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Review

Cold Chain Logistics and Joint Distribution: A Review of Fresh Logistics Modes

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Abstract: With the continuous development of the global logistics industry, cold chain transportation and joint distribution, as critical strategies in supply chain management, are gradually becoming key means to ensure the safe transportation of perishable goods, pharmaceuticals, and other temperature-sensitive commodities. The present study is dedicated to an in-depth exploration of cold chain logistics and joint distribution, with a particular focus on a review of fresh food logistics modes, aiming to comprehensively understand their operational modes, advantages, challenges, and future development trends. The present study elucidates the basic concepts of fresh food logistics and underscores its significance in supply chain management. Through comparative analysis of different operational modes, it reveals their advantages in enhancing efficiency, reducing costs, and mitigating environmental impacts. The present study focuses on the operational mode of joint distribution, discussing its application in cold chain logistics and its differences from traditional logistics modes. Through case studies and empirical analysis, it evaluates the impact of joint distribution on logistics efficiency and costs, as well as its potential to enhance transportation efficiency and reduce carbon emissions. Lastly, the present study provides an outlook on the future development trends of cold chain logistics and joint distribution, discussing the influences of technological innovation, policy support, and industry collaboration and offering recommendations and prospects to drive the sustained development of the industry. Through a comprehensive summary of fresh food logistics, cold chain logistics operational modes, and joint distribution operational modes, this paper aims to provide in-depth theoretical support and practical guidance for related research and practices.

Keywords: cold chain logistics; joint distribution; fresh logistics; joint delivery operation mode

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1. Introduction

Cold chain logistics is a critical component of the supply chain that ensures the preservation of perishable goods from the point of origin to the consumer. The significance of cold chain logistics has escalated in tandem with the global demand for fresh and safe food products, pharmaceuticals, and other temperature-sensitive items. For cold chain logistics, advances in predictive algorithms, data analytics, and optimization techniques have opened new avenues for improving decision-making, reducing waste, and ensuring product quality. The study acknowledges the pivotal role of these innovations in addressing the dynamic challenges faced by the industry, such as the trade-off between product quality and transportation costs, the optimization of delivery routes, and the integration of multi-temperature delivery systems.

Moreover, cold chain logistics is not merely a technical problem but also a strategic one, involving decisions that are influenced by market dynamics, competitive behavior, and investment returns. The exploration of decision-making methods in fresh food delivery, for instance, highlights the interplay between scheduling algorithms, strategic choices, and investment in freshness preservation.

The present study aims to comprehensively examine the current state and future prospects of cold chain logistics, with a particular emphasis on the application of advanced algorithms and models to optimize operations, the strategic implications of decision-making in the industry, and the imperative of sustainable development. The research aims to provide theoretical guidance, practical insights, and decision support for stakeholders in the cold chain logistics sector, contributing to the advancement of the field and the well-being of the global community.

2. Fresh Food Logistics

2.1. Fresh Food Logistics

Fresh food logistics plays a crucial role in today's supply chain management, especially with the promotion of smart cities and the e-commerce trend. With the continuous development of the global logistics industry, the production, distribution, and sale of fresh agricultural products have formed a large and complex supply chain network, involving multiple processes such as planting, harvesting, packaging, transportation, warehousing, and sales. In this extensive network, determining how to achieve efficient distribution of fresh products and ensure their quality has become a pressing issue for logistics managers [1].

The use of Intelligent Distribution Multi-Objective Optimization Models (FAPs) in fresh food logistics evaluation is becoming increasingly widespread. This model optimizes distribution routes with the goal of minimizing costs and maximizing customer satisfaction, providing technical support for the efficient operation of urban fresh food logistics. Compared to traditional algorithms, the FAP model can save up to 28.98% of costs and increase customer satisfaction by 21.67% [2]. Its successful application not only improves the efficiency of urban fresh food logistics but also enhances customer experience and satisfaction.

The MIP model for joint decision-making in the production and distribution of fresh agricultural products also plays an important role in optimizing agricultural supply chain management. The model aims to maximize profits by making joint decisions to maximize the income of farmers. This joint decision-making model, compared to traditional single allocation decision-making methods, can better coordinate production and distribution processes, improve resource utilization, and thereby increase overall profitability. Analysis of planting area and profits shows that the joint planning model has a significant effect on increasing farmers' income, providing new ideas and methods for the sustainable development of agricultural supply chains [3].

