

A Possibility Evaluation Model for Road Transportation of Hazardous Chemicals Based on Bow-tie Theory and Bayesian Model

Jian Zhao^{1, a}, Mingguang Zhang^{1, b *}

¹ College of Safety Science and Engineering, Nanjing Tech University, Nanjing 211816, China;

² Jiangsu Key Laboratory of Hazardous Chemicals Safety and Control, Nanjing, Jiangsu, 210009, China

^A 756965939@qq.com, ^b mingguang_zhang@njtech.edu.cn

Abstract. This paper collected 1115 road transportation accidents of hazardous chemicals in China from 2013 to 2021, and constructed a total of 120 accident chains, among which the most common accident chain was "impact → rear-end collision → fuel tank damage → leakage", with a total of 195 times. Based on the analysis of historical accident data, the occurrence mechanism of road transportation accidents of hazardous chemicals was discussed. Based on the bow-tie theory, the bow-tie diagram was established to realize the construction of qualitative reasoning bow-tie diagram for multi-disaster coupling accidents in road transportation of hazardous chemicals. The mapping rules between Bow-tie model and Bayesian network were established, and the structure of Bayesian network for road transportation of hazardous chemicals was constructed. The prior probability and conditional probability of Bayesian network nodes are determined by multi-source data, and the real-time accident probability evaluation is realized by combining quantitative and qualitative methods. Finally, a real time evaluation of the possibility of multi-disaster coupling accidents is realized every 30 seconds through a numerical example, which reflects the influence law of multi-disaster coupling scenarios on risks.

Keywords: Hazardous chemical road transport; Bow-tie theory; Bayesian model; Real-time possibility assessment;

1. Introduction

The process of road transportation accidents of hazardous chemicals is a comprehensive process of traffic accidents and hazardous chemical accidents. Feng et al. proposed a domino effect coupling analysis model for accidents, which considered the coupling effects of thermal radiation, shock wave overpressure and debris impact[1]. At present, there is a certain research basis for the traffic accident mechanism and accident mechanism of fixed chemical equipment similar to road transport tank cars. However, there are few researches on the accident mechanism and hazard coupling in the whole process of the occurrence and development of road transport accidents of hazardous chemicals, which is difficult to support the research on the risk of multi-hazard hazard coupling accidents of road transport of hazardous chemicals.

In the process of real-time possibility assessment of road transport accidents of hazardous chemicals, scholars have different choices of influencing factors. Godoy S M et al., 2007, evaluated the stochastic uncertainty of atmospheric parameters[2]. Wei Shanshan et al found that the sum of leakage, fire and explosion in the initial accident pattern was only 21.8% from 2016 to 2020, but in the final accident pattern, leakage, fire and explosion accounted for 86%, 10.3% and 3% respectively. However, in the final accident pattern, the proportion of leakage, fire and explosion accidents are 86%, 10.3% and 3% respectively [3]. Qiao et al considered the influence of path dependent variables and path independent variables [4]. Yang K et al. used the dual induction coil detector to count the number of vehicles, average speed and occupation time on the one hand, and to extract accident data, including date, time, collision type, weather conditions and traffic conditions on the other hand[5]. The main problems in the real-time possibility assessment of road transport accidents of hazardous chemicals are as follows: there is no comprehensive and systematic statistical analysis and utilization of static and dynamic data from the five aspects of human,

machine, material, environment and management. With the rapid development of modern information technology such as the Internet of Things and big data, dynamic data collection in five aspects has been established on the basis of hardware and software. Therefore, it is necessary to develop and apply real-time acquisition of dynamic multi-source data to realize real-time risk assessment.

Accident probability evaluation model. Kokkinos K et al. considered the impact of road use on transportation probability through the payload factor[6]; Accident probability assessment method. Yu R et al introduced the classification regression tree model and support vector machine model for real-time collision assessment[7]; Leung et al proposed an approach based on an extended Dempster-Shafer evidence theory [8]; Li P et al applied a long and short-term memory convolutional neural network[9]. The main problems in the study of the evaluation model and method of the possibility of hazardous chemical road transportation accidents are as follows: the real-time data used in the model is not strong, which can not effectively evaluate the risk in real time, and the practicability is not strong. At the same time, considering the multi-hazard coupling of road transport accidents of hazardous chemicals, the consequences evaluation needs innovative development.

