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Analysis of Accidents of Mobile Hazardous Sources on Expressways from 2018 to 2021

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Highlights:

- Targeted analysis of 523 highway mobile hazard source accidents in China from 2018 to 2021.
- Accident characteristics and accident causes of mobile hazard sources on highways are studied.
- A comprehensive management framework for highway mobile hazard accidents is discussed.

Abstract: A total of 523 accident cases during 2018–2021 in China were studied in terms of accident year, region, road section, and time to reduce the probability of expressways mobile hazardous source transportation accidents. The characteristics and causes of accidents of moving hazardous sources on expressways are analyzed, and preventive measures are put forward. The results indicated that the number of expressways mobile hazardous source transportation accidents fluctuated less in the past four years. Provinces with a higher degree of industrialization are more prone to accidents, with 80.02% of accidents occurring on normal road sections. Summer is the high accident season and accidents are prone to occur at 7:00 and 8:00 every day. External factors cause 47.99% of accidents, liquid class mobile hazards quickly cause accidents, leakage accidents account for the heaviest proportion, and explosive accidents have the highest chance of causing secondary accidents. In order to reduce the probability of accidents, a comprehensive management framework suitable for the mobile hazard sources of expressways is proposed.

Keywords: expressways; sustainable transportation; mobile hazardous sources accidents; analysis of characteristics; cause of the accident

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1. Introduction

The China's 14th Five-Year Plan points out that it is necessary to comprehensively and effectively curb serious safety accidents of hazardous chemicals and establish a higher level of safe China [1]. The transportation of hazardous chemicals is an accident-prone link in the industrial chain of hazardous chemicals [2]. If a transportation accident occurs, it will cause significant harm to the human body, facilities, and environment [3]. Its potential temporal and spatial dynamics will cause considerable challenges to traffic safety supervision. For example, on 13 June 2020, an explosion of a liquefied petroleum gas tanker on the G15-Shenhai Expressway in Wailing, Taizhou, Zhejiang Province, killed 20 people, injured 175 (24 seriously injured), and caused direct economic losses of USD 14.05 million [4]. On 6 July, an oil tanker explosion in Colombia caused 20 deaths, seven missing persons, and many injuries [5]. Therefore, it is essential to investigate the characteristics, causes, and preventive measures of hazardous chemical transportation accidents to effectively curb serious safety accidents of hazardous chemicals.

Hazardous chemicals are flammable, explosive, and highly toxic. In this paper, the hazardous chemicals in transportation are called mobile hazardous sources from the perspective of accident analysis. The existing research on accidents of mobile hazard sources take railway transport [6–8], road transport [9–12], and maritime transport [13] as the research subjects. Moreover, a complete research system has been formed in terms of accident statistical analysis [14–16], formation mechanism [17], analysis of influencing factors [18–20], safety risk assessment [21–23], path optimization [24–26], and emergency response [27,28]. Among them, domestic and foreign scholars have been involved in the primary analysis of accident statistics. For example, Oggero [29] et al. studied 1932 hazardous chemical accidents from the early 20th century to July 2004. They found that the number of accidents was on the rise, with more than half of them taking place on the road and the most common accident being a leak. Gorzelanczyk [30] et al. assessed the risks associated with transporting dangerous goods by discussing the relevant theoretical information and the results of the control of dangerous goods transport carried out by the Road Transport Inspectorate of Poznań Province in 2015–2017. Li [31] et al. according to the monthly number of road transport accidents involving dangerous goods from 2013 to 2019, established a transport accident time series and an autoregressive moving average (ARMA) forecast model. Zhou [32] et al. analyzed the fatal accidents of hazardous chemicals in China from 2015 to 2021 and proposed countermeasures for accident prevention and control. Macioszek [33] reduces road transport accidents by researching the securing technology of road transport loads. Marta [34] et al. studied government restrictions on mobility and the impact of the COVID-19 virus on urban road traffic system loads. However, although the transport structure in China is continuously optimized [35], the transport of mobile hazardous sources is still dominated by roads. Highway transportation accounts for many of them, and highway roads are characterized by fast vehicle speed and large traffic flow; also subject to tunnels, bridges, sharp curves, and other special sections of the objective environmental factors, with great danger. However, few studies involve the analysis of mobile highway hazards transportation accidents.

By collecting 523 transportation accidents of expressway mobile hazard sources in China from 2018 to 2021, this paper focuses on analyzing the accident's area, road section, time, causative factors, etc. The paper aims to reveal the mechanism and characteristics of transportation accidents of moving hazardous sources on expressways and propose preventive measures to reducing the probability of accidents. The specific organizational structure of this paper is as follows: Section 2 introduces the data sources and analysis methods. The Section 3 analyzes the accident occurrence law in detail, such as the temporal characteristics, spatial characteristics, and causative factors of the accident. Section 4 proposes an integrated management framework for mobile hazards. Section 5 summarizes the analysis results.

2. Materials and Methods

2.1. Data Sources

In this paper, the data are mainly obtained from the following three sources: (1) Chemical Accident Information Network operated by the Chemical Registration Center of the Ministry of Emergency Management [36], which published chemical accidents in production, operation, storage, and transportation since 2012. (2) Disaster accident information platform of the Ministry of Emergency Management of the People's Republic of China [37], which publishes investigation reports of significant accidents, including chemical accidents. (3) China Hazardous Chemical Logistics Network operated by the China Federation of Logistics and Purchasing Hazardous Chemical Logistics Branch [38], publishes domestic and international hazardous chemical logistics and transportation accidents. The statistical period of this expressway mobile hazard accident was from 1 January 2018 to 31 December 2021, and a total of 678 cases were collected.

2.2. Data Filtering

Data collection through the above data platforms can effectively ensure the comprehensiveness and integrity of the data. However, there are still defects such as case records and duplicate records of non-highway mobile hazardous source transportation accidents. In order to collect the highway mobile hazardous source transportation accident data more accurately, Python programming is used to establish the search criteria, as shown in Figure 1.

