Optimization Ideas for Risk Control in Hazardous Materials Transportation Under the Background of Artificial Intelligence

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Abstract: In recent years, with the development of global industrialization, the demand for hazardous goods has been on the rise, and the logistics of hazardous materials must also undergo a high-quality transformation toward safety, environmental friendliness, and efficiency. However, the safety factors involved in the transportation of hazardous goods cover a wide range of aspects, making regulation difficult, and there is a shortage of professional personnel. These issues lead to high risk control costs and low efficiency in the transportation of hazardous materials. Therefore, this study aims to explore the application prospects of artificial intelligence (AI) technology in the transportation of hazardous goods, and discuss how to use AI to reduce the difficulty and cost of risk control in hazardous materials transportation, thereby effectively improving the efficiency and safety of hazardous goods transportation.

Keywords: Hazardous Materials Transportation; Artificial Intelligence; Risk Control

1. Introduction

With the development of industrialization in China, the transportation of hazardous goods between regions has become increasingly frequent, which has significantly increased the pressure on the regulation of hazardous materials transportation (hereinafter referred to as "hazardous materials transportation"). Hazardous goods are hazardous as they may harm the environment, so ensuring a high level of safety and rationally planning processes during transportation are the top priorities. However, the sources of risks and safety factors in hazardous materials transportation are numerous, resulting in high regulatory difficulty and low efficiency. Enterprises have to bear high costs, which affects the development of both the hazardous materials transportation industry and the entire chemical industry.

Nevertheless, with the iteration of high-tech information technologies, the application of technologies such as AI, big data, and blockchain in various industries has become a research hotspot. By studying literature data and interviewing enterprises related to hazardous materials transportation, this paper explores the application prospects of AI in the hazardous goods transportation industry. It aims to use this technology to reduce the difficulty and cost of risk control in hazardous materials transportation and provide the industry with safer, greener, and more economical risk control ideas.

2. Current Status of Risk Control in Hazardous Goods Transportation

2.1 Current Status of Research on Classification of Risk Factors and Measurement Models in Hazardous Goods Transportation

Hazardous materials transportation involves a large number of factors, each with different degrees of impact. Scholars mainly focus on the classification of risk factors and the measurement of risk values, aiming to quantify and avoid risks through classification and estimation, thereby preventing accidents.

There are various types of hazardous goods in transportation. The selection of transportation vehicles, packaging, transportation methods, and routes, as well as the supervision during transportation, all affect the safety of hazardous materials transportation. Risk control measures are also mostly implemented targeting these factors.

Studies have shown that the occurrence of accidents and risks in hazardous materials transportation is significantly related to the mode of transportation: the risk probability of road transportation accidents exceeds 75%, while that of air transportation and railway transportation is

12% and 11.7% respectively [1]. In addition, factors such as personnel, equipment, management methods, and road conditions are also closely related to these risks, which may trigger accidents and cause different degrees of impact. The mode of transportation, routes, and the quantity and density of hazardous goods have a great impact on the estimation of risk coefficients [1].

A study on 1,721 road transportation accidents of hazardous goods shows that the risk factors can be categorized into 6 major types: hazardous goods themselves, drivers, locations, environments, vehicles, and accidents. Association rule algorithms indicate that adverse weather, incomplete transportation facilities, and low-grade road sections with poor lighting are prone to inducing accidents [2]. However, due to the lack of data on driver-related factors, this study failed to evaluate the accident risks caused by drivers, which is crucial for road transportation safety. Cao Jian et al. (2020) pointed out that drivers are one of the most unstable factors in hazardous materials transportation, and more than 68% of accidents are caused by their improper driving behaviors [3]. However, their research only focuses on road tank truck accidents and does not involve other transportation modes. Guo and Luo (2022) comprehensively discussed the recent risk assessment algorithm models for hazardous goods transportation, and mentioned that factors such as drivers, roads, and environments may lead to uncertainties in assessment methods and models [4]. This increases the difficulty in managing and measuring these risk factors, which requires stronger computing power and advanced hybrid models to address-reflecting the high difficulty of risk management and control in hazardous materials transportation.

2.2 Current Status of Application of Risk Control Technologies in Hazardous Goods Transportation

To efficiently conduct risk control in hazardous materials transportation, carrier vehicles and companies often install and use a series of risk control devices, mainly including reverse safety devices, anti-overflow devices, and defensive driving systems.

The reverse safety devices of hazardous materials transportation vehicles differ from those of ordinary transportation vehicles in design. It can be seen from the camera coverage, sound-light dual alarms, stronger explosion-proof performance, and mandatory data recording and storage functions that the reverse devices of hazardous goods transportation vehicles have stricter requirements for safety.

In addition, hazardous materials transportation vehicles are also equipped with anti-overflow devices, which are mainly used to monitor the loading capacity of storage tanks or tank trucks and prevent leakage. In case of abnormal situations such as overfilling and abnormal liquid levels, the device will issue an early warning, automatically cut off the feeding process, record data, and upload the data to the enterprise or supervision platform if necessary.

