Research on Route Planning for Instant Logistics Distribution Considering Carbon Emissions and Customer Satisfaction

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Abstract: Amidst the dual imperatives of achieving national “Dual Carbon” goals and meeting rising consumer expectations, the logistics distribution industry confronts the twin challenges of reducing carbon emissions and enhancing customer satisfaction. As a pivotal element within distribution operations, route optimization serves as a critical leverage point for balancing these two objectives. Grounded in practical operational contexts, this paper explores optimization strategies for logistics distribution routes that concurrently lower carbon emissions and improve customer satisfaction. It approaches the issue from four dimensions: innovation in distribution models, vehicle operation management, service collaboration, and route planning support tools. The findings offer actionable insights to support the green transformation and quality-oriented development of logistics enterprises.

Keywords: Logistics distribution; Carbon emissions; Customer satisfaction; Operational strategies

I. Introduction

With the sustained and rapid development of e-commerce, the logistics distribution industry has entered a period of rapid growth while simultaneously facing increasingly urgent carbon emission pressures. According to the "China Green Logistics Development Report (2023–2024)" released by the China Federation of Logistics & Purchasing, carbon emissions from China's logistics industry account for approximately 9% of the national total, with goods transportation and distribution contributing as much as 85% of this share. Moreover, this proportion continues to rise annually, making it a critical area for regulation in achieving the "Dual Carbon" goals. Meanwhile, the State Council, in its "2024–2025 Energy Conservation and Carbon Reduction Action Plan", explicitly calls for a 5% reduction in carbon dioxide emission intensity in the transportation sector by the end of 2025 compared to 2020 levels, providing a clear practical direction for the low-carbon optimization of logistics distribution routes. Furthermore, consumer expectations for logistics services continue to rise, with delivery timeliness, service quality, and operational flexibility becoming key factors influencing corporate market competitiveness. Against this backdrop, researching logistics distribution route optimization strategies that balance carbon emission reduction with customer satisfaction holds significant practical reference value for promoting the industry's green transformation and enhancing service efficiency.

In related research, Kopfer[1] was among the early scholars to address the environmental aspects of transportation routes, incorporating vehicle type as a factor when analyzing influences on carbon emissions and fuel consumption. Poonthalir[2] introduced vehicle speed variation constraints to develop a green vehicle routing model with dual objectives of fuel efficiency and low-carbon transportation. Zhang Mingwei[3] established a low-carbon dynamic rescheduling distribution model with optimization objectives including carbon emissions, travel distance, and time. Zhang Keyong[4] constructed a bi-level cost optimization model involving government and cold chain distribution enterprises to explore the impact of carbon reduction subsidies and carbon emission trading on low-carbon decision-making. Regarding customer satisfaction, American scholar Cardozo[5] first introduced the concept into the marketing field in 1965, investigating factors influencing product satisfaction, with subsequent research gradually expanding to other disciplines. In the logistics domain, customer satisfaction theory has been applied to common problems such as vehicle routing and distribution center location, with evaluations often focusing on the timeliness of deliveries. For instance, Teodorovic[6] studied vehicle routing problems under uncertain customer demand, using fuzzy numbers to represent customer preferences and employing heuristic sweep algorithms to solve the model. Wang Yong[7] developed a vehicle routing problem (VRP) model minimizing total costs—including fixed, transportation, and penalty costs—under constraints defined by a time window satisfaction function.

II. Core Influencing Factors of Carbon Emissions and Customer Satisfaction in Instant Logistics Distribution

A. Core Influencing Factors of Carbon Emissions

Carbon emissions in the logistics distribution stage are predominantly derived from the fuel consumption of transport vehicles, influenced by several interconnected factors: travel distance and route structure, where longer and more circuitous routes typically elevate energy use and emissions; vehicle load and utilization rate, as underutilization due to empty or light loads raises the carbon intensity per unit of cargo; vehicle technology and fuel type, given that older, high-displacement models reliant on conventional fossil fuels exhibit significantly higher emission intensities compared to more efficient or new energy vehicles(NEVs); road conditions and driving behavior, since congested, stop-and-go traffic and poor habits like rapid acceleration and harsh braking substantially increase fuel consumption; and the spatial layout of the distribution network and nodes, which systematically affects route rationality, transportation efficiency, and overall emission levels.

