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Review on Road Transportation Route Optimization of Dangerous Goods

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Abstract **-In recent years, with the continuous improvement of China's economic level, the business of dangerous goods transportation has also developed by leaps and bounds. Dangerous goods are 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, storage, etc., and therefore need to be handled in a special way. Research on hazardous materials logistics is divided into risk assessment problem, path optimization problem, facility location problem and network design problem. Risk assessment is the basis for the latter three, and this paper focuses on reviewing the current status of research on risk assessment and route optimization of dangerous goods transportation routes. For risk evaluation, it is mainly based on risk evaluation index, risk evaluation model and relationship evaluation between risk sources. For the optimization of dangerous goods road transport routes, the main distinction is made between single mode of transport and multimodal transport, in which single mode of transport is carried out from both single and multiple objectives; multimodal transport is carried out mainly through the optimization of combined modes and algorithms, and finally the focus and weaknesses of current research are derived to provide relevant suggestions for future research directions and contents.**

Index Terms- Dangerous goods transportation, route optimization, risk evaluation model

I. INTRODUCTION

In recent years, with the continuous improvement of China's economic level, the business of dangerous goods transportation has also been developed rapidly. Dangerous goods are goods or substances with characteristics such as explosive, flammable, radioactive, infectious, etc. These goods or substances will cause damage to personal health and social environment if improperly handled in the process of production, transportation, operation, storage, etc., so they need to be handled specially . However, on the one hand, due to dangerous goods transport enterprises self-produced, relying on the business model, but the current dangerous goods transport is still in the transport risk, the development of a low level of modernization of the situation, on the one hand, due to most transport enterprises self-produced, relying on the business model of operation, on the other hand, the lack of unified standards and quality and safety system supervision and other perfect management system. In order to ensure the safety of people's lives and property and the economic benefits of dangerous goods transportation industry, it is important to study the optimization of the road transportation route of dangerous goods to improve the safety and development level of China's dangerous goods transportation industry.

Research on hazardous materials logistics is mainly divided into risk assessment problem, path optimization problem, facility location problem and network design problem [1], and the latter three often need to be based on the evaluation results of risk assessment. Dangerous goods logistics links mainly include transportation, loading and unloading, storage and other processes, but the main risk is concentrated in the transportation link, which is also the main direction of current research.

II. A REVIEW ON RISK EVALUATION OF DANGEROUS GOODS TRANSPORTATION ROUTES

Scholars at home and abroad have conducted relevant researches on risk evaluation of dangerous goods transportation, mainly including risk evaluation indexes and risk evaluation models, risk factor importance and relationship assessment, and risk evaluation model methods. The development path is basically based on the initial accident statistical analysis, combined with fuzzy data, environmental impact assessment and other

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multidisciplinary theoretical methods to quantify the probability of risk occurrence, forming a complete risk evaluation system including statistical data, modeling methods and information technology [2].

A. Risk evaluation indicators and risk evaluation model of dangerous goods transportation

Erkut et al. (1995) established a multilevel risk evaluation model including transport distance, personnel and social risk, accident probability and time probability as criteria [3]. On this basis, Fabiano et al. (2002) added two indicators of index route characteristics and crowd exposure sensitivity to establish a new risk assessment model [4]. Ren Changxing et al. (2006) and RAO et al. (2004) proposed a risk evaluation index model of dangerous goods road transport including three components of transporting dangerous goods risk index, route impact factor and compensation factor of safety measures [5] [6]. Wu Jinzhong (2015) comprehensively analyzed the main influencing factors of dangerous goods road transport from dangerous goods, vehicle equipment, personnel and transport routes and other 5 aspects of risk, and established a risk evaluation index system [7]. Some scholars added new indicators for consideration of the evaluation system, Chen Yue (2018) improved the risk grading index model made by previous authors and constructed a new risk evaluation index model for dangerous goods road transport, adding indicators for considering the corrosiveness of dangerous goods, etc [8]. Wang Xinzhi (2020) comprehensively analyzed the main influencing factors of dangerous goods transportation risks under different transportation modes from the perspective of human-machine-environment, established a risk evaluation index system, and studied the evaluation system of dangerous goods transportation risk classification index [9]. Zuo Borui et al. (2020) obtained a functional risk index based on FUZZY FRAM model with fuzzy inference technology to overcome the defects of the analysis of dangerous goods transportation accidents that cannot be analyzed quantitatively [10]. Li Shengzhao (2020) constructed a fuzzy comprehensive evaluation matrix based on AHP and entropy weight calculation method to evaluate the risk of dangerous goods road transportation [11].

