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Review Article

Fleet Scheduling Optimization of Hazardous Materials Transportation: A Literature Review

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To comprehensively understand the research progress of the fleet scheduling for hazardous materials, the study has summarized the corresponding research results from three aspects (a) hazardous materials transportation risk, (b) route optimization, and (c) fleet scheduling, and then pointed out potential problems from six aspects: (a) the coupling risk of the transport fleet; (b) the screening of time and space for the transport of hazardous materials; (c) the scheduling optimization for transport fleets; (d) taking insufficient account of transport risks fairness; (e) insufficient robustness of scheduling schemes; and (f) lacking of research results on fleet scheduling of transport in the context of antiterrorism. After that, by considering the existing shortcomings of the current research, five research directions are presented that should be further explored in the future. Subsequently, both rough set and association rule theory is applied to explore the cause chain of transportation accidents for hazardous materials, and analyze the mechanism of transport accident for hazardous materials. Next, the Bayesian network is presented to predict the accident rate of hazardous materials transportation under different temporal and spatial conditions, and the dynamic rolling scheduling method of hazardous materials transport fleet is constructed under normal and antiterrorism background.

1. Introduction

Hazardous materials are referred to those substances and articles with explosive, inflammable, toxic, infectious, corrosive, and other dangerous characteristics that are liable to cause human casualties, property damage, or environmental pollution in the course of production, management, transportation, storage, use, and disposal, which is required special protection. It is estimated that four billion tons of hazardous materials are transported worldwide every year. Particularly, over one billion tons of hazardous materials are transported by road in China every year. There are about 11,600 enterprises, about 32 million people involved, and more than 360,000 vehicles engaged in the road transport of hazardous materials,

A large number of inflammable, explosive, highly toxic, and corrosive hazardous materials are transported on the road, forming a flow of hazard sources [1]. Although the accident rate of transport of hazardous materials is relatively low (generally 10^{-8}–10^{-6}/km), the safety situation cannot be ignored due to its large volume, complex transport environment, and numerous risk influencing factors [1]. In recent years, transport accidents of hazardous materials have occurred frequently in China, which not only causes harm to vehicles and humans, but also produces serious damage and pollution to the environment around the route. For example, on June 13th, 2011, a tank truck loaded with 30 tons of methyl acetate fell over three meters under the Badu Bridge in LongQuan city, Zhejiang province. The accident caused water pollution and seriously affected the normal lives of local people; On July 26th, 2012, two cars collided on the Shenhai expressway, leaking 20 tons of liquefied natural gas, and more than 2000 villagers were evacuated; On February 1st, 2013, at

the Yichang Bridge in Mianchi section of Lianhuo expressway, Henan province, a truck loaded with fireworks exploded, causing the south half of the bridge to be destroyed, and leading to 10 deaths and 11 injuries. Two small cars and six large vehicles were found from the crash site, causing heavy economic losses; On July 19th, 2014, a truck loaded with ethanol rear-ended the vehicle in front of it at 1309 kilometers of Hukun expressway in ShaoYang City, Hunan Province. A large amount of ethanol leaked out and burst into flames, resulting in 54 deaths, 6 injuries, and more than 53 million yuan of direct economic losses. Similar accidents happen frequently, and the safety situation of hazardous materials transportation is rather severe.

Hazardous materials transportation is an important part of the life cycle, which often goes through town or areas of the crowd, and in the event of an accident, heavy casualties may occur, leading to pollution of the environment for a long time and huge economic losses. More importantly, the public and the media are very sensitive and accidents can cause social instability to a certain extent. For example, the transportation accident of explosive hazardous materials may cause serious harm to the tunnels and bridges on the transportation route, or even cause the transportation route to be paralyzed for a long time. Meanwhile, the explosion may also cause a large number of casualties, property losses, and even fatalities. Highly toxic and hazardous materials leak into the water of the transportation route, which will pollute the water resources and adversely affect the production and life of the region.

In addition, under the background of escalating violent crimes and terrorist attacks, hazardous materials may become potential targets of terrorist attacks due to their special dangerous characteristics. Once a terrorism attack happens to transport vehicles carrying hazardous materials, the consequences will be too ghastly to contemplate. Moreover, the transport system of hazardous materials is characterized by high openness to the public, large flow, long operation lines, multiple points, wide coverage, and great difficulty in preventing terrorism. Strengthening antiterrorism research on the transportation of hazardous materials is not only a forward-looking theoretical issue, but also an objective and realistic need to ensure social stability and the security of people's lives and property. There are many similar accidents and the safety situation of hazardous material transportation. It is an urgent issue to dig into the rules of transport accidents of hazardous materials and put forward effective countermeasures to prevent accidents. Fleet scheduling optimization of hazardous materials transport is to deeply analyze the characteristics of the transportation accidents, reveal the mechanism of accidents, and dig accident cause-and-effect chain so as to quantify measuring risk of hazardous materials transportation scientifically. Based on this, the robust dispatching models, solving algorithm, and dynamic rolling dispatching system of transport at fleet, are constructed to achieve safe, economic, and efficient dispatching of transport fleet. The results are of great significance to prevent the occurrence of hazardous material transportation accidents and ensure the security of people's lives and properties.

2. Transport Risk of Hazardous Materials

Risk measurement of hazardous materials transportation is the basis of safe dispatching of fleet, whose goal is to conduct qualitative or quantitative analysis of the risk of accidents in the process of transportation, and evaluate the possibility of accidents and the severity of accident consequences, so as to seek for the lowest accident rate and the least loss. It can be seen that the transport risk of hazardous materials and transport accidents are closely related. Since the 1970s, scholars have been devoting themselves to the research on transport accidents and transport risks of hazardous materials. The research results have roughly gone through four stages: the first stage (before 1985), was mainly focused on the accident analysis of nuclear fuel and its waste; the second stage (1985–1989) was mainly concentrated on the probability of transportation accidents and casualties of hazardous materials. The third stage (1990–1999) mainly used traditional methods to study the risk measurement model of hazardous materials transportation, while the fourth stage (from 2000 to now) employed modern information technology to analyze the transport risk of hazardous materials. It can be found that the research on transportation accidents and transportation risk of hazardous materials has been gradually deepened with the change of new technology. Figure 1 shows the keywords cooccurrence network of hazardous materials studies, in which it can be found that previous studies were mainly focused on road network, risk analysis, optimization, dangerous goods, methodology, and so on.

