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Research on Order Picking Path Optimization Based on Linear Programming

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Abstract:

Order picking plays a crucial role in logistics and supply chain management, directly affecting efficiency, cost, and customer satisfaction. With the continuous development of e-commerce and the increasing demand for fast order fulfillment, optimizing order-picking paths has become more important than ever before. This article reviews the latest research on picking path optimization, with a focus on the application of linear programming (LP) in this field. By analyzing a large number of studies and practical cases, the effectiveness of the LP model in improving order picking was evaluated. The research results indicate that LP significantly reduces picking time and travel distance, thereby improving efficiency. However, challenges still exist, especially when adapting to complex dynamic environments, where real-time response and computational efficiency are key issues. Future research directions include combining advanced algorithms and multi-objective optimization techniques. Overall, the study emphasizes the potential of LP in improving order picking while recognizing its current limitations.

Keywords: Order picking; path optimization; linear programming.

1. Introduction

1.1 Background

Order picking is a critical operation for logistics and supply chain management departments. It involves retrieving items from the warehouse to fulfill customer orders, which has a significant impact on the cost and efficiency of the distribution center. With the continuous development of the e-commerce and retail industry, optimizing the order-picking path has become an urgent task. The efficiency of this process directly affects delivery speed, customer satisfaction, and operating costs.

1.2 Literature Review and Research Progress

Recent research has emphasized the importance of optimization techniques in improving order-picking efficiency. Li Shizhen's work in optimizing picking

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operations provides fundamental insights into various strategies for simplifying the order-picking process [1]. Zhang Yigong and Wu Qinglie explored how to apply linear programming to enhance the path planning of distribution centers in their research on logistics path optimization based on LP [2]. Wang Xiongzhi's research further expanded these concepts, focusing on the specific optimization methods of picking [3]. These studies collectively emphasize the progress in applying linear programming to solve the problem of sequential selection.

1.3 Motivation and Research Framework

The motivation of this article is to review the current research on order-picking path optimization and focus on exploring the application of linear programming (LP) in this field. The review framework combines theoretical models with practical case studies to evaluate the effectiveness of LP methods in real-world scenarios. By reviewing existing research, this article not only highlights the practical applications of linear programming but also provides profound insights into its impact on operational performance.

2. Explain the Sequence Selection Path Planning

2.1 Relevant Theoretical Knowledge and Core Knowledge

Order picking path planning involves determining the most efficient path in the warehouse to minimize picking time and distance. This problem has the following characteristics: 1) Complexity: limited by factors such as warehouse layout, product location, and order combination. 2) Dynamic: Order demand and product location may change, affecting the results of path optimization. 3) Target diversity: including minimizing total distance, reducing picking time, and lowering costs [4].

The optimization of picking paths is usually solved using linear programming (LP) models. The LP model involves the following core knowledge: 1) Decision variables: variables that define specific path choices. 2) Constraints: including warehouse layout, product location, and path selection restrictions. 3) Objective function: Minimize the total picking distance or time. These models are typically solved through optimization algorithms and take into account various factors such as picking orders, product storage location, and warehouse layout [5].

2.2 Model Principles and Processes

The basic principle of the LP model is to solve the optimal solution by establishing an objective function and constraints. The typical process includes: 1) Modeling: Define objective functions and constraints. 2) Solution: Use optimization algorithms to solve linear programming models, such as simplex or interior point methods. 3) Application: The optimization results are applied to actual picking path planning [6].

3. The Application Results of a Model or Method

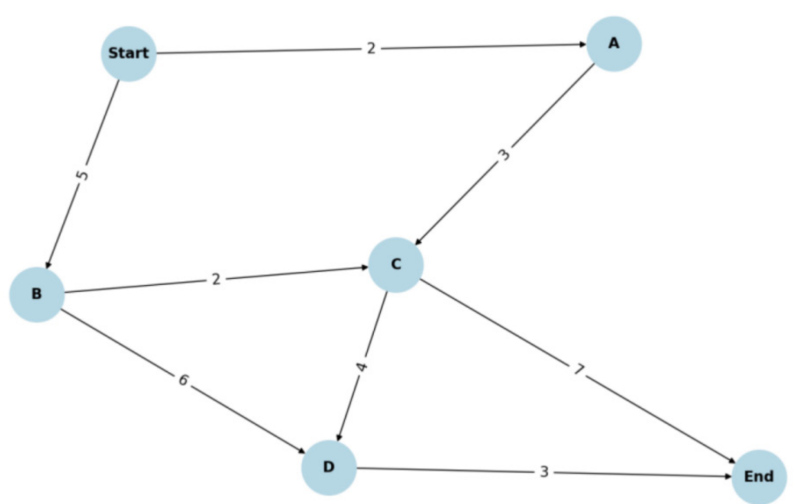

Fig. 1. Order Picking Path Optimization (Photo credit: Original)