With the uncertainty brought by events like the pandemic affecting the growth of online sales of fresh products, the application of phase change materials in the cold chain logistics of fresh e-commerce has also attracted attention. These phase change materials not only extend the shelf life of fresh products but also reduce energy consumption and carbon emissions during transportation, thereby improving logistics efficiency and environmental friendliness. The application of this technology will further drive the development of fresh e-commerce, enhance user experience, and promote the healthy development of the industry [4].

As an important component of supply chain management, the continuous innovation and improvement of the operation mode and technical means of fresh food logistics will further promote the improvement of urban logistics efficiency, optimize the distribution process of fresh products, and inject new vitality into the sustainable development of the industry and the construction of smart cities [5].

2.2. Fresh Delivery

Fresh food delivery plays a crucial role in modern supply chain management, ensuring the freshness and quality of perishable goods while enhancing delivery efficiency. Scientifically evaluating the sustainable development performance of fresh food delivery is a current research hotspot, employing various research methods and models. For in-

stance, Liao et al. proposed a hierarchical model for assessing the sustainable development performance of fresh food supply chains, considering multiple performance indicators and generating eight performance rankings. Through the application of this model, it was found that employee training is one of the key factors in improving the sustainable performance of fresh food supply chains [6]. Additionally, Wang et al. introduced the MCRS model, aimed at optimizing key metrics such as total cost, vehicle load, and the minimum number of refrigerated vehicles in fresh food delivery processes. The research findings indicate that the newly proposed method significantly outperforms traditional approaches in optimization results, even with slightly higher computational time [7]. These studies provide practical evaluation models and optimization methods for the sustainable development of fresh food delivery.

Furthermore, the exploration of optimal decision-making methods in the field of fresh food delivery has been conducted through the development of various algorithms and models. For example, Thakur et al. developed an initial discrete firework algorithm based on type-1 and type-2 fuzzy logic to address scheduling issues in fresh food delivery. The research results demonstrate that this algorithm exhibits significant advantages compared to other commonly used algorithms, offering new insights and methods for improving the efficiency and accuracy of fresh food delivery [8]. Moreover, Liu and Wang proposed an evolutionary game model to study the relationship between company strategic choices and investment in freshness preservation in fresh food delivery. The results of the model indicate that strategic choices are closely related to investment returns and the behavior of competitors, thus influencing decision-making and outcomes in the delivery process [9]. These studies offer theoretical guidance and decision support for the development of the fresh food delivery industry, providing important references for improving delivery efficiency.

2.3. Fresh E-Commerce

Fresh e-commerce has emerged as a rapidly growing field in recent years, playing a crucial role in the sales and delivery of fresh food products. The evaluation of efficiency and sustainability of fresh e-commerce is a key focus of current research, with Guo et al. proposing a two-stage forward/reverse logistics network and path planning model to assess different algorithms' optimization processes and logistics node selection outcomes, thereby validating the model's effectiveness [10]. Additionally, dynamic control models have provided vital support for the development of fresh e-commerce, allowing e-commerce retailers to set optimal sales area scales based on actual circumstances, thus enhancing delivery efficiency and service quality [11]. These studies lay a theoretical foundation and offer practical guidance for the continued development and efficiency improvement of fresh e-commerce.

On the other hand, past research has explored optimal logistics models and strategies in fresh e-commerce by constructing various models and algorithms. For instance, different logistics models have been proposed based on whether fresh e-commerce platforms introduce proprietary brands, and empirical analyses have yielded conclusions crucial for guiding enterprises in selecting the best logistics strategies [12]. Moreover, ontology-based packaging design methods have introduced innovative solutions for the logistics aspect of fresh e-commerce, significantly reducing packaging costs, enhancing production efficiency, and operational stability, thereby offering practical packaging design guidelines for e-commerce enterprises [13]. Additionally, leveraging convolutional neural network (CNN) text mining models, sentiment analysis of consumer reviews on logistics services has identified key focus areas and influencing factors, providing directions for enterprises to enhance logistics services [14]. These studies provide theoretical guidance and practical experience for the development of the fresh e-commerce industry, offering important references for improving logistics efficiency.

3. Cold Chain Logistics Operation Modes

3.1. Traditional Algorithms

The application of traditional algorithm optimization in the operation mode of cold chain logistics is significant in reducing costs, improving efficiency, and enhancing satisfaction. Taking the DCCL model as an example, this model aims to minimize the total distribution cost within a working day, including transportation costs, penalty costs for rejected orders, and costs associated with the loss of goods quality [15]. Research results indicate that the BACS algorithm, compared to other methods such as ACS and ACS-DVRP, can more effectively reduce the number of rejected orders and secondary vehicles, thereby enhancing customer satisfaction and lowering overall costs. Additionally, the multi-objective scheduling decision model supporting IGSS-CCL incorporates operational costs, vehicle usage, and carbon emissions as optimization objectives, and utilizes the TSOA algorithm to achieve better convergence and distribution [16]. The results demonstrate significant improvements in optimizing maximum costs and carbon emissions with the TSOA algorithm, which effectively contributes to alleviating urban congestion and promoting energy conservation.