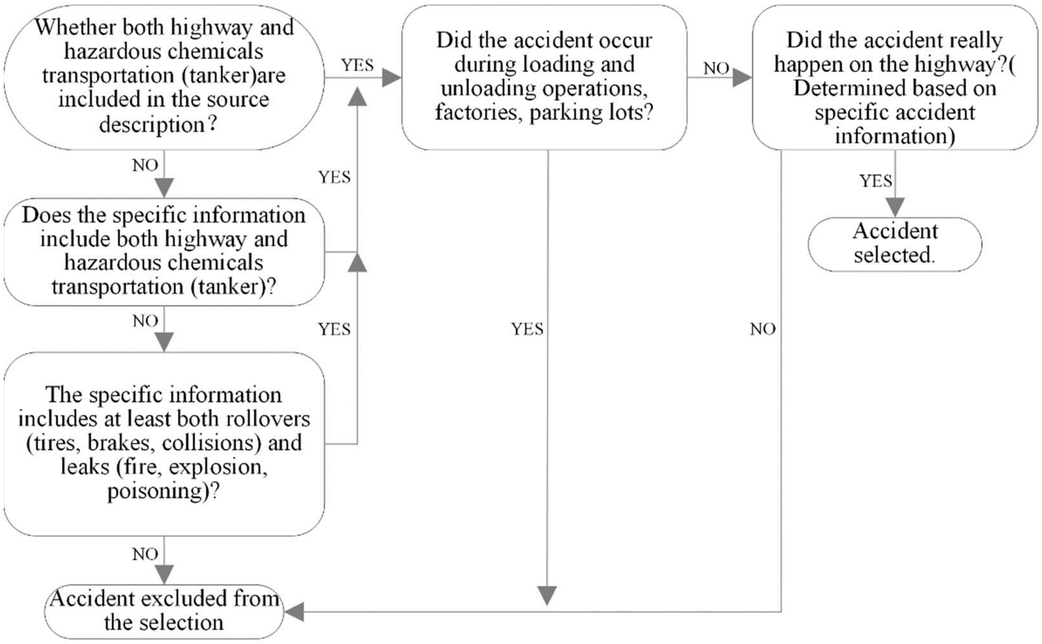

Figure 1. Data screening flowchart.

After screening the collected 678 accidents according to the criteria shown in Figure 1, 523 highway mobile hazard source accidents were obtained. The authors extracted the required information from the screened accident reports and then converted the data into a database in Excel format. Then, they used mapping software such as Origin to analyze the statistical results carefully from time, space, causative factors, types of mobile hazards, and accident types.

3. Results and Analysis

3.1. Time Characteristics

3.1.1. Years Characteristics

According to incomplete statistics, 523 cases of highway mobile hazardous source transportation accidents, including two significant accidents, occurred during the four years from 2018 to 2021, resulting in 90 fatalities and 254 injuries. The specific distribution of the data is shown in Figure 2, in which Figure 2b does not contain the number of fatalities and injuries in significant accidents.

It can be seen from Figure 2 that in 2018, there were the fewest mobile hazard source accidents on expressways and the most in 2020, but the overall number of accidents did not fluctuate much. Figure 2a shows that in 2020, the number of injured persons in accidents involving moving hazard sources on expressways is the largest, and the deviation is far from the whole. However, on 13 June 2020, a major explosion accident of a liquefied petroleum gas tanker on the G15-Shenhai Expressway in Wenling, Taizhou, Zhejiang Province, caused 175 injuries and caused a large fluctuation in the overall number of casualties. When the number of casualties in major accidents is excluded (Figure 2b), the number of casualties in 2020 decreased significantly, and the overall number of deaths and injuries changed little over the four years.

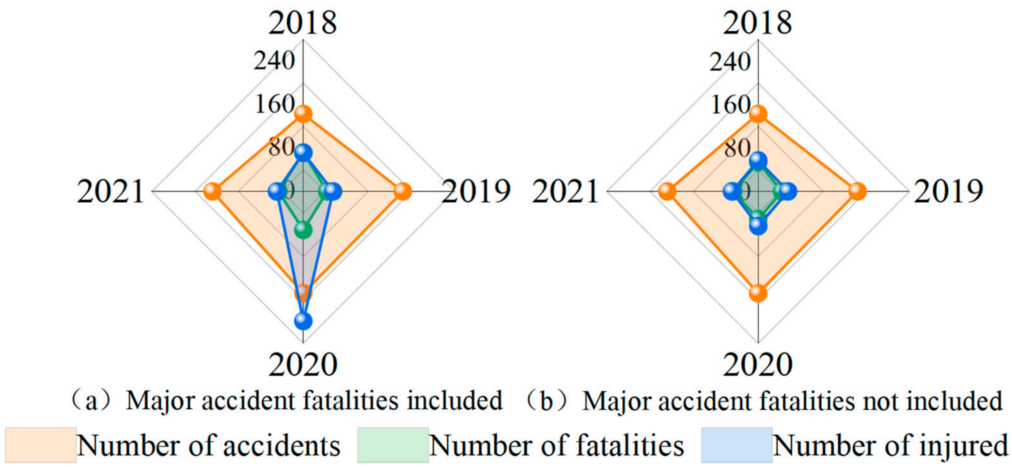

Figure 2. Overall distribution of accidents.

From 2018 to 2021, China has formulated the Measures for the Safety Administration of Road Transport of Dangerous Goods to strengthen the safety management of road transport of dangerous goods and prevent accidents in the road transport of dangerous goods. The "Rules for the Road Transport of Dangerous Goods" was completed to solve the problems of prominent fragmentation of the road transport standard system for dangerous goods and the lack of effective connection between standards. It also revised and improved a series of regulations such as the "Regulations on the Administration of Road Transport of Dangerous Goods". Moreover, according to statistics, from 2018 to 2021, the number of mobile hazard vehicles in China has increased every year [39], indicating that Chinese mobile hazard transportation control measures have been continuously improved and have achieved remarkable results.

3.1.2. Month Characteristics

Figure 3 shows the relationship between the frequency and monthly distribution of transportation accidents of mobile hazard sources on expressways.

