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A Review of Research on Optimization of Road Transportation Routes for Dangerous Goods

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***Abstract*—Route optimization of dangerous goods transportation is an important and complex problem in the field of road transportation. This paper collects and summarizes the existing researches and sorts out the research status of the problem of route optimization of dangerous goods road transportation. In this paper, the research on the optimization of the road transportation route of dangerous goods is divided into three categories, namely, the research on the optimization of the road transportation route of dangerous goods, the research on the optimization method of the road transportation route of dangerous goods, and the case application of the optimization of the road transportation route of dangerous goods, and the progress and shortcomings of the existing research are discussed. Based on the analysis of the shortcomings of the existing research, the paper analyzes and summarizes the possible future development directions of the research on the optimization of the road transport route of dangerous goods.**

***Index Terms*—dangerous goods; transportation route optimization; route optimization model; case application; review**

I. INTRODUCTION

China is a major producer and user of dangerous goods, and the volume of dangerous goods transported in China is increasing。According to statistics, the transportation volume of dangerous goods in China has exceeded 1.7 billion tons in 2017, and the total transportation volume of dangerous goods accounts for more than 30% of the total road freight, and its proportion is also maintaining the trend of expansion year by year. Dangerous goods refers to goods or substances with characteristics such as explosive, flammable, radioactive, infectious, etc. These goods or substances will cause damage to personal health, social environment, etc. if improperly handled in the process of production, transportation, operation and storage, so they need to be handled in a special way. China's dangerous goods transport industry in the process of rapid development has also encountered a number of serious accidents, not only to the people's lives, property security caused huge losses, but also damage the economic benefits of China's transport industry. Therefore, it is of great significance to study the optimization of the road transportation path of dangerous goods to improve the safety and development level of China's dangerous goods transportation industry. In this paper, we summarize the shortcomings of the related research by sorting out and classifying the related research at home and abroad, and discuss the development direction of future research, so as to provide relevant reference for theoretical research in this field and provide theoretical support for optimizing the management level of dangerous goods road transportation.

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II. RESEARCH ON THE OPTIMIZATION OF ROAD TRANSPORT ROUTES FOR DANGEROUS GOODS

The research on optimization of dangerous goods road transport paths has been kept quite hot in academic circles for many years. Most scholars have studied the text of dangerous goods road transportation path optimization based on single-objective and multi-objective perspectives.

A. Single-objective dangerous goods road transport route optimization problem

Glickman (1983)[1] conducted an early study on the optimization of road transport routes with a single objective, and he used the minimization of population coverage of transport routes as the objective to optimize the transport routes of dangerous goods. Kessler(1986) [2] defined hazardous materials transportation risk as the product of the probability of a transportation accident and the consequences of the accident disaster. He studied hazardous materials transportation routes in the Dallas-Fort Worth area and obtained the route with the least transportation risk by using the Federal Highway Administration's risk assessment method. Subsequently Batta and chiu (1988) [3] improved the algorithm for finding the optimal route by defining the objective of hazardous materials transportation route optimization as the minimum total distance between the hazardous materials transportation vehicles and the population gathering centers within the disaster impact area.Akgun (2007) [4] argued that weather factors also have an impact on the safety of hazardous materials cargo transportation, and he used a heuristic algorithm to find risk-minimizing dangerous goods transportation path with the objective of minimizing the number of fatalities in transportation accidents. Qin Junchang et al. (2009) [5] similarly considered the impact of special transportation conditions on transportation routes. They developed and solved a robust optimization model with the objective of risk minimization for different meteorological factors and the influence of decision makers' risk preferences on the transportation path. Yunpeng Wang et al. (2009) [6]

