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Study on emergency response rank mode of flammable and explosive hazardous materials road transportation

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Abstract

Hazardous Materials (Hazmat) road transport is a hot issue of societal public safety, and it is extremely important to quickly response and rescue emergency accidents. In this paper, according to fire risk characteristics of transporting flammable and explosive hazmat by road, it was identified and analyzed on the representative hazmat leakage scenarios and the methods of determination of accident emergency regions, and a comprehensive systematic framework of emergency response rank mode for hazmat accidents by road was proposed. Moreover, some recommended practice about initial accident region of transportation of hazmat from NFPA471 and ERG2008 was described, and it was put forward on a quantitative approach to determine the emergency response rank for hazmat road accidents, based utilizing death toll, individual risk and societal risk as an emergency rank criterion. This research pays a very important role in the emergency response and helps the fire commanders to implement the rescue efficiently in hazmat transport accidents by road.

Keywords: safety; flammable and explosive hazardous materials (hazmat); transportation by road; emergency response rank; potential impact distance

Nomenclature

λ	impact radius of (m)
F	the cumulative frequency per year
K	grading on fire hazard for flammable and explosive hazmat
N	the number of fatalities
R_1	lethality radius of (m)
R_2	second-degree burns radius of (m)
R_3	first-degree burns radius of (m)

1. Introduction

Along with the development of industrialized societies, the production capacity and transport volumes of hazardous materials (hazmat), or dangerous goods (DG) rapidly boost annual year, which create opportunities for incidents, including traffic, and pose an increasing potential danger and a significant threat to human health and natural environment. In China, about 95% hazmat must be transported from producers to end-users, more than 80% amount of which are through road, and annual traffic volume is up to near two hundred million tons. In resent years, due to the increasing of hazmat shipment volumes, high road accident rates and poor safety management level, some catastrophic accidents involving hazmat

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transport frequently occurred, which usually resulted in high casualties and great environment damage. A number of accidents involving a large number of fatalities clearly show that the risk associated to the transport of hazmat may be significant.

Clearly, hazmat road transport is not only a hot issue of societal public safety, but also an important strategy and tactic decision-making problem. Moreover, the hazmat accidents statistical data from home and abroad showed that hazmat transportation accidents constituted from 30 to 40 percent of all reported hazmat accidents, and traffic accidents were main causes. Among of them, the predominant hazmat released were flammable and combustible liquids, and explosives, gases or poisonous materials always resulted in catastrophic consequences and bad societal influence [1].

Recently, it has been a hot issue and problem on dealing with responses to hazardous materials incidents of societal public safety and operating guidelines for responding to hazardous materials incidents for fire fighting. Moreover, how to quickly forecast the potential death area of hazmat accidents after leakage, and to determine guard zone and evacuation zone, are the chief tasks and key steps of responding to hazmat incidents for fire commanders [2]. In this paper, a quantitative approach and framework to determine the emergency response rank for hazmat accidents by road was proposed, which was based utilizing death toll, individual risk and societal risk as an emergency rank criterion. This study helps decrease some major and catastrophic accidents, and plays an important role in dealing with responses to hazmat incidents by road.

2. Emergency response rank mode of flammable and explosive hazmat road accidents

2.1. Response rank framework of road accidents for hazmat

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Transportation of hazmat involves different parties, including shippers, regulators and surrounding communities. Due to significant and growing domestic flows of hazmat, release of hazmat at a location may pose a significant threat to the health of neighboring population. And this is clear that human error and traffic accidents are far more likely to result in severe hazmat incidents than other causes [1]. The risk factors of emergency response for hazmat road accidents are many, including their chemical, physical or toxicological properties, human capability, road characteristics, weather condition, traffic status, emergency response plan, impact people distribution, safety supervise and so on. There, a comprehensive and systemic framework to determine the emergency response rank mode of hazmat road accidents was established, shown by the following (Fig1.), which utilized death toll, individual risk and societal risk as an emergency rank criterion.