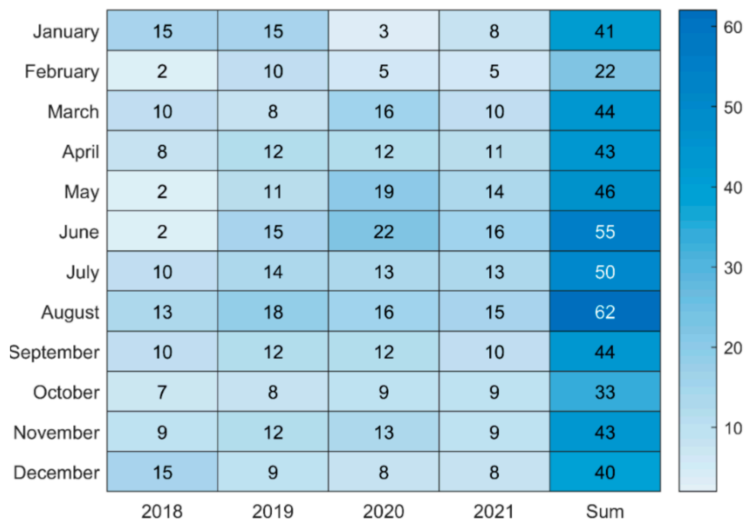

Figure 3. The relationship between accident frequency and month distribution.

It can be seen from Figure 3 that the months with more than 15 accidents are January and December 2018; January, June, and August 2019; March, May, June, August 2020; June and August 2021. The high-incidence months were from June to August, with 55, 50, and 62 incidents. Summer is the high-incidence period of highway mobile hazardous source accidents. This is because the temperature in summer is high and changes frequently, and most hazardous chemicals are flammable and explosive, which can easily lead to volatilization, leakage, and deflagration of hazardous chemicals during transportation. Moreover, it is easy to make the transport personnel sleepy, tired, and misoperational. January is the last working month before the Spring Festival. Most enterprises will increase their transportation tasks to complete their annual turnover. At the same time, there is much icy, snowy weather in January, and accidents such as rear-end collisions and rollovers are prone to occur, so accidents are also serious. The month with the lowest accident frequency is February, which coincides with the Spring Festival when most chemical companies choose to suspend production and have the smallest transportation volume. In addition, during the Spring Festival, the government will strengthen the supervision of hazardous chemicals, so the accident rate is the lowest. However, the number of people returning home during the Spring Festival has increased significantly. As an essential means of inter-provincial transportation, expressways are densely populated by traffic and people. Once an accident occurs, it will cause more severe consequences and worse impacts.

3.1.3. Hour Characteristics

A total of 404 accident cases in this collection contain specific times. After analysis, it is found that the transportation accidents of expressway mobile hazard sources also show certain regularities at specific times of the day, and the time distribution characteristics are shown in Figure 4.

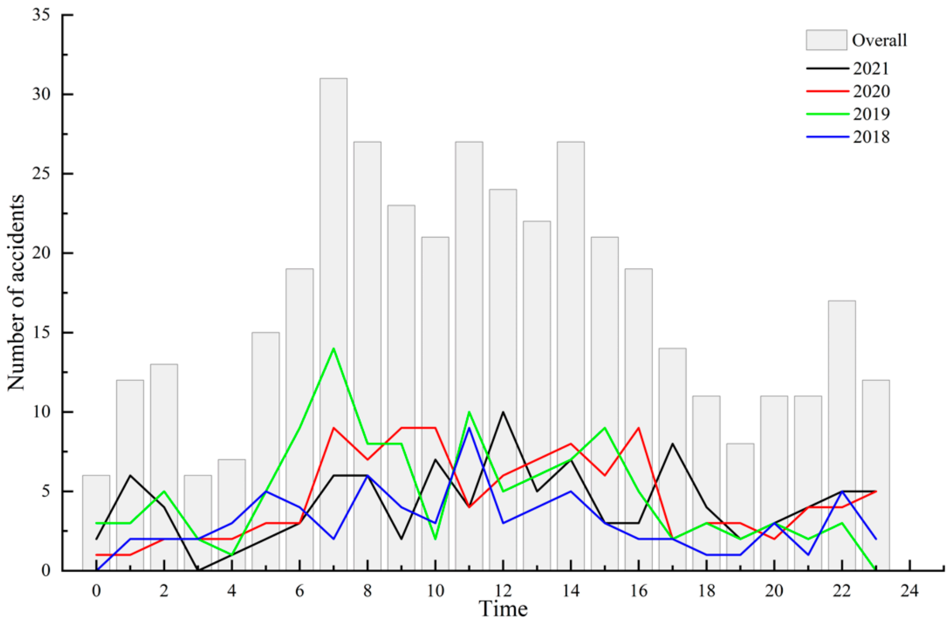

Figure 4. The relationship between accident frequency and time distribution.

It can be seen from Figure 4 that the accident peak time is 11:00 in 2018, 7:00 in 2019, 7:00, 9:00, 10:00, 16:00 in 2020, and 12:00 in 2021. Overall, the peak time of the accident is 7:00, 8:00, 11:00, and 14:00, which also needs attention. When the mobile hazard has been transported on the road, it is not restricted by day or night. However, after 8:00 p.m., human arousal levels decline and do not recover until 5:00 a.m. the next morning [40]. This causes the driver high level of mental stress when driving at night. Therefore, drivers will be relaxed from 6:00 am to 10:00 am as arousal levels continue to rise, during which time drivers are more prone to errors. Moreover, 7:00 and 8:00 are the morning rush hours, the traffic flow on the expressway is large, and the transport personnel have not fully entered the working state, hence more prone to accidents. 7:00 to 18:00 is the main period for the transportation of mobile hazard sources, and the frequency of accidents is significantly higher than at other times.