Traditional algorithm optimization also involves the comprehensive consideration of multiple indicators such as transportation costs and carbon emissions. The TDGVRP model minimizes transportation costs, including various fixed costs, refrigeration costs, fuel consumption costs, etc., thereby achieving superior cost-effectiveness [17]. Furthermore, the CCL multi-objective optimization model, considering customer satisfaction, employs the DDNSGA-II algorithm to achieve the goals of minimizing carbon trading costs, minimizing network costs, and maximizing customer satisfaction [18]. Research results indicate that the DDNSGA-II algorithm, compared to the traditional NSGA-II algorithm, achieves superior outcomes in terms of carbon trading costs and network costs, with faster convergence rates and higher precision. Therefore, traditional algorithm optimization in the operation mode of cold chain logistics provides essential technical support for achieving comprehensive optimization of multiple objectives [19].

The application of traditional algorithm optimization in cold chain logistics operations plays a crucial role in reducing carbon emissions and improving efficiency. For instance, the travel time model and TDGVRPTW model aim to minimize the total cost, including transportation costs, refrigeration costs, carbon emission costs, and labor costs [20]. The research findings indicate that compared to other heuristic methods such as ALNS, ACO, and GA, the TSHSA algorithm demonstrates superior performance in both solving time and quality, effectively reducing costs and enhancing efficiency. Additionally, the JD-GVRP model has achieved significant results in minimizing total costs and carbon emissions [21]. It has been observed that the adoption of combined delivery methods can effectively reduce fleet size by approximately 7.69% and decrease delivery distances by approximately 34.91%, thereby reducing operational costs and carbon emissions. The graphic interpretation model combined with the global artificial fish swarm algorithm has effectively addressed the optimization problem of cold chain logistics delivery routes considering carbon tax costs [22]. These studies provide important technical and theoretical guidance for reducing costs, minimizing carbon emissions, and enhancing efficiency.

The HVRPTW model and IVRPCSC model also explore the application of traditional algorithms in cold chain logistics. The HVRPTW model, through the generation of extended instances, ultimately achieves lower total costs. Compared to the typical PFIH heuristic algorithm, the initialization heuristic algorithm demonstrates higher efficiency and competitiveness [23]. The IVRPCSC model exhibits lower gap solutions on the test dataset, outperforming commercial solvers by providing low-gap solutions for datasets of varying scales in a shorter time frame [24]. The results of solving practical cases demonstrate that the model can save approximately 9.25% of total distribution costs compared to the current organizational expenditure.

The traditional algorithm optimization application in the cold chain logistics operation plays a significant role in addressing multi-objective optimization problems such

as cost and carbon emissions. Research indicates that the application of multi-objective models can effectively reduce total delivery costs, fuel consumption, and quality losses and enhance customer satisfaction [25]. Among multiple algorithms compared, NSGA-II and IBEA demonstrate superior performance, particularly IBEA, which exhibits outstanding performance in average HV values, followed by NSGA-II, while SPEA2 outperforms GrEA. Furthermore, the improved ant colony algorithm exhibits significant advantages in cost, carbon emissions, and customer satisfaction compared to traditional ant colony algorithms [26]. Through sensitivity analysis of temperature variations and goods damage coefficients, this algorithm discovers that temperature control and goods damage coefficients have significant impacts on carbon emissions and delivery costs. With an increase in the number of customers, delivery costs and carbon emissions show a positive correlation. Integrating logistics distribution centers and enhancing their capacity to handle more delivery tasks can reduce carbon emissions in handling multiple distribution centers with smaller customer quantities.

Traditional algorithm optimization applications also involve addressing the optimal vehicle service route problem and optimizing vehicle loading plans and routes. The HGA-SIH model demonstrates excellent capabilities in effectively balancing the management of vehicle quantity and minimizing total travel distance [27]. However, slight discrepancies exist in total distance compared to BKS under certain circumstances, indicating the need for continuous algorithm improvement to achieve higher precision. Moreover, the hybrid transportation scheme optimization model for the three-tier cold chain logistics network effectively solves complex cold chain logistics transportation problems, improving vehicle utilization, reducing travel paths, saving transportation costs and inventory costs, and enhancing customer satisfaction [28]. The application of two-stage hybrid heuristic algorithms further enhances the solving speed of the problem model and the rationality of the optimal solution, validated through practical case studies.