Transportation accidents and transportation risks of hazardous materials have been investigated step by step. Glickman et al. analyzed the probability of hazardous materials leakage accidents and transportation risks from vehicle types, loading forms, and road conditions [2, 3]. Considine studied the accident frequency and consequence of hazardous materials transport vehicles passing through the tunnel [4]. List et al. combined the risk assessment and line selection mode of hazardous materials transportation to conduct comprehensive analysis [5]. Abkowitz et al. considered the risk aversion attitude in decision-making, proposed the perceived risk model, and considered the risk preference of decision-makers by adding weight parameters [6]. Erkut and Verter have long been engaged in the research on the risk evaluation of hazardous materials transportation, and established and improved six kinds of risk evaluation models commonly used. They mainly evaluated the transportation risk from the two perspectives of accident probability and accident consequence, and proposed three axioms to measure the correctness of the risk model [7, 8]. Leonelli et al. built a new personal risk and social risk assessment model by comprehensively considering factors such as transportation mode, hazardous materials category, meteorological conditions, seasonal conditions, and personnel distribution, improving the accuracy of risk assessment of hazardous materials transportation [9]. Erkut and Ingolfsson built three disaster avoidance models on the basis of studying the damage degree of transport accidents of hazardous materials [10]. Kang and Kwon introduced the value-at-risk model and conditional value-at-risk theory into the field of hazardous materials

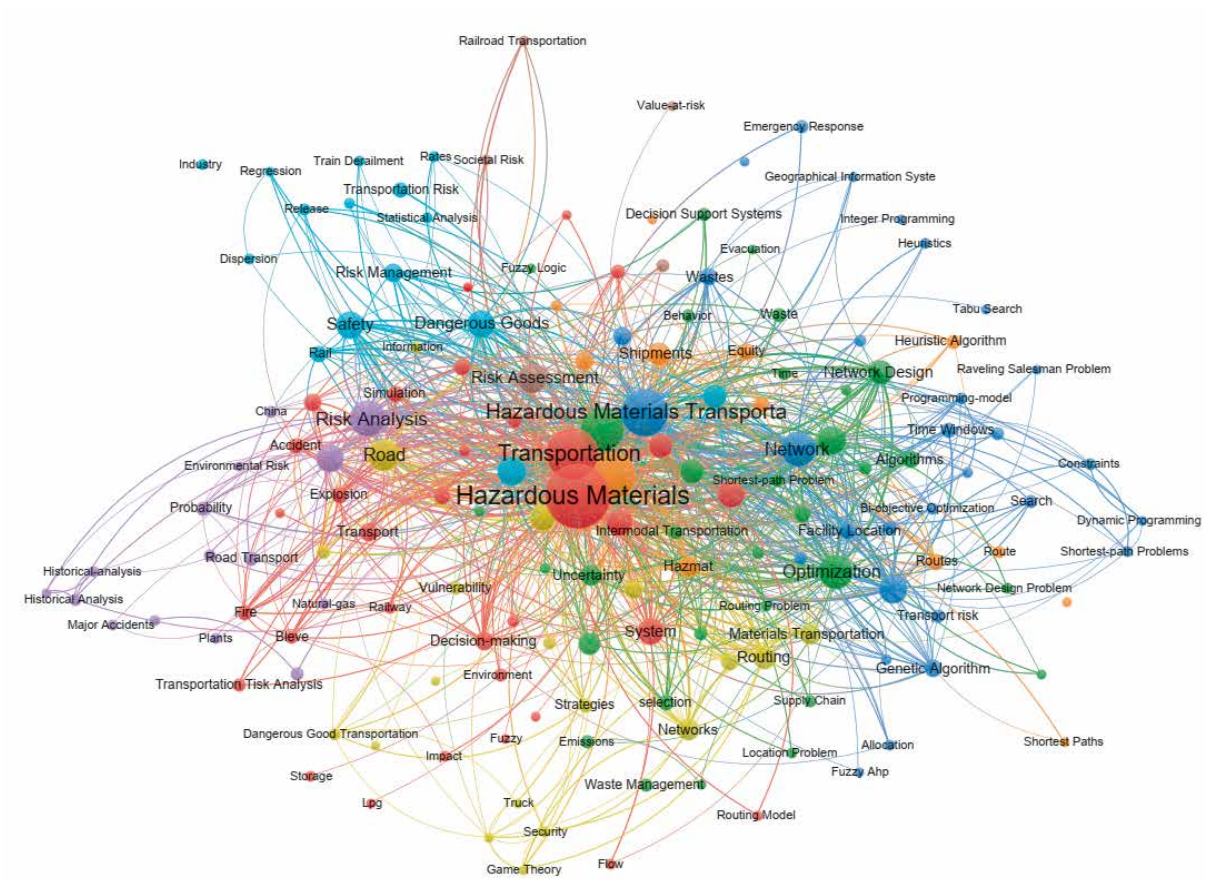


Figure 1: Keyword co-occurrence network of hazardous materials studies.

transportation, which can meet the risk preference requirements of decision-makers and solve the weaknesses of previous models such as lack of scalability and expressiveness [11, 12]. Fabiano et al. based on hazardous materials transport accidents such as statistical analysis, from the characteristics of roads, weather conditions, and traffic conditions in six aspects, such as the risks in the process of hazardous materials transportation to expand or slow factors, proposed a face to the scene of the accident of hazardous materials transportation risk evaluation and decision system, and modelled for evaluating the probability and the death toll [13]. Verter and Bubico et al. put forward a GIS-based risk analysis framework for hazardous materials transportation, and used GIS to obtain the spatial distribution of risks [14, 15]. Zografos and Androutsopoulos integrated risk assessment, route optimization, and emergency management of hazardous materials transport to build a decision system to ensure the safety of hazardous materials transport [16]. Torretta et al. established risk source leakage model, exposure model, and consequence model, and built a risk assessment decision support system [17]. It can be seen that scholars have paid much attention to the hazardous materials transportation accidents and transportation risks earlier, and they have experienced three processes of accident analysis-risk, modeling-building, and decision-making platform, and gradually deepened. For accident analysis of hazardous materials transportation, risk assessment, and accident prevention provide an important theoretical support.

In China, the studies on transport accidents and transport risks of hazardous materials started a little late, and the results can be divided into qualitative analysis and quantitative research. In terms of qualitative analysis, Gao et al. summarized the cases of transport accidents of hazardous materials in recent seven years in China, analyzed the influences of different transport environments and indicators on the accidents, and summarized the rules of accidents [18]. Based on the data statistics of typical domestic accidents, Sheng et al. analyzed and summarized the main factors leading to frequent accidents, such as the lack of supervision, imperfect management system, weak safety awareness, complex road conditions, and changeable climate, and proposed specific improvement measures [19]. Zhao et al. analyzed the causes and characteristics of the 1565 hazardous chemical accidents that occurred in China from 2005 to 2008 from the aspects of accident time, place, and occurrence [20]. Xin and Wang systematically sorted out the theories and methods of analyzing the historical data of hazardous materials transportation accidents in recent 20 years, providing important guidance for the research on the risk of hazardous materials transportation [21]. In terms of quantitative research, Bi and Wang constructed the transportation cost of hazardous materials, transportation risk measurement model, and multiobjective path selection model