Some scholars considered the influence of time factor, and He Zhengzang et al. (2017) considered the time-varying characteristics of dangerous goods transportation and constructed a population risk assessment model to derive the optimal departure time, which provides a new way to effectively reduce the population risk of dangerous goods transportation [12]. Most previous studies considered risk sources as existing independently of each other, Huang Wencheng et al. (2016) and Yang Ting et al. (2019) added the interaction between risk sources within the consideration and analyzed the impact of coupling factors focusing on risk between risk sources on risk [13] [14]. Xueqin Liang (2022) considered the problem of ambiguity and randomness of evaluation indexes, cited the entropy weight method to obtain the evaluation index weights, and proposed a comprehensive evaluation method of risk level of dangerous goods road transportation based on two-dimensional cloud model [15].

B. Risk evaluation method of dangerous goods transportation

The existing evaluation methods mainly include data collection and analysis methods, accident tree analysis methods, fuzzy comprehensive evaluation methods, hierarchical analysis methods, fuzzy hierarchical analysis methods, gray correlation analysis methods, neural network-based evaluation methods, and evaluation methods based on cluster analysis.

Data collection and analysis methods: including literature method, expert consultation method, experimental method, etc. Through collecting and analyzing relevant data, we evaluate the road transportation of dangerous goods.

Accident tree analysis method: By constructing an accident tree model, the accident risk of road transportation of dangerous goods is analyzed and evaluated.

Fuzzy comprehensive evaluation method: by using fuzzy mathematical theory, multiple factors of dangerous goods road transportation are fuzzy evaluated. Zuo Borui et al. (2020), Wu Jinzhong (2015) and Liu Haoxue (2006) applied the fuzzy comprehensive evaluation method to establish the risk evaluation model of dangerous goods road transportation [16] [17].

Hierarchical analysis (AHP) is a decision analysis method that decomposes the elements always related to decision making into levels such as objectives, criteria, and scenarios, on the basis of which qualitative and quantitative analysis is performed. This method was adopted by Shi Shih et al. (2021) and Li Shengzhao (2020) [18].

Fuzzy hierarchical analysis (Fuzzy AHP) is a hierarchical analysis method based on fuzzy mathematical theory, which can be used to make fuzzy comprehensive evaluation of decision problems. Zhang Zengbo et al. (2011) analyzed five main factors affecting the safety of railroad dangerous goods transportation and established a comprehensive evaluation model of dangerous goods transportation safety by using the basic principles and evaluation methods of fuzzy hierarchical analysis [19]

Gray correlation analysis method: By conducting gray correlation analysis on multiple factors affecting the road transportation of dangerous goods, the correlation and importance between the factors are determined.

Neural network-based evaluation method: By establishing a neural network model, we simulate and evaluate several factors such as safety, economy and environmental protection of dangerous goods road transportation.

Evaluation method based on cluster analysis: through cluster analysis of multiple factors of dangerous goods road transportation, the similarity and correlation among factors are determined, so that the transportation path can be optimized. Huang Wencheng et al. (2016) and Yang Ting et al. (2019) are among the representatives.

III. A REVIEW ON THE OPTIMIZATION OF DANGEROUS GOODS TRANSPORTATION ROUTES

According to the different modes of transportation and the combination of different modes of transportation, the target area of dangerous goods transportation path optimization is divided into single mode transportation path optimization and multimodal transportation path optimization.

A. Single mode transportation path optimization

a. Single-objective transport path optimization

Due to the lack of initial technical development and the relative lack of multi-objective research, the initial scholarly research mainly focused on simple single-objective path optimization, with the single-objective focus on selecting the optimal path to reduce transportation risk. Domestic and foreign research on single-objective transportation path optimization was concentrated in the 1980s to the beginning of the 21st century.

Foreign scholars Kessler (1986) was the first to study the optimization of road transport paths with a single objective, and first proposed that the definition of hazardous materials transport risk is the product of the probability of a transport accident and the consequences of the accident disaster [20]. Subsequently Batta and chiu improved the algorithm for finding the optimized path based on the optimization for the criteria, and expanded the criteria for hazardous materials transportation path optimization to the sum of the minimum weighted distance lengths between the hazardous materials transportation vehicles and the population gathering centers within the disaster impact area [21]. JOY et al. (1981) conducted an empirical study on the path optimization of radioactive waste and derived the shortest path algorithm [22] .