3.2. Reinforcement Learning

The optimization application of reinforcement learning algorithms in cold chain logistics operations plays a crucial role in reducing costs and carbon emissions and improving service quality. Research indicates that the RNAeACO algorithm, applied in the optimization model for low-carbon cold chain logistics paths, significantly reduces total costs and carbon emissions compared to traditional ant colony algorithms, achieving outstanding performance in terms of optimal values and shortest distances [29]. Additionally, the BP neural network-based shelf-life prediction model effectively addresses the perishability issue in cold chain transportation, thereby enhancing service quality by providing real-time insights into vehicle operations and product quality [30]. Furthermore, the Haugh Unit (HU) prediction model based on deep learning, utilizing transfer learning techniques, non-destructively predicts egg freshness, thereby further enhancing product quality and operational efficiency in cold chain logistics [31].

The optimization application of reinforcement learning algorithms also involves the development of new methods to improve prediction accuracy and automation levels. The novel approach for predicting fruit freshness based on multisensory technology and machine learning algorithms provides new insights and methods to enhance the automation, intelligence, and precision of fruit freshness prediction [32]. Moreover, experimental results demonstrate that machine learning models can accurately predict temperatures in real-time, even in imperfect prediction scenarios, thereby providing essential preventive measures for cold chain logistics operations [33]. In summary, the optimization application of reinforcement learning algorithms in cold chain logistics operations provides crucial technical support and theoretical guidance for reducing costs, enhancing efficiency, and improving service quality.

In the operation mode of cold chain logistics, the optimization application of reinforcement learning algorithms has shown significant effects in various aspects. One study proposed a cold chain logistics demand prediction method based on an improved PCA-BP

neural network model [34]. This model combines principal component analysis (PCA) with the backpropagation (BP) neural network algorithm to effectively utilize key influencing factors of cold chain logistics demand, such as the GDP growth rate and industrial value added, achieving accurate prediction of cold chain logistics demand. Experimental results demonstrate that compared to traditional BP neural network models, the improved PCA-BP model exhibits higher prediction accuracy and faster prediction speed, providing more reliable decision support for cold chain logistics operations. Another study explored the application of a hybrid model based on reinforcement learning and tree regression methods for optimizing vehicle routing in cold chain logistics [35]. This model considers the changing demands and uncertainties in the transportation environment, effectively enhancing the profits of logistics institutions. Experimental results indicate a profit increase of up to 37.63% compared to conventional methods, with the model's applicability and practicality validated through multiple real-world case studies. These studies illustrate that the optimization application of reinforcement learning algorithms in cold chain logistics operations can enhance prediction accuracy, reduce costs, increase profits, and demonstrate good practicality and feasibility.

On the other hand, the optimization application of reinforcement learning algorithms also involves improving the automation, intelligence, and accuracy of fruit freshness prediction [36]. Researchers proposed a new method based on multimodal sensing technology and machine learning algorithms, which enables more accurate prediction of fruit freshness, thereby enhancing the automation level of fruit freshness prediction and further improving the efficiency and quality of cold chain logistics operations. Additionally, for the efficient logistics scheduling problem in cold chain logistics distribution centers, researchers introduced the pointer network-based Deep Q Network (DNQ) algorithm and its improved versions [37]. Experimental results show that the DNQ algorithm exhibits superiority in solving the logistics scheduling problem of single fresh product distribution service centers, and the improved DNQ algorithm significantly improves the model's solution efficiency in addressing the logistics scheduling problem of multiple fresh product distribution service centers, providing effective technical support for cost reduction, efficiency improvement, and service quality enhancement. The optimization application of reinforcement learning algorithms is of great significance for improving the operation mode of cold chain logistics and demonstrates immense potential and advantages in various aspects [38].

3.3. Predictive Research

In the context of cold chain logistics operations, the optimization application of predictive algorithms has demonstrated significant importance across various domains. Firstly, a study conducted an analysis of the impact of blockchain technology on cold supply chain efforts, wholesale prices, order quantities, and profits [39]. The results indicated that adopting blockchain technology can enhance the profitability of cold chain logistics while maintaining stability in wholesale prices and order quantities, thereby increasing the level of service preservation efforts. This highlights the positive impact of blockchain technology on improving operational efficiency and economic benefits in cold chain logistics. Secondly, another study proposed a risk-quantified cold chain logistics path planning model using the K-nearest neighbor algorithm and the genetic algorithm [40]. This model accurately extracts traffic congestion risks and other risk factors to select the shortest and smoothest transportation routes, effectively reducing transportation time, mitigating transportation risks, and enhancing decision-making effectiveness in cold chain logistics. These research findings underscore the significant application prospects and practical value of predictive algorithms in cold chain logistics path planning and decision optimization.