established an Arc GIS path optimization model based on the objective of risk minimization, and combined with accident cases to find out the path with the least risk for hazardous materials transportation in the area. k shortest path algorithm was established by Dadkar et al. [7] (2008) to diversify hazardous materials transportation paths so that transportation fleets do not have to repeatedly passing through the same population gathering area to reduce the transportation risk. Chunlin Xin (2016) [8] established a shortest path selection model for hazardous materials transportation under time-varying conditions with the objective of minimizing the weighted values of cost and risk, and proposed a Dijkstra improvement algorithm, and verified that its model and algorithm are reasonable. In summary, the research on single-objective dangerous goods road transportation path optimization problem is mostly aimed at minimizing transportation risk, and there is relatively little research on other objectives such as transportation cost, transportation efficiency and transportation time. For the single-objective dangerous goods transportation path optimization model, scholars mostly use a single exact algorithm to solve it, but since there are many uncertain and abrupt factors in reality, using the exact algorithm to solve it may affect the effectiveness and rationality of the results.

B. Multi-objective dangerous goods road transport route optimization problem

With the improvement of transportation conditions of dangerous goods transportation and the improvement of research level, more and more scholars study the multi-objective dangerous goods road transportation route optimization problem based on the multi-objective perspective. Current (1988)[9] carried out research on the multi-objective dangerous goods road transportation route optimization problem as early as 1980s, and he believed that the optimal route of dangerous goods transportation should be based on the minimum number of transportation miles and transportation route population coverage. Kara (2004)[10] considered the influence of regulatory agencies and transport enterprises on the transport routes of dangerous goods, and constructed a two-level planning model including the factors of government and transport enterprises and transformed it into a single objective for solving. Verma (2009) [11] constructed a dual-objective optimization model for minimizing transportation risk and transportation cost, and used GIS technology to obtain relevant data to solve the model to obtain the optimal route of dangerous goods transportation. Lijuan Ji et al. (2012)[12] considered the cascading failure characteristics of complex networks, constructed a dual-objective decision model with the objectives of minimizing the risk of transportation path and minimizing the total importance of transportation road strength, and solved the model by using the marker method, and believed that the dangerous goods transportation path should avoid the road sections with high importance, so as to reduce the negative impact of dangerous goods transportation on the road network. Lijuan Yang et al. (2017) [13] took the distance, cost and risk minimization of dangerous goods transportation as the objective, established a static single-point multi-objective constrained hazardous materials road transportation path optimization model, and obtained the optimal path by solving the model with an optimization algorithm. Meng Zhang et al. (2018) [14] established a dual-objective model with minimal impact of accident consequences and minimal transportation cost, and studied the impact of real-time loading on transportation cost using the ε-constraint method. Yixin Liu et al. (2020) [15] constructed an on-the-fly optimization model with the objective of minimizing the expected value of transportation risk and transportation cost, taking into account the influence of uncertainty in the demand of hazardous materials and population size, and solved the model using a hybrid multi-objective particle swarm algorithm. Li Li et al. (2021) [16] established a comprehensive, dynamic, multi-objective DG transport path optimization model considering the impact of DG transport accident rate, accident consequences and DG transport cost on DG transport path, and solved the model using the improved NSGA-II algorithm to find out the optimal hairy DG transport path with Tianjin port as the research object. Qin Wang et al. (2022) [17] established a dynamic multi-objective optimization model of dangerous goods transportation path under uncertain environment considering the uncertainties in the process of dangerous goods transportation, and solved the model using hybrid NSGA-II algorithm with the optimization objectives of total transportation risk, total transportation vehicle travel, and minimum number of transportation vehicles used. Xiaoquan Wang et al. (2022) [18] also considered the uncertainties in the process of dangerous goods transportation, took transportation risk, transportation cost and carbon emission minimization as the optimization objectives, constructed a dynamic uncertain risk assessment model considering the uncertain distribution of traffic flow near the dangerous goods transportation path and the change of transportation volume, and solved the model attacking with the improved NSGA-II algorithm. Mingxin Liu (2022) [19] established a dual-objective hazardous materials transportation path optimization model with the objective of minimizing hazardous materials transportation risks and transportation costs, and used the NSGA-II algorithm to find the optimal path for hazardous materials transportation. Jia Wang et al. (2023) [20] constructed a multi-objective path optimization model with the objectives of minimizing the total cost of dangerous goods transportation, minimizing the total risk impedance of dangerous goods transportation path and minimizing the possibility of excessive risk in local sections, taking into account the influence of the cost of dangerous goods transportation and the risk of dangerous goods transportation path en route, and solved the model using NSGA-III algorithm to obtain a balanced economic and safe The optimal path of dangerous goods transportation is obtained which balances the economy and safety. In summary, NSGA-II algorithm, ε-constraint method, weighting method and other algorithms are still mostly used to solve the multi-objective dangerous goods transportation path optimization problem, each of these methods has some defects, such as the weighting method is difficult to accurately select the weights, NSGA-II algorithm can not obtain the complete Pareto front, etc.

