Study on Features of Hazardous Goods Transport Accidents on Highway

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Abstract: This paper presents a collection of 202 hazardous goods transport accidents on road and analyses of time and spatial distribution features, inducements and forms of these accidents. The analyses results show: Frequent hazardous goods accidents occur in June and July and in the period of 8:00-10:00 each day; most accidents occur on an expressway, leading to more serious consequences if they occur inside a tunnel; major causes of hazardous goods accidents are drivers' misoperation and vehicle fault; leakage is the most common form of accident; explosions and fires cause the most serious consequences; flammable liquid, flammable gas and toxic chemicals are three substances most commonly seen in hazardous goods accidents. At the end of this paper, a number of targeted recommendations are provided to prevent hazardous goods transport accidents based on the above results.

1. Introduction
Hazardous goods mean objects or substances that may endanger personal safety, health or damage transport tools, equipment and other properties under certain conditions such as leakage, collision, extrusion, high temperature and open fire [1]. The malfunction or traffic accident of a vehicle carrying hazardous goods will unavoidably result in leakage and even fire, explosion and poisoning, endangering life and road safety.

On March 1, 2014 the rear-end of two articulated vehicles carrying methanol in Yanhou Tunnel of Jincheng-Jiyuan Expressway in Shanxi led to leakage of methanol from the vehicle in the front causing a fire. Another two hazardous chemical vehicles and 31 coal transport vehicles in the tunnel were ignited by the fire and exploded. This accident resulted in 40 deaths, 12 injuries and direct economic losses of RMB81.97 million [2].

On April 8, 2011 the rear-end of two heavy oil tankers in the New Qidaoliang Tunnel in Gansu resulted in combustion and explosion of 40t solvent naphtha carried by the two tankers, causing 4 deaths and serious damages to tunnel facilities [3].

On May 23, 2017 the combustion and explosion of a semi-trailer truck carrying sodium chlorate inside Futuyu 5# Tunnel of Zhangjiakou-Shijiazhuang Expressway led to 15 deaths and severe burns to three people. The accident spread to over 40 households below the expressway bridge, causing cumulative economic losses of RMB42 million.

The above accidents suggest hazardous goods transport accidents often cause severe casualties, economic losses and social impacts. It is therefore necessary to study and analyze such accidents. This paper presents data on 202 typical hazardous goods transport accidents on road collected from China
Chemical Safety Association website and through interviews and provides analyses of their accident features and distribution patterns in order to offer reference and advice for prevention of hazardous goods transport accidents.

2. Spatial and Temporal Distribution Features of Hazardous Chemical Accidents

2.1. Temporal distribution features of hazardous chemical accidents

2.1.1. Monthly distribution features of hazardous chemical accidents. Hazardous chemical accidents are statistically analyzed by month. See Fig 1.

As shown in Fig 1, the period of June to August sees the most hazardous goods transport accidents in China (totaling 78 accidents accounting for 38.61% of all cases); the number of accidents is also high in December (totaling 19 accidents). Possible reasons for these features: roads in summer are in a hot and wet environment resulting in larger loads on the engine and tire than in other seasons; such environment makes hazardous goods more active increasing the risk of leakage, combustion and explosion thereof. In addition, bright sunlight and stiflingly hot environment make drivers more prone to fatigue and impatient, thus increasing the possibility of misoperation. The large number of accidents in December is a result of increased trade volumes of hazardous fuels after winter has set in, whereas January and February coincides with the Spring Festival so accidents are relatively few [4].

2.1.2. Hourly distribution features of hazardous chemical accidents

In order to reflect the pattern of hazardous goods transport activity throughout a day and the influence of day and night on transport safety, the 24h in a day is divided into 12 periods for statistical analysis of accidents. See Fig 2 for the result.
As shown in Fig 2, the number of accidents gradually increases from wee hours to 10:00 in the morning every day possibly because: hazardous goods vehicles are more likely to collide with other vehicles due to large traffic volumes and complex vehicle conditions on the road in the morning; lighting conditions are poor in wee hours and during night leading to inadequate visibility; drivers' fatigue accumulates, causing increased accidents[5].