Additionally, research endeavors have focused on analyzing the development trends and future demands of cold chain logistics in the Beijing–Tianjin–Hebei region to support regional cold chain logistics industry development and planning [41]. Through PEST analysis and SWOT analysis models, researchers found that the demand for cold chain logistics in the Beijing–Tianjin–Hebei region is steadily increasing, proposing the development

model and prospects for constructing a regional cold chain logistics circle. Furthermore, a study utilized the fractional order GM model to forecast the future demand for cold chain logistics in the Beijing–Tianjin–Hebei region [42]. The results indicated continued growth in cold chain logistics demand in the region over the next few years, providing crucial decision-making references for governments and enterprises. These research endeavors provide important data support and strategic guidance for the sustainable development of the cold chain logistics industry.

On another note, predictive algorithms play a crucial role in forecasting fresh e-commerce logistics demand. A study proposed a Bi-LSTM-based model for predicting fresh e-commerce logistics demand and evaluated its performance [43]. The results demonstrated the model's capability to accurately forecast fresh e-commerce logistics demand with small prediction errors and high accuracy, meeting the timely requirements of fresh e-commerce companies and providing effective support for their logistics operations. Furthermore, research employing a support vector machine model based on the grey wolf optimizer accurately predicted seafood cold chain logistics demand, demonstrating superior accuracy and performance compared to traditional models [44]. In summary, the application of predictive algorithms in cold chain logistics operations holds broad application prospects and significant practical implications, providing effective technical support and decision-making references for enhancing operational efficiency, reducing costs, and improving service quality in cold chain logistics operations.

In the operation model of cold chain logistics, the optimization application of predictive algorithms plays a crucial role in enhancing efficiency, reducing costs, and improving service quality. One study established a predictive model for the storage time of fruits and vegetables based on the principles of heat theory [45]. This model derived equations for calculating the storage time of fruits and vegetables at different temperatures using the principle of energy conservation. Such a predictive model aids cold chain logistics enterprises in better planning the storage and transportation of goods, thereby enhancing operational efficiency and resource utilization in cold chain logistics. Furthermore, another study employed an autoregressive moving-average model to evaluate the prediction of cargo temperature in cold chain logistics using metrics such as the deviation prediction success rate, prediction error, and execution time [46]. The research found that NLC performed best in adaptive methods, particularly in deviation prediction and prediction error. These results provide effective predictive tools for cold chain logistics enterprises to accurately monitor trends in cargo temperature and take timely measures to ensure product quality.

The optimization application of predictive algorithms is also reflected in enhancing the intelligence and real-time capabilities of cold chain logistics systems. One study utilized the adaptive Kalman filtering method to assess the data collection, processing, and communication capabilities of cold chain logistics systems [47]. The results demonstrated that this method effectively completes data collection and processing, with minimal system error and timely elimination of occasional errors, while also exhibiting small prediction errors. Moreover, in terms of the communication success rate, the method showed good anti-interference performance, providing reliable support for real-time monitoring and alerting in cold chain logistics systems. Another study employed a triangular fuzzy-gray correlation evaluation model to assess the low-carbon competitiveness of regional cold chain logistics [48]. The model effectively evaluated the low-carbon logistics competitiveness of different cities and provided corresponding development recommendations, thereby offering crucial insights for the sustainable development of regional cold chain logistics.

Evaluation of low-carbon competitiveness in cold chain logistics and forecasting demand trends in agricultural cold chain logistics represent significant aspects of predictive algorithm optimization applications in cold chain logistics operation models. By adopting the triangular fuzzy-gray correlation evaluation model, researchers comprehensively assessed the low-carbon logistics competitiveness of regions in Henan Province [49]. This model integrated expert scores and weights for evaluation indicators, categorized 18 cities into different competitiveness levels through empirical research, and analyzed the develop-

ment of low-carbon cold chain logistics using the diamond model. The results indicated that Zhengzhou led in low-carbon cold chain logistics competitiveness, while cities like Luoyang, Xinxiang, Nanyang, and Zhoukou exhibited moderate development levels. The remaining 13 cities were categorized as low-development areas, necessitating tailored strategies to enhance their low-carbon cold chain logistics competitiveness. This study provides essential guidance for the sustainable development of regional cold chain logistics, facilitating the advancement of low-carbon economies and the enhancement of regional cold chain logistics competitiveness.