3.2. Spatial Characteristic

3.2.1. Regional Characteristics

Hazardous chemicals are vital industrial raw materials and fuels and contribute significantly to urban development. The higher the degree of industrialization, the greater the demand for hazardous chemicals, and the GDP can reflect the degree of industrialization of a region to a certain extent. The expressway density in each province is also the main factor affecting the accident frequency of moving hazard sources on expressways. At the same time, the market distribution of the demand for hazardous chemicals also affects the areas where the accident of moving hazard sources on the expressway occurs to a certain extent. Therefore, this paper draws the spatial distribution map of highway mobile hazard source accident frequency and provincial GDP and highway density (2021), as shown in Figure 5. The regional market structure of China's hazardous chemicals logistics in 2020 is shown in Figure 6.

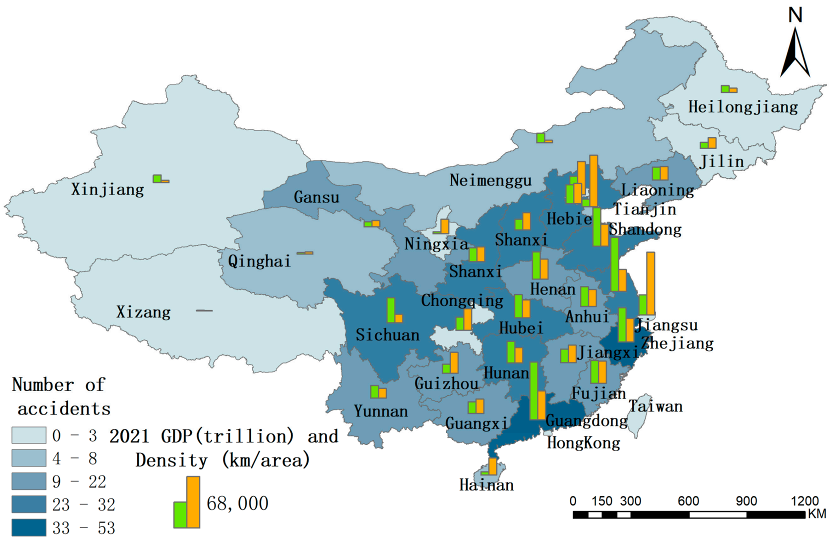

Figure 5. Spatial distribution map of accident frequency and provincial GDP and expressway density.

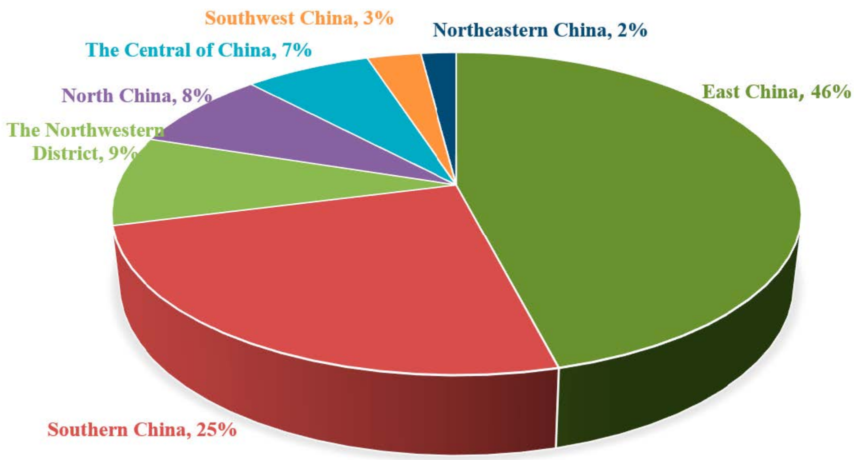

Figure 6. Regional market structure of China's hazardous chemicals logistics in 2020.

It can be seen from Figure 5 that the accident rates in Guangdong and Zhejiang provinces are as high as 10.1% and 8.4%, respectively. Second, the accident rates in Beijing, Shanghai, Zhejiang, and other provinces are also in the forefront. The accident rate in Ningxia, Xinjiang, and other places is only 0.4%. Tibet has not had any accidents involving moving dangerous sources on expressways in the past four years. China's top 5 provincial-level administrative regions for expressway density are Shanghai, Tianjin, Beijing, Guangdong, and Zhejiang. These provinces are also highly industrialized. At the same time, more than 90% of the customers of China's hazardous chemical logistics enterprises are chemical enterprises. As can be seen from Figure 6, most of the market-consuming enterprises are concentrated in the eastern coastal provinces, and the eastern and southern China regions account for more than 70% of China's market share. The regional market distribution of hazardous chemical transportation enterprises is close to the distribution trend of service entities, and the distribution in the southeast coast is dense. Combining with Figure 5, it can be seen that the frequency of transportation accidents of expressway mobile hazard sources in the southeast coastal area is higher than that in other areas. This proves that similar to hazardous chemical accidents [41,42], highway mobile hazard accidents are unevenly distributed in different regions. The higher the degree of industrialization, the higher the transportation volume of mobile hazard sources and the higher the accident rate. The main reasons for the frequent occurrence of mobile hazard accidents on expressways in these areas are that the petrochemical industry is relatively developed, the probability of personnel engaged in chemical production, storage, transportation, sales, use and disposal is high, and the expressway network is more developed, hence increasing the likelihood of accidents with moving hazards on highways. Therefore, for emergency management in China, special attention should be paid to the safety management of provinces with high highway mobile hazard accidents, such as Guangdong and Zhejiang, and to minimize the accident rate.

3.2.2. Road Characteristics

In addition to straight roads, expressways include tunnels, bridges, curves, toll stations, and service areas. In this paper, toll stations, tunnels, service areas, exits, bridges, and curves are defined as special road sections, and other road sections other than special road sections are collectively referred to as normal road sections. Due to the high speed of expressway vehicles, traffic accidents can occur when the driving environment changes when entering a special road section. The frequency of accidents on different road sections is shown in Figure 7.