The defensive driving system is equipped with devices such as cameras inside the vehicle to detect whether the driver's eye movements and behaviors are abnormal, determine whether the driver has abnormal or improper driving behaviors, remind the driver to make adjustments, and report the situation to the enterprise and supervision platform at the same time. Supervision platforms and enterprises are equipped with safety monitoring and management systems to monitor, alarm, and conduct statistical analysis on drivers' driving behaviors and hazardous goods transportation operations.

2.3 Application of Artificial Intelligence (AI) in Hazardous Goods Transportation

At present, the application of AI technology in the field of transportation is no longer uncommon. In the transportation of waste logistics, the application of AI can reduce the transportation distance by up to 36.8%, save costs by up to 13.35%, and cut down time by up to 28.22% [5]. Meanwhile, Sarkar's (2023) research found that in the transportation of biomedical hazardous waste, the use of AI can reduce the transportation volume by 15% and the waste quantity by 90% [6]. From the pilot implementation of autonomous taxis, autonomous light rail, and drone delivery in various regions, China has accumulated rich practical experience and experimental data in AI-assisted autonomous driving technology.

In the current field of hazardous materials transportation, AI is mainly applied in combination with technologies such as satellite navigation and positioning, geographic information systems (GIS), communication computer networks, and sensors to play an

auxiliary role. It tracks and monitors vehicle positioning, driving routes, and drivers' driving behaviors, and provides real-time early warning, alarm, recording, and analysis for abnormal situations such as collisions and robberies [7]. However, the current application of AI technology in hazardous goods transportation is mostly concentrated on the monitoring during transportation and statistical analysis after transportation. There is a lack of application and research in assisting drivers during transportation and supporting the training of hazardous materials transportation driving talents.

3. Dilemmas in Risk Control of Hazardous Goods Transportation

3.1 Risk Management and Control of Transportation Personnel and Roads

In the research related to the classification of risks in hazardous materials transportation, there is relatively little research and risk valuation on transportation personnel such as drivers and escorts. Nevertheless, it is undeniable that these personnel play a crucial role in the risk management and control of hazardous goods transportation. Drivers' driving status, including their physical condition, psychological state, and so on, will affect driving safety [8]. Although the physical status of drivers can be initially tested through simple physical examinations before getting on the vehicle, sudden physical discomfort during transportation may also pose a threat to road and hazardous materials transportation safety. In addition, the detection of psychological status is easily overlooked. If drivers encounter extreme events or have mental health problems, the possibility of causing driving accidents will increase. However, it is very difficult to monitor the psychological status of drivers during hazardous goods transportation.

3.2 Aging of Frontline Personnel and Talent Shortage in Hazardous Materials Transportation

Most frontline personnel in hazardous goods transportation (especially drivers of large oil tankers) are over 45 years old. Due to the strict approval of professional qualifications, there is already a shortage of talents in this field. Although the application conditions for C and B driving licenses were relaxed in 2022, the types of vehicles applicable to these licenses are limited, making it difficult to meet the needs of large companies. Moreover, the increase in small hazardous materials transportation vehicles has also increased the difficulty of risk control in some aspects. In addition, young people have low willingness to engage in this profession, and families and schools rarely train relevant talents, making it difficult to develop hazardous goods transportation capacity. This further exacerbates the talent shortage, which pushes up the cost of frontline personnel-becoming the largest cost item in the hazardous materials transportation industry and a major concern for enterprises.

To seize the market and increase benefits, enterprises tend to maximize hazardous goods transportation volume. However, the talent shortage leads to frontline personnel often working overtime and overloading, which invisibly increases transportation risks and affects the safety of hazardous materials transportation.

Since risk control in hazardous goods transportation is the focus of attention from all parties, enterprises need to invest a lot of costs in risk control, such as equipping protective monitoring devices, hiring escorts and supervisors, recruiting qualified drivers, and conducting regular training. However, the current logistics market is highly competitive, with new companies constantly entering the hazardous materials transportation market and lowering quotations. Enterprises have to make high investments in risk control even with meager profits, which makes their living environment more severe. Ensuring the sustainable development of enterprises is crucial; otherwise, they may fall into a vicious cycle of price wars, cost reduction, and service quality decline, or even be eliminated from the hazardous goods transportation market.

4. Optimization of Risk Control in Hazardous Goods Transportation Driven by Artificial Intelligence Technology

The development of AI technology has brought changes to various industries and positions. Industries that can seize this opportunity are more likely to find new development directions and solutions, especially the labor-intensive logistics and transportation industry.

4.1 Operation Records and Road Accident Records of Hazardous Goods Transportation Driven by AI Algorithms and Blockchain

At present, the risk management and control for hazardous materials transportation personnel and the roads passed mainly focuses on three links: pre-transportation planning, in-transit supervision, and post-accident alarm and recording. However, the standardization of personnel operation details-such as records of whether there is fatigued driving or illegal parking for getting on/off during hazardous goods operations-has not been strictly incorporated into the risk management and control system, nor has it been linked to the vital interests of relevant personnel.