based on the definition of primitive sections [22]. In order to make the risk assessment of hazardous materials transportation more accurate, Guo and Li constructed a transportation risk measurement model based on accident classification [23]. Wang made an in-depth analysis of the common risk measurement models of hazardous materials transportation, summarized the characteristics of each model, and put forward the risk comprehensive evaluation method [24]. Ren and Wu built the hazardous materials transportation route selection model by increasing the risk impact factor, comprehensively considering the factors such as the minimum accident probability and the minimum population exposure, and made a detailed comparison of the advantages and disadvantages of the commonly used risk measurement model [25, 26]. Qin et al. took risk minimization as the goal and considered the weather change to construct a robust optimization model for the selection of hazardous materials transportation route [27]. Zhao and Cheng analyzed the transport risk of hazardous chemicals from the perspective of accident rate estimation, and adopted Poisson regression model to fit the transport accident data of hazardous chemicals in Shanghai from 2000 to 2006. By comparing the solution results of the normal distribution, they proposed a probability estimation method for the transport risk of hazardous chemicals [28]. Chang has built a social risk assessment model and an environmental risk assessment model for hazardous materials by comprehensively considering factors such as accident probability, population impact, and environmental impact [29]. Based on the DEA theory, Huang et al. constructed the transport efficiency model of road hazardous materials in Beijing, selected indexes from the perspective of input and output to construct the evaluation index system, and took 15 districts and counties in Beijing as research objects to calculate and evaluate their comprehensive efficiency, pure technical efficiency, and scale efficiency [30].

It can be seen that many scholars have carried out a large number of studies on transport accidents and transport risks of hazardous materials, and established a lot of risk measurement models, especially the three risk axioms proposed by Erkut and Verter to evaluate the correctness of the transport risk model, which provides an important basis for our research on transport risks of hazardous materials. Shown from the existing research results, it can be found that the current research on the transport risk of hazardous materials is only for a single dangerous vehicle, and there is no relevant research on the transport risk of hazardous materials fleet.

3. Route Optimization of Hazardous Materials Transportation

The route optimization of hazardous materials transportation is not only a sensitive public safety problem, but also an important strategic decision-making problem, which has attracted great attention from governments and the public of various countries. Many experts and scholars have explored this issue from various aspects. For example, Joy conducted some empirical studies in the transportation of hazardous materials with the shortest path algorithm [31]. Glickman, Ivancie, Pijawka, and Kessler studied the path selection of hazardous materials in the transportation with the target of the minimum population coverage [32–35]. Batta and Chiu took the minimum product of the distance between the population gathering centers in the area affected by the transport of hazardous materials and the total number of people affected as the line selection standard and conducted a preliminary study [36]. All the research results above belong to the path optimization of hazardous materials between single objective and single starting and ending points.

Because the single objective model cannot describe the process of hazardous materials transportation precisely, the multiobjective network optimization model of hazardous materials transportation has attracted the attention of some scholars. Shorys studied multiobjective problems at the earliest, and he considered two goals: minimizing mileage and population coverage [37]. Saccamonno and Chan examined three different hazardous materials transportation strategies: minimizing risk, minimizing accident rate, and minimizing operating cost, and analyzed the winners and losers in each strategy [38]. Current et al. proposed a dual-objective model to generate a feasible hazardous materials transportation route by minimizing the number of people covered by the route and the mileage traveled [39]. Abkowitz and Cheng put forward a dual-objective route model considering risk and cost. They integrated disaster, injury, and property loss into a whole to represent the risks in the transportation of hazardous materials, and finally obtained a satisfactory transportation path [40]. Zografos and Davis proposed a multicriteria shortest path problem and solved the problem with priority object program [41]. Karkazis and Boffey established an optimization model for the transportation path of hazardous materials to minimize the expected population risk and cost, and carried out numerical experiments with the branch and bound algorithm [42]. Helander and Melachrinoudis integrated the route problem and the expected death number problem in the transport of hazardous materials to achieve the optimal design of the transport route of hazardous materials [43]. Akgun et al. pointed out that the problem of route selection of hazardous materials transportation has important research significance, and proposed a method to generate candidate path set [44]. Kara and Verter have established a dual-objective two-level programming model that pursues the least number of people with the shortest transport path [45]. Zografos and Androutsopoulos defined the transport problem of hazardous materials as a dual-objective path problem, specifically pursuing the following goals: the lowest risk and the lowest cost, and proposed a new heuristic algorithm [46, 47]. Akgun et al. considered the impact of road segment attributes on risks, established a path optimization model to pursue the minimum risk and cost, and conducted computational experiments [48]. Erkut and Alp constructed a hazardous materials transportation model, which considered three factors including accident rate, population exposure, and running time, and proposed a quasi-polynomial dynamic programming algorithm to solve the model [49]. Dadkar et al. realized that the diversity of transportation routes of hazardous materials could provide opportunities for drivers to switch between different routes, so as to avoid putting the same population at risk. Based on this, a path optimization model was established and solved by a heuristic algorithm [50]. Erkuta and Gzara determine the

transport network of hazardous materials between single starting and ending points by minimizing transport risks and costs [51]. Renee and Mary established a new transport risk analysis model and a Bayesian network decision model based on the existing hazardous materials transport data, which plays an auxiliary role in the optimization of transport network [52]. Marti et al. studied the dual-target path problem of hazardous materials, proposed a new algorithm and carried out computational experiments [53]. For the transportation of hazardous materials, Verma established a dual-objective optimization model with the goal of minimizing risk and cost, and solved it with the risk-cost boundary algorithm [54]. Jassbi and Makvandi [55] studied the framework of multiobjective optimization for the transport of hazardous materials, pursuing the following goals: the shortest mileage, the least number of affected residents, the least social risk, and the least accident probability. Kang et al. [11] proposed a risk-value model for the transport of hazardous materials and used it to solve the problem of single transport route selection. Considering different decision-makers, Minciardi and Robba proposed an optimization model for the transportation route of hazardous materials by minimizing transportation costs and risks [56]. Vasiliki et al. established an optimization model for the transportation route of hazardous materials that takes into account both transportation risks and transportation costs, and conducted simulation analysis with Monte Carlo method. The research results have certain reference value for the optimization design of transportation network between single start and end points [57]. Xie and Waller proposed an improved labeling algorithm to solve the dual-objective route optimization model of hazardous materials transportation between single starting and ending points [58]. The research results above have revealed a certain adaptability to the transportation path optimization of hazardous materials between single starting and ending points, but they are not adequate enough to the problems of the transportation network optimization of hazardous materials between multiple starting and ending points and the anti-terrorist, and the optimization results are not robust.