Regarding the forecast of demand trends in agricultural cold chain logistics in Guangxi Province, researchers employed the Markov optimization mean GM(1,1) model [50]. This model outperformed others in predicting agricultural cold chain logistics demand, with predictions closer to actual values, higher accuracy, and smaller errors. Forecasted results indicated a continuous growth in demand for agricultural cold chain logistics in Guangxi Province over the next few years, with an average annual growth rate exceeding 6%. Notably, demand prediction accuracy was high for vegetables, bananas, citrus fruits, and aquatic products and moderate for longans, lychees, and meat products. Forecasting agricultural cold chain logistics demand provides robust decision-making support for enterprises of various scales, aiding in investment rationalization, cost reduction, and fostering rapid enterprise development. This study furnishes critical reference points for agricultural cold chain logistics enterprises, facilitating strategic planning, resource allocation, improved logistics efficiency, and the healthy development of agricultural supply chains.

4. Joint Delivery Operation Mode

Collaborative delivery, as an important strategy in modern logistics, can effectively reduce operating costs, control fixed costs and energy consumption, and improve the reliability and efficiency of cold chain logistics by optimizing the vehicle routes of mixed fleets. The study also points out that collaborative delivery can increase overall revenue levels by establishing cooperative alliances and fairly distributing benefits, further enhancing the profits of alliance members. In addition, the study proposes a Deep Q Network (DNQ) algorithm based on pointer networks to solve the logistics scheduling problem of cold chain logistics distribution centers. The algorithm performs well in solving the logistics scheduling problem of a single fresh product distribution service center, and its improved version significantly improves the solving efficiency in handling the logistics scheduling problem of multiple fresh product distribution service centers, providing effective technical support for cost reduction, efficiency improvement, and service quality enhancement.

4.1. Operational Mode

The joint delivery operation mode holds significant importance in the modern logistics domain. By establishing a cooperative delivery alliance among express delivery companies and fairly allocating the interests of alliance members using the JDA incentive model [51], it has been demonstrated that this novel form of horizontal cooperation based on JDA can increase the profits of alliance members, effectively enhancing the overall revenue level. Furthermore, employing an integrated model for optimizing terminal nodes in express delivery for joint delivery purposes leads to a notable reduction in costs and an increase in node utilization rates [52]. The experimental results indicate that this model outperforms others in terms of average and minimum costs, highlighting its high efficiency and cost-effectiveness in joint delivery operations. Additionally, a shared logistics resource joint delivery system achieves cost differentiation through real-time routing optimization of delivery personnel paths [53]. The study reveals that, with an increase in order volume, this system yields higher profits, demonstrating significant advantages. These research findings collectively illustrate that joint delivery operation modes can enhance logistics efficiency, reduce costs, and strengthen competitive advantages through rational resource utilization and optimized route planning.

In urban logistics delivery systems, employing the 3E-LDP model with the consideration of time window constraints for joint delivery minimizes total transportation time and transportation costs [54]. The experimental results demonstrate significant reductions in total transportation time and costs, thereby improving logistics efficiency. Additionally, utilizing an improved Shapley value model for profit distribution in a two-tier logistics joint delivery network enables the identification of optimal profit allocation schemes [55]. The study finds that each optimal sequence alliance entry leads to varying degrees of cost reductions, further enhancing the system's economic benefits. Finally, in the coordination delivery system of electric vehicles and drones, using an economic model of cost functions achieves coordination between energy costs and time costs [56]. The research results indicate that, compared to pure electric box truck delivery plans, coordinated delivery can save up to 27.25% in delivery costs, demonstrating favorable economic benefits. In conclusion, joint delivery operation modes in various domains have yielded significant achievements, providing crucial support and guidance for improving logistics efficiency, reducing costs, and enhancing competitiveness.

Optimizing joint distribution systems involving vehicles and drones, with considerations ranging from customer priority to environmental impact is also a trend for study of joint distribution system. Wang et al. explore vehicle-drone path optimization emphasizing customer priority [57]. Liu et al. optimize UAV-vehicle routes in mountainous cities [58]. Du et al. address multi-objective optimization for joint delivery, considering carbon emissions in online shopping contexts [59]. Ren et al. develop a multi-center joint distribution model prioritizing carbon emissions and customer satisfaction [60]. Zhang et al. examine the behavior of urban joint distribution alliances under government supervision for sustainable development [61].