2.2. Spatial distribution features of hazardous goods accidents

2.2.1. Road type. Different types of road have different traffic volumes, road environments and strategic values, hence different frequencies and consequences of hazardous goods accidents. Roads on which 202 accidents occurred are divided into expressway, ordinary road and city road for statistical analyses of accidents and casualties. See Fig 3 for the analysis result.

As shown in Fig 3, 166 accidents (82.2%) occurred on expressway causing 292 deaths and 605 injuries; 30 accidents (14.9%) occurred on ordinary roads causing 44 deaths and 78 injuries; only 6 accidents occurred on city roads causing 2 deaths and 2 injuries. This is because hazardous goods are produced/consumed in different regions of China, calling for the need to transport them from one province/region to another, thereby leading to many hazardous goods accidents on expressways; vehicles run slowly on city roads due to the dense population and complex building environment in the city and strict restrictions are imposed on passage of hazardous goods vehicles, leading to the smallest number of accidents on city roads.
2.2.2. Tunnel and open road section. A tunnel is a closed structure that is distinctly different from the open road section. The following statistics are presented for the purpose of examining the severity of accidents on open road sections and inside tunnels. See Fig 4.

![Fig 4. Comparison of accidents on open road sections and in tunnels](image)

As shown in Fig 4, of 202 accidents 155 occurred on open road sections and 47 occurred in tunnels. Calculation shows each accident on open road section caused 1.92 deaths and 3.19 injuries on average while each accident in tunnels caused 2.32 deaths and 4.06 injuries on average. This means hazardous goods accidents in tunnels often have more severe consequences and cause more casualties.

3. Inducement Distribution Features for Hazardous Goods Accidents
Causes of hazardous goods transport accidents are roughly classified into human factors, vehicle factors and environmental factors. The number of accidents attributed to each category is counted. See Fig 5.

![Fig 5. Distribution of accident causes](image)

As shown in Fig 5, human factors caused 140 accidents representing 69.3% of all accidents; vehicle factors caused 56 accidents representing nearly 27.7%; environmental factors caused 6 accidents making up 3% of all accidents.

3.1. Human factors
Human factors contributed to the largest share of accidents. The inducements include rear-end, collision/scratch, rollover and illegal transport. Rear-end accidents are the most frequent. Therefore, rear-end accidents are divided into passive rear-end (dangerous goods vehicle in front), active rear-end (dangerous goods vehicle behind) and multi-car rear-end and separately analyzed. See Fig 6 for the result.
As shown in Fig 6, of the 72 rear-end accidents the number of accidents with dangerous goods vehicle in front is 51, accounting for 70.8% of all rear-end accidents. This is because large hazardous goods vehicles travel relatively slowly, making themselves prone to being rear-ended; meanwhile, hazardous goods vehicles with a tank on the back are more susceptible to direct impact and squeezing when rear-ended.

3.2. Vehicle factors

In order to study the impact of vehicle factors on hazardous goods accidents and their pattern, vehicle factors causing hazardous goods accidents under consideration are divided into vehicle fire (ignition of vehicle structure without direct external impact), mechanical failure (vehicle uncontrollable due to component damage and fault) and tank leakage. See Fig 7.

As shown in Fig. 7, vehicle fire (tire fire, engine fire, battery fire and container fire) caused 24 hazardous goods accidents making up 42.9%; mechanical failure (tire flat, cooling tube rupture and body disintegration) caused 12 accidents making up 21.4%; tank leakage caused 20 accidents making up 35.7%. Tire problems caused 24 accidents making up 42.9% of all accidents attributed to vehicle factors.

3.3. Environmental factors

Environmental factors mean the possibility of road problems and occasional problems causing hazardous goods transport accidents. For example, at 11:19 July 7, 2019 a tanker carrying 32.6t benzene traveled to National Road 108 in Caluo Township, Shimian County, Ya'an City when it was hit by a flying stone from the mountain. This led to tank cracking and leakage.
4. Form Distribution Features of Hazardous Goods Transport Accidents

4.1. Accident type distribution features

The forms of 202 accidents and the number of casualties in each type of accidents are statistically analyzed (the form with the biggest impact is defined as the form of the accident. For example, an accident involving both explosion and leakage is determined to in the form of explosion, and so on). See Fig 8 for the result.