Blockchain has a record function that cannot be manually modified. When combined with AI algorithms to calculate and judge the standardization of operations of drivers and relevant operating personnel in real time, it can accurately record the complete operation process and operation details of each operator. This is equivalent to equipping the hazardous materials transportation process with a tireless, fair, and impartial "electronic escort" and "intelligent supervisor".

When using this method to supervise and manage the operation details of hazardous goods transportation personnel, the operation detail records can be simultaneously entered into the annual assessment system for hazardous materials transportation qualification certificates and the supervision platform of the transportation department. By means of quantitative scoring, standardized operations are directly linked to the license renewal of certified personnel, eligibility for vehicle and equipment use, and salary grades [9].

4.2 Intelligent Driving Assistance Technology Opens Up Talent Channels and Reduces Labor Costs

In terms of talents for hazardous materials transportation drivers, there are currently few personnel capable of undertaking large-scale hazardous goods transportation tasks. Most drivers are older and prone to physical dysfunction that cannot adapt to overloaded work. At the same time, enterprises that independently train hazardous goods transportation talents face difficulties such as shortage of coach resources and high practical training costs. The number of relevant majors offered by colleges and universities is far from meeting the market demand gap, leading to a serious imbalance between supply and demand in the talent market. In the long run, to fill job vacancies, some enterprises may illegally hire uncertified personnel, which further increases the difficulty of risk control in hazardous materials transportation.

Intelligent driving technology based on AI deep learning may provide a new solution to this dilemma. At present, vehicle intelligent driving systems and technologies are key research areas in China. The pilot projects of unmanned public transportation carried out in many cities such as Wuhan and Shenzhen have accumulated rich practical experience and massive operation data. However, due to the special safety requirements for hazardous goods transportation, coupled with the fact that intelligent driving technology is not yet fully mature and relevant laws, regulations, and infrastructure are still incomplete, the public acceptance of unmanned hazardous materials transportation vehicles is relatively low [10]. Therefore, it will take a long time for the hazardous goods transportation industry to fully enter the era of unmanned driving.

However, AI learning technology can act as an "accelerator" in this long-term development process. In hazardous materials transportation vehicles equipped with AI learning systems, when experienced hazardous goods transportation drivers perform transportation operations, the system can real-time capture the action data of drivers in handling emergency events through on-board cameras and sensors. After algorithm modeling, the system conducts self-learning and generates a library of standardized handling solutions for different emergency situations in hazardous goods transportation. At the same time, AI can decompose the latest traffic regulations and hazardous materials transportation rules into specific operation instructions, and remind drivers of specific operations in real time through voice.

The AI-driven driving assistance system after systematic training can be installed in the simulation operation cabins of hazardous goods transportation vehicles, remote supervision platforms, and talent training systems:

In the training link, new drivers practice handling various dangerous situations in hazardous materials transportation through the simulation cabin, and the system scores their performance in real time and corrects mistakes;

During actual transportation, the system monitors driving behaviors throughout the

process and provides early warnings for risks in hazardous goods transportation;

In the qualification promotion link, the accident-free driving hours and standardized operation rate recorded by the system are used as core assessment indicators for upgrading from a C-class driving license to an A-class driving license for hazardous materials transportation.

This model can reduce the difficulty for enterprises to independently train talents, shorten the training cycle of hazardous goods transportation talents from the traditional 3 years to 1.5 years, and effectively open up the promotion channel from C-class to A-class driving licenses for hazardous materials transportation. Ultimately, the social transportation capacity of the hazardous materials transportation industry will increase significantly, labor costs will decrease, and the saved resources can be invested in risk control links such as vehicle explosion-proof modification and real-time monitoring system upgrading for hazardous goods transportation, thereby ensuring the safety of drivers, the public, and the environment.

5. Conclusion

At present, the core dilemma faced by the hazardous goods transportation industry is the structural imbalance between the growing market demand and the insufficient supply of professional talents, which makes it difficult to achieve coordinated optimization of transportation safety and economic benefits. The application of AI algorithms and machine learning technologies can provide a more convenient and efficient solution to this dilemma. Specifically, first, the combination of AI algorithms and blockchain technology can help enterprises and relevant supervision departments conduct real-time monitoring, full-process recording, and in-depth analysis of the operation details of hazardous materials transportation personnel, thereby enhancing the accuracy of process supervision. Second, intelligent driving technology and machine learning models in the field of AI can be applied to the talent training link for hazardous goods transportation. Through methods such as simulation training, they can reduce training difficulty, shorten training cycles, and thus reduce investment in labor costs. Third, the application of the aforementioned AI technologies will ultimately reduce the long-term costs of the industry-including the reduction of direct costs in hazardous materials transportation talent training and supervision links, as well as the reduction of implicit costs in risk management and control by optimizing human resource allocation (such as reasonably adjusting the number of escorts and background monitoring and recording personnel for hazardous goods transportation).

On this basis, enterprises will have significant room for improvement in economic benefits after effectively controlling costs, and the entire hazardous goods transportation industry is expected to be empowered by AI technology to embrace new vitality for development.

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