4.2. Application of Joint Delivery

Unified delivery plays a crucial role in the modern logistics sector. Research has shown that establishing a unified delivery model combining freight electric vehicles (EVs) and traditional vehicles can effectively reduce operating costs, especially by optimizing the routes and vehicle replacement strategies of mixed fleets, further lowering carbon emissions and enhancing overall efficiency [62]. With the increase in time windows or battery life, the proportion of electric vehicles in fleets will also correspondingly increase, providing more possibilities for green logistics practices.

On the other hand, the application of unified supply chain network models has brought new avenues for cost optimization in the logistics sector. By minimizing the total costs of equipment, inventory, and transportation, this model provides enterprises with more precise supply chain planning and resource allocation [63]. Studies have found that when using the 3PL-lip model, the GBD method has significant advantages in terms of calculation time and result variance compared to the traditional CPLEX method. With the increase in the number of third-party logistics suppliers, total cost savings also increase, providing enterprises with more choices when selecting supply chain partners [64].

Research on the last-mile logistics unified delivery discusses the ethical risks faced by carriers in avoiding the selection of related agents under the shared agent model [65]. The results show that adopting a coordinated unified distribution model can effectively increase total revenue and reduce competition among agents, thereby promoting the healthy development of the logistics market. Additionally, studies have shown that the unified allocation model can significantly reduce total costs and carbon emissions in the simultaneous pickup and delivery vehicle routing problem [66]. Furthermore, this research explores the positive impact of carbon trading mechanisms under unified delivery conditions on the sustainable development of logistics enterprises, providing new insights for green logistics practices.

In summary, the application of unified delivery in modern logistics covers various aspects, including optimizing operating costs, optimizing supply chain networks, last-mile delivery, and environmentally friendly logistics. These studies provide practical methods

and strategies for the logistics industry, helping to improve efficiency, reduce costs, and drive the logistics industry toward a more sustainable direction.

4.3. Application of Joint Delivery in Cold Chain Logistics

Joint delivery plays a crucial role in modern logistics, especially in the context of cold chain logistics. Research indicates that optimizing vehicle routes in mixed fleets can effectively reduce operational costs and control fixed costs and energy consumption [67]. The robustness of this model makes it suitable for various parameter changes, thereby enhancing the reliability of cold chain logistics. Additionally, studies on hub location problems highlight the trade-off between product quality and total transportation costs in cold chain logistics [68]. As factors such as the lifespan of perishable products, the number of hubs, and demand rates change, the relationship between total transportation costs and product quality within the supply chain also shifts. Managers and decision-makers need to fully understand these factors' impacts on cold chain logistics to formulate reasonable hub location strategies that ensure product quality while minimizing overall costs.

Moreover, research on urban cold chain mixed vehicle delivery route optimization demonstrates that employing different types of delivery vehicles' route models can effectively achieve multi-objective optimization considering delivery costs, carbon emissions, and delivery distances [69]. By flexibly selecting routes for smaller-capacity internal combustion engine refrigerated trucks and larger-capacity electric refrigerated trucks and adjusting vehicle combinations according to different objectives, transportation costs, carbon emissions, and delivery distances can be comprehensively optimized, thereby enhancing the efficiency and environmental friendliness of cold chain logistics.

Furthermore, studies on the loading methods and route optimization problems of multi-temperature joint delivery of fresh agricultural products provide effective strategies to reduce delivery costs, increase loading capacity, and enhance delivery efficiency [70]. Two different models, considering or not considering delivery time requirements, offer flexible compartment size ranges and allow order-splitting strategies to improve logistics delivery efficiency and reduce overall transportation costs. Particularly, the proposed enhanced simulated annealing algorithm outperforms traditional variable neighborhood search algorithms in terms of total delivery costs and algorithm efficiency.

Research on the optimization problem of the path of fresh meat joint delivery systems has also achieved significant results [71]. By determining the service scope of each distribution center and customer group, transforming multi-center optimization problems into single-center optimization problems, and using genetic algorithms to obtain joint delivery solutions, the efficiency of meat delivery has been successfully improved. The implementation of a joint delivery mode rationalizes spatial matching between distribution centers and customers, significantly improving delivery system efficiency. Additionally, under joint delivery mode, the number of delivery vehicles used, operation time, and travel distance are all effectively reduced, further enhancing the operational efficiency of meat delivery systems in core areas.