Firstly, it should be carried out to identify hazmat road accidents scenarios according to type and quantity of hazmat, road characteristics, weather condition, transport vehicles or tank and vessel, driver skills, sensitive environments region, population density, accident impact area and so on.

Secondly, estimation hazmat road accident probabilities is a key step to determine to the possibility of transportation accidents, referring to flammable and explosive hazmat release frequency and ignition probabilities from open statistic data.

Thirdly, determination of hazmat accidents consequence by road is a main step to assess the associated hazmat risk from the way of hazmat quantity and properties, traffic environment condition, weather characteristics and so on. At the same time, it is important to select the appropriate fire and explosion models of accidents scenarios, and to calculate the population death probabilities according to thermal radiation or blast-overpressure probit equations.

Fourthly, the exposure population distribution of accident region need be shown and described, based on hazmat accidents scenarios and consequence analysis. There impact area or radius of hazmat accidents is a key factor to estimate the influence population number.

Fifthly, determination of death toll of exposure population due to hazmat toad accidents is estimated, which is used to calculate the individual risk and societal risk of hazmat.

Finally, emergency response rank for hazmat road accidents could be determined.

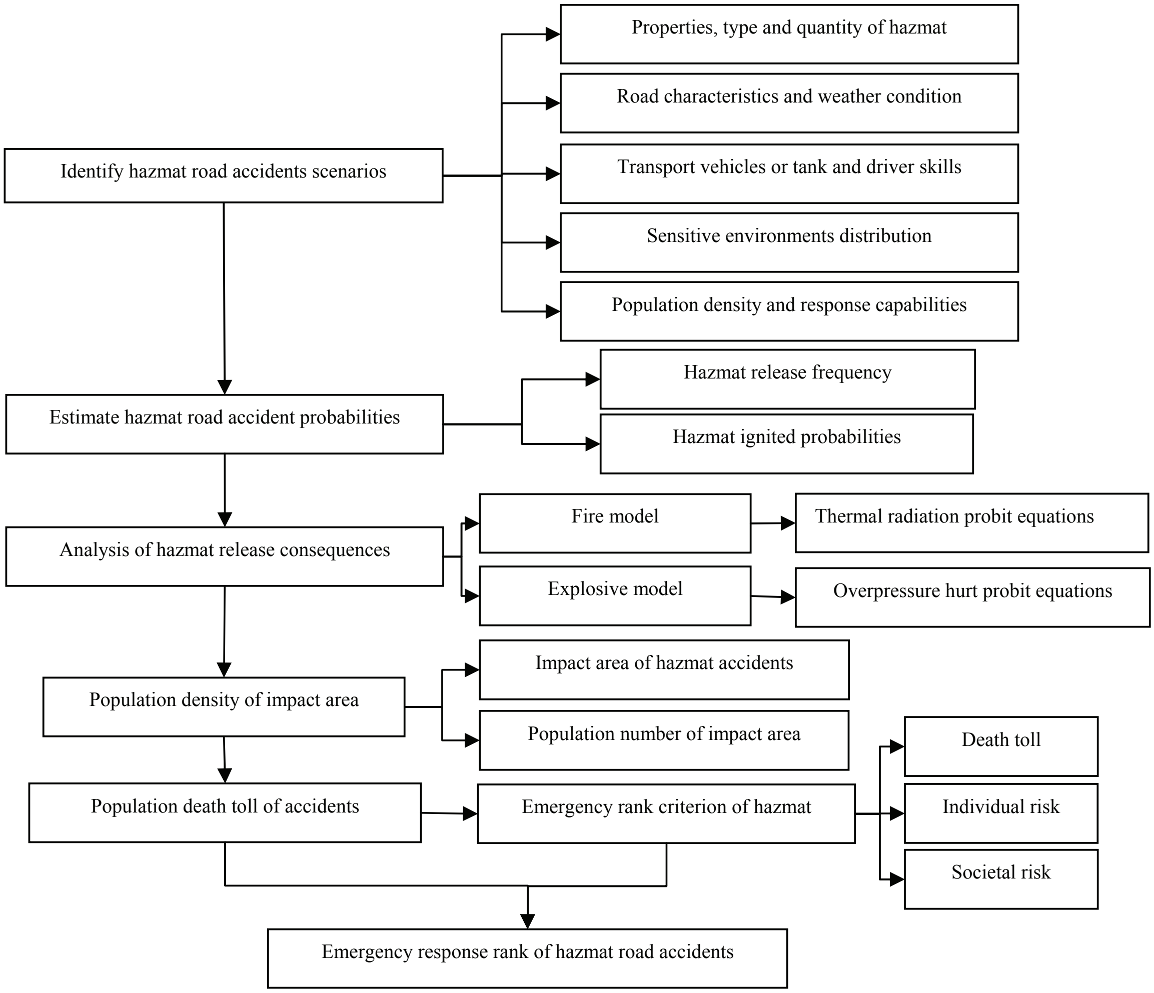

