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Optimization of Vehicle Scheduling for Joint Distribution in Logistics Park based on Priority

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Abstract: With the rapid development of logistics industry, the joint distribution mode has been paid more and more attention. As an important gathering place of logistics activities, logistics park faces the dual challenges of improving distribution efficiency and reducing operating costs. In the complex environment of multi-stakeholder coordination and resource sharing, vehicle scheduling optimization in logistics park has become the key to improving the operational efficiency of logistics park. Therefore, this paper focuses on the optimization of vehicle scheduling for joint distribution in logistics parks, in order to provide an effective optimization scheme reference for vehicle scheduling in logistics parks and help logistics parks achieve efficient operation under the background of digital economy.

Keywords: Logistics Park, Joint Distribution, Vehicle Scheduling, Priority Level, Scheduling Optimization.

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1 INTRODUCTION

With the rapid development of the global economy and the continuous evolution of the logistics industry, logistics parks have become key nodes in modern supply chains, taking on multiple functions such as cargo collection, distribution, storage, and delivery. The common distribution model in logistics parks is considered an effective way to improve logistics efficiency and reduce operational costs. It can reduce the repeated movement of vehicles, optimize the flow paths of goods, alleviate urban traffic pressure, and reduce environmental pollution. As the scale of the logistics industry expands, logistics parks face increasing demand for cargo flow and increasingly fierce market competition. Ensuring service quality while improving delivery efficiency and reducing costs has become a common concern for logistics park managers and participants. Against this backdrop, an optimization strategy for vehicle scheduling based on priority, which takes into account the urgency and importance of cargo delivery, can achieve more efficient logistics services through reasonable resource allocation and optimization of delivery sequences and routes. Therefore, this paper conducts an optimization study on the joint distribution vehicle scheduling problem in logistics parks based on the concept of priority, aiming to provide theoretical support for the efficient and economical operation of logistics parks.

He Wenzhong (2023) pointed out that developing a path suitable for the park based on its own positioning and segmented market is the key to success [1]. He Xinyun (2023) proposed a multi-level joint distribution network planning and studied the application of the DEA evaluation method to assess the efficiency values of express delivery outlets [2]. Ma Haoming (2023) introduced a "courier + instant logistics" joint distribution model to address issues of resource sharing and industry integration, proposing terminal joint distribution outlet selection and delivery route planning schemes for this model [3]. Huang Yunyi (2022), based on the realistic conditions of Company Y, proposed a shared distribution model and a vehicle optimization configuration model focused on long-term development [4]. Fu Chaohui et al. (2021) considered changes in customer service relationships and the heterogeneity of customer demand, designing a shared logistics model that shares customer demand, delivery vehicles, and logistics centers [5]. He Jinhai (2015) in constructing an optimized vehicle scheduling model for a logistics park's joint distribution center, considered time penalty costs and over-mileage penalty costs, as well as the priority levels of the distribution tasks to determine the urgency of different distribution tasks [6].

2 JOINT DISTRIBUTION IN LOGISTICS PARKS

2.1 DEFINITION OF JOINT DISTRIBUTION IN LOGISTICS PARKS

Joint distribution in logistics parks refers to different logistics companies within a specific logistics park sharing

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resources and coordinating operations to achieve increased distribution efficiency and reduced logistics costs. The core of joint distribution in logistics parks is resource sharing and collaborative operations, which optimize delivery routes, reduce empty mileage, and effectively lower overall logistics costs through economies of scale. Participants achieve efficient management of information flow, logistics, and capital flow during the distribution process through information sharing, resource sharing, and collaborative operations. Moreover, joint distribution in logistics parks involves complex management and coordination issues. Participants need to establish effective communication mechanisms and cooperative relationships to ensure smooth distribution activities. In practice, participants can use logistics management software for order processing, vehicle scheduling, inventory management, and other tasks to support this complex collaboration. Additionally, joint distribution reduces the number of vehicle trips and mileage, effectively lowering carbon emissions and energy consumption, contributing to environmental protection.

2.2 Significance of Joint Distribution in Logistics Parks

In a highly competitive market environment, the joint distribution model can integrate logistics resources such as vehicles, personnel, and storage space to achieve economies of scale and reduce logistics costs. It can also reduce carbon emissions and energy consumption by decreasing the number of vehicle trips and driving distances, contributing to green logistics and sustainable development goals. On the other hand, through unified scheduling and management, joint distribution can better adapt to changes in market demand, provide more flexible and efficient logistics services, enhance the market competitiveness of logistics parks, and offer higher-quality logistics services to enterprises within the park, thereby promoting the economic development of the entire region. With the development of digital and intelligent technologies, logistics parks can leverage advanced information technology and automated equipment to unlock the potential of joint distribution, achieve higher levels of precise scheduling and real-time monitoring, and improve the overall responsiveness and service quality of logistics operations.

