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Research on Safety Risk of Dangerous Chemicals Road Transportation Based on Dynamic Fault Tree and Bayesian Network Hybrid Method

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ABSTRACT

Hazardous chemicals occur widely in the production and living facilities. During the transport process of hazardous chemicals, once an accident occurs, major casualties and property damage will follow and the surrounding environment will experience serious damage. Therefore, the research for safety risk of road transportation of dangerous chemicals is quitenecessary. The safety risk study on road transportation of hazardous chemicals is a reliable basis for the government to formulate transportation planning and preparing emergent schemes, but also is an important reference for safety risk managers to carry out dangerous chemicals safety risk management. In order to study the reliability of the whole road transport system and take into account the dynamic changes of the safety risk, based on the analysis of the transport safety risk of dangerous chemicals at home and abroad, this paper studied four main factors influencing the safety risk of road transportation, and presents the dynamic fault tree and Bayesian network hybrid method to identify and evaluate the dynamic safety risk of the road transportation of dangerous chemicals. Finally, the feasibility of the model is verified by the case study of road transportation of liquefied natural gas in a real enterprise.

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1. INTRODUCTION

After a tremendous explosion event that occurred in Tianjin, China, the hazardous chemical industry has aroused widespread public concern. With the progress of society and the development of science and technology, hazardous chemicals occur widely in the production and living facilities. The global annual transportation of hazardous chemicals is estimated at 4 billion tons. Due to the nature of explosive, flammable, toxic, corrosive, radioactive and other properties, in the transport, handling and storage, custody process of hazardous chemicals, once an accident occurs, will cause major casualties and property damage, and the surrounding environment will be seriously damageed. National Bureau of Statistics figures show that in 2015, 89.77 million tons of sulfuric acid, 30,026,600 tons caustic soda, 25.918 million tons soda ash, and 5791.4 million tons of ammonia were produced in China (National Bureau of Statistics data, 2016). The above four kinds of hazardous chemicals are classified as conventional industrial products, hazardous products. With the development of economy for many years, China's major hazardous chemicals production ranks first in the world [1]. In The catalog of hazardous chemicals (2015 version), there are the dangers of a total of 2828 entries, whether it is petrochemical, pharmaceutical or cosmetic industry, all kinds of hazardous chemicals is the production of raw materials indispensable. Rapid development of chemical industry gave birth to a huge amount of hazardous chemical logistics needs. According to statistics, China's annual transport of hazardous chemicals on the road has exceeded 300 million tons; the amount of dangerous chemicals transported on the river is also close to this figure.In the Yangtze River port alone, there are throughput of 170 million tons of hazardous chemicals. Production and logistics of hazardous chemicals are the two most common parts of the accident [2]. According to the China Chemical Safety Association's accident information, from January to August 2016, in China,

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there are a total of 232 chemical incidents, an average of 29 cases per month; almost an accident every day! Of these accidents, 96 (41.68%) accidents involved hazardous chemicals. These 232 accidents caused a total of 199 fatal and 400 wounded incidents. Almost every 10 hours there is an injury or even death because of chemical accidents [3]. Faced with such a heavy loss, the research for safety risk of road transportation of dangerous chemicals is very necessary.

There is still no set of systematic theory and method that have operability for safety risk research of road transportation of dangerous chemicals. It is urgent to establish a safety risk assessment model of hazardous chemicals transportation according to the characteristics and transportation conditions of hazardous chemicals and put forward the corresponding solutions.

2. ANALYZING SOME RELATED REFERENCES

Hazardous transportation safety risk research focuses on safety risk identification and analysis, which can provide parameters and the basis for the hazardous chemicals transportation plan at national or enterprise level. Since the general process of transport safety risk analysis has been established, the American Transportation Association has developed methodologies for quantitative safety risk analysis and evaluation and applied them to the actual transport of hazardous chemicals, representing the birth of an application method for assessing the safety risk of dangerous chemicals The Domestic and foreign scholars are also active in qualitative and quantitative research.