In China, Shuai, and Zhong took the minimization of route risk value, operation time, and operation cost as the objective function of the route optimization model of hazardous materials transportation, and used the weight of risk preference to describe the different risk preference characteristics of decision-makers, and used the labeling algorithm to achieve the selection of the optimal route [59]. Peng and Sun established a hazardous materials transport network model with the maximum risk constraint, which considered the influence of social vehicles on the travel time of hazardous materials vehicles and the total network risk in the network, and adopted particle swarm optimization algorithm to solve the established model [60]. Song et al. [61], Chu et al. [62], Chen and Shuai [63], Zha and Sun [64], Sun [65], Shen et al. [66], and others have respectively established a double-layer optimization model for the transportation path of hazardous materials from different perspectives, in which only risk and cost minimization are considered. Song et al. [67] established an anti algorithm-based route optimization algorithm for the transportation of hazardous materials, and solved the optimization problem of a single transportation path. Ma et al. established a stochastic opportunity constrained programming model for hazardous materials transportation path and a stochastic correlation opportunity constrained programming model based on the opportunity-constrained and related opportunity-constrained programming theory for the uncertainty of impedance, and the hybrid intelligent algorithm solves and finally obtains a satisfactory transportation path [68–71]. Yang et al. designed the hazardous materials transportation safety management system under the vehicle-infrastructure connected environment [72]. It can be seen that many gratifying results in the optimization of hazardous materials transportation network have reached, but the research results are lack of fairness, smoothness as well as consideration of the uncertain parameters, thus the optimized results do not show strong robustness.

4. Fleet Scheduling of Hazardous Material Transportation

Fleet Scheduling Problem (FSP) is referred to the management of a fleet of vehicles by consisting of a certain number of transport vehicles within a certain length of the service period. Under the condition that certain constraints are met (such as the model requirements of the vehicle, the type requirements of the transportation tasks, the time window requirements of the transportation tasks, etc.), the transportation tasks at each node in the transportation network are completed, thereby achieving the maximum benefit or the minimum cost.

The studies began with Beaujon and Turnquist, who designed an optimization model for the problem of empty vehicle size and distribution in the transportation network, and successfully solved the model using a network approximation algorithm [73]. Powell and Carvalho studied the dynamic scheduling problem of multivehicle vehicles with time windows [74]. Powell and Carvalho used the logistics queuing network to study the dynamic management of the fleet. They decomposed the dynamic scheduling problem into many subproblems from the perspective of control parameters, and used multiple adjustment strategies to continuously adjust the control parameters to achieve the purpose of solving the problem [75]. Imran et al. used the variable neighborhood search algorithm to solve the traditional fleet scheduling model, using the scanning method, and 2-opt method to generate the initial scheduling scheme, and adopted a variety of different local search algorithms [76]. Repoussis and Tarantilis proposed a novel adaptive memory algorithm to solve the hybrid fleet scheduling problem with time windows [77]. Brandão used the tabu search algorithm to solve the hybrid fleet scheduling problem of a certain scale, and achieved satisfactory results [78]. Bettinelli et al. used the branch and bound algorithm to solve the multivehicle hybrid fleet scheduling problem with time windows, and carried out feasibility verification [79]. Tirado et al. mainly introduced the maritime transport fleet scheduling problem under stochastic dynamic conditions, and designed three heuristic algorithms for solving and analyzing [80]. Barkaoui and Gendreau successfully solved the fleet scheduling model using genetic algorithms [81]. Naji-Azimi and Salari proposed a heuristic algorithm based on integer linear programming for hybrid fleet scheduling

problems [82]. Luo et al. proposed two effective parametric control methods for dynamic scheduling of fleets [83].

In China, Zhang adopted the multistage decision-making idea and dynamic programming method to systematically analyze the vehicle deployment form, the factors affecting the dispatching and the dispatching process, and established the dynamic scheduling model of single-vehicle and multivehicle fleets [84]. According to the characteristics of the hybrid fleet scheduling problem, Chen et al. [85] improved the variable neighborhood search algorithm to make the problem better solved. Xuan [86] analyzed a class of fleet scheduling problems with time windows, established a mathematical programming model, and designed a heuristic algorithm. Based on the detailed description of the hybrid fleet scheduling problem, Hao used the progressive method to study the hybrid fleet scheduling problem from the perspective of whether there is a customer time window and whether it is distributed in batches. It is of significance for enterprises to improve the economic benefits of logistics and realize the modernization of logistics [87]. Li et al. [88] constructed a mathematical programming model for a class of fleet scheduling problems based on the shortest running distance. Since the model was difficult to solve directly, the author constructed a network diagram to describe the fleet problem. By solving the minimum spanning tree of the fleet dispatching network map, the connection line between the vehicle and the vehicle in the minimum spanning tree was removed, and the problem was decomposed into single-vehicle scheduling problems, and finally a satisfactory solution was obtained. Li et al. [89] studied the variable-cycle stochastic dynamic fleet scheduling problem that allowed storage, introduced the queuing principle to design the transportation task generation mechanism and the model separation parameter fitting process, and established a bilevel programming model. Wang et al. [90] incorporated specific models into the constraints, constructed a hazardous materials transport vehicle scheduling model with the minimum hazardous materials transport time as the objective function, and solved the model using multilayer coding genetic algorithm. Qiang and Mou [91] comprehensively considered factors such as vehicle scheduling cost and vehicle load limit, and construct a mixed-integer programming model with the goal of maximizing profit and minimizing risk cost. The Aixia system [92] studied the problem of hazardous materials transport vehicle scheduling under the environment and uncertain environment (transport time is fuzzy or random parameters). Ye [93] systematically studied the problem of hazardous materials transport vehicle scheduling when the demand or transportation risk is an interval number. The standard deviation was used to measure the fairness of risk among the population gathering areas, and the mathematical model of hazardous materials transportation vehicle scheduling considering the risk distribution fairness was constructed. The two-stage algorithm was designed to solve the problem, but the research results are not specific. For the transport fleet, the robustness of the scheme was not considered [94–98].

It can be seen that there have been more research results in the dispatching of ordinary cargo transport fleets, while the research results for the dispatching of hazardous materials transport fleets are sparse, and the scheduling schemes obtained by the research are not robust.

5. Problems in Current Research

Based on the previous studies [99–103], there have been a variety of scholars and institutions from various countries and regions working on hazardous materials transportation, and the visualization of hazardous materials transportation can be found through collaboration network analysis, as shown in Figure 2.