III. RESEARCH ON THE OPTIMIZATION METHOD OF ROAD TRANSPORT ROUTES FOR DANGEROUS GOODS

After years of research and development by a large number of research scholars, the methods on how to get the optimal path have formed the following five categories. The first is

Shortest Path Algorithm, the second is Dynamic Programming, the third is Artificial Neural Networks (ANNs), the fourth is Heuristic Algorithms, and the fifth is Multi-Criteria Decision Analysis. The following will summarize these research results in detail.

A. Shortest Path Algorithm

This method involves using graph theory to find the shortest path between two locations. This method is usually used for simple routing optimization problems with the goal of minimizing travel distance or time. In the case of different number and spacing of intermediate stations between two destinations, the path to minimize transportation costs and transportation costs is sought.This method has been extended and improved by many scholars. In 1989, Drezner, Z.& Wesolowsky, G.O (1989) [21]proposed a solution for the planning of pipelines that may include the transportation of toxic substances by a set of given paths or locations of paths to maximize the minimum weighted distance from the given point to the path. The first algorithm finds a nonlinear path by iteratively solving the minimum cut set problem of the network. The second algorithm solves the problem that the routing is limited to linear. J.M. Díaz-Báñez（2005）[22] proposed an approximation algorithm based on dichotomy to improve the shortest path algorithm. He specified the maximum distance l of the aircraft to transport dangerous goods, and calculated the shortest path under several distances between the origin and the intermediate station and the destination. Fulu Wei et al. (2020) [23] used the improved KSP method to set the necessary constraints such as path risk to improve the shortest path search algorithm, and established a hazard value model, which can effectively reduce the transportation risk according to the dangerous path selection scheme under different confidence levels.

B. Dynamic Programming

This method includes decomposing a complex routing problem into smaller sub-problems, and then solving them recursively. This method is suitable for solving multi-criteria problems. For example, the dynamic optimal planning of highway route is to divide the whole route into many route segments. After trying to calculate the objective function value of each segment, a recursive relationship is used to make the optimal decision one by one, so as to achieve the optimal result of the whole route and minimize the travel time, cost and risk exposure. Peilin Zhang et al. (2011) [24] improved the traditional method of port scale determination, established a dynamic optimization model of dangerous goods port scale from the perspective of disaster economic theory, proposed a dynamic programming algorithm, and finally designed the calculation steps of port scale dynamic optimization. Sumeet Desai, Gino J. Lim (2013) [25] constructed a stochastic dynamic traffic network. Suppose our goal is to select routes for dangerous goods vehicles to minimize the expected risk population. Ping Li et al. (2019) [26] studied the expansion of the road-rail intermodal transport network of dangerous goods composed of multiple path periods. Comparing the multi-cycle dynamic programming method with the single-cycle method, the results show that the total transportation cost of the multi-cycle road-rail intermodal transportation network is significantly better than that of the single-cycle planning method.

