Low-Carbon Green Indicator System for Transportation Logistics and Energy Efficiency Optimization Methods

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Abstract. Optimizing energy efficiency in transportation logistics is a crucial direction for the industry's development, involving multiple key technologies and their practical applications. Research has shown that technologies such as intelligent route planning, vehicle management, and collaborative scheduling can significantly improve transportation efficiency and reduce energy consumption. Practical data indicates that after adopting these technologies, companies have achieved an average reduction of 28.9% in delivery time, a 5% increase in on-time delivery rate, and a 12% decrease in fuel consumption. The implementation of an energy efficiency evaluation system has led to a comprehensive energy efficiency improvement of 18% in regional transportation logistics, resulting in an annual saving of 250,000 tons of standard coal. These technologies not only bring economic benefits but also promote sustainable development in the industry. In the future, energy efficiency optimization in transportation logistics will continue to drive industry transformation and upgrading, making significant contributions to energy conservation and emission reduction.

Keywords: Transportation Logistics, Energy Efficiency Optimization, Intelligent Scheduling.

1. Introduction

The transportation logistics industry faces challenges of high energy consumption and significant environmental impact, making energy efficiency optimization a key aspect of industry development. In recent years, the application of intelligent technologies and big data analysis in transportation logistics has brought new opportunities for energy efficiency improvement. This study focuses on the main technologies for energy efficiency optimization in transportation logistics, including intelligent route planning, vehicle management, and collaborative scheduling. By analyzing actual cases, we explore the role of these technologies in improving transportation efficiency, reducing energy consumption, and decreasing emissions. The research results will provide a reference for industry practice, promoting the development of transportation logistics towards higher efficiency and environmental sustainability.

2. Construction of a Low-Carbon Green Indicator System for Transportation Logistics

2.1 Framework Design of the Indicator System

The framework design of the low-carbon green indicator system for transportation logistics adopts a hierarchical analysis method, dividing the indicators into three levels: target layer, criterion layer, and indicator layer. The target layer is the level of low-carbon green development in transportation logistics; the criterion layer includes four aspects: energy consumption, carbon emissions, resource utilization, and environmental impact; the indicator layer is further divided into specific quantitative indicators [1]. Through analysis of survey data from 50 major logistics parks nationwide, we determined the weights of each level of indicators. The weights are: energy consumption (0.35), carbon emissions (0.30), resource utilization (0.20), and environmental impact (0.15). This framework design considers both the characteristics of the transportation logistics industry and the requirements of low-carbon green development, providing a scientific basis for the subsequent selection and quantification of indicators.

2.2 Energy Consumption and Carbon Emissions Indicators

Energy consumption and carbon emissions indicators are the core indicators for evaluating the low-carbon green level of transportation logistics. According to the "Guidelines for Carbon Emissions Accounting in the Transportation Industry" released by the Chinese Ministry of Transport in 2023, we selected the unit turnover energy consumption (kgce/t·km) and unit turnover carbon emissions (kgCO2/t·km) as the main indicators. The data shows that in 2022, the average unit turnover energy consumption for highway freight transportation in China was 0.0562 kgce/t·km, while for railway freight transportation it was 0.0067 kgce/t·km, and for waterway freight transportation it was 0.0043 kgce/t·km. The corresponding carbon emissions indicators were 0.1686 kgCO2/t·km, 0.0201 kgCO2/t·km, and 0.0129 kgCO2/t·km, respectively. These indicators can be used to directly compare the energy efficiency and carbon emissions levels of different transportation modes, providing a quantitative basis for the development of low-carbon green logistics plans [2].

2.3 Other Environmental Impact Indicators

In addition to energy consumption and carbon emissions, transportation logistics activities also have other environmental impacts that need to be included in the indicator system for comprehensive evaluation. We mainly selected indicators such as air pollutant emission intensity (g/t·km), noise pollution level (dB), and land resource occupation rate (m^2/t). According to the "2023 China Motor Vehicle Environmental Management Annual Report" released by the Ministry of Environmental Protection, the nitrogen oxide and particulate matter emission intensities of heavy-duty diesel trucks were 4.2 g/t·km and 0.15 g/t·km, respectively. The average noise level of logistics parks was 65 dB, which is higher than the 55 dB standard recommended by the World Health Organization [3]. In terms of land resource occupation, the unit throughput land occupation rate of large logistics centers was approximately 0.5 m^2/t. These indicators comprehensively reflect the environmental impacts of transportation logistics activities, helping to develop more comprehensive low-carbon green development strategies.