At present, there are no reports on the models and methods for real-time assessment of the likelihood of occurrence of various accident patterns in the field of hazardous chemical road transport accident assessment, and it is urgent to develop a model for real-time assessment of the likelihood of occurrence of hazardous chemical road transport accidents based on the current situation of hazardous chemical road transport activities. In this paper, we develop a model for real-time accident likelihood assessment of various accident patterns in hazardous chemical road transportation based on Bow-tie and Bayesian models with multiple sources of data as the driving force.

2. Theory and Method

2.1 Methodology

In this paper, 1115 historical accidents are counted, the accident chain is constructed and the accident mechanism is explored. Then, the Bow-tie theory is used to construct a qualitative reasoning model, and the Bayesian model network structure is constructed to evaluate the real-time possibility of the accident mode of road transportation of hazardous chemicals. Finally, the prior probability and conditional probability of Bayesian network nodes are determined by multi-source data. Finally, an example is used to verify the feasibility of the model.

2.2 Construction of qualitative Bow-tie model

Figure 1 can be obtained through four steps: identification of critical events, construction of fault tree, construction of event tree and construction of bow-tie graph.

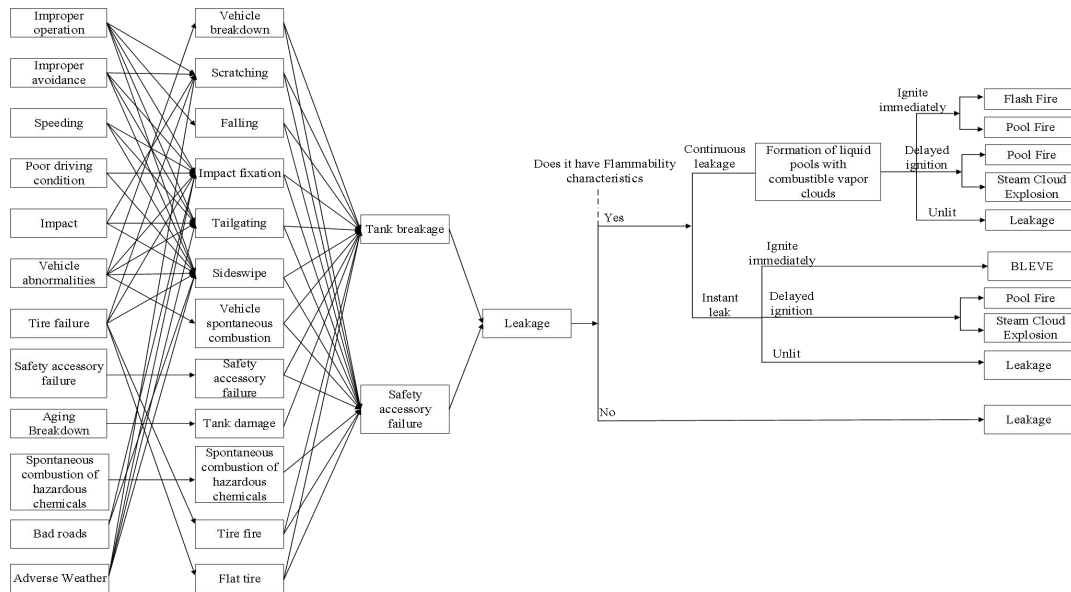


Fig.1 Qualitative reasoning Bow-tie for multi-hazard coupled accidents in hazardous chemical road transport

2.3 Construction of quantitative Bayesian model

The Bayesian network model can be divided into the following four steps:

(1) Bow-tie transformation into Bayesian networks

The transformation of Bow-tie model to Bayesian network is divided into three steps, 1) determine the Bayesian network nodes; 2) transform the left fault tree of Bow-tie butterfly diagram into Bayesian network; 3) transform the right event tree of Bow-tie butterfly diagram into Bayesian network. The specific transformation rules are shown in Fig.2.