C. Artificial Neural Networks

This approach involves using artificial intelligence and machine learning techniques to simulate complex relationships between different variables and determine the best routing solution. This method is suitable for solving complex problems with large amount of data.
Erdem Doğan & Ali Payıdar Akgüngör (2013) [27] used ANNs to predict road development and planning under the development of public railways in Turkey. Zhao et al. (2021) [28] used a neural network-based identification method for dangerous goods transport vehicles to identify dangerous goods vehicles running in highway tunnels. A dynamic identification system for dangerous goods transport vehicles was built to improve the accuracy of dangerous goods vehicle identification in highway tunnels and ensure the safety of highway tunnel traffic operations. Based on the collision situation of dangerous goods transport vehicles based on environmental complexity, Li Gao et al. (2022) [29] used neural network fitting to establish a quantitative model of environmental complexity, collected real vehicle data of dangerous goods transport vehicles with ordinary early warning systems on real road sections and made decisions to improve the safety of dangerous goods transport vehicles. Zheyu Jin (2022) [30] used improved BP neural network to carry out safety risk analysis modeling planning for railway dangerous goods transportation, and objectively analyzed the safety status of railway dangerous goods transportation enterprises.

D. Heuristic Algorithms

These algorithms involve using a set of rules or strategies to find the best routing solution. Examples of heuristic algorithms include Ant Colony Optimization, Genetic Algorithms, and. Tabu Search.Genetic algorithm is a search algorithm based on natural selection and population genetic mechanism. It simulates the phenomenon of reproduction, hybridization and mutation in natural selection and natural genetic process. When genetic algorithm is used to solve the problem, each possible solution of the problem is encoded into a ' chromosome ', that is, an individual, and several individuals constitute a population—all possible solutions. Liu Liping et al. (2021) [31]used multi-objective genetic algorithm to verify the necessity of considering risk fairness in the optimization model of dangerous goods transportation routes, and established a model and a multi-objective genetic algorithm based on linear weighting to find the optimal route that meets the expectations of the government, carriers and the public.In nature, ants leave a string of pheromones when they travel, and other ants can follow them to find food sources. The ant colony algorithm imitates this behavior and uses probability rules to determine the next access node based on the number of graph edge pheromones. The edges containing more pheromones are more likely to be selected, and artificial ' ants ' are used to explore possible solutions to the optimization problem. In the transportation route of dangerous substances, ant colony algorithm can find the optimal or near-optimal path by simulating the behavior of ants searching for the shortest path between two points.Wang Haixing et al. (2013) [32]designed an improved hybrid ant colony algorithm (HACA) to achieve the purpose of balancing route risk and cost based on ACA principle, and established a dangerous goods route optimization model with minimum total cost. Xiaoquan Wang et al. (2022) [18] improved the NSGA-II algorithm by considering factors such as traffic flow and minimizing transportation risks, transportation costs, and carbon emissions. The random disturbance operation is added in the population initialization stage, which can effectively optimize the distribution path of dangerous goods in the city.The principle of Tabu Search is to start the current node and compare it with the values of the surrounding neighbor nodes. If the current node is the largest, then return the current node as the maximum value (the highest point of the mountain) ; on the contrary, the current node is replaced by the highest neighbor node, so as to achieve the purpose of climbing to the height of the mountain.Pasquale Carotenuto al. (2007) [33] proposed a no-wait job shop scheduling model, which includes alternative job routes and tabu search algorithms. These algorithms were evaluated experimentally on real test problems defined on the Italian regional road network, and also evaluated the solutions provided, including minimum route length and minimum route risk. Nicolas Zufferey and Manish Verma (2011) [34]used tabu search to establish a model. Plans and arrangements for the multimodal transport of dangerous goods by rail trucks from a group of suppliers to a group of customers. Yue Teng et al. (2020)[35]proposed a hybrid algorithm combining ε-constraint method and tabu search, and embedded a vehicle matching strategy in the algorithm, which can provide decision support for the formulation of transportation plans for dangerous goods carriers.