Fig. 1. General framework of emergency response rank for hazmat road accidents.

2.2. Hazmat consequence scenarios of road accidents

The accident scenarios of transporting flammable and explosive hazmat by road are mostly associated with type and quantity of hazmat for a given release of hazmat. Fig.2 illustrates possible incident outcomes in the case of a hazmat release. Due to different types of types of hazmat and uncertain condition, their outcomes pose different scenarios of leakage. Usually, in case of flammable liquids ignition for both immediate and delayed ignitions, the final outcome is a pool fire with potential radiant heat effects. Moreover, ignition of released flammable liquefied gases will result in several possible outcomes, such vapor cloud explosion, fire ball, jet fire, flash fire and so on.

2.3. Hazmat impact area of road accidents

According to NFPA 471, control zones of hazmat incidents are divided and established based on criticality and risk level at all hazardous materials incidents [3]. The committee has used the terms cold, warm, and hot to describe these zones because the words are easily understood and clearly suggest the nature of the situation one would expect to encounter within the zones. The relationship between these zones at the incident site is shown in Fig.3. This diagram of control zones show the cold zone contains the command post and such other support functions as are deemed necessary to control the incident.

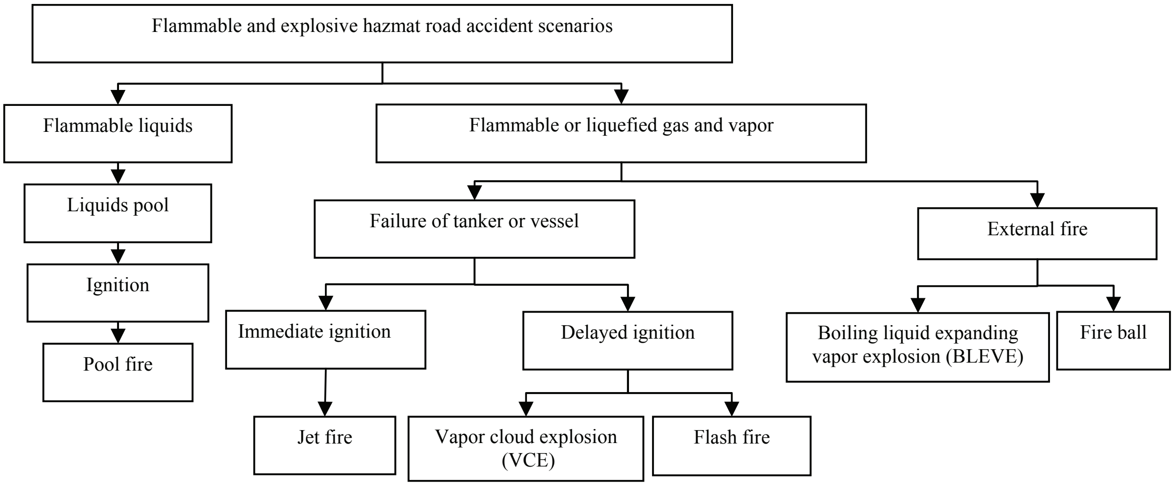

Fig. 2. Accident scenarios of flammable and explosive hazmat by road.