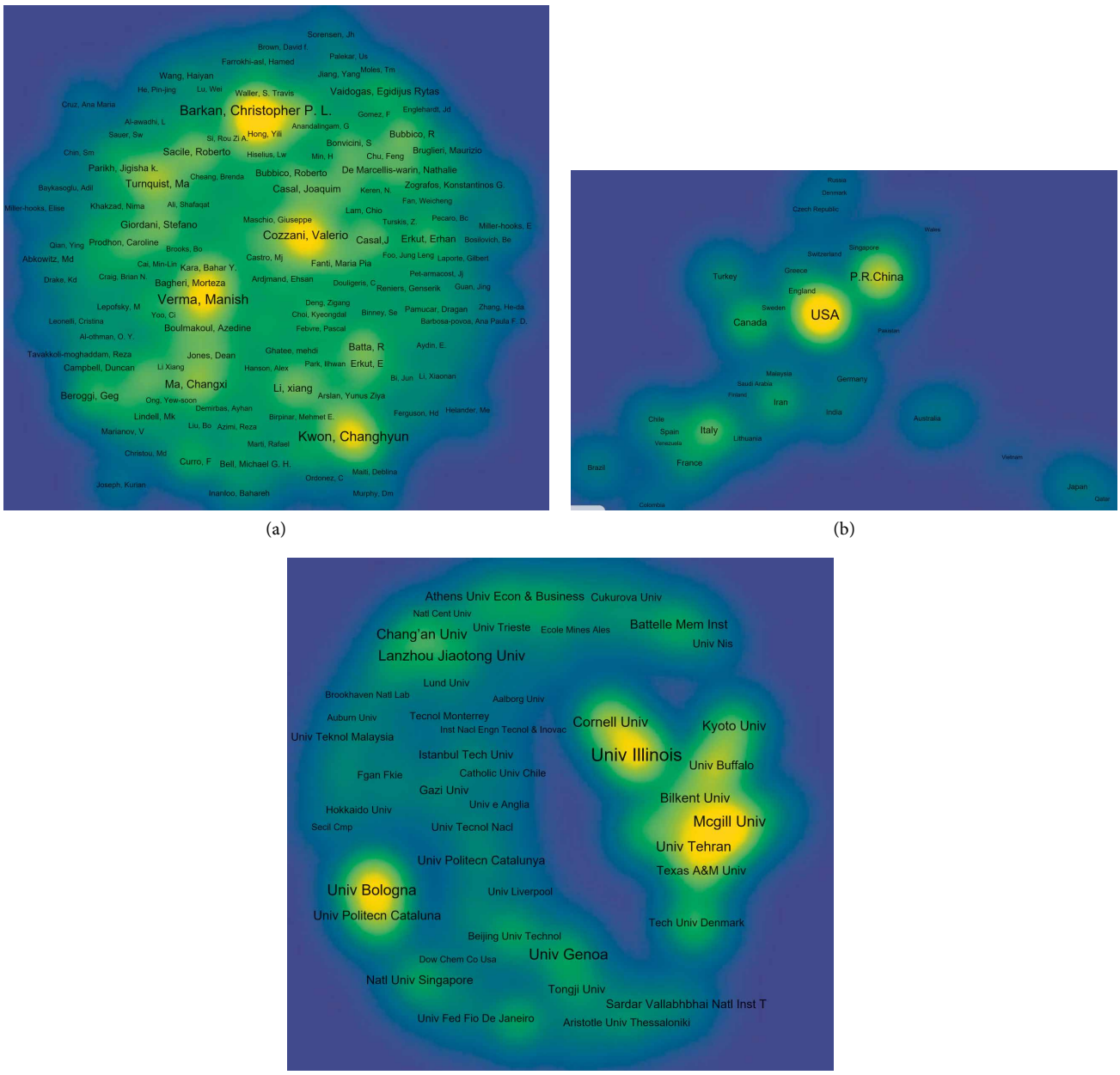
Going through the research results [104–110], we can figure out that there have been some achievements in the risk measurement of hazardous materials transportation, transportation route optimization, and transport fleet scheduling, including at least the following six aspects:

(1) The risk models of hazardous material transportation are applicable to the risk measurement of a single hazardous materials vehicle on the roadway, but not suitable for hazardous material fleets. For hazardous materials, the fleet formed by multiple vehicles cannot be directly added by the single-vehicle transportation risk. Therefore, it is necessary to construct a transportation risk model of hazardous material fleet specifically for this situation.

(2) Not all time and space (referred to as space-time, the same as followings) are suitable for transporting hazardous materials. The existing research results on the dispatching of fleets have not covered the topic of "space-time screening of alternative transport of hazardous materials" [111–118]. However, this topic must be determined before optimizing the dispatch plan of hazardous materials transport fleet. Moreover, the problem cannot be easily determined by simple experience. It is necessary to combine accident data, population, and important site distribution data, important hazard source distribution data, key protection units, and facility distribution data. By using advanced data mining technique, the cause-and-effect chain of hazardous materials transportation accidents under different space-time conditions is excavated, and the time and space that are not suitable for safe transportation of hazardous materials are found out. In turn, it provides a safe and low-risk alternative space-time network for the later optimization of fleet scheduling.

(3) At present, scholars have conducted in-depth research on the dispatching problem of ordinary cargo transport fleets, but rarely involved the dispatching of hazardous materials transport fleets. However, the problem of fleet scheduling for hazardous material transport is different from the dispatching problem of ordinary cargo, mainly lying in:

(a) When the dispatching problem of hazardous material transport fleet is studied, it is necessary to consider the minimum risk of total hazardous materials transportation and the balance of transportation risk distribution, as well as taking into account the interests of the government, transportation enterprises, and residents along the transportation line. Residents along the route of hazardous materials hope to have as less hazardous materials as possible or transport vehicles



(a) (b) (c)

Figure 2: Visualization of hazardous materials transportation in current studies: (a) the citation network among productive authors; (b) the countries among productive authors; (c) the collaboration network among research institutions.

with less hazardous materials through their living, working, studying or recreational areas [119]. The traditional fleet scheduling problem does not need to pay attention to the objectives of total transportation risk, the balance of risk distribution, etc., or to consider the interests of residents along the transportation line.

(b) Due to the special physical and chemical characteristics of hazardous materials, when hazardous materials are transported, a certain safety distance must be maintained between the various transport vehicles in the fleet, and the size of the fleet should not be too large to prevent accident chain reactions, such as serial explosions.

(c) When different hazardous materials are in direct contact, a severe chemical reaction will occur and the risk factor will be multiplied (known as the incompatibility of hazardous materials). Therefore, in order to reduce the risk of hazardous materials transportation, the incompatibility of hazardous materials should be considered when optimizing the dispatch plan of hazardous materials transport fleet. It is supposed to isolate these hazardous materials in time or space and maintain sufficient space–time distance to prevent potentially huge dangers. For example, in 2011, "Solvent Oil Explosion Accident of Xinqidaoliang Tunnel in Gansu 4·8 Lanlin Expressway", "Methanol

Explosion Accident in Shanxi Jinji Expressway Post-Rail Tunnel in 2014", 2016 "Shandong 6.18 Jiqing Expressway" Natural gas explosion accidents and so on. All of them are accidents caused by collisions between hazardous material vehicles, or secondary accidents caused by hazardous material transportation accidents, producing accidents in the same direction. The consequences of the accidents cannot be imagined and the losses are huge.