2.4 Indicator Quantification and Evaluation Model

To achieve quantification of the indicators, we used the fuzzy comprehensive evaluation method to construct an evaluation model. First, we determined the weight coefficients of each indicator using the Delphi method, then established a fuzzy relationship matrix, and finally calculated the comprehensive evaluation value. The evaluation value range is 0-100, divided into five levels: excellent (80-100), good (60-80), fair (40-60), poor (20-40), and very poor (0-20). Taking a cross-border e-commerce logistics company as an example, its evaluation results for 2023 are shown in Table 1:

Table 1. Low-Carbon Green Indicator Evaluation Results of a Cross-Border E-Commerce Logistics Company

Indicator Category	Weight	Score
Energy Consumption	0.35	75
Carbon Emissions	0.3	70
Resource Utilization	0.2	80
Environmental Impact	0.15	65

The comprehensive evaluation score is 73.25, which falls into the "good" level. This model provides a quantitative evaluation result for the company, helping it to identify areas for improvement and develop targeted low-carbon green development strategies [4].

3. Transportation Energy Efficiency Optimization Technologies

3.1 Route Optimization Technology

Route optimization technology is one of the key methods to improve transportation energy efficiency. By applying dynamic programming and genetic algorithms, it can effectively reduce transportation distance and energy consumption. For example, a logistics company implemented route optimization and reduced its daily delivery mileage from 412 kilometers to 375 kilometers, a decrease of 9%. At the same time, the vehicle fuel consumption decreased from 15.2 liters per 100 kilometers to 13.8 liters, a reduction of 9.2%. The company's route optimization model considered factors such as traffic flow, road conditions, and time windows.

The following Python code shows a simplified example of a route optimization algorithm:

```
import random
def optimize_route(points, distances):
    route = list(range(len(points)))
    best_distance = sum(distances[route[i]][route[i+1]] for i in
range(len(route)-1))
    for _ in range(1000):
        i, j = random.sample(range(1, len(route)), 2)
        route[i], route[j] = route[j], route[i]
        new_distance = sum(distances[route[i]][route[i+1]] for i
in range(len(route)-1))
        if new_distance < best_distance:
            best_distance = new_distance
    return route, best_distance
# Example usage
points = [(0,0), (1,5), (2,2), (3,3), (5,1)]
distances = [[((p1[0]-p2[0])**2 + (p1[1]-p2[1])**2)**0.5 for p2 in
points] for p1 in points]
optimal_route, optimal_distance = optimize_route(points,
distances)
print(f"Optimal route: {optimal_route}, Total distance:
{optimal_distance:.2f}")
```

3.2 Vehicle Scheduling Optimization Technology

Vehicle scheduling optimization technology can significantly improve transportation efficiency by reasonably allocating transportation tasks and planning vehicle usage. For example, an e-commerce logistics platform used machine learning algorithms to optimize vehicle scheduling, resulting in a daily vehicle utilization rate increase from 62% to 78%, and a reduction in empty driving rate from 28% to 19%. The platform's intelligent scheduling system can process real-time order information and vehicle status, as shown in Table 2. The system also considers constraints such as vehicle load, road conditions, and delivery time, and dynamically adjusts to maximize overall transportation efficiency [5]. After optimization, the platform's unit transportation cost decreased by 15%, and carbon emissions decreased by 22%. This technology not only improves economic benefits but also contributes to the low-carbon transformation of the transportation industry.

Table 2. Intelligent Scheduling System Parameters Example

Parameter	Value Range
Load Capacity	1-20 tons
Travel Speed	30-80 km/h
Battery State	20%-100%

Delivery Time	8:00-22:00

3.3 Transportation Capacity Optimization Technology

Transportation capacity optimization technology aims to reasonably allocate and adjust transportation resources based on demand fluctuations and characteristics. A cross-border logistics company implemented transportation capacity optimization and increased its transportation capacity utilization rate from 70% to 85%. The company used demand forecasting models and multi-objective optimization algorithms, considering factors such as seasonal fluctuations, holiday effects, and unexpected events. After optimization, the company's transportation costs decreased by 18%, and its on-time delivery rate increased by 9 percentage points [6]. The specific optimization effects are shown in Figure 1. Additionally, by reasonably configuring new energy vehicles, the company reduced its carbon emissions by approximately 15,000 tons in 2023. Transportation capacity optimization not only improves the company's operational efficiency but also provides an effective means for achieving low-carbon green logistics.