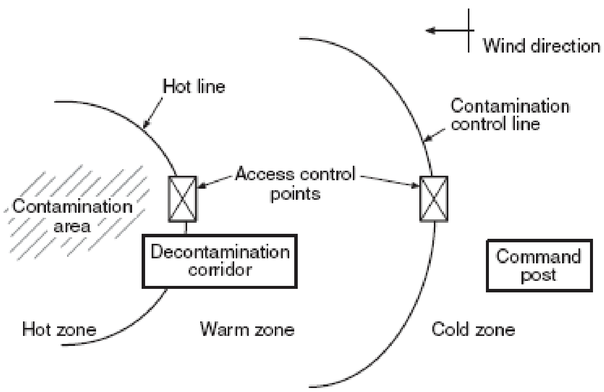

Fig. 3. Control zones shown in relation to the incident site from NFPA471.

The 2008 Emergency Response Guidebook (ERG 2008) was developed jointly by Transport Canada (TC), the U.S. Department of Transportation (DOT), the Secretariat of Transport and Communications of Mexico (SCT) and with the collaboration of CIQUIME (Centro de Información Química para Emergencias) of Argentina, for use by fire fighters, police, and other emergency services personnel who may be the first to arrive at the scene of a transportation incident involving hazmat. In this response guidebook, initial isolation and protective distance of some hazmat was list by table [4]. Moreover, it was translated and published by national workplace emergency management center [5]. These will assist responders in making initial decisions upon arriving at the scene of a hazmat incident. In the research by He Ning et al, based on the toxicant concentrations criterion and toxicant concentration-time criterion, combining the characteristics of toxic chemicals leakage and its emergency response procedures, the two sections of predicting the control zone and evacuation zone during the emergency practice are proposed, and the predicting methods in connection with the different sections and criterions are introduced. The above study comes from statistic data within local road environment and weather condition, which helps the fire commanders to implement the rescue efficiently in hazmat accidents.

As a rule, the impact area of flammable and explosive hazmat road accidents is characterized by impact radius (λ, equation(1)) of accidents, which is the neighboring area along hazmat transportation road with some hurt effects of exposure population [6]. This is shown in Fig.4, which is illustrated by some rectangle or circle along the transporting hazmat road. And impact radius (λ) of hazmat road accidents is described by lethality radius (R_1), second-degree burns radius (R_2), and first-degree burns radius (R_3), which were analyzed and illuminated by the reference [7–8]. On the side, the fire risk properties of transporting hazmat by road are taken into account in detail, which are characterized by grading on fire hazard (K, equation(2)) for flammable and explosive hazmat [9].

$$\lambda = \begin{cases} R_1(1+k)\ , & \textbf{Hot zone radius} \\ R_2(1+k), & \textbf{Initial isolation distance} \\ R_3(1+k)\ , & \textbf{Evacuation distance} \end{cases} \tag{1}$$

$$k = \begin{cases} k \le 0.1, & \textbf{III} \\ 0.1 < k \le 0.2, & \textbf{II} \\ 0.2 < k \le 0.3, & \textbf{I} \end{cases} \tag{2}$$

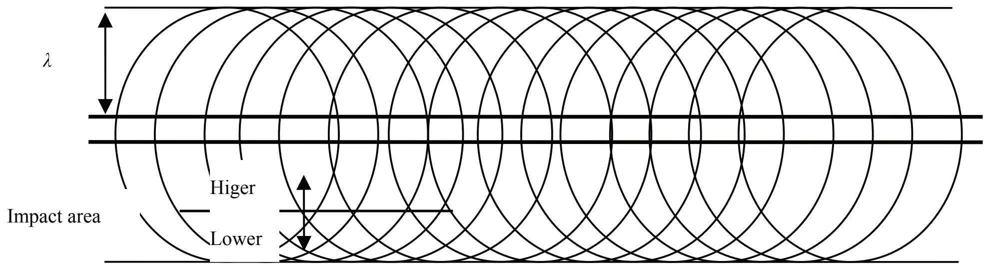

Fig. 4. Impact region of hazmat accidents by road.