2. 1. Qualitative Safety Risk Analysis Jiang et al. [4] summed up the safety risk of road transport of dangerous chemicals at home and abroad from both qualitative and quantitative aspects, and pointed out that the domestic quantitative models are relatively few, and the transportation safety risk mathematical model is often based on various assumptions leading the output of the model to have a large degree of uncertainty. Mahmoudabadi et al. [5] studied the dynamic variables of the safety risk of transport of dangerous chemicals and the selection of optimal path and optimal location on the basis of chaos theory, and established the Dangerous Goods Distribution Center. Ambituuni et al. [6] taken Nigeria as an example to analyze the oil tanker accident of 2318 dangerous goods trucks from 2007 to 2012. Their results showed that 79% of the accidents were caused by man-made factors, mainly careless and dangerous driving. 70% of accidents caused fire and explosion, 81% lead to injury, death or both. The local government has stepped up supervision and improved policies to stimulate reduction of the occurrence of accidents. Babrauskas et al. [7] have taken ammonium nitrate (an explosive substance) as an example (its explosion happens frequently, and the consequent damages are usually large.) to point out that investigations normally focused on finding some unique reason for the accident, rather than examining what is common among the accidents. It is found that, for explosions in storage or transportation, 100% of these disasters had a single causative factor—an uncontrollable fire. Thus, such disasters can be eliminated by eliminating the potential for uncontrolled fire. Two actions are required to achieve this: (1) adoption of fertilizer formulations which reduce the potential for uncontrolled fire and for detonation; and (2) adoption of building safety measures which provide assurance against uncontrolled fires.

2. 2. Quantitative Safety Risk Analysis Fabiano et al. [8] made model building research on the construction of the orientation-oriented framework for the risk assessment of hazardous chemicals transportation and the development of emergency plans and optimization of theoretical methods. Bermana et al. [9] designed the best professional team network to deal with the occurrence of unexpected accidents in order to establish a hazardous transportation transport emergency network. Tena-Chollet et al. [10] taking oil and gas transportation as an example, conducted a global risk assessment study to develop a predictive code to analyze the risks of people, infrastructure and the environment on different supply routes, on the one hand Risk scenarios and high-risk elements of the vulnerability of the risk assessment method, on the other hand is based on the existing geographic information system for modeling development tools to Paris, France as an example of risk analysis to determine the optimal route. Saata et al. [11] described a quantitative and environmental risk analysis model, and establish an environmental impact model of an integrated geographic information system (GIS) to estimate the risk of different leak scenarios Possibility, risk analysis combined with the cost of clean development and utilization, annual traffic volume, China train accident rate and tanker safety characteristics, etc., with a quantitative method to effectively manage the risk of transporting hazardous materials. Liu et al. [12] Taking the road transport of hazardous chemicals as an example, pointed out that the US government is more interested in considering two combinations to reduce transport risk, using Pareto optimal technology to maximize the reduction given Level of risk, the strategy proposed in this paper is designed to help manufacturers better solve the risk of transporting dangerous chemicals for the region and the entire system. Zegordi et al. [13] studied to identify and rank the risks in these power plant projects. The proposed model allows risks to be ranked based on management priorities using a combined fuzzy analytic network process (fuzzy-ANP) and fuzzy Technique for Order Preference by Similarity to Ideal Solution (fuzzy-TOPSIS) method. Khezri et al. [14] presented a fuzzy expert system for breast cancer prognosis. This approach is capable enough to capture ambiguity and imprecision prevalent in the characterization of the breast cancer. Mousavi et al. [15] presented a new multiple criteria decision-making (MCDM) approach with interval numbers is introduced to evaluate the appropriate risk response actions (RRAs) for higher risks of mega projects.

The qualitative class of the above references is based on the specific data of the dangerous goods transportation accident to explain the frequent occurrence of the accident and the dangers of the accident, from these two aspects to illustrate the necessity of dangerous chemical transport safety risk research. From the past to find the main cause of the accident, and for the main reasons for the relevant measures for the relevant departments for reference, quantitative literature mostly uses the accident tree or the combination of geographic information systems (GIS) to establish a quantitative model, without taking into account the occurrence of dangerous chemicals transport accidents are dynamic with the passage of time, the safety risk also has a dynamic change This paper analyzes the influence of dynamic change of safety risk on the reliability of transportation process, finds out the failure mode with large degree of influence, and provides the control basis for safety risk control measures. At the same time, according to the safety risk mode of transport, put forward the corresponding safety risk control measures, and makes safety risk management throughout the dangerous goods road transport process.