3 VEHICLE SCHEDULING OPTIMIZATION THEORY

3.1 Basic Principles of Vehicle Scheduling Optimization

Through scientific and reasonable planning and scheduling, vehicle scheduling optimization can maximize the utilization of vehicle resources, reduce transportation costs, and improve transportation efficiency. In practical applications, vehicle scheduling optimization involves route planning, load optimization, travel time management, and rapid response to emergencies. These aspects require consideration of factors such as cargo loading and unloading efficiency, delivery time windows, and traffic conditions to find the most cost-effective and efficient delivery plan, thus precisely planning the vehicle operating routes. Vehicle scheduling faces uncertainties and dynamic changes in actual operations, so effective vehicle scheduling strategies need to be flexible and adaptive. Technologies such as the Internet of Things (IoT) and big data analysis can be applied to vehicle scheduling optimization strategies, enabling vehicle scheduling to be based on real-time data, quickly respond to these changes, and adjust scheduling plans in a timely manner.

3.2 Application of Priority in Vehicle Scheduling

In vehicle scheduling, factors such as the delivery time required by customers, the nature of the goods (e.g., perishable or fragile items), the value of the order, and the importance of the customer are comprehensively considered. These factors help identify and differentiate the urgency and importance of various delivery tasks. By assigning different priorities to different delivery tasks or orders, critical tasks can be prioritized, thus improving the overall efficiency and responsiveness of the logistics system. Priority scheduling strategies require precise control and processing of information flow within the logistics system, relying on advanced logistics management software and real-time data tracking systems to ensure real-time updates and accuracy of all relevant data. This enhances the feasibility and accuracy of priority scheduling, ensuring that logistics operations are more transparent and systematic. As competition in the logistics industry intensifies and customer demands diversify, adopting a priority-based vehicle scheduling strategy will become an important means for logistics enterprises to improve service levels and enhance market competitiveness.

4 CONSTRUCTION OF AN OPTIMIZED VEHICLE SCHEDULING MODEL FOR JOINT DISTRIBUTION IN LOGISTICS PARKS

4.1 Objectives and Assumptions

The objective of constructing an optimized vehicle scheduling model for joint distribution in logistics parks is to minimize costs and maximize service levels. The model needs to optimize vehicle delivery routes and schedules to reduce travel distance and time, lower fuel consumption and labor costs, and ensure timely and accurate completion of delivery tasks. Therefore, the following assumptions are proposed: 1. All vehicles are of the same type and capacity. 2. Vehicles can start delivery tasks at any time. 3. All delivery

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points can be reached within the specified time.

There will be no traffic delays or other unexpected situations during vehicle deliveries.

4.2 Model Parameters and Variable Definitions

4.2.1 Decision Variables:

X_{ijk}: A binary variable, where it is 1, if vehicle k travels directly from delivery point i to delivery point j , and 0 otherwise.

T_k: Total travel time of vehicle k.

D_k: Total travel distance of vehicle k.

4.2.2 Parameters:

N: Total number of delivery points.

M: Total number of available vehicles.

Q_k: Maximum carrying capacity of vehicle K

d_{ij}: Distance between delivery points i and j.

q_i: Cargo demand at delivery point i.

C_k: Unit travel cost of vehicle K.

S_i& E_i: Service start time and Service end time for delivery point i.

4.2.3 Auxiliary variables

L_{ik}: The cargo load of vehicle k at delivery point i.

4.3 Construction of the Mathematical Model

The objective of the vehicle scheduling optimization model is to minimize the total delivery cost. The objective function is as follows:

$$\min Z = \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{M} C_k \cdot d_{ij} \cdot X_{ijk} + \alpha \cdot \sum_{k=1}^{M} T_k$$

Where, α is the coefficient of time cost.

The constraints are as follows:

4.3.1 Each delivery point is visited by only one vehicle exactly once:

$$\sum_{i=1}^{N}\sum_{k=1}^{M} X_{ijk} = 1, \forall j \in \{1,2,\dots,N\}$$

4.3.2 Vehicle capacity constraints:

$$\sum_{i=1}^{N} q_i \cdot X_{ijk} \le Q_k, \forall k \in \{1,2,\dots,M\}$$

4.3.3 Time window constraints:

$$S_i \le \sum_{j=1}^{N} t_{ij} \cdot X_{ijk} \le E_i, \forall i \in \{1,2,\dots,N\}, \forall k \in \{1,2,\dots,M\}$$

Where, t_{ij} is the travel time from point i to point j.

4.3.4 Ensure that vehicles that depart from the logistics park could return back:

$$\sum_{j}^{N} X_{0jk} = \sum_{i=1}^{N} X_{i0k} = 1, \forall k \in \{1,2,\dots,M\}$$

Where, 0 represents the logistics park.

