	Allocation of emergency supplies	50	20
13		Regional supplies sharing	120	20
14	Emergency technique	Emergency data sharing	60	10
15		Emergency expert support	120	30
16	Emergency case	Accident case search	60	10
17	Rescue plan	Accident analysis	90	30

Simultaneously, since the emergency plan necessitates the support and cooperation of pertinent personnel, in practical operation, personnel may exhibit deficiencies in the corresponding training and in awareness dissemination. These may result in the system's functionality not being fully harnessed, ultimately impacting the effectiveness of disaster and emergency response. Consequently, to address this issue, personnel training ought to be intensified to ensure that the relevant personnel are knowledgeable regarding the operational procedures and the utilization of the emergency rescue system. For instance, training sessions can be conducted and operational manuals can be developed to enhance personnel's emergency response capabilities and proficiency with system application.

In conclusion, this emergency drill, which was predicated on the emergency command system, yielded notable outcomes. The process guidance and structured emergency plan featured on the command screen facilitated the company's swift emergency decision making and deployment, directing various functional departments to execute emergency rescue operations in an orderly fashion. These, in turn, enhanced the scientific approach to the company's emergency response, significantly mitigating fire losses and averting the occurrence of secondary derivative accidents.

4. Conclusions

The emergency command system developed in this study is capable of structuring emergency plans, facilitating information management, efficiently recommending analogous emergency plans based on an SVM algorithm, evaluating the efficacy of emergency plans, and enhancing the scientific rigor in the preparation of such plans.

(1) The emergency plan management in this study has nine functions for realizing the information and organizational management of emergency plans.
The system automatically recommends similar emergency plans by performing similarity calculations from the case base, thereby enhancing the efficiency of the emergency plan preparation process.

(2) By utilizing the fuzzy analytic hierarchy process, more reasonable and scientific feature weights can be obtained, enabling the scientific evaluation of emergency plans and enhancing their practicability.

(3) Considering the current landscape of accidents and disasters involving multiple types of operations and hazards, the structured emergency plan and intelligent recommen-

dation system developed in this research can be applied for a range of urban public safety rescue efforts. This provides a novel reference method for enhancing modern urban emergency response capabilities.

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