Liu Haoxue et al. (2006) established a set of dangerous goods transportation safety evaluation index system based on the idea of fuzzy comprehensive evaluation method, and determined the transport route scheme with the least hazard and performed fuzzy comprehensive calculation based on this evaluation system; Ren Changxing et al. (2007) analyzed several dangerous goods road transport risk indexes based on Pareto's optimization processing method, and selected the minimum transport risk route [23]; Wang Yunpeng et al. (2009) used GIS to establish a road network for a specific area in order to reduce the hazards of dangerous goods urban transportation, and analyzed the factors affecting dangerous goods urban transportation, considered the hazards generated by the accident, the risks caused by the accident and the ability to remedy the accident, and established a GIS-based route optimization model for dangerous goods urban transportation [24].

b. Multi-objective transport path optimization

In recent years, in addition to considering the transport risk itself, some scholars began to study the multi-objective hazardous materials transport route optimization problem including transport cost, transport distance, transport time, accident rate, transport loss and other factors.

While foreign research is relatively early, List (1991) et al. analyzed the risks of hazardous materials road transport, emphasized the importance of a dual-objective transport path optimization model, and proposed a method for selecting optimal paths for hazardous materials road transport [25]. Saccamanno et al. (1993) proposed multiple criteria for hazardous materials transport path optimization on this basis, in which the criteria of minimum population exposure, minimum accident probability, minimum transportation cost, and other criteria [26]. V. Akgün et al. (2000) analyzed in detail three existing methods for selecting a series of dissimilar road transport optimization paths, namely, the iterative penalty model (IPM), the network management shortest path (GSP) method, and the great minimal method, and also described the p-discrete model for analyzing the dissimilarity of the selected road transport paths [27Erkut et al. (2008) proposed that the selection of DG transport paths should be based on the objective of minimizing transport risk and transport cost, and used the unregulated model, over-regulated model, two-step model, and two-layer model to analyze the optimal path selection problem [28]. Current et al. (2010) proposed two criteria for the optimization of DG road transport paths, mainly based on the minimum population exposure and the minimum Current et al. (2010) proposed two criteria for the optimization of hazardous materials road transport routes, mainly the minimum population exposure and the shortest transport distance as the core criteria for route optimization [29].

Zhang Jiaying et al. (2010) established a two-layer planning design transportation network with risk minimization as the goal while taking into account cost minimization, and wrote a genetic algorithm program in Python to output the individual with maximum fitness obtained during evolution as the stable optimal solution, yielding a transportation risk lower than that under no control and close to minimum risk on the design network [30]. Lupin et al. used the gene permutation operator of the uniparental genetic algorithm, which allowed to obtain feasible solutions while fully implementing the functions of the traditional crossover operator of PMX. A roulette wheel selection method was used to ensure that the optimal individual with greater fitness enters the next generation, and examples were given to compare the difference between risk and cost reducing optimization paths [31]. Xin Chunlin et al. (2016) used the minimum-maximum criterion combined with the algorithm Dijkstra,which solves the shortest circuit of the network, to design an improved heuristic algorithm to construct a two-layer planning model with stronger robustness for the transportation network to solve the risk interval type of hazardous materials transportation network problem [32]. Yong Yin et al. (2017) used an improved non-dominated ranking genetic algorithm with an elite strategy to simulate a safe path selection model with the objective of considering traffic congestion and hazardous materials rescue points. MATLB was used to determine the safety assessment value of roadway cascade failures, and the network traffic congestion index was used as an index to evaluate the safety performance of roadway cascade failures. The elite strategy is selected based on the congestion distance and ranking level to select the best individual for genetic operation [33]. Meng Zhang et al. (2018) established a dual-objective model with minimum maximum accident consequences and minimum transportation cost, and studied the effect of real-time loading on transportation cost based on the ε-constraint method, which was improved by the nature of the lower bound of ε, the preprocessing of circumvented dominated solutions and the infeasible path prohibition constraint [34]. Wang Wei et al. (2018) constructed a two-layer planning model based on the total risk and time cost weighted minimum of the network and the total time cost of the transportation firm based on the vehicle speed limit. The particle swarm algorithm is used to solve the lower-level planning model using the shortest-circuit algorithm, and the adaptation value of the particles is evaluated by the objective function of the upper-level planning model, and the inertia weights and learning factors decrease linearly as the iteration proceeds, and then the optimal solution is sought [35]. He Zhengzang (2018) established a time-varying path selection model based on conditional value-at-risk for hazardous materials road transport, and used it to evaluate the risk of each feasible path. Li Shumin et al. (2019) proposed a multi-objective optimization model considering all three factors in transportation network planning based on the multi-layer attributes of transportation risk, transportation cost and transportation time for hazardous materials in the process of road transportation[36] . Yue Teng et al. (2020) considered the multi-model vehicle problem on the dual-objective model and proposed a hybrid algorithm solution combining the ε-constraint method and the taboo search to convert the multi-objective into a single-objective problem, generate the initial solution using the improved CW saving algorithm, generate the domain solution by moving the operator, and then solve the optimal solution using the taboo search algorithm for several consecutive iterations to satisfy multiple groups of transportation solutions with different demands []. 37]. Li Li et al. (2021) studied the optimization of dangerous goods transportation path based on the improved NSGA-II algorithm[38] . Zhang Shengzhong (2021) proposed the optimal design of special lanes for dangerous goods transportation based on two-layer planning considering the master-slave game relationship between planners and travelers .[39]