3. THE ANALYSIS OF HAZARDOUS CHEMICAL LOGISTICS TRANSPORTATION

Hazardous chemicals refer to highly toxic chemicals and other chemicals that are harmful to humans, facilities and the environment, which are toxic, corrosive, explosive, burning, combustion and other properties. According to the relevant state departments and media reports, there were 232 hazardous chemical accidents before August 31 in 2016 in China, of which 121 accidents occurred in the transport links, resulting in 47 deaths, 70 Injured, which accounted for 77 accidents, accounting for 64%, fire accidents 22, accounting for 18%, 10 explosions, accounting for 8%, 12 accidents, 10% of the accident. China's road transport hazardous chemicals will also maintain the growth momentum, long distance, large tonnage of the transport situation will continue. Hazardous chemicals road transport involves hazardous chemicals, transport vehicles, related personnel, road conditions, the surrounding environment. in the event of an accident, with a large impact, spread to a large extent. According to the Ministry of Public Security statistics, only November 15, 2009 to December 11, less than a month in Hubei Province there were 4 highway dangerous goods accidents resulting in 5 dead, 7 injured, roads and nearby houses seriously Loss and a large number of hazardous materials leak. Therefore, the safety risk of dangerous chemicals road transport accident can not be overlooked.

The hazardous logistics system includes production, management, warehousing, transportation and other links. This paper is to study of the safety risk of transport links. The road transport of hazardous chemicals can be considered as a dynamic hazard source. Hazardous Chemicals Road transport accidents are characterized by sudden, hazardous and diversity of dangerous chemical accidents. But its liquidity increases the uncertainty of accident safety risk assessment; so that the safety risk and the fixed place accident safety risk are significantly different.

The occurrence of road transport accidents and the driver itself, transport vehicles, the surrounding environment, the goods themselves are closely related. And with the change of time the accident probability is also changing, leading to the dynamic characteristics of transport safety risk.

In view of the above analysis, the safety risk of road transport has dynamic characteristics, so this paper uses dynamic fault tree to carry out safety risk analysis and modeling.

4. THE DYNAMIC FAULT TREE AND BAYESIAN NETWORK HYBRID METHOD

The safety risk research is focused on safety risk analysis and evaluation. The researchers of road transport safety risk mainly consider human factors, equipment factors, environmental factors and the goods themselves. Therefore, this paper intends to establish a dynamic fault tree model from these four aspects.

A dynamic fault tree (DFT) is a fault tree that contains at least one dedicated dynamic logic gate. The introduction of dynamic fault tree is to solve the problem of reliability modeling and analysis of systems or equipment with dynamic characteristics such as fault recovery and timing correlation. The causal relationship with the fault cannot be described by the traditional static fault tree, structural function, etc. DFT has extended the traditional static fault tree to have sequence dependency, various repairable systems, public resource pools, and cold and hot spare parts [18]. The dynamic logic gates mainly include priority and gate (PAND), function-related gate (FDER), Sequential Correlation Gate gate (SEQ), cold spare door (CSP), warm spare door (WSP) and hot spare door (HSP).

On building dynamic fault tree, firstly, determine that one of the least anticipated an event is the top event (Er) that the hazardous product is not safe; Secondly, people, equipment, the environment and the goods problems will directly lead to the occurrence of top events, so they are used to "or" to connect.

The construction of the dynamic fault tree is based on the following assumptions:

(1) Each vehicle is equipped with two drivers, in which one of the physical or other reasons cannot continue to work, the other one can be replaced;

(2) In the process of vehicle failure if the failure to repair the case will lead to the top of the event occur;

(3) Each vehicle is equipped with an emergency protection device and can be switched to work status at any time;

(4) "cargo damage" represents the possibility of causing the goods to fail.

The dynamic fault tree is shown in Figure 1. The meaning of each event representative is shown as Table 1.

The Bayesian network analysis algorithm developed in recent years is superior to the Markovian state transition process analysis algorithm in avoiding the combinatorial explosion problem. Therefore, this paper is intended to transform the dynamic fault tree into a discrete time Bayesian network.