B. Core Influencing Factors of Customer Satisfaction

Customer satisfaction with logistics distribution services is shaped by five interrelated dimensions: timeliness, which encompasses both overall delivery duration and punctuality, with delays directly diminishing satisfaction; reliability, reflected in the consistent fulfillment of promises such as on-time delivery and cargo integrity, where damaged goods or inconsistent performance erode trust; flexibility, referring to the service's ability to adapt to personalized needs such as scheduled deliveries or self-pickup options, thereby directly enhancing the user experience; information transparency, which emphasizes real-time and accurate updates on order progress, as information lags readily trigger dissatisfaction; and service encounter quality, involving the attitude and professionalism of delivery personnel as well as the condition of goods upon handover. Together, these factors interact to form the customer's overall evaluation of the distribution service and determine the extent to which their core needs are met.

C. Synergy and Conflict Between the Two Objectives

There exists both synergy and trade-off between controlling carbon emissions and enhancing customer satisfaction. For instance, striving to fully meet precise delivery time windows for every customer to boost satisfaction may lead to circuitous routes and increased travel distance, thereby driving up carbon emissions. Conversely, focusing solely on minimizing travel distance to reduce emissions may make it difficult to accommodate the timeliness requirements of geographically dispersed customers, negatively affecting satisfaction.

However, there is also significant potential for synergistic optimization. Leveraging big data for demand forecasting and intelligently consolidating orders can both improve vehicle load factors and reduce total travel distance for emission reduction, while also maintaining basic timeliness through consolidated deliveries to preserve customer satisfaction. Furthermore, utilizing information technology for accurate estimated time of arrival (ETA) prediction and flexible interaction can effectively improve the customer experience without significantly increasing travel distance.

Therefore, the key to route optimization lies not in a simple trade-off between singular objectives, but in relying on systematic strategies and intelligent technology to drive the dual optimization of carbon emissions and customer satisfaction through dynamic balance.

III. Instant Logistics Distribution Route Optimization Strategies Considering Carbon Emissions and Customer Satisfaction

A. Innovate Distribution Models to Strengthen Synergistic Carbon Reduction and Efficiency Gains

Promote Collaborative Distribution to Integrate Resources, Reduce Costs, and Cut Carbon: Facilitate resource sharing among different logistics companies or across different business lines within the same enterprise. Integrate order resources from surrounding areas and implement unified planning of delivery zones and centralized dispatch of transport vehicles. This effectively reduces the frequency of duplicate deliveries and vehicle empty-running mileage, lowering the carbon emission intensity per unit of cargo. Simultaneously, the collaborative distribution model can significantly enhance the coverage density and overall operational efficiency of the distribution network, shortening order fulfillment times and thereby improving customer satisfaction. For example, fostering deep cooperation between convenience stores, fresh food supermarkets, and logistics enterprises around communities to establish consolidated distribution nodes can offer consumers diversified options like home delivery, scheduled pickup, etc., achieving a two-way improvement in delivery efficiency and service flexibility.

Optimize Last-Mile Delivery to Tackle the "Final Mile" Challenge: As the final link in the logistics chain, last-mile delivery directly impacts carbon emission levels and the customer experience, making it a key leverage point for dual-objective optimization. Establishing a three-tier last-mile network ("Distribution Center – Community Hub – Consumer") can drastically reduce the frequency of direct-to-door vehicle deliveries. For communities with dense order volumes, use small NEVs for consolidated delivery to community hubs, where staff then handle final sorting/delivery or guide customers for pickup. For remote areas or customers with dispersed orders, implement scheduled delivery models, aggregating demand before batch delivery to avoid energy waste from multiple vehicle trips. Additionally, actively promote the use of smart devices like unmanned hubs and smart parcel lockers to meet customers' 24/7 pickup needs, further enhancing service flexibility and convenience.

B. Strengthen Vehicle Operations Management for Precise Carbon Emission Control

Adopt Scientific Vehicle Selection and Configuration to Enhance Operational Efficiency: Phase out high-energy-consumption, high-emission fossil-fuel delivery vehicles and vigorously promote the application of NEVs (e.g., pure electric vehicles, hybrid vehicles) in distribution scenarios, especially in urban short-haul delivery, to fully leverage their core advantage of zero or low emissions. Simultaneously, precisely match vehicle types based on cargo category, weight, volume, and delivery distance to eliminate resource waste from underutilized capacity ("using a sledgehammer to crack a nut") and improve vehicle load factors. For instance, use small electric vans for lightweight, small-item, short-distance intra-city instant delivery; select fuel-efficient heavy-duty trucks for large-item, long-distance inter-city trunk line delivery, achieving optimal allocation of transport capacity resources.