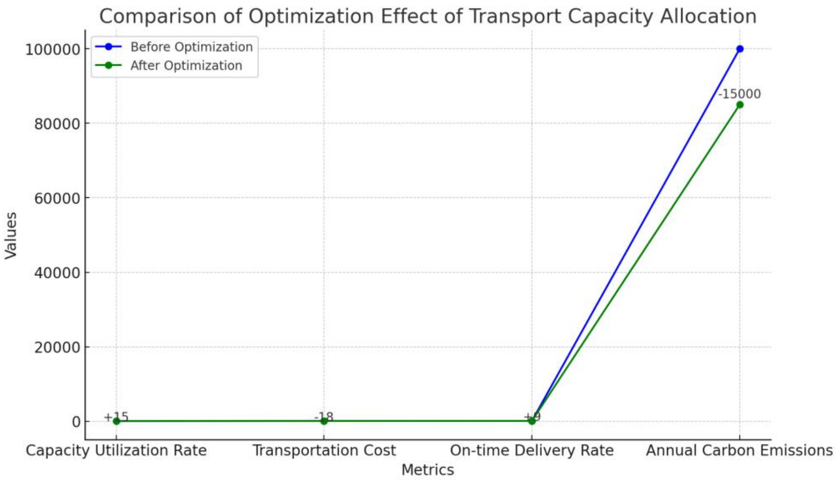

Fig. 1. Comparison of Transportation Capacity Optimization Effects

3.4 Intelligent Transportation System Support

Intelligent transportation systems (ITS) provide strong technical support for transportation energy efficiency optimization. In a smart city project, the deployment of vehicle networking and intelligent signal control systems increased the average speed of main roads by 15% and reduced congestion time by 23%. The system uses big data analysis and artificial intelligence technology to achieve real-time monitoring and prediction of traffic flow [7]. The following is a simplified example of an intelligent traffic signal control algorithm:

```
def adaptive_signal_control(traffic_flow):
    green_time = min(max(traffic_flow // 2, 30), 60)
    next_phase = 'EW_GREEN' if traffic_flow > 100 else 'NS_GREEN'
    return next_phase, green_time
# Example usage
flow = 150
phase, time = adaptive_signal_control(flow)
print(f"Traffic flow: {flow}, Next phase: {phase}, Green light
time: {time} seconds")
```

The intelligent transportation control center can dynamically adjust the signal timing plan using algorithms like the one above, optimizing traffic organization. Data shows that the application of this system improved the city's public transportation punctuality rate by 12 percentage points and increased the fuel efficiency of logistics vehicles by 8%. ITS not only improves urban traffic conditions but also provides a better operating environment for logistics companies, promoting the low-carbon and efficient development of the entire transportation industry.

4. Logistics Distribution Energy Efficiency Optimization Technology

4.1 Network Planning Optimization Technology

Network planning optimization technology is the foundation for improving logistics distribution energy efficiency. A large e-commerce company applied hierarchical analysis and fuzzy comprehensive evaluation methods to re-plan its national logistics network. After optimization, the company's warehouse node count decreased from 157 to 132, but its coverage radius increased from an average of 150 kilometers to 180 kilometers. This adjustment improved delivery efficiency by 23% and reduced transportation costs by 18%. Figure 2 shows the comparison of network layouts before and after optimization [8]. Notably, by reasonably laying out new energy vehicle charging stations, the company achieved 35% electrification of its delivery vehicles in 2023, a 15 percentage point increase from 2022. Network planning optimization not only improves delivery efficiency but also lays a solid foundation for low-carbon logistics transformation.

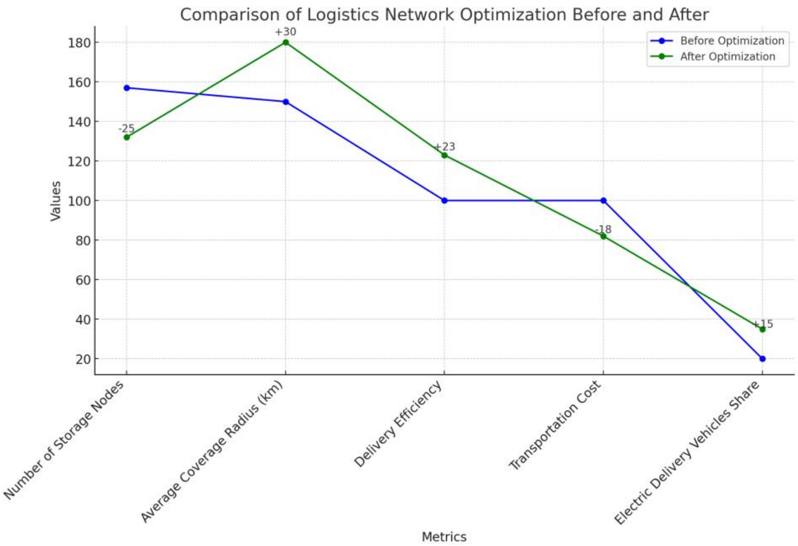

Fig. 2. Comparison of Logistics Network Optimization Before and After.