The system only needs to define the initial network and transfer network, you can effectively avoid the combination of space explosion problem. If the top event Er occurs within the task time T, then the occurrence of Er must be {(0,Δ), (Δ, 2Δ)… [(n-1)Δ, nΔ]} in any one of the intervals, and thus Er in the task time T occurs within the probability of:

$$P(\mathrm{T}) = \sum P(E_r = [(\mathrm{x}-1)\Delta, \mathrm{x}\,\Delta]) \tag{1}$$

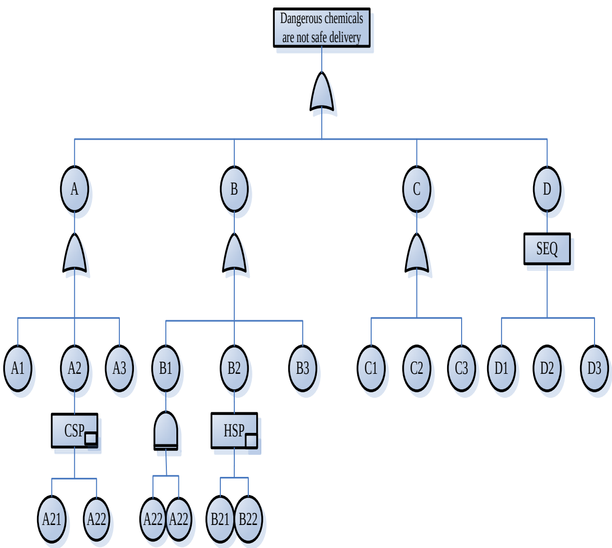

Figure 1. Dynamic fault tree

TABLE 1. the meaning of each event representative

Intermediate Event	Event Meaning	Intermediate Event	The Event Meaning
A	person factor	A21	failure
A1	driving skills	A22	timely replacement
A2	health status		
A3	safety awareness		
B	Vehicle Factor	B11	Vehicle failure
B1	vehicle condition	B12	not repaired in time
B2	emergency protection equipment	B21	equipment failure can not repair
B3	vehicle maintenance and monitoring	B22	emergency protection equipment work
C	environmental factors	D	cargo factors
C1	road condition	D1	appears cargo damage
C2	weather condition	D2	found in time
C3	traffic	D3	rescue invalid

P(Er= [(x-1)Δ, xΔ]) can be obtained directly by means of joint probability distribution:

$$P(\mathrm{E}_r = [(\mathrm{x}-1)\Delta, \mathrm{x}\,\Delta]) = \sum E_1 \ldots E_{M-1} P\{(E_1 = e_1, \ldots e_{M-1}), \mathrm{E}_r = [(\mathrm{x}-1)\Delta, \mathrm{x}\,\Delta]\} \tag{2}$$

Where, event Ei(1<i<M-1) Corresponding to the non-leaf nodes in the discrete-time Bayesian network, M is the number of nodes, and $e_i \in$ {(0,Δ), (Δ, 2Δ),…, [(n-1)Δ, nΔ], (T, ∞)}.

From (1) (2), we can get the probability that Er occurs within the task time T, ie:

$$P(T) = \sum_{0<X<n} E_1 \ldots E_{M-1} P\{(E_1 = e_1, \ldots e_{M-1}), \mathrm{E}_r = [(\mathrm{x}-1)\Delta, \mathrm{x}\,\Delta]\} \tag{3}$$

The calculation steps of the dynamic fault tree analysis algorithm based on Bayesian network can be summarized as follows:

Step 1. Each dynamic logic gate in the dynamic fault tree is transformed into a dynamic Bayesian network;

Step 2. Each static logic gate in the dynamic fault tree is transformed into a dynamic Bayesian network;

Step 3. Dynamic Bayesian network integration: According to the dynamic fault tree in the connection between the logic of the gateway, all the dynamic Bayesian network integration, superimposed on the same node, to maintain its connection relationship unchanged, and then get the dynamic Bayeux Network;

Step 4. Dynamic fault tree analysis: using the dynamic Bayesian network, according to (1)-(2) to calculate the top event probability, importance and other analysis results.

5. CASE STUDIES

In this paper, taking A company (a large group directly under the large-scale specialized transport logistics enterprises) as an example, the company mainly involves oil transport (desert transport), gasoline and diesel distribution, chemical raw materials distribution, aviation oil transport, natural gas transportation, Overtaking large transport, international transport, vehicle repair for the main business, with transport vehicles 23,000, nearly 40,000 employees. Among them, the company will look the group of hazardous chemicals road transport business as a top priority, priority development of business, including refined oil, chemical raw materials, aviation kerosene, liquefied natural gas, liquefied petroleum gas and other hazardous chemical transport.

This paper mainly studies the safety risk of the road transport section of liquefied natural gas with gas from Shijiazhuang section to Tianjin section,

This paper uses the questionnaire form method to get the following data.

The company has a vehicle (all its own vehicles) types shown as Table 2.