Standardize Driving Behavior to Ensure Efficient Vehicle Operation: Enhance professional training and daily management of delivery drivers, guiding them to adopt habits of smooth and steady driving to reduce energy-wasting behaviors like rapid acceleration and harsh braking, thereby lowering vehicle fuel consumption and emissions. Establish scientifically sound delivery time standards to prevent drivers from speeding to meet deadlines, reducing energy consumption while ensuring road safety. Furthermore, establish a robust system for regular vehicle maintenance and inspections, routinely checking the operational status of key components like engines, tires, and braking systems, and promptly troubleshooting and repairing faults to ensure vehicles are always in optimal condition, further improving fuel utilization efficiency.

C. Deepen Service Collaboration to Comprehensively Enhance Customer Satisfaction

Build a Precise Demand Alignment System to Improve Delivery Suitability: Rely on online service platforms to aggregate customer delivery requirements in advance, including key information such as delivery time windows, drop-off locations, and special handling instructions for goods. Use this data to precisely plan delivery routes and fulfillment schedules. For example, prioritize evening or weekend deliveries for working professionals; establish green delivery channels for time-sensitive, safety-critical goods like fresh produce or medicine to ensure product freshness and transport safety. Simultaneously, establish a real-time delivery progress push mechanism to promptly update customers on order dispatch status, real-time vehicle location, and estimated time of arrival(ETA), enhancing service transparency and the customer's sense of control over the process.

Optimize Delivery Personnel Service Capabilities to Solidify Service Quality Foundations: As the frontline service representatives directly interacting with customers, the attitude and professional competence of delivery personnel are decisive for customer satisfaction. Strengthen systematic service training for delivery staff, covering core modules such as communication skills, cargo handling protocols, and exceptional case handling. Require personnel to use courteous language, handle goods with care, and perform duties compliantly. For potential issues like delivery delays or damaged goods, establish rapid response and emergency handling mechanisms, proactively communicating with customers to explain situations and offering targeted solutions like reshipment, fee reduction, or compensation, effectively resolving dissatisfaction and maintaining positive customer relationships.

D. Leverage Simple Auxiliary Tools to Enhance the Scientific Rigor of Route Planning

Utilize Mapping Tools and Real-Time Traffic for Dynamic Optimal Route Planning: Make full use of the real-time traffic query functions of mainstream navigation apps to accurately avoid bottlenecks like congested or construction zones, selecting optimal routes that are smooth and time-efficient. This reduces vehicle stop-start frequency and idle travel time, lowering carbon emissions. Simultaneously, based on order distribution in the delivery area, precisely mark delivery points on the map and manually plan a logical delivery sequence, prioritizing orders that are geographically close or time-sensitive to improve efficiency. For example, for multiple orders within the same residential compound or commercial area, plan circular or radial delivery routes to avoid backtracking and reduce total delivery mileage.

Establish Regional Delivery Logs for Standardized Route Planning: Systematically collate data for long-term cooperative clients and fixed delivery areas to establish comprehensive regional delivery logs. These should detail key information such as delivery point coordinates, order frequency, demand characteristics, and timeliness requirements. Based on this log data, rationally define fixed delivery zones and plan regular delivery routes, reducing the time spent on route planning before each delivery and enhancing service stability and efficiency. Establish a dynamic update mechanism for the logs, promptly optimizing zone divisions and route plans based on changes in order volume or customer requirements, ensuring the ongoing rationality of route planning.

IV. Concluding Remarks

Looking ahead, with the deepening penetration of digital technologies like the Internet of Things(IoT) and big data, logistics enterprises can build upon existing optimization strategies by further leveraging simple, practical technological tools to enhance route optimization outcomes. For instance, using IoT devices to monitor real-time vehicle status and key indicators like cargo temperature/humidity for dynamic adjustment of delivery plans; relying on big data analytics to uncover patterns in order distribution across different regions and time periods for precise optimization of delivery zone division and vehicle dispatch schedules. Simultaneously, the industry should strengthen inter-enterprise collaboration, establishing broader collaborative distribution networks to propel the logistics distribution sector towards a more efficient, greener, and more consolidated direction. This will enable the continuous elevation of both carbon emission control levels and customer satisfaction, achieving a synergistic win-win for ecological and economic benefits.

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