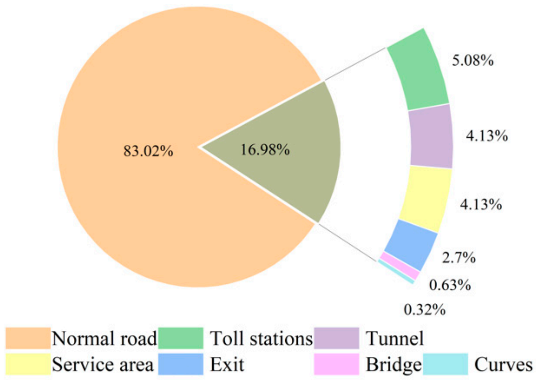

Figure 7. The relationship between accident frequency and road segment characteristics.

It can be seen from Figure 7 that 80.02% of accidents occurred on normal road sections, and 16.98% of the transportation accidents of mobile hazard sources on expressways occurred in special road sections. 5.08% occurred near toll stations, 4.13% near tunnels and service areas, 2.7% near exits, and 0.63% and 0.32% near bridges and curves. It can be seen that although special road sections account for a small proportion of expressway mileage, attention should still be paid. There are warning signs to alert drivers of potentially dangerous situations before special road sections. As a result, mobile hazard drivers are always more attentive when passing special road sections. On the contrary, there are few changes in normal road sections, and drivers are prone to slack. Therefore, attention should be paid to driving safety and safety management should be strengthened while transporting mobile hazardous sources on expressways.

3.3. Accident Causes

The cause of the accident is mainly analyzed from four aspects: human, machine, environment, and management. No management factor appears in the analysis of the cause of the collected accident cases. In addition, the causes of traffic accidents are easily affected by external factors besides their factors. Therefore, this paper takes the direct cause of the accident as the causal factor and sorts and categorizes the accident from personnel errors, equipment failures, environmental factors, and external reasons, as shown in Figure 8.

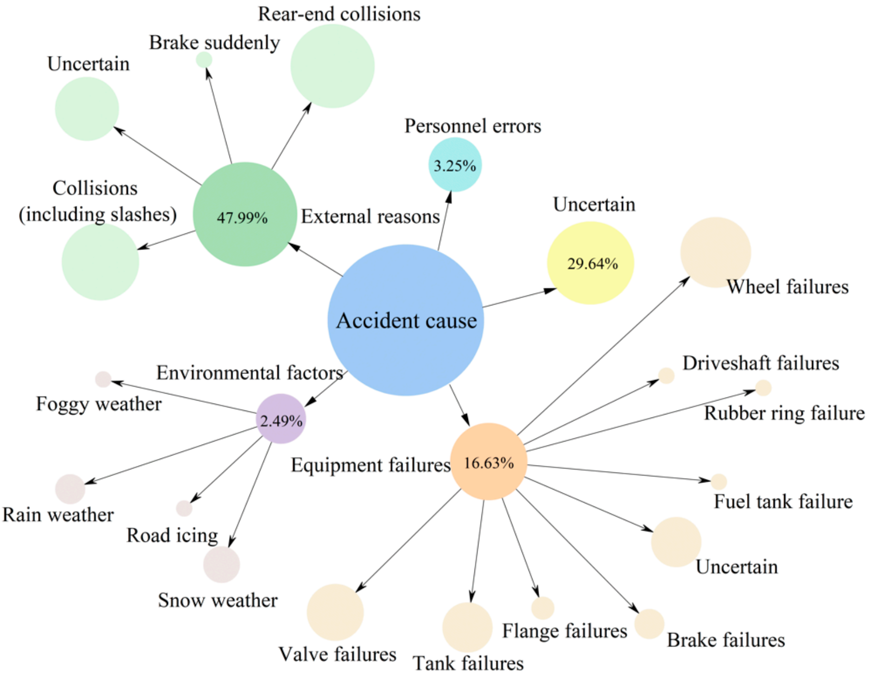

Figure 8. Accident cause network diagram.

It can be seen from Figure 8 that external reasons account for 47.99% of the transportation accidents of mobile hazard sources on expressways, equipment failures account for 16.63%, personnel errors account for 3.25%, environmental factors account for 2.49%, and 29.64% of the accidents are unknown.

Among the 251 accident cases caused by external causes, rear-end collisions accounted for more than half, followed by collisions (including slashes), accounting for 27.09%. Among the equipment failures, wheel failures (36.78%) accounted for the most significant proportion, followed by valve failures (20.69%), tank failures (16.09%), brake, flange, and driveshaft failures. Among the environmental factors, rain and snow weather has a more significant impact, and fog and road icing will also have a particular impact. Although the proportion of accidents caused by personnel errors is relatively small, there have been two significant accidents in the past four years: 6.13 major traffic accidents in Wenling, Zhejiang and 6.29 major road traffic accidents in the Hengdong section of the Beijing-Hong Kong-Macao Expressway in Hengyang City, Hunan Province. The direct cause was driving human error.

3.4. Types of Mobile Hazard Sources

Different types of mobile hazards are affected by accident causative factors, their characteristics, and transportation volume, and the probability of accidents is also very different, as shown in Figure 9. The numbers in Figure 9 represent the number of accidents.

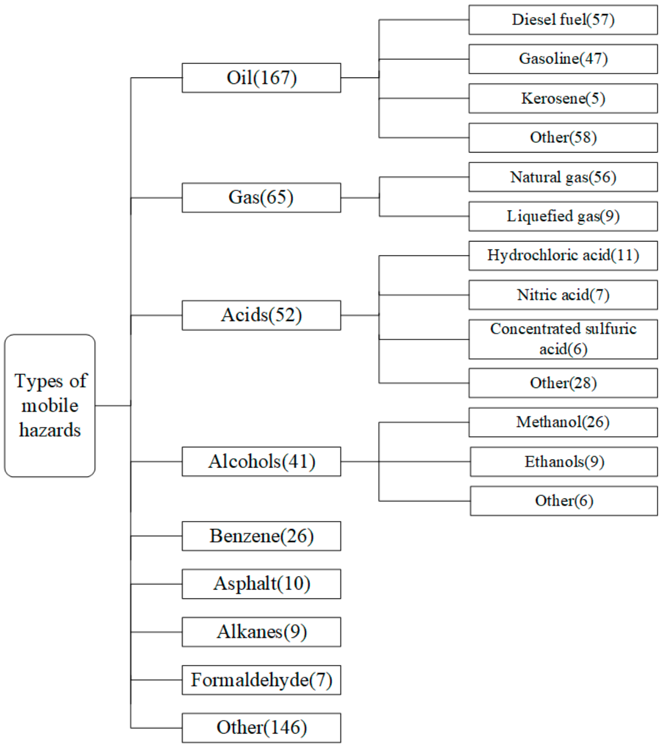

Figure 9. Relationship between accident frequency and types of mobile hazards.