Because of the three differences above, the research results of the existing general cargo transport fleet scheduling problems cannot be directly applied to the dispatch of hazardous materials transport fleets. Moreover, the existing research results on the Vehicle Scheduling Problem (VSP) do not consider the factors of the transport fleet size, fleet transportation risk and compatibility. Therefore, the existing research results on the scheduling of transport vehicles for hazardous materials cannot be directly applied to the dispatch of hazardous material transport fleets.

At present, a large number of transport fleets for hazardous materials are driving on the roads. However, there are few research results on the dispatching of transport fleets, and it is urgent to carry out in-depth and systematic research.

(4) Through the existing research results, it can be found that there are various studies in the optimization of transportation routes, while the research results on the optimization of transportation networks are few. The essence of the optimization of transportation route is to solve the problem of transportation route selection between single and single points, while the essence of transportation network optimization is to solve the problem of optimization of transportation routes between multiple defects. Due to the special nature of hazardous materials, if the studies between the single points are simply promoted and applied directly to form a transportation network, it is easy for some road sections to be repeatedly selected by different OD pairs. It is easy to cause serious imbalance in the risk of hazardous material transportation. Hazardous materials are "disgusting" to residents near the road section. Multiple OD pairs repeatedly select the same road section, which makes it easy for some residents to bear more transportation risks. Fairness is difficult to guarantee and safety is also threatened. The existing literature considers this issue insufficiently. It is very essential to establish a multipoint optimization method for transportation networks from the perspective of fairness and OD data. Combining the actual data, the theory, and the reality can finally form a practical method and strategy that can guide the actual production.

(5) Before dispatching transport fleets, it is necessary to collect and calculate OD data and transportation risk parameters of hazardous materials. However, due to the reasons of hazardous materials manufacturers, and data statisticians, and the time-varying characteristics of transportation risks, there are certain uncertainties in OD data and transportation risk parameters. However, a small uncertainty in the input data may make the traditional optimal solution have a huge investment waste in practice. Importantly, the price paid is not only money, but also some lives (being dead due to hazardous materials transport accidents). The robust scheduling model and robust optimal solution are expected to solve this problem better. Robust optimization is a powerful tool for solving uncertain optimization problems. It describes the uncertainty through the "collection" form, and the obtained robust solution can be used for any element in the "set", which has good adaptability to uncertainty. Therefore, it is necessary to analyze the uncertainty of OD data and transportation risk of transportation system, introduce robust optimization theory to establish the corresponding robust scheduling model of transport fleet, and design a solution to the immune system of uncertainty data. Then the robust solution of the transport fleet scheduling problem is calculated, so as to improve the adaptability of the transport fleet scheduling scheme to uncertainty and ensure the safe operation of the transport fleet.

(6) At present, terrorist attacks are more frequent in certain special areas, and hazardous material transport vehicles may become one of the main targets of criminal attacks. Antiterrorism needs to be considered when optimizing the modeling of transport networks in the region. Because of the special dangerous characteristics of hazardous materials, in the event of a terrorist attack on a transport vehicle loaded with hazardous materials, the terrorist consequences will be multiplied. Against the background of escalating violent crimes and terrorist attacks, strengthening antiterrorism research on hazardous materials transportation is not only a forward-looking theoretical issue, but also an objective and realistic need to ensure social stability and the safety of people's lives and property. Predecessors have considered this issue insufficiently and need to conduct in-depth research on such issues.

6. Research Prospect

(1) The in-depth analysis on the characteristics of transportation accidents, comprehensive use of rough sets, and association rules, and other theories to deeply explore the causal chain of hazardous materials transportation accidents, and analyze the mechanism of transportation accidents should be performed, specifically including:

(a) The time, place, weather, cause, type of accidents, and the consequences of accidents caused by hazardous materials transportation have been analyzed in the past 20 years, and statistical analysis methods are employed to analyze the causes of accidents, focusing on weather conditions, road conditions, vehicle speed, vehicle status, etc., to determine the influencing factors.

(b) An accident information table that reflects the relationship between the cause of the transportation accident and the type of accidents has been established.

(c) The method of fusion for rough sets and association rules is used to attribute reduction and rule extraction to the redundant information in the accident information table above, to deeply explore the causal chain of transportation accidents, and to refine the mechanism of transportation accidents.

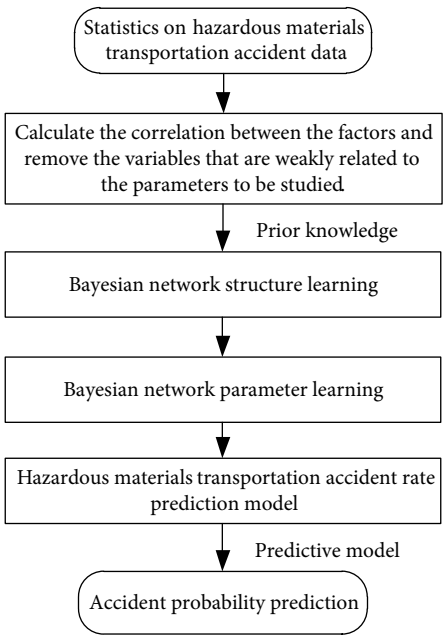


Figure 3: Flow chart of prediction of hazardous materials transportation accident rate.

(2) Bayesian network is used to predict the accident rate of hazardous materials transportation under different time and space conditions, and the transportation risk model of hazardous materials fleet is constructed according to the "risk axiom" proposed by Erkut and Verter, specifically including:

(a) According to the Bayesian network theory, the Bayesian network structure learning is carried out on the sample data of transportation accidents. Bayesian parameter estimation method is adopted to learn the parameters, and the Bayesian network-based transportation accident prediction model is established. The process of predicting the accident rate of hazardous material transportation is shown in Figure 3.

(b) Transportation risk analysis and transportation risk modeling of hazardous material transport fleets are proposed. On the basis of previous studies, the vehicle fleet characteristics are constructed in forms of the accident rate prediction and the three axioms proposed by Erkut and Verter are verified.

(c) The data are collected on population and important place distribution of hazardous materials OD, the distribution data of important hazard sources, key protection units and facility distribution data, transportation accident data, and various regions' weather forecast data, and then deep learning theory to the cargo in time and space for screening and unsuitable transportation is excavated. These data and methods provide a safe and low-risk alternative space-time network for further optimization of transport fleet scheduling. With the deep confidence network theory based on the limit Boltzmann machine, the population and important place distribution data, important hazard source distribution data, transportation accident data, and other information are combined to screen out the time and space suitable for transporting hazardous materials. The calculation flow chart is shown in Figure 4.