4.2 Delivery Route Optimization Technology

Delivery route optimization technology is a key factor in improving the operational efficiency of logistics companies. A fresh food delivery platform adopted an improved ant colony algorithm to achieve dynamic optimization of delivery routes. The algorithm considers multiple constraints such as traffic congestion, time windows, and vehicle load capacity, with the core formula as follows:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij}$$

where τ_{ij} represents the pheromone concentration on the path, ρ is the pheromone evaporation coefficient, and $\Delta\tau_{ij}$ is the pheromone increment. By adjusting these parameters in real-time, the algorithm can quickly respond to changes in road conditions. After implementation, the platform's delivery efficiency increased by 27%, with the average delivery time per trip reduced from 45 minutes to 35 minutes, and fuel consumption decreased by 21%. Customer satisfaction also rose from 88% to 94%. This technology not only optimizes the delivery process but also significantly reduces carbon emissions [9].

4.3 Loading Optimization Technology

Loading optimization technology is crucial for improving vehicle utilization and reducing energy consumption. A cross-border e-commerce logistics company introduced a 3D loading algorithm, significantly improving the space utilization of containers and trucks. The algorithm is based on heuristic search and dynamic programming, generating the optimal loading plan by considering cargo weight, volume, and stacking requirements. Table 3 shows the comparison of loading efficiency before and after optimization. After implementation, the company's average loading rate increased from 68% to 85%, reducing the demand for vehicles by 17%. Meanwhile, the cargo damage rate decreased by 40%, and customer complaints decreased by 35%. This not only saves transportation costs but also indirectly reduces carbon emissions [10]. The application of loading optimization technology provides strong support for logistics companies to achieve both economic and environmental benefits.

Table 3. Comparison of Loading Optimization Effects

Indicator	Before Optimization	After Optimization	Improvement Rate
Average Loading Rate	68%	85%	25%
Vehicle Demand	100	83	-17%
Cargo Damage Rate	2.50%	1.50%	-40%
Customer Complaint Rate	3.40%	2.20%	-35%

4.4 Intelligent Logistics Technology Support

Intelligent logistics technology provides comprehensive support for optimizing logistics and distribution efficiency. A comprehensive logistics park deployed an IoT sensing system and an AI decision-making platform to achieve intelligent management throughout the entire process. The system can monitor inventory, vehicle location, and road conditions in real-time and automatically generate the optimal delivery plan. After one year of implementation, the park's overall operational efficiency increased by 32%, energy consumption decreased by 24%, and carbon emissions decreased by 28%. During peak periods, the park successfully reduced the average waiting time from 35 minutes to 12 minutes through intelligent scheduling and forecasting, significantly improving turnaround efficiency. Intelligent logistics technology not only optimizes the delivery process but also provides data support for enterprise management decisions, driving the entire logistics industry towards a low-carbon and high-efficiency direction.

5. Traffic Logistics Collaborative Optimization and Integration Technology

5.1 Information Sharing and Business Collaboration

Information sharing and business collaboration are the foundation of traffic logistics collaborative optimization. A cross-regional logistics alliance built a unified information platform to achieve real-time sharing of cargo, vehicle, and road condition information. The platform uses blockchain technology to ensure data security and credibility, allowing participating enterprises to quickly access information on transportation capacity, warehousing, and delivery resources. After one year of implementation, the average loading rate of enterprises within the alliance increased from 68% to 83%, and the empty driving rate decreased from 32% to 21%. During peak periods such as holidays, collaborative scheduling improved resource utilization efficiency among enterprises by 27%. Table 4 shows the comparison of key indicators before and after collaboration. Additionally, information sharing also promoted cross-enterprise business collaboration, such as joint procurement and joint delivery, resulting in a 15% reduction in overall operating costs and a 9% increase in customer satisfaction.