As shown in Figure 9, in the past four years in China's highway mobile hazardous source transportation accidents, oil mobile hazardous source accidents with 31.93% ranked first, followed by gas and acid mobile hazardous source, with accident rates 12.43% and 9.94%, respectively. Gasoline and diesel accounted for 62.3% of the oil moving hazards accidents. According to the analysis of solid, liquid, and gaseous states, the transportation accidents of liquid mobile hazard sources are the heaviest, followed by gaseous ones, and solid ones are the lightest. Since there are still many accident statistics that do not reflect the types of mobile hazards, specific statistics cannot be carried out.

3.5. Types of Incidents

There are five main types of transportation accidents of mobile highway hazards: leakage, fire, explosion, explosion, and vapor cloud. Each accident may fall into one or more of these categories, as a particular accident may be classified into multiple categories; if leakage causes an explosion or leakage causes fire after the explosion. Based on this, a tree diagram of accident types is drawn (Figure 10). The numbers in parentheses represent the number of incidents of that type. The numbers below represent the likelihood (the ratio of lower-level accidents to the number of higher-level accidents). The numbers at the end of each branch indicate the overall probability of each specific accident. A total of 486 incident types were described in the collected data.

It can be seen from Figure 10 that:

(1) Based on the analysis of initial accident types, among all accidents, leakage accidents accounted for the heaviest, accounting for 74%; fire and explosion accidents accounted for 16.1% and 2.87%, respectively. One leakage accident in every 1.35 accidents, one fire accident in every 6.21 accidents, and one explosion accident in 34.84 accidents. Considering only the accident types, the proportions of leakage, fire, explosion, explosion, and steam cloud accidents are 75.72%, 18.59%, 4.40%, 0.19%, and 0.19%, respectively. 7.07% of the accidents did not give a specific accident type.

(2) Among all accidents, leakage accidents that did not cause secondary accidents accounted for the highest proportion, accounting for 72.3%, followed by fires (89.2%) and explosions (1.91%) that did not cause secondary accidents. Among the accidents

with secondary accidents, the leakage-fire series (1.34%) accounted for the most significant proportion, followed by the fire-leakage series (1.15%), fire-explosion accidents (0.96%), and explosion-fire accidents (0.77%), leakage-fire-explosion accident and fire-leak-explosion accident all accounted for 0.38%, explosion-fire-leakage accident accounted for 0.19%.

(3) The probability of secondary accidents caused by explosion accidents is the highest, 33.33%. Followed by fire accidents (15.47%) and leak accidents (2.33%).

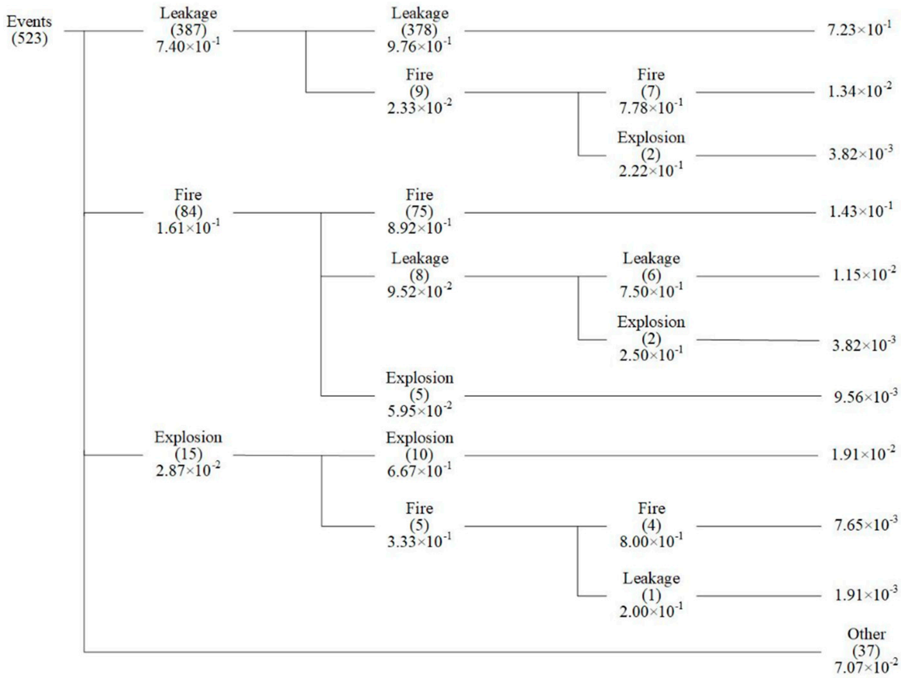

Figure 10. Accident type tree diagram.

It can be seen from the above analysis that the leakage accident is the most common transportation accident of highway mobile hazard sources, followed by fire and explosion. This is related to the flammable and explosive characteristics of most mobile hazards. Therefore, during the transportation of mobile hazard sources, the safety supervision of leakage, fire, explosion, and other accidents should be strengthened, especially the safety supervision of the corresponding mobile hazard sources that are likely to cause such accidents.

4. Integrated Management Framework

4.1. Management Measures

4.1.1. Management Status

The United States manages mobile hazards through an information disclosure system requiring companies to accurately report hazardous chemicals' management. The EU has the world's largest substance classification database, the Chemical Classification and Labelling Catalogue, which can be used to identify and manage hazardous chemicals [43]. The United Nations Committee of Experts on the Transport of Dangerous Goods issued the "Recommendations on Model Regulations on the Transport of Dangerous Goods" to manage the transport of hazardous chemicals, providing a unified management framework for the safe transport of hazardous chemicals worldwide [44].