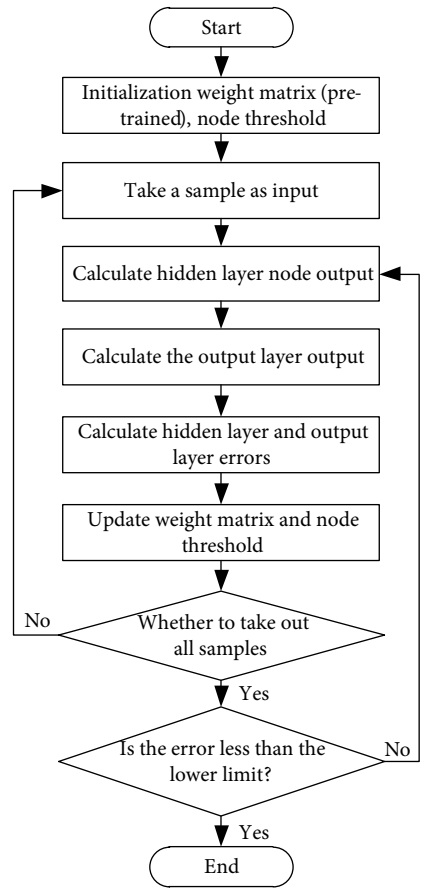


Figure 4: Calculation flow chart based on deep confidence network.

(3) By considering transportation risk, fairness, economy, fleet size, adjacent vehicle safety spacing, and incompatibility, respectively, a multiobjective robust scheduling model should be constructed.

The multistage decision-making idea can be used to systematically analyze the deployment form and process of transport fleet, and divide the whole service period into several task periods. The system is studied in two cases: static (time impedance is fixed) and dynamic (time impedance is a function of flow).

(a) Multiobjective robust scheduling model and algorithm for transport fleet under static conditions should be established. For the scheduling of transport fleet under static conditions, it is assumed that the time impedance is fixed. Under the premise that the OD data of hazardous materials and transportation risk parameters are bounded interval values, the vehicle robust scheduling plan is determined for hazardous materials. It is proposed to establish a multiobjective robust scheduling model for transport fleets. The

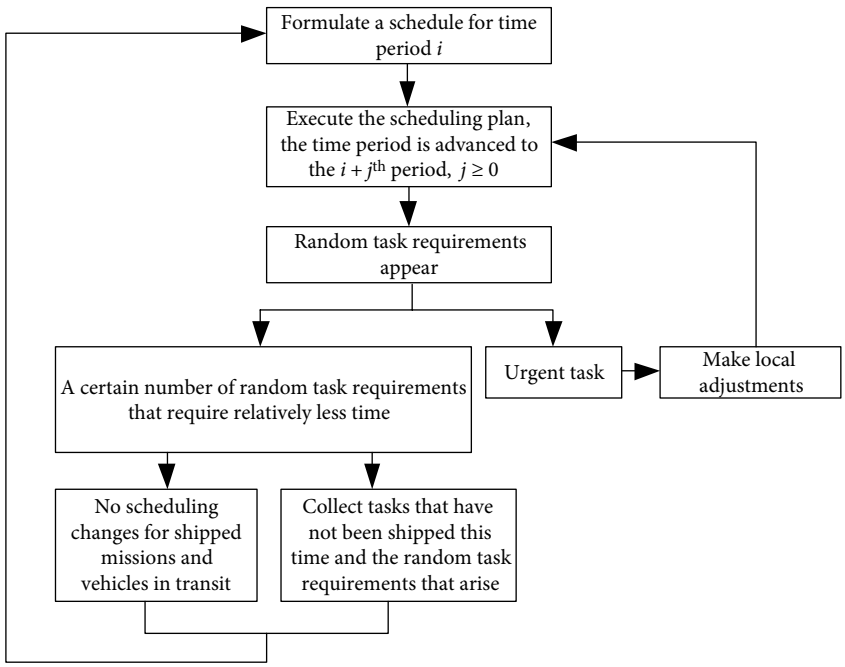


Figure 5: Rolling scheduling strategy for hazardous materials transport fleet.

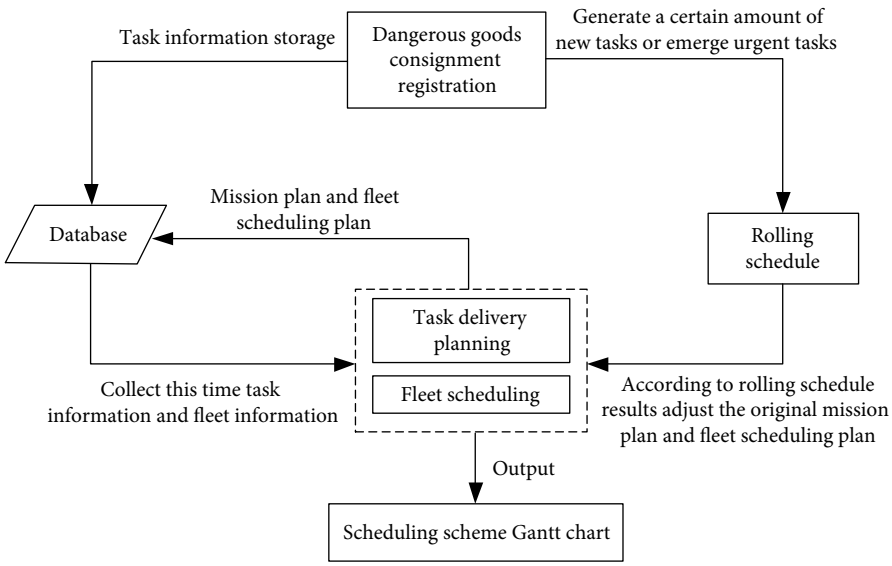


Figure 6: Rolling schedule process for hazardous materials transport fleet.

objectives pursued in the model include minimum transportation risk, the most economical transportation, and the best fairness (the smallest difference in risk among residents around the road, the same below). The involved constraints are fleet size, adjacent vehicle safety spacing, and incompatibility and so on.

(b) Multiobjective two-layer robust scheduling model and algorithm for transport fleet under dynamic conditions should be constructed. For the dispatching of transport fleet under dynamic conditions, it is assumed that the time impedance is a function of the flow rate. Under the premise that the OD data and the transportation risk parameters are bounded interval values, the fleet robust scheduling plan is determined for the hazardous materials. By assuming that the time impedance on the roadway segment is a function of traffic flow, it is proposed to construct a multiobjective two-layer robust optimization model for transportation fleets. The upper model pursues the objectives of minimum total transportation risk, transportation cost and fairness, while the lower model is a hybrid balancing model for social vehicles and hazardous material vehicles, taking into account constraints such as fleet size, adjacent vehicle safety spacing, and incompatibility.