The models are equipped with GPS; In this company, some datas about the culture level and driving time of drivers are shown as Table 3.

And each vehicle is equipped with two drivers, making use of the above data. a dynamic fault tree model of dangerous chemicals are not timely arrivals caused by human factors can be established, shown as Figure 2. The meaning of each event is shown as Table 4.

The spare parts have a failure rate of 0 before the working parts fail, and the working parts of the spare parts in the cold spare parts depend on the working parts and the output of the cold spare doors depended on all input events, with A21 is cold Reserve parts, the A21, A22 formed by the cold spare door into a dynamic Bayesian network as shown Figure 3.

The Sequential Correlation Gate gate includes several input events, which require that the input events occur in a specific order (from left to right), the Sequential Correlation Gate into a dynamic Bayesian network as shown Figure 4. By the A business 2005 - 2016 16 years Shijiazhuang section to Tianjin section of liquefied petroleum gas road transport accident occurred in 41 accidents, the driving skills problems caused by the accident accounted for 2, the proportion of 4.9%, the health status. The number of problems accounted for 4, the proportion of 9.7%, after the replacement of an accident occurred in 1, the proportion of 2.4%, caused by the safety awareness of the accident has 3, the proportion of 7.3% Of the formula (4) available P (A2) = 2.4%.

TABLE 2 the vehicle statistics results of A Company

No.	Vehicles	Number	Proportion (%)
1	semi-trailer	7	10
2	tank vehicles	60	88
3	Van	1	2

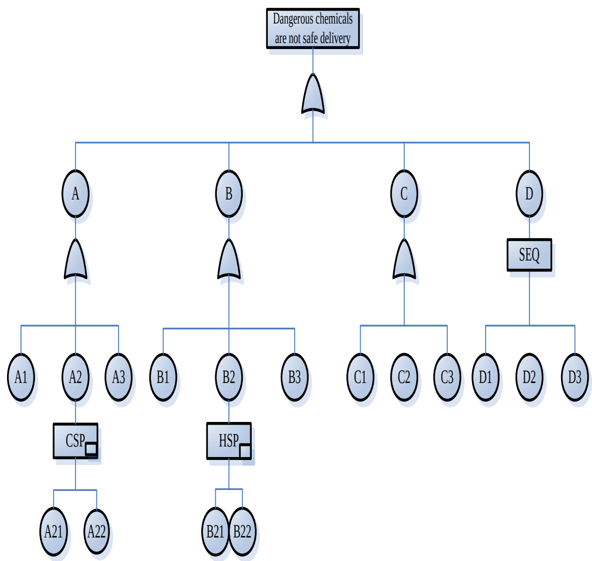

Figure 2. the dynamic fault tree model

TABLE 3. the culture level and driving time of drivers

No.	Cultural level	Quantity	Proportion	Driving age	Quantity	Proportion (%)
1	illiterate	0	0%	1 - 3 years	0	0
2	Primary school level	3	4%	3 - 5 years	9	13
3	junior high school graduation	24	35%	5-8 years	11	16
4	High school graduation	41	61%	8 - 10 years	26	38
5	College and above	0	0%	10 years or more	22	33

TABLE 4. The meaning of each event

Intermediate Event	Event Meaning	The probability of occurrence	Intermediate Event	The Event Meaning	The probability of occurrence
A	person factor		A21	failure	0.062
A1	driving skills	0.191	A22	timely replacement	0.088
A2	health status	0.15			
A3	safety awareness	0.23			
B	Vehicle Factor				
B1	vehicle condition	0.084			
B2	emergency protection equipment	0.052	B21	equipment failure can not repair	0.011
B3	vehicle maintenance and monitoring	0.078	B22	emergency protection equipment work	0.041
C	environmental factors		D	cargo factors	
C1	road condition	0.056	D1	appears cargo damage	0.036
C2	weather condition	0.042	D2	found in time	0.021
C3	traffic	0.045	D3	rescue invalid	0.014

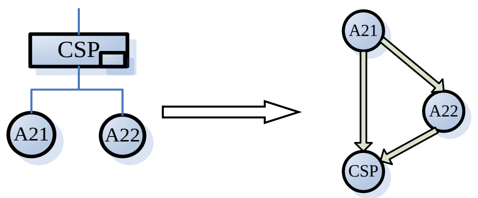

Figure 3. the conversion of from cold spare doors to dynamic Bayesian network

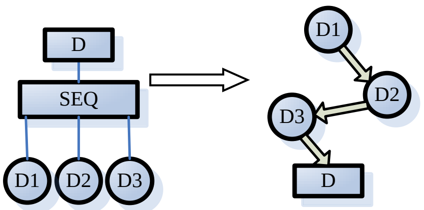

Figure 4. the conversion of from Sequential Correlation Gate to dynamic Bayesian network