4.3.5 Prevent sub-cycles in the paths to ensure the continuity of vehicle routes:

$$\sum_{i=1}^{N} X_{ijk} - \sum_{j=1}^{N} X_{ijk} = 0, \forall i \in \{1,2,\dots,N\}, \forall k \in \{1,2,\dots,M\}$$

5 PRIORITY-BASED VEHICLE SCHEDULING STRATEGY

5.1 Methods for Determining Priority

Determining priority requires first assessing the urgency of customer demands, which can be comprehensively considered by customer order time, expected delivery time, and order importance. If a customer requires delivery at a specific time, such orders should be assigned higher priority. To improve delivery efficiency, orders that are nearby or in the same direction can be assigned the same or similar priority to facilitate simultaneous delivery during one trip, reducing repeated travel distances and increasing overall delivery efficiency. On the other hand, if a vehicle's capacity is nearing full load, the priority of subsequent orders should be correspondingly reduced. To determine order priority, a dynamic adjustment mechanism can be used. In practice, computer algorithms and artificial intelligence technologies can adjust order priorities based on real-time conditions to ensure timely and accurate scheduling decisions. Determining priority helps enhance the quality of delivery services and customer satisfaction, effectively reducing logistics costs and improving the overall efficiency of the delivery process.

5.2 Design of Priority Scheduling Strategy

The design of a priority scheduling strategy needs to comprehensively consider multiple aspects of delivery tasks to ensure the efficiency and cost-effectiveness of joint

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distribution in logistics parks. (1) Orders with shorter slack times should be assigned higher priority, as logistics companies need to ensure deliveries within the specified time. The scheduling strategy should prioritize orders with urgent delivery requirements to reduce the possibility of delayed deliveries, enhance service quality, improve customer satisfaction, and boost the company's reputation. (2) For customers with consistently high delivery volumes, it is advisable to elevate the priority of their orders to strengthen relationships with important clients and improve overall delivery efficiency. At the same time, vehicle loading rates and transportation efficiency should be optimized while maintaining service quality. (3) Orders that are prone to high penalties or losses, including those with time sensitivity or special requirements, should be given higher priority. Prioritizing these orders can effectively reduce potential economic losses and enhance customer trust. (4) Ideally, high-revenue orders should be prioritized, but there must also be a balance between customer fairness and maintaining long-term relationships to maximize the logistics company's revenue. (5) Orders from stable long-term partners or strategically significant customers can be considered for higher priority to solidify relationships with core clients and build a strong brand image in the market.

5.3 4.3 Implementation of Scheduling Strategy

All parties involved, including logistics park managers, logistics companies, drivers, and other relevant personnel, need to fully understand and accept the priority-based vehicle scheduling strategy. Relevant departments in the logistics park can use training sessions, workshops, and regular communication meetings to clarify the objectives, operational processes, responsibilities, and expectations of the scheduling strategy. An effective communication and feedback mechanism should be established to ensure that any issues encountered during implementation are resolved promptly. On the other hand, the logistics park needs to establish an integrated order management system, a real-time vehicle tracking system, and efficient data processing and analysis tools. The order management system should be capable of automatically calculating and updating order priorities while providing real-time order status and location information to schedulers. The real-time vehicle tracking system can help schedulers monitor the actual travel conditions of vehicles and make adjustments as needed. Data processing and analysis tools can be used to analyze historical data and identify potential opportunities for optimizing scheduling strategies. In the integrated information system, an emergency response mechanism should be set up to handle sudden events such as traffic congestion or vehicle breakdowns. This mechanism should allow for order reallocation, route changes, and temporary priority adjustments to maximize the efficiency and effectiveness of joint distribution in the logistics park, thereby enhancing customer service levels and the company's competitiveness.

6 CASE ANALYSIS AND MODEL VALIDATION

6.1 Case Selection

This paper selects Logistics Park A as the case study subject. Logistics Park A hosts multiple logistics companies and covers various logistics service areas, including warehousing, distribution, and transportation. Its complex logistics activities and diverse service demands provide an ideal testing environment for validating the priority-based vehicle scheduling optimization model. The park is home to numerous companies, processes a large volume of orders daily, and handles a variety of order types, making the need for optimized scheduling strategies particularly urgent. With its favorable geographic location, connecting several major transportation routes, Logistics Park A can significantly impact logistics efficiency. Through discussions and interviews with the park management, logistics companies, and drivers, extensive actual data and information regarding logistics operations, order processing, and vehicle scheduling were collected. An in-depth analysis of this information provides a solid foundation for understanding the actual demands and issues in joint distribution within the logistics park, thereby supporting the construction and validation of the model.