E. Multi-Criteria Decision Analysis

This method involves evaluating different routing options based on multiple criteria, such as cost, time, risk, and environmental impact, and identifying the best solution using decision analysis techniques.Monprapussorn S et al. (2009)[36]Monprapussorn S et al. (2014) [37]uses a combination of multi-criteria decision analysis (MCDA) and geographic information system (GIS) methods to solve hazardous waste transport problems. Mohammad Noureddine & M. Ristić (2019)[38]and Zafer Yilmaz & Vedat Verter (2022) [39]used Multi-Criteria Decision-Making to consider a number of scenarios to propose practical ways to find the best route for dangerous goods transportation.

IV. Case Application of Route Optimization for Road Transportation of Dangerous Goods

Most scholars, after constructing a hazardous materials transportation route optimization model and its solution algorithm, will test the rationality and effectiveness of their model and algorithm through specific practical case applications. Kessler (1986)[2] used the hazardous materials transportation route in the Dallas-Fort Worth area as a case study, and obtained the route with the least transportation risk in the area through the risk assessment method of the Federal Highway Administration. Jovanović et al. (2010) [40] used risk and economic efficiency as important reference factors and conducted an empirical study using Belgrade gas station supply network routes as the object of analysis to find the shortest path for hazardous materials transportation by using Djikstra's algorithm, and also using a well-established heuristic algorithm to determine the number of vehicles required to transport hazardous materials, so as to find the optimal path for hazardous materials road transportation. K Nguyen-Thong et al. (2017) [41] integrated GIS GIS with agent-based and equation-based models into a new model, and then empirically investigated the optimal path for transporting mainly domestic waste hazardous materials in Ha Giang City, Vietnam by using the Clark Wright mileage saving algorithm, and finally successfully confirmed the effectiveness of the integrated model in a dynamic environment context. Angelica Lozano et al. (2011)[42] used the local oil and chlorine transportation in Mexico City as an analytical case, and conducted an empirical study by building a risk minimization model, using the population exposure index as an indicator to determine the transportation risk, and finally successfully determined the road transportation route for hazardous materials with minimum risk. Funda (2013)[43] Using the Marmara region as an actual case for empirical research, the local geographic information data was obtained by using GIS geographic information system, and combined with factors such as transportation costs, operating costs of hazardous materials recycling centers, and population exposure risks to construct a path optimization model for the transportation and recycling and disposal of industrial hazardous materials, and finally achieved the optimization of industrial hazardous materials transportation paths in the region. Lijuan Yang et al. (2017) [13] examined the transportation path of hazardous materials from Jiangyin to Wuxi of a domestic company in China, and used the GRA method to obtain a multi-objective transportation path optimization model based on the minimization of transportation costs, consequences and risks, and obtained the closest to the "absolute optimal route" in the region. The suboptimal route of dangerous goods transportation in the region is the closest to the "absolute optimal route". Fulu Wei,et al. (2020) [23] used the hazardous materials transportation route of Changchun gas station as the object of study and solved the TR model based on the optimal design algorithm of hazardous materials route based on risk value to obtain the optimal route of hazardous materials transportation under the condition that the hazard level is accepted. Li Li et al. (2021) [16] used the main line of Tianjin port of dangerous goods transportation route as the case study object for empirical examination, modeled the dangerous goods transportation network of Tianjin port, and used the dangerous goods transportation route optimization model and the improved NSGA-II algorithm to find the optimal route of dangerous goods transportation. Mingxin Liu (2022) [19] took LNG as the studied dangerous goods, selected some dangerous goods transportation roads in Tianjin for case empirical test, established a dual-objective dangerous goods transportation path optimization model with the objective of minimizing transportation risk and transportation cost, and used NSGA-II algorithm to find the optimal path.