As shown in Fig 8, there are 21 explosions, 54 fires, 8 poisonings and 119 leakages without causing other serious consequences. It can be seen that the major form of hazardous goods accidents is explosion, followed by fire, explosion and poisoning. This pattern is in line with the mechanism of hazardous goods accidents: leakage occurs first and leads to fire, explosion and other secondary impacts.

Calculation shows each fire caused 3.94 deaths on average; each explosion caused 3.14 deaths on average; each leakage caused 1.09 deaths and each poisoning caused 0.87 deaths. This suggests fire and explosion are the most fatal incidents because fires and explosions develop rapidly and affect a large area, leaving people little time to get out of danger before losing their lives.

4.2. Distribution of hazardous goods categories

Usually hazardous goods are grouped into 8 categories according to their physical property and hazard level: explosives, flammable gas, flammable liquid, oxidizing substance, toxic substance, radioactive material, corrosive substance and miscellaneous substances [6]. Accidents are counted by category of hazardous goods involved. See Fig 9.

Fig 8. Distribution of hazardous goods accident forms

Fig 9. Distribution of accidents by hazardous goods categories
As shown in Fig 9, the top three categories of hazardous goods are flammable liquid, flammable gas and toxic substance, accounting for 36.6%, 23.8% and 16.8% respectively. This is because the transport volumes of flammable gas, flammable liquid and toxic substance are high, leading to more accidents during their transport. Meanwhile, hazardous goods accidents involving flammable gas, flammable liquid and toxic chemicals tend to cause more severe consequences and should receive adequate attention from the authority and transport enterprises.

5. Prevention and Improvement Measures
To effectively prevent hazardous goods transport accidents and keep road traffic unobstructed and safe, the following preventive and improvement measures are proposed taking into account relevant features of such accidents:

(1) In view of the distribution features of hazardous goods accidents, more work shall be done to inspect and track hazardous goods transport vehicles in the season of frequent accidents. Emergency drills to handle hazardous goods accidents shall be carried out. Meanwhile, special drills for hazardous goods accidents in tunnels should be carried out considering the more severe consequences of such accidents when they occur in tunnels.

(2) In view of causes of accidents, human and vehicle factors play a dominant role, indirectly suggesting management of professional drivers and vehicles in the hazardous goods transport industry is still inadequate. Therefore, more emphasis shall be put on selection and education of drivers, routine maintenance and inspection of transport vehicles, following the principle of "no release unless specified criteria are satisfied".

(3) To address unqualified transport and illegal transport, more efforts are needed to inspect vehicles on the road and impose strict penalties on offenders. Additionally, the mechanism to review hazardous goods transport enterprises shall be improved to clean up unqualified enterprises and perform unscheduled inspection on routine production activity of qualified enterprises.

(4) Hazardous goods transport vehicles shall be obliged to be equipped with protection and firefighting facilities as required, and to have video monitoring equipment installed. Periodic fire protection education shall be provided to transport personnel.

(5) For certain critical and special road sections, detailed restrictions shall be imposed on when and whether to allow hazardous goods vehicles to pass.

(6) A supervisory platform for hazardous goods vehicles shall be put in place to identify and track hazardous goods vehicles on the road and provide timely alert for accident-prone vehicles by suitable means so as to effectively reduce accidents.

6. Conclusions
(1) Hazardous goods accidents are frequent in the summer and in the morning of every day; most such accidents occur on expressways.

(2) Major factors contributing to hazardous goods accidents are driver misoperation and vehicle failure. The driver misoperation mainly takes on the form of rear-end.

(3) The most common substances involved in hazardous goods transport accidents are flammable liquid, flammable gas and toxic chemicals. The main form of hazardous goods accidents is leakage, followed by fire and explosion. Fire and explosion cause the most severe casualties.

(4) Emphasis shall be put on driver selection and education and routine inspection and maintenance of transport vehicles. The mechanism to review hazardous goods transport enterprises shall be enhanced. Necessary management measures are required for special road sections. A supervisory and management platform for hazardous goods vehicles shall be put in place so as to ensure safe transport of hazardous goods.

(5) A complete "monitoring-warning-treatment-rehabilitation" technical management system shall be formed in the future for hazardous goods transport by road to improve the safety of road operation and transport in China.
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