Fig. 1 shows a linear programming chart that depicts a typical warehouse layout optimized for order extraction. In Fig. 1, each node corresponds to a different storage location in the warehouse. For example, node A may represent an area for storing electronic products, while node B may be dedicated to clothing. Each node can have specific attributes, such as the number of items to be selected, the type of products stored, and the priority of these items. These attributes are crucial for determining the importance of accessing certain nodes and are key to optimizing the selection process.

Furthermore, the edges in Fig. 1 represent potential routes between different storage locations, corresponding to actual channels or paths within the warehouse. Each edge has a weight, usually reflecting the distance or time from one node to another. The goal is to minimize the total weight, thereby reducing the total travel distance or time. In addition, there may be constraints at the edge, such as traffic congestion or restricted access during specific times, which must be taken into account for optimization. Specifically, the main objective of a linear programming model is to minimize the total distance or time required to extract the order. This is achieved by selecting the optimal path that connects all required nodes while adhering to the given constraints.

It's worth mentioning that the solution must ensure that the selected path accesses all nodes that need to be selected. In other words, the solution must ensure that each node is accessed only once. If there are limitations on the number of items that can be picked up during a trip or the carrying capacity of the picker, these need to be included as constraints in the model. Time windows: If certain nodes can only be accessed within a specific time period, these time windows need to be integrated into the optimization model.

This problem is mainly solved using linear programming, with the goal of minimizing the total travel distance or time under certain constraints. In addition to linear programming, heuristic algorithms and intelligent optimization algorithms can also be used to solve this problem, but this article mainly focuses on the solution methods of linear programming (LP). Various linear programming solvers can be used to find the optimal solution to the problem. The detailed information is consistent with the chart (Fig. 1) and provides insights into various components and their significance in optimizing sequence selection paths [7-9].

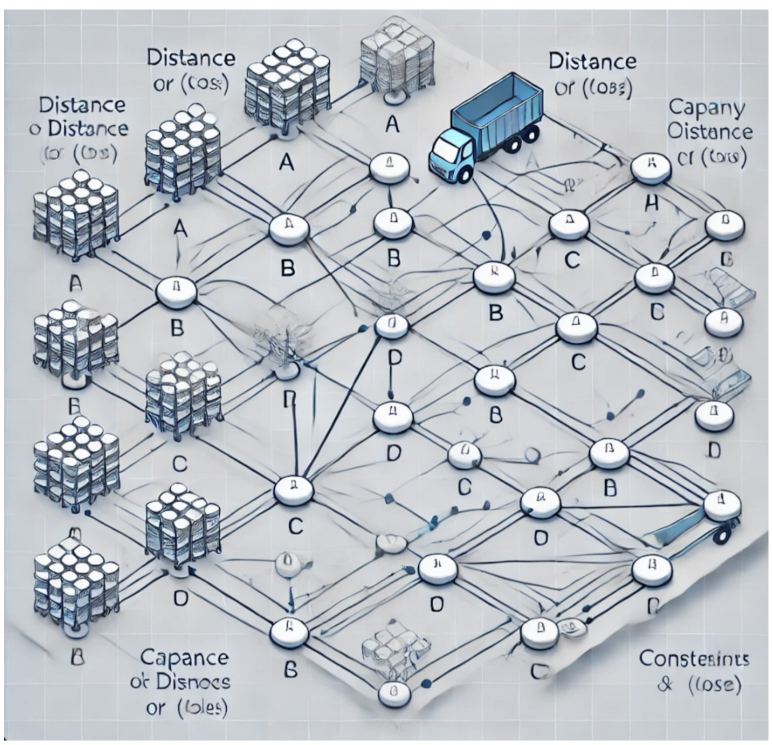

Fig. 2. Order picking Path Optimization (Photo credit: Original)

This Fig. 2 illustrates the use of linear programming techniques to optimize order picking paths within warehouses or distribution centers, to minimize travel distance or time. This flowchart visually illustrates the complexity of optimizing picking paths to improve logistics efficiency and reduce costs while adhering to constraints.