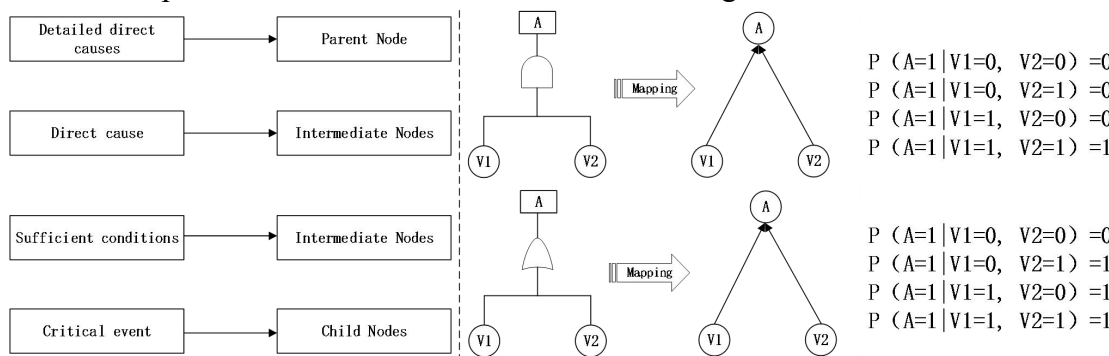


Fig.2 Transformation rules

(2) Determine the conditional probability value of the Bayesian network model

Using 1115 historical accident data as the training set, the conditional probabilities of the Bayesian network nodes were determined using the EM algorithm with the help of the GeNIe analysis software parameter learning function. Table 1, Table 2 shows the conditional probabilities of some nodes, "Y" means the node occurs and "N" means the node does not occur".

Tab.1 Conditional probability table of node "leakage"

Tank breakage	Y		N	
Safety accessory failure	Y	N	Y	N
Y	0.99974	0.97494	0.98947	0
N	0.00026	0.02506	0.01053	1

Tab.2 Conditional probability table for node "fire"

Flammability characteristics	Y		N	
Leakage	Y	N	Y	N
Y	0.12104	0	0	0
N	0.87896	1	1	1

(3) Quantitative inference Bayesian network model

In summary, the constructed quantitative inference Bayesian network model for multi-hazard coupled accidents of hazardous chemical road transportation is as follows:

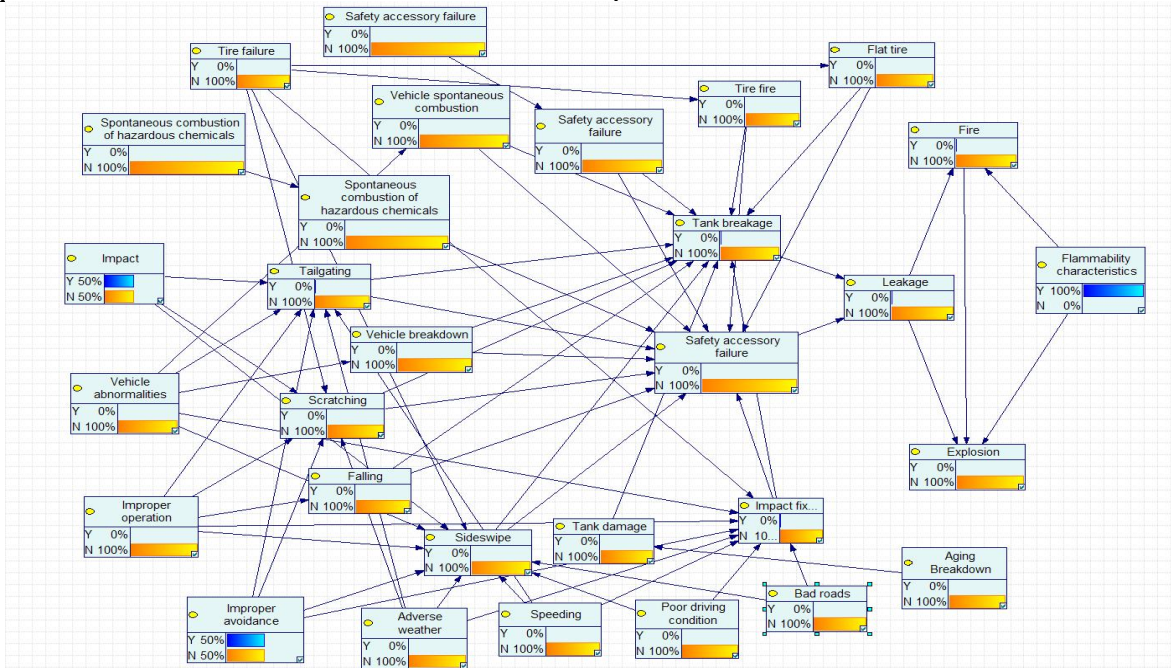


Fig.3 A quantitative inferential Bayesian network model for multi-hazard coupled accidents in hazardous chemical road transport

3. Result and Discussions

3.1 Application example

The transport activity occurred on January 9, 2023, from 10:30:07 a.m. to 11:45:15 a.m. Data were collected every 30 s. A total of 31 times of data were collected, and the total length of the route was about 17.4 km, located in a section of Nanjing bypass highway. The hazardous chemical being transported is liquefied natural gas with a capacity of 10 tons.

In order to realize the real-time assessment of the possibility of road transportation accidents of hazardous chemicals, real-time alarm data, real-time environmental data and transportation management data are collected every 30 seconds. The data were input into the multi-hazard coupled real-time risk assessment model for road transportation of hazardous chemicals, and three accident probabilities of "leakage", "leakage → fire" and "leakage → fire → explosion" were output.

3.2 Case conclusion

In the process of road transportation, the risk is dynamically changed in real time, and the risk can be prevented and behavior modified according to the risk value of each detection cycle. Collection points 17 and 26 have the highest risk value, because collection point 17 has both rapid deceleration alarm and over-close alarm, and collection point 26 has rapid deceleration alarm and forward collision alarm, which can be avoided by timely alarm. In Bayesian accident probability network, the prior probability of improper avoidance and collision of two parent nodes is 0.5, which greatly improves the possibility of accident. High and low risk values can be detected within 30

seconds for effective real-time assessment. Therefore, this model can realize real-time risk assessment of multi-disaster coupling accidents of hazardous chemicals on road transportation, and provide important data support for safety decision-making of hazardous chemicals on road transportation.

4. Summary

Road transportation of hazardous chemicals occupies an important position in the process of hazardous chemicals transportation. In the process of transportation, vehicles, drivers and external environment are in the process of real-time dynamic changes, and once accidents of hazardous chemicals road transportation occur, the consequences of accidents are complex and diverse, which seriously threaten people's safety. Therefore, it is of great theoretical value and practical significance to evaluate the real-time possibility of accidents in the process of hazardous chemical road transportation.

Historical accident data are statistically analyzed, 1115 accident chains are constructed, the accident mechanism is investigated based on the accident chains, and multi-source data including historical accident data, real-time monitoring data and management data of transportation enterprises are constructed, Bow-tie theory is used for the construction of qualitative inference model of hazardous chemical road transportation accidents, and the Bow-tie model and multi-source data are used to realize The Bayesian network structure and the determination of node prior probabilities and conditional probabilities are used to construct a model for the assessment of the real-time likelihood of various accident patterns in hazardous chemical road transportation and to evaluate the real-time likelihood of various accident patterns. The real time assessment of the possibility of various disaster coupling accidents every 30s is realized according to the example verification, which reflects the influence law of risk under the multi-disaster coupling scenario, which is conducive to the control of accident risks that may be caused by drivers, the management of enterprise vehicle transportation and the risk analysis of urban areas.

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