6.2 Application of the Model and Results Analysis

6.2.1 Basic Data

First, data for 10 delivery tasks from Logistics Park A were collected, as shown in Table 1. In this data, a smaller numerical value for each task's priority indicates a higher priority.

TABLE 1 DATA FOR DELIVERY TASKS

Delivery Task	Cargo Weight (t)	Cargo Arrival Time Requirement (h)	Service Time (min)	Priority
1	2.5	24	30	1
2	1.2	48	45	2
3	3.5	36	60	3
4	4	24	30	1
5	2	48	40	2
6	1.5	60	50	4
7	3	72	35	5
8	2.8	30	40	3
9	1.8	24	30	2
10	2.2	42	45	1

Second, distance information between the 10 task points was collected, as shown in Table 2.

TABLE 2 DISTANCE BETWEEN 2 TASKS

Task	1	2	3	4	5	6	7	8	9	10

1	0	47	64	67	67	9	83	21	36	87
2	70	0	88	12	58	65	39	87	46	88
3	81	37	0	77	72	9	20	80	69	79
4	47	64	82	0	88	49	29	19	19	14
5	39	32	65	9	0	32	31	74	23	35
6	75	55	28	34	0	0	36	53	5	38
7	17	79	4	42	58	31	0	65	41	57
8	35	11	46	82	91	0	14	0	53	12
9	42	84	75	68	6	68	47	3	0	52
10	78	15	20	99	58	23	79	13	85	0

6.2.2 Virtual Distance Calculation

The virtual distance data reflects the distances between tasks after considering priorities. The virtual distance table is shown in Table 3, which uses the simplified formula: Virtual Distance = Actual Distance / Priority.

TABLE 3 VIRTUAL DISTANCE BETWEEN 2 TASKS

Task	1	2	3	4	5	6	7	8	9	10
1	0	23.5	21.33	67	33.5	2.25	16.6	7	18	87
2	70	0	29.33	12	29	16.25	7.8	29	23	88
3	81	18.5	0	77	36	2.25	4	26.67	34.5	79
4	47	32	27.33	0	44	12.25	5.8	6.33	9.5	14
5	39	16	21.67	9	0	8	6.2	24.67	11.5	35
6	75	27.5	9.33	34	0	0	7.2	17.67	2.5	38
7	17	39.5	1.33	42	29	7.75	0	21.67	20.5	57
8	35	5.5	15.33	82	45.5	0	2.8	0	26.5	12
9	42	42	25	68	3	17	9.4	1	0	52
10	78	7.5	6.67	99	29	5.75	15.8	4.33	42.5	0

6.2.3 Model Solution

During the model solution process, specific data for delivery tasks, virtual distances, and other relevant parameters are first input into the LINGO program. These parameters include fixed costs, unit costs, vehicle weight limits, operating speed, time penalty cost coefficients, and excess mileage penalty cost coefficients. The fixed cost is set at 150 yuan, the unit cost is 5 yuan, variable costs amount to 1,066 yuan, each vehicle has a weight limit of 3 tons, vehicle speed is 40 km/h, and the time cost coefficient is 300. The results show that the optimal cost for the joint distribution vehicle scheduling optimization model in the logistics park is 1,120 yuan, with fixed costs at 400 yuan, variable costs at 720 yuan, time penalty costs at 0 yuan, and excess mileage penalty costs at 0 yuan. This indicates that all logistics companies can meet delivery customer demands within the specified time frame. Detailed results are shown in Table 4. It requires three vehicles to complete the delivery tasks. This method ensures that joint distribution activities within the logistics park can achieve both high efficiency and cost-effectiveness.

TABLE 4 PRIORITY-BASED JOINT DISTRIBUTION VEHICLE SCHEDULING OPTIMIZATION PLAN

Vehicle No.	Sequence of Delivery tasks	Delivery Route
Vehicle 1	Task1, Task5, Task7	0-1-5-7-0
Vehicle 2	Task2, Task4, Task10	0-2-4-10-0
Vehicle 3	Task3, Task6, Task8, Task9	0-3-6-8-9-0

7 CONCLUSION

This paper comprehensively considers multiple key factors such as the priority of delivery tasks, vehicle load limits, and delivery time windows to construct a priority-based vehicle scheduling optimization model for joint distribution in logistics parks, ensuring the feasibility and practicality of the plan. The case study demonstrates that the optimized scheduling strategy can effectively reduce vehicle travel distance, lower total costs, and successfully enhance the efficiency and cost-effectiveness of vehicle scheduling in the logistics park. The case analysis also validates the model's application value in actual operations. By using the optimized model, logistics parks can better handle complex delivery tasks. This paper aims to provide logistics parks with an effective vehicle scheduling optimization tool and offer theoretical and practical guidance for the efficient operation of the logistics industry.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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