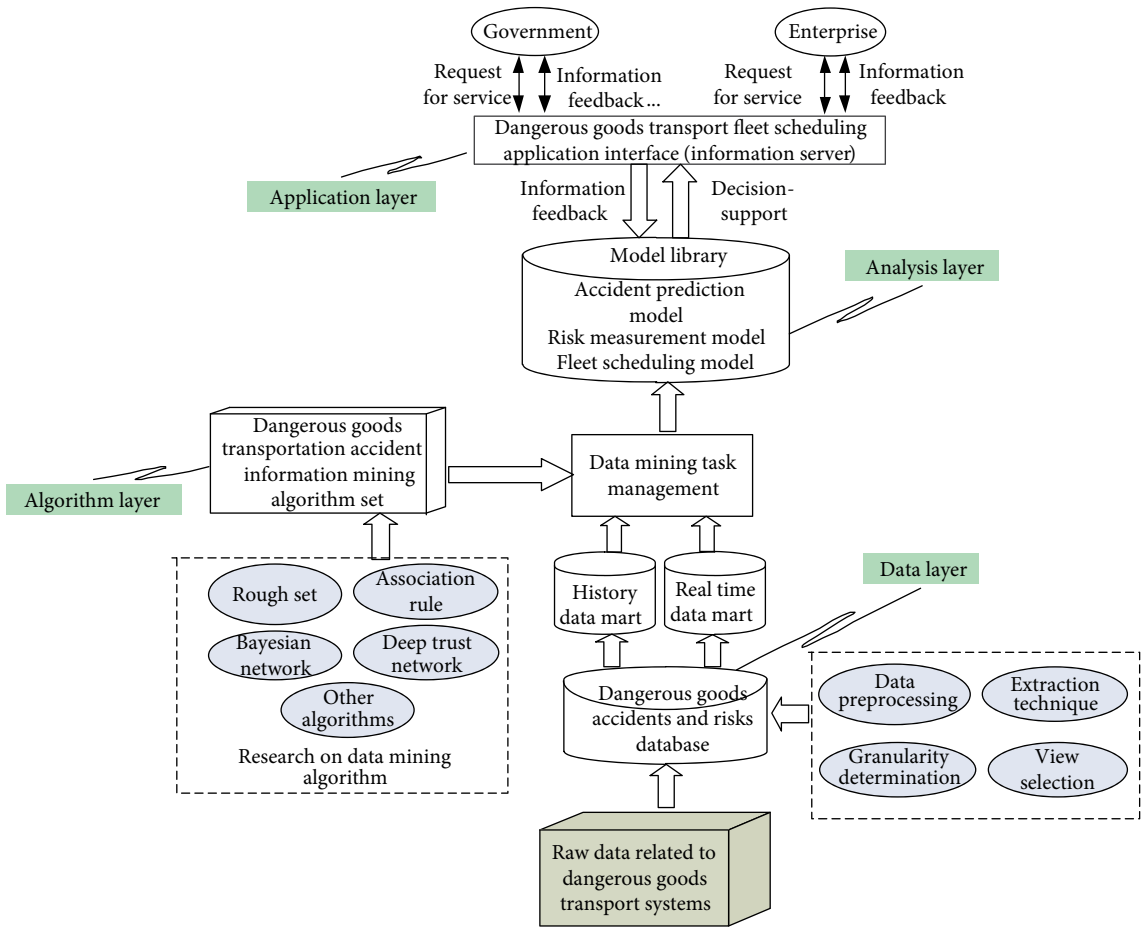


Figure 7: Framework of hazardous materials transport fleet dispatching system.

(4) By constructing a dynamic rolling scheduling method for transport fleets, and establishing a robust dispatching system for transport fleets by means of ArcGIS platform, data mining method, database technology, and Socket network technology, are integrated to realize dynamic rolling scheduling of transport fleets. Details are as follows:

(a) The main factors affecting the rolling schedule of transport fleets are analyzed, and the corresponding rolling time-domain window and rolling adjustment strategy are designed to construct a comprehensive rolling scheduling method for transport fleet.

(b) With the powerful data storage, data fusion, and visualization functions of Geographic Information System (GIS), the integrated use of ArcGIS, database technology, etc., the multisource data involved in the transport fleet scheduling system are stored in the background in the form of attribute fields. Hazardous materials are transported in time and space for screening; the robust scheduling model and algorithm of transport fleet are used to design the dispatching module of the system to realize the generation and visualization of the robust dispatching plan; management functions can achieve dynamic updates, real-time query and effective management of information such as drivers, hazardous materials vehicles, hazardous materials, accident information, transportation risks, and scheduling plans.

The rolling scheduling strategy of the transport fleet is shown in Figure 5. The rolling scheduling process is shown in Figure 6, and the system framework is shown in Figure 7.

(5) Research on robust optimization of transport fleet under the background of antiterrorism.

Based on the fact that most of the current terrorist attacks are clustered, this subsection studies the multiobjective robust optimization model of transportation network. The objectives pursued in the model include the least risk of terrorist attacks, the minimum overlap of the total transportation network, and total transportation. The risk is the smallest, the reliability is the best, and fairness is the best, the transportation cost is the smallest, or the transportation time is the shortest. An improved intelligent algorithm can be designed to solve the problem, and the robust optimal Pareto solution set for transport fleet under antiterrorism background can be obtained. In this case, each solution in the robust optimal Pareto solution set is a satisfactory solution (with less risk of terrorist attacks and a smoother transport environment, etc.). When implementing hazardous material transportation, decision-makers can randomly select a satisfactory solution from the Pareto solution to complete the transportation. This mechanism, i.e., robust optimal Pareto solution with random selection, can not

only reduce the risk of terrorist attacks, but also to some extent confuse the terrorists.

7. Conclusion

(1) Nowadays, traffic accidents in the transportation process of hazardous materials always occur from time to time. Although the accident rate of the hazardous material transportation is low, its safety situation cannot be ignored due to many factors including large volumes, complicated transportation environments, and many other risky influencing factors. By using advanced data analysis and data mining algorithms, we can investigate deeper into the transportation accident cause chains, and reveal the rule of transportation accidents, then to clarify the team safety transport mechanism and predict accident rate under different temporal and spatial conditions. At last, the transport risk model should be built, where the scientific measurement should be realized for the transportation risk of hazardous material transportation, and this process can produce a solid foundation for safe dispatching. It is of great significance to prevent the transportation accidents of hazardous materials and protect the safety of people's lives and properties.

(2) Predecessors have done a lot of studies in the three aspects: (1) hazardous material transportation risk, (2) transportation route optimization and transport fleet scheduling, and (3) fruitful research results. However, through the review of relevant literature, it is found that the existing studies have shortcomings in six aspects, and the research directions that can be further explored in the future are pointed out.

(3) The real transportation scene is often a combination of a variety of situations, and this constructs a multiobjective robust scheduling model and needs advanced algorithms for transport fleets under the background of normal and terrorist attacks. By using ArcGIS platform, data mining method, the socket network technology, database technology and other advanced data mining algorithms, we can build robust scheduling system platform and realize dynamic rolling scheduling of transport fleet. Through the theoretical analysis and empirical research, a scientific fleet robust scheduling method can be built, and the method can guide the safe dispatching of hazardous materials.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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