V. Outlook

To sum up, as more and more scholars carry out research about the optimization problem of dangerous goods road transport path, further in-depth research can be carried out in the future from the following aspects: First, in the research of multi-objective transport path optimization problem, most of the research only considers risk, cost objectives and static network, without setting dynamic change values, and most of them use exact algorithm to solve, and the model considers parameters The model considers limited parameters, thus making the solution range limited and there are cases that do not match with reality. In the future, more optimization objectives with practical significance can be considered in the model according to the actual situation, and a model with multiple dynamic uncertainties and optimization objectives can be established. Second, at present, the solution of multi-objective DG transport path optimization problem still mostly adopts NSGA-II algorithm, ε-constraint method, weighting method and other algorithms, each of these methods has some defects, such as the weighting method is difficult to accurately select the weights, NSGA-II algorithm can not obtain the complete Pareto front, etc. Therefore, the future research on the optimization of dangerous goods transportation path can try to develop and improve the new solution algorithm with more applicability and rationality, or integrate the original model to build a new model to analyze the optimization of dangerous goods transportation path with higher complexity. Thirdly, most of the case studies on the optimization of dangerous goods road transport paths have been selected for their short transport paths, resulting in short transport time, which cannot well analyze the dynamic uncertainties that may be faced during the transport, and future case studies can be selected for longer transport paths. Fourth, the existing research on the optimization of the road transport path of dangerous goods cargo lacks the refinement of transporting dangerous goods. The types of dangerous goods in China are rich and diverse, and different types of dangerous goods have different risk coefficients and cause different consequences of accidents. Future research can further refine the types of dangerous goods, and establish targeted path optimization models and solution algorithms according to the characteristics and properties of different dangerous goods. Finally, as China's artificial intelligence, big data analysis and "5G+Beidou" technology are gradually improved, future research on the optimization of dangerous goods road transportation can make more use of the data obtained from 5G communication base stations and Beidou positioning system for monitoring dangerous goods transportation, and at the same time, build a model of dangerous goods transportation route optimization based on artificial intelligence and big data analysis. At the same time, we can build a dangerous goods transportation route optimization model based on artificial intelligence and big data analysis, so that the results of dangerous goods transportation route optimization can be more accurate.

VI. Conclusion

Optimization of dangerous goods transportation routes is an important and complex issue in the field of road transportation. The traditional solutions of dangerous goods cargo transportation have certain potential risks due to the lack of optimization. In order to minimize risks and improve transportation efficiency and safety, researchers have done a lot of work on optimization of dangerous goods cargo transportation routes. In this paper, these research results are reviewed, and the results show that: first, more and more research on the optimization of dangerous goods road transport routes has shifted from single-objective to multi-objective, and scholars gradually take into account the time-varying uncertainties in the multi-objective dangerous goods transport route optimization research. Secondly, there are five main algorithms for the optimization of dangerous goods road transport path in academia. The first is Shortest Path Algorithm, the second is Dynamic Programming, the third is Artificial Neural Networks (ANNs), the fourth is Heuristic Algorithms, and the fifth is Multi-Criteria Decision Analysis. Most scholars use the shortest path algorithm and heuristic algorithm to solve the path optimization model. Thirdly, the research object of the case application of the optimization of the path of dangerous goods road transport is mainly the dangerous goods transport network within a single city, and the selected path of the optimization of the road transport of dangerous goods is relatively short. The existing research has some room for improvement, and the future research outlook is: first, to establish a dangerous goods transportation path optimization model that takes into account multiple dynamic uncertainties and contains multiple optimization objectives; second, to try to develop and improve new solution algorithms with more applicability and rationality, or to integrate the original model to build a new model to analyze the more complex dangerous goods transportation path optimization problems; Thirdly, the case study of DG transport path optimization can be selected to study longer transport paths; fourthly, to establish targeted path optimization models and solution algorithms according to the characteristics and properties of different DG; finally, to make more use of the data obtained from 5G communication base stations and Beidou positioning system for DG transport monitoring, and to build DG transport path optimization models based on artificial intelligence and big data analysis. Optimization model based on artificial intelligence and big data analysis.

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