Finally, for the integrated optimization problem of order allocation for fresh agricultural community retail and last-mile multi-temperature joint delivery, scientific decision support solutions are proposed through integrated optimization models and multi-objective optimization models [72]. The use of a mixed genetic algorithm can effectively reduce CPU time and iteration numbers, optimizing delivery costs, maturity penalty costs, and refrigeration costs, thereby improving the overall efficiency of cold chain logistics systems. These research findings provide effective technical support and practical guidance for the cold chain logistics field, contributing to the improvement of delivery efficiency and quality of cold chain products and promoting the sustainable development of the cold chain logistics industry.

5. Future Development Trends and Prospects

Technological innovation and industry collaboration play crucial roles in shaping the future development trends of the cold chain logistics sector. Technological innovations, such as the application of phase change materials, extend the shelf life of fresh products, reduce energy consumption and carbon emissions, and enhance logistics efficiency and environmental sustainability. This will further drive the development of fresh e-commerce, improve the user experience, and foster the healthy growth of the industry. Additionally, the application of predictive algorithms also significantly influences future development trends. For instance, predictive algorithms play a critical role in forecasting demand for cold chain logistics, providing vital decision-making references for governments and enterprises. Furthermore, industry collaboration is a key factor in driving the future development of the cold chain logistics sector. By optimizing vehicle routes and implementing joint delivery, it is possible to effectively reduce operating costs and control fixed costs and energy consumption. These factors collectively contribute to the sustainable development of the cold chain logistics sector.

5.1. Advantages of Joint Delivery in Conjunction with Cold Chain Logistics

Combined delivery plays a crucial role in the modern logistics industry, especially in the cold chain logistics sector. Studies have shown that optimizing vehicle routes for mixed fleets can effectively reduce operating costs and control fixed costs and energy consumption. Furthermore, combined delivery can also increase overall revenue levels by establishing cooperative alliances and fairly distributing benefits to enhance the profits of alliance members. Utilizing a unified delivery model with a combination of freight electric vehicles and traditional vehicles can effectively reduce operating costs, particularly by optimizing routes for mixed fleets and vehicle replacement strategies, thereby further reducing carbon emissions and enhancing overall efficiency. Combined delivery can also achieve energy and time cost coordination by coordinating the delivery systems of electric vehicles and drones, saving up to 27.25% of delivery costs and demonstrating superior economic benefits. In summary, combined delivery in conjunction with cold chain logistics has achieved significant results in various fields, providing crucial support and guidance for improving logistics efficiency, reducing costs, and enhancing competitiveness.

The future development of cold chain logistics will focus on technological innovation, industry collaboration, demand forecasting, route optimization, collaborative delivery strategies, and improvements in multi-temperature collaborative delivery methods. By applying advanced forecasting models and optimization algorithms, such as the Markov-optimized average GM(1,1) model and Deep Q Network algorithm, logistics efficiency can be improved, costs reduced, carbon emissions decreased, and product quality enhanced. Additionally, research will focus on low-carbon competitiveness assessment and the enhancement of intelligent and real-time monitoring systems, to achieve sustainable development of the entire supply chain.

5.2. Research Based on Spatiotemporal Prediction

For cold chain logistics, research on spatiotemporal forecasting is also a major trend. Past studies have focused on predicting the demand trends for agricultural cold chain logistics, assessing the competitiveness of low-carbon logistics, and applying forecasting algorithms in cold chain logistics operations. Research indicates that the accuracy of demand forecasting for agricultural cold chain logistics is crucial for government and corporate decision-making. Additionally, the assessment of low-carbon logistics competitiveness provides development recommendations for different cities, helping to enhance their competitiveness in low-carbon cold chain logistics. Furthermore, the application of forecasting algorithms in cold chain logistics has also achieved significant results, including accurate predictions of demand for fresh e-commerce logistics and storage time predictions for fruits and vegetables.

Looking ahead, prospects include blockchain-based cold chain logistics path-planning models, the application of forecasting algorithms in cold chain logistics path planning, and the potential application of multimodal sensing technology and machine learning algorithms in predicting fruit freshness. These prospects provide important references for the future development of cold chain logistics, aiming to improve operational efficiency, reduce costs, increase profits, and promote industry sustainability.

In conclusion, research based on spatiotemporal forecasting is of significant importance to the cold chain logistics field. Future directions include further improving the accuracy and real-time performance of forecasting algorithms, promoting the development of low-carbon logistics, and enhancing the intelligence and automation level of cold chain logistics systems. Research and practices in these areas will provide crucial support and guidance for the sustainable development of the cold chain logistics industry.

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