Compared with developed countries, Chinese safety management of hazardous chemicals is still in the development stage. In China, multiple departments such as the Ministry of Emergency Management, Transportation, and Public Security oversee the safety management of hazardous chemicals. In 2016, China proposed implementing a dual prevention mechanism of risk classification control and hidden danger investigation to prevent hazardous chemical accidents and achieve source control. In 2019, the Ministry of Emergency Management formulated several policies and regulations such as "Guidelines for Safety Risk Investigation and Treatment of Chemical Parks (Trial)" and "Guidelines for Safety Risk Investigation and Treatment of Hazardous Chemical Enterprises". In 2020, the "Administrative Measures for the Safety of Road Transportation of Dangerous Goods" was issued to strengthen the safety management of road transportation of hazardous chemicals.

Despite the continuous improvement of the current international safety management system for hazardous chemicals, the risk of mobile hazard accidents remains as long as the industry uses many hazardous chemicals. As a result, we will continue to face risks from the transportation of mobile hazards.

4.1.2. Existing Problems

According to statistics, from 2018 to 2021, more than 500 accidents took place involving moving hazards on expressways in China. Although the number of such accidents has decreased in recent years, serious highway mobile hazard accidents still exist, and safety management still faces many challenges.

(1) The laws, regulations, and standards for managing hazardous chemicals are not perfect. Currently, Chinese management of hazardous chemicals is mainly based on the " Safe Production Law of the People's Republic of China" formulated by the Standing Committee of the National People's Congress. In addition, the "Fire Prevention Law of The People's Republic of China", "Law of The People's Republic of China on Road Traffic Safety" and other regulations also address requirements for the management of hazardous chemicals. This situation makes it difficult to implement the responsibility for managing hazardous chemicals, and the responsibility for the accident is unclear. In addition, the State Council and ministries/commissions/bureaus have promulgated various regulations on managing hazardous chemicals. The content of the rules and regulations of different departments may be duplicated, and it is difficult to unify the standards, which leads to difficulties in implementation.

(2) Ineffective government supervision is one of China's root causes of mobile hazard accidents on highways [45]. The Ministry of Emergency Management of China is responsible for product safety issues in various industries, including fire rescue and emergency response to natural disasters. As a result, grass-roots emergency managers are not familiar with supervising hazardous chemicals and lack sufficient professional skills, weakening safety management functions. At the same time, accidents involving mobile hazard sources on highways in China involve the Ministry of Emergency Management, the Ministry of Communications, the Ministry of Public Security, and other departments. Therefore, the supervision system of highway mobile hazard sources is imperfect, and the supervision functions are not precise.

(3) The safety management level of hazardous chemical transportation enterprises needs to be improved. More than 300,000 dangerous goods transportation enterprises are in China, and about 90% of chemical raw materials must be transported in different places. About 80% of SMEs are underinvested in security and lack training and education for their employees. Some enterprises have imperfect safety management institutions, and it is difficult to implement the primary responsibility of enterprises, resulting in management loopholes.

(4) The emergency management of mobile hazard transportation on expressways in China is still in the stage of development and improvement. The key technologies for emergency response cannot cover all possible accident scenarios. For unconventional highway mobile hazard accidents, the practicability of critical technologies for emergency response is limited. In addition, the public lacks scientific understanding of hazardous chemicals and cannot effectively protect their safety in a timely and effective manner after a highway mobile hazard accident occurs. Therefore, after the accident, the public emergency response capability of hazardous chemical leakage is an important factor affecting social stability.

4.1.3. Future Work

By analyzing the characteristics of mobile hazard source accidents on highways in China from 2018 to 2021, a management framework is put forward based on the current situation of transportation management of mobile hazard sources on highways in China (Figure 11). That is to reduce the accident risk of mobile highway hazards from four dimensions: laws and regulations, government supervision, corporate responsibility, and emergency response.

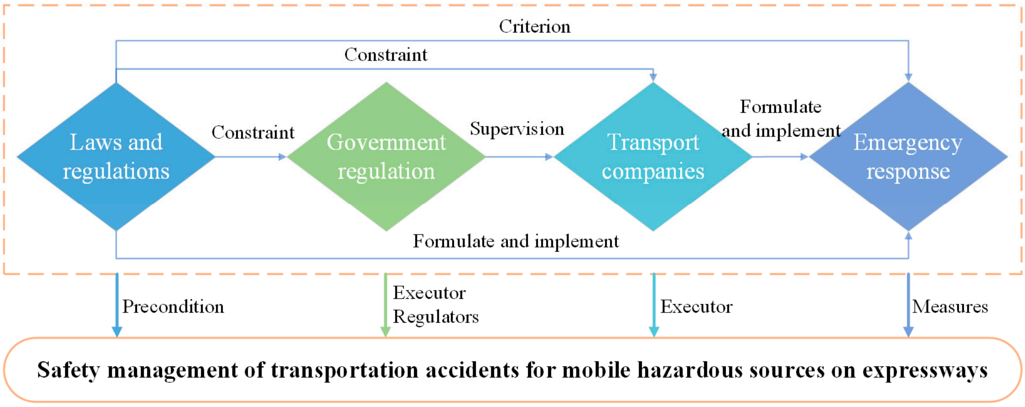

Figure 11. Guidelines for comprehensive management of mobile hazardous sources on expressways.

(1) Laws and regulations

Perfect laws and regulations are the premises of enhancing the management of mobile hazard sources on expressways. China can learn from the management experience of developed countries, draw on the experience of major accidents in the transportation of highway mobile hazard sources, establish and improve the legislative framework, and unify the management standards for highway mobile hazard sources [46]. Taking China as an example, the "Safe Production Law of the People's Republic of China" and the "Regulations on the Safe Management of Hazardous Chemicals in China" can be the main body, supplemented by local and departmental regulations, to improve the safety legal and regulatory system.