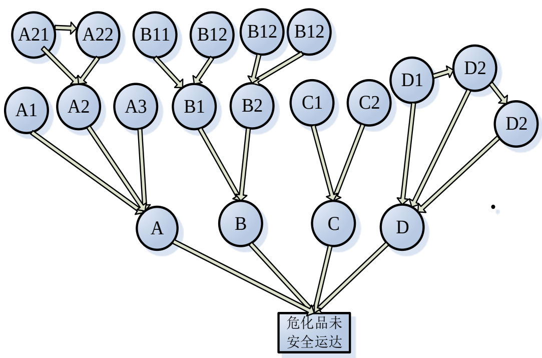

Figure 5. the conversion of from dynamic fault tree to dynamic Bayesian network

Upstream method: bottom-up analysis of the results of the event (the results of the event for the analysis of the object).

If the result is an AND gate, the cause event is written as the product of the distribution algebra; If the result is an OR gate, the cause event is written as the sum of the distribution algebra.

So the total probability of the safety risk is P (A1) + P (A2) + P (A3) = 4.9% + 2.4% + 7.3% = 14.6%, the total reliability is 1- 14.6%=85.4%

6. CONCLUSIONS

In the fault tree analysis of reliability study, the ascending method starts from the bottom event, and carries on the collection operation of the event from bottom to top. In the process of solving each layer, making use of the probability gotten by the statistical method of each basic event, according to Boolean algebra to simplify it, get the fault tree minimum cut set, and then can get the probability of the top event.

The probability of occurrence of accidents caused by human factors, vehicle factors, environmental factors and cargo factorsis are shown as follows:

0.571,0.214,0.143,0.071;

It can be seen that the level of the influencing factors is: human factors> factors of the vehicle> environmental factors> factors of the goods.

By above empirical analysis, the transport risks of dangerous chemicals were caused by the four main factors, the proportion of people is the largest. Therefore, should strengthen the people skills of this link.

This paper studies the identification and evaluation of the safety risks caused by dangerous chemicals in the process of road transport. The main consideration is the four aspects of people, vehicles, environment and goods. With the passage of time, the safety risk is dynamic, In order to study the reliability of dangerous road transportation safety risk, the dynamic fault tree and Bayesian network hybrid method is presented. Finally, the model is verified by examples. The presented detailed methods and steps can provide an important reference for the safety risk study of dangerous chemicals road transportation.

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چکیده

مواد شیمیایی خطرناک به طور گسترده در تولید و امکانات زندگی رخ می دهد. در طی فرایند حمل و نقل مواد شیمیایی خطرناک، زمانی که یک اتفاق رخ دهد، تلفات عمده و آسیب های ملکی و محیط اطراف جدی خواهد بود. بنابراین، تحقیق برای ایمنی حمل و نقل جاده ای مواد شیمیایی خطرناک کاملا ضروری است. مطالعات ایمنی حمل و نقل جاده ای مواد شیمیایی خطرناک یک اساس قابل اعتمادی برای دولت برای طراحی برنامه ریزی حمل و نقل و تهیه طرح های در حال ظهور است، اما مرجع مهمی برای مدیران ایمنی برای پیشبرد مدیریت ایمنی مواد شیمیایی خطرناک است. به منظور بررسی قابلیت اطمینان کل سیستم حمل و نقل جاده ای و توجه به تغییرات دینامیکی خطر ایمنی براساس تجزیه و تحلیل خطر ابتلا به مواد شیمیایی خطرناک حمل و نقل در داخل و خارج از کشور، در این مقاله چهار عامل اصلی تاثیرگذار بر ایمنی خطر حمل و نقل جاده ای و ارائه یک درخت گنگ پویا و روش ترکیبی شبکه Bayesianبرای شناسایی و ارزیابی خطر ایمنی پویای حمل و نقل جاده ای مواد شیمیایی خطرناک ارائه شده است. در نهایت، امکان سنجی مدل توسط مطالعه موردی حمل و نقل جاده ای گاز طبیعی مایع در یک شرکت واقعی تایید شده است.

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