B. Multimodal transport path optimization

With the development of logistics industry, a single mode of transportation can no longer adapt to the real world, which requires each different mode of transportation to work together for combined transportation, i.e. multimodal transportation. Finding the shortest, fastest and lowest cost optimal path allows for maximum transfer of goods in the multimodal transport process.

a. Optimization of dangerous goods transportation mode combination

The main modes of dangerous goods transportation include highway, waterway, railroad, pipeline and airline. Considering the limitations of pipeline and airline, including the singularity of transported goods and transportation cost, they are not the mainstream modes of dangerous goods transportation. Roads, waterways and railroads are the main modes of dangerous goods transportation, and scholars at home and abroad have conducted relevant researches on their combined modes.

REDDY (1995) and DUIN et al. (1998) studied the combination problem and optimal route selection problem of rail and waterway transportation of dangerous goods, and established a mathematical model with the sum of transportation and transit costs as the main influencing factors [40] [41]. KARA et al. (2004) conducted the first study on the optimal design of dangerous goods transportation network [42]; VERMA etal. (2009. 2012) delved into the problem of optimization of intermodal rail and public transport routes for dangerous goods [43] [44]. ASSADIPOUR et al. (2015) considered congestion in multimodal terminals [45].

Most of the above studies are based on 2 modes of transportation, railroad and road, however, with the increase of realistic needs (cost, risk, environment, road conditions, etc.), research on optimization of the combination of 3 and more modes of transportation is still relatively scarce; considering the time window and other realistic factors can better control the cost and risk, the current research is still insufficient; the combination of multiple modes makes the calculation problem more and more complex, and with a wide algorithms with wide applicability are still relatively few.

b. Research on multimodal transport algorithm for dangerous goods

For the study and solution of multimodal transportation problems, which are more complex than single-modal transportation, in the existing literature, researchers usually use a variety of methods to optimize multimodal transportation paths for hazardous materials transportation. Among them, the most commonly used methods include heuristic algorithms, genetic algorithms, simulated annealing algorithms and so on. Different methods are usually based on different theoretical foundations and mathematical models.

Heuristic algorithm is based on Bayes' theorem and probabilistic model, which is an intuitive or empirically constructed algorithm to find the solution space of a problem through a trial-and-error problem solving approach.MARIE et al. (2012) studied the shortest path problem of multimodal transportation with a focus on reducing environmental and social impacts, established a multi-objective mathematical model, and proposed a heuristic algorithm The algorithm can effectively find the optimal path from a large-scale transportation network [46].

Genetic algorithms are based on the principles of natural selection and evolution, such as Xin Chunlin et al. (2016) studied the multimodal dangerous goods route optimization problem under time-varying conditions based on the strong time-varying characteristics of transportation cost and population risk, established the shortest path selection model for multimodal transportation of dangerous goods under time-varying conditions, and proposed Dijkstra's improved algorithm [47].

The simulated annealing algorithm is based on the principle of minimum maximum and thermodynamics.BRAEKERS et al. (2012) studied the multimodal container terminal vehicle path problem, where an asymmetric bi-objective planning model containing a time window was developed with the number of vehicles and distance as the objectives, with the departure or destination unknown in advance, and the best results were obtained by simulated annealing and forbidden search algorithms [48].

IV. CONCLUSION AND OUTLOOK

For the current risk evaluation indexes and models of dangerous goods road transport, the current research focuses on keeping up with the times, constantly adding new evaluation indexes in line with reality, further improving the evaluation index system, while enriching the evaluation model's relevance, but there is a relative lack of research on the relationship between the risk sources themselves.

For the optimization of hazardous materials single transport mode path is increasingly focused on multi-objective research, but most of the research focus is still biased towards static analysis, and relatively little research has been done on time-varying properties.

For multimodal transport risk research in the main focus on rail-water intermodal transport, public-rail intermodal transport, lack of attention to dangerous goods public-water intermodal transport to, three intermodal transport and more ways to combine, while the real society actually exist such needs. The methods of multimodal research are mostly single heuristic algorithms, lacking the integrated application of multiple algorithms. At the same time, many multimodal research methods still consider only a single objective, yet multimodal transport involves multiple objectives such as cost, time and risk, which should be covered in the design algorithms to make them more realistic.

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