The key components include: 1) Nodes represent specific storage locations, while paths represent possible routes between them, as well as associated costs such as distance or time. The path starts from a specified point and ends when all items are collected. 2) The binary variable represents whether the path between nodes is included in the optimal route. 3) The goal is to minimize the total cost, such as travel distance or time. 4) Ensure that the path

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starts and ends at the specified point, access each required node once, and comply with capacity and time constraints. The linear programming model shown in Fig. 2 is a powerful and direct tool for optimizing sequential picking paths. This model analyzes various possible routes and constraints systematically to determine the most effective path, ultimately saving costs and improving operational efficiency [10,11]. Applications of the model include the following: 1) Warehouse management: This model is used to improve the efficiency of picking orders in the warehouse, thereby reducing labor costs and accelerating order completion speed. 2) Logistics and supply chain: It plays a crucial role in simplifying the logistics process by reducing the time and resources required to select and transport orders. 3) E-commerce fulfillment: This method is particularly beneficial for large-scale e-commerce operations, where quickly completing orders is crucial for maintaining customer satisfaction.

4. Limitations and Future Prospects

Current research indicates that linear programming is highly effective in optimizing picking paths. Both single objective and multi-objective optimization methods have shown their advantages in practical applications. However, existing research still has certain limitations.

4.1 Limitations

Most current LP models assume a static warehouse layout where product positions and order requirements remain unchanged during the picking process. This assumption does not take into account real-time fluctuations, such as dynamic changes in order volume, product location, or unexpected interruptions in the warehouse environment, which can have a significant impact on the optimization process. When applied to large or complex distribution centers, the computational cost of LP models may become very high. As the number of nodes (storage locations) and constraints increases, the size of the model grows exponentially, resulting in longer computation time. This may hinder the real-time applicability of the model, especially in fast-paced environments that require quick decision-making. Although LP models are suitable for small and medium-sized warehouses, they may be difficult to efficiently scale in larger or more complex operations. An increasing number of products, storage locations, and picking routes may overload the model, leading to suboptimal solutions or requiring significant computational resources. The objective function in LP models usually focuses on minimizing travel distance or time. However, this simplification may not fully capture the complexity of real-world warehouse operations. Factors such as picker fatigue, warehouse traffic, and different order priorities are often not included in the model, which may result in suboptimal solutions in practice. Many LP models are designed for single objective optimization, which may be inconsistent with the multifaceted objectives of modern logistics operations. For example, a warehouse may need to strike a balance between minimizing picking time and maximizing picker safety or reducing energy consumption. LP models typically require significant modifications or extensions to effectively handle multiple objectives. The adaptability of LP model to real-time changes in warehouse environment is limited. In a dynamic environment where product positions or order priorities frequently change, traditional LP models may not update quickly enough to provide the best solution. This lack of real-time adaptability may lead to low efficiency or increased operating costs [12].

4.2 Future Outlook

Firstly, in terms of real-time adaptability, it is crucial to develop models that can efficiently process real-time data and quickly adapt to various dynamic changes in an increasingly complex and ever-changing logistics environment. This requires in-depth research on how to utilize the latest advances in machine learning and artificial intelligence technology to accurately predict changes in order demand and real-time fluctuations in product location. Based on these predictions, it is necessary to further explore how to dynamically adjust the picking path to ensure the flexibility and responsiveness of logistics operations, in order to meet customer needs and optimize overall operational efficiency.

Secondly, in the field of algorithm improvement, actively explore the potential applications of heuristic algorithms and intelligent optimization algorithms in picking path optimization. These advanced algorithms are expected to significantly improve computational efficiency, enabling more effective handling of complex problems such as large-scale order processing and multi product picking. Through continuous iteration and optimization of algorithms, we can expect greater breakthroughs and progress in picking path planning.

Finally, to achieve overall optimization of the logistics system, it is necessary to closely integrate picking path optimization with other key logistics functions such as inventory management and transportation scheduling. This integration will help provide a more comprehensive and integrated logistics solution. In this process, it is necessary to fully utilize multi-objective optimization methods, comprehensively consider multiple dimensions such as cost, time, and resource utilization, to ensure the achievement of global optimality. This method not only requires technological innovation, but also a profound transformation of the overall logistics management strategy. These efforts are expected to lead to more efficient, intelligent, and sustainable development in the field of logistics in the future [13].

5. Conclusion

This article reviews the research progress of using linear programming to optimize ordered picking paths, and emphasizes its key