(2) Government regulation

Government supervision is an important means to manage mobile hazard sources on expressways. First, the government should comprehensively investigate the mobile hazard sources of expressways within its jurisdiction and improve the information supervision system for the entire life cycle of transportation of expressway mobile hazard sources. In addition, dynamic risk management of moving hazard sources on highways should be achieved by establishing a risk-based regulatory model. Second, improve the safety supervision team of highway mobile hazard sources, especially the overall ability of grassroots units. In addition, it is necessary to strengthen the safety education of mobile hazard sources to the public, so that the public can understand the basic characteristics of mobile hazard sources and emergency response methods, to improve accident prevention and response capabilities. Finally, according to the needs of different provinces and local conditions, the safety management of mobile hazard sources on expressways should be strengthened.

(3) Transport companies

Transportation enterprises are the executors of the transportation management of mobile hazard sources on expressways. Strengthening the awareness of corporate responsibility plays an important role in reducing accident risks. First of all, we should establish a long-term mechanism for the safety supervision of mobile hazard transportation, strengthen the linkage between departments, strengthen risk prevention and control, form a "closed loop" safety supervision, and curb accidents from the source, strengthen the communication and cooperation between transportation enterprises and improve the level of safety management. Second, follow the laws of highway mobile hazard source accidents and arrange transportation tasks reasonably. Another important task is to strengthen the corporate training system to improve employees' work skills and professional qualifications. In addition, a dynamic risk assessment system needs to be established to eliminate hidden dangers through self-examination. In particular, enterprises should pay attention to equipment maintenance and establish a real-time monitoring system to ensure that the damaged equipment is replaced in time. Finally, the safety culture system should be improved to enhance employees' sense of responsibility.

(4) Emergency response

Many developing countries such as China are still in the initial stage of construction of emergency management systems. They face many challenges in preventing and mitigating mobile hazard accident risks. Therefore, the emergency management department must first establish a "people-oriented" emergency management concept, and formulate a scientific and professional emergency management system emergency plan. Accident and disaster mitigation must be prioritized to prevent secondary disasters during emergency response. The second is to strengthen the construction of emergency response teams, ensure the investment of emergency funds, cooperate with third-party professional rescue teams, and cultivate high-quality emergency management talents. Finally, an intelligent emergency management system based on Internet technology must be established to realize emergency resource sharing and dynamically select appropriate emergency plans according to different situations.

4.2. Technical Measures

4.2.1. Transport Vehicle

Mobile hazard vehicles are the carriers of mobile hazard transportation, and improving the safety factor of vehicles is of great significance in preventing mobile hazard accidents. In this regard, cab rearward movement, lane deviation warning, tire pressure explosion-proof emergency device, automatic emergency braking, fatigue driving warning, electronic stability system, rear collision avoidance warning, 360° surround view, loading and unloading safety interlock, etc., can be adopted to protect the overall safety of transportation. At the same time, new materials, technologies, and processes are adopted to make the vehicles have high safety, reliability, and comfort.

4.2.2. Smart Logistics System

The use of informatization and Internet technology to build a smart logistics system can effectively break down regional barriers and information barriers and make the transportation of mobile hazards on expressways safer and more effective. For example, you can analyze the driving trajectory through the blockchain technology of online maps, including artificial intelligence technology and big data technology, and you can know whether the vehicle has rapid acceleration, rapid deceleration, or overspeed during transportation. Unreasonable driving behavior, once the vehicle is in the process of transportation, the alarm can be triggered when the route deviation is found. These technologies can also be used to plan the most reasonable and safe routes to improve transportation efficiency. In addition, with the help of intelligent positioning services, the location of the accident can be accurately located after an accident occurs, thereby improving rescue efficiency.

5. Conclusions and Discussion

In China, roads are divided into five technical levels: expressways, first-class roads, second-class roads, third-class roads, and fourth-class roads. China's expressway network is developed, and long-distance transportation is mainly carried out through expressways. The highways have the characteristics of fast and uninterrupted driving speed, which effectively reduces transportation costs. Through the case analysis of highway mobile hazard source accidents, the occurrence law of highway mobile hazard source accidents can be obtained, which is helpful for accident prevention and reduction of accident risks. However, due to the different standards for road classification in different countries, the research on mobile hazard sources is generally aimed at all roads. There are few specific studies on different grades of roads. To this end, this paper takes the expressway as the carrier to study 523 cases of highway mobile hazard source accidents from 2018 to 2021. It is found that the number of accidents involving mobile hazard sources on expressways has generally fluctuated less in the past four years and had decreased slightly in 2021. Provinces with a higher degree of industrialization are more prone to accidents. 80.02% of accidents occur on normal road sections, and accidents are more likely to occur at 7:00 and 8:00 every day and in summer. From the analysis of the cause of the accident, the accidents of mobile hazard sources on highways are mostly caused by external factors such as collisions and rear-end collisions; liquid mobile hazard sources are easy to cause accidents; leakage accidents account for the largest proportion, and explosion accidents have the highest probability of secondary accidents. In order to reduce the accidents of moving hazard sources on expressways, a comprehensive management framework suitable for moving hazard sources on expressways is proposed.

However, the data statistics of highway mobile hazard source accidents in this paper come from the network, and some accident information is not comprehensive enough. In the next step, we can carry out research on the highway mobile hazard source accident statistics platform and related accident statistical standards, which is convenient for researchers to find accident laws and analyze accident mechanism to prevent the recurrence of similar accidents. Moreover, to reflect the impact of causative factors on highway mobile hazard accident accidents more intuitively and concisely, this paper only takes the direct cause of the accident as the causal factor for analysis. In the future, the influence of multi-factor interaction on highway mobile hazard source accidents should be analyzed more deeply and meticulously. Due to limited channels, this paper does not collect data on the transportation volume of hazardous chemicals in each province and the monthly shipment volume of hazardous chemicals. Data on the length and traffic volume of road sections such as curves, bridges, and tunnels were also not collected. Therefore, the conclusions obtained have certain limitations to a certain extent. These data should be improved in future research to make the conclusions more accurate and detailed.

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