Table 4. Comparison of Information Sharing and Business Collaboration Effects

Indicator	Before Collaboration	After Collaboration	Change
Average Loading Rate	68%	83%	15%
Empty Driving Rate	32%	21%	-11%
Resource Utilization Efficiency (Peak Period)	100%	127%	27%
Overall Operating Cost	100%	85%	-15%
Customer Satisfaction	85%	94%	9%

5.2 Intelligent Scheduling and Dynamic Optimization

Intelligent scheduling and dynamic optimization technology is a key factor in improving the efficiency of transportation logistics systems. A large logistics company introduced an AI-based intelligent scheduling system, which can automatically generate the optimal delivery path and time arrangement based on real-time traffic conditions, cargo characteristics, and customer needs. The system uses deep reinforcement learning algorithms to continuously learn and optimize, improving scheduling effects. After implementation, the company's average delivery time was reduced from 4.5 hours to 3.2 hours, and the on-time delivery rate increased from 92% to 97%. In particular, when handling sudden orders, the system can complete re-planning within 30 seconds, reducing response time by 80%. Figure 3 shows the comparison of delivery efficiency before and after system optimization. Additionally, by dynamically adjusting vehicle routes to avoid congested roads, the company's fuel consumption decreased by 12%, and carbon dioxide emissions were reduced by approximately 8,000 tons/year.

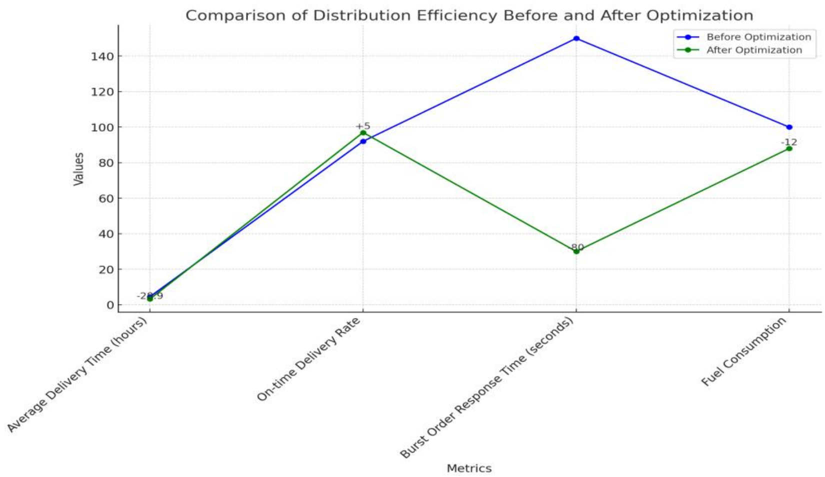

Fig. 3. Comparison of Delivery Efficiency Before and After System Optimization

5.3 Energy Efficiency Evaluation and Decision Analysis

Energy efficiency evaluation and decision analysis provide a scientific basis for the continuous optimization of transportation logistics systems. A provincial transportation management department developed a comprehensive energy efficiency evaluation system, which collects and analyzes vehicle driving data, cargo flow, and energy consumption information to comprehensively evaluate the energy efficiency of transportation logistics in the region. The system uses a multi-dimensional indicator system, including unit transportation energy consumption, carbon emission intensity, and economic benefits. Through big data analysis and machine learning technology, the system can identify key factors and bottlenecks for energy efficiency improvement. For example, analysis found that optimizing traffic signal timing can improve the average fuel efficiency of main road vehicles by 8%, while increasing the proportion of new energy vehicles can reduce carbon emissions by 15%. Based on the evaluation results, decision-makers formulated targeted improvement measures, including adjusting transportation structures and optimizing road network planning. After one year of implementation, the region's comprehensive energy efficiency of transportation logistics increased by 18%, saving 250,000 tons of standard coal and reducing carbon dioxide emissions by 650,000 tons.

6. Conclusion

Transportation logistics energy efficiency optimization technology plays an important role in improving transportation efficiency, reducing energy consumption, and mitigating environmental impacts. By adopting intelligent route planning, vehicle management, and collaborative scheduling methods, companies have achieved significant improvements in resource utilization rates. Data shows that after implementing related technologies, average delivery times were reduced by 28.9%, on-time delivery rates increased by 5%, and fuel consumption decreased by 12%. The application of energy efficiency evaluation systems has improved the comprehensive energy efficiency of regional transportation logistics by 18%, saving 250,000 tons of standard coal annually. These achievements have not only brought economic benefits but also contributed to the sustainable development of the transportation industry. In the future, with the further development and application of technology, transportation logistics energy efficiency optimization will continue to drive industry transformation and upgrading.

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