Clearly, it comes to light that fire scope of flash fire is within lower fire limit (LFL) of flammable vapor clouds. If flammable vapor clouds are ignited, flash fire often occurs, and it is assumed that 100% lethality is within the LFL and 0% lethality is outside the LEL. At the same time, outcome of vapor cloud explosion is on the assumption that with 100% lethality is outside the overpressure area beyond 0.03 MPa and 0% lethality is within the overpressure area of 0.01 MPa.

2.4. Hazmat guard zones and response rank of road accidents

According to emergency plan framework of nation burst public incidents and emergency plan of work safety major accidents in China, early warning of emergency incidents is divided into four class, including Red-class I, Orange-class II, Yellow-class III and Blue-class IV. State department No.493 of China also shows that work safety accidents are classified by especially major accident, major accident, larger accident and common accident according the number of fatalities of a given release of hazmat. In order to quickly make the emergency rank, guard zone and response rank of flammable and explosive hazmat road accidents were illustrated in Table 1, which were based on the criterions of lethality radius and fire limit range of flammable vapor clouds and Pop was the number of fatalities.

Table 1. Guard zone and response rank of flammable and explosive hazmat road accidents

Impact radius of accidents area (λ)	Guard area and response rank
Flammable vapor clouds within 100% LEL	Guard zone
Flammable vapor clouds within 60% LEL	Evacuation zone
Lethality radius of fire ball, pool fire and jet fire, flash fire within the LFL, and vapor cloud explosion	≥30, Red, class I 10≤Pop<30, orange, class II 3≤Pop<10, yellow, class III Pop≤2, blue, class IV

In order to estimate and compare risks of transporting hazmat by road, the criterions of individual risk and societal risk are commonly adopted. For individual risk, it is considered the upper acceptability criterion set down in Netherlands in new situations or new developments, corresponding to 10^{-6} per year. For societal risk, the limit curves of the ALARP zone are usually adopted, according to HSC [10]. In particular, the Dutch F-N limit curve of societal risk is a straight line on a log–log paper passing through the points (N=10, F=10^{-4} events a^{-1}) and (N=100, F=10^{-6} events a^{-1}) [11], where F is the cumulative frequency per year and N the number of fatalities. According to the above risk acceptability criterion, the emergency response rank based on societal risk of hazmat road accidents is shown in Table 2.

Table 2. Response rank based on social risk of hazmat road accidents

Response rank	Criterion	Explanation
Red, class I	$F \geq 10^{-3}/N^2$	Risk intolerable: risk cannot be justified even in extraordinary circumstances
Orange, class II	$10^{-4}/N^2 \leq F < 10^{-3}/N^2$	Tolerable only if risk reduction is impracticable or if its cost is grossly in disproportion to the improvement gained
Yellow, class III	$10^{-5}/N^2 < F < 10^{-4}/N^2$	Tolerable risk if cost of reduction would exceed the improvements gained
Blue, class IV	$F \leq 10^{-5}/N^2$	No need for detailed studies; Check that risk maintains at this level

3. Conclusions

In case of hazmat road accidents, hazmat release consequences always are catastrophic, and a great lot people have to be evacuated and protected. Therefore, it is very important to firstly determine emergency area and response rank of hazmat road accidents, which helps optimize emergency resource and carry out some reasonable emergency action. Based utilizing death toll, individual risk and societal risk as an emergency rank criterion, a quantitative approach to determine the emergency response rank for hazmat road accidents was proposed, which is primarily a guide to aid first responders in quickly identifying the emergency zone and response rank, and could protect the general public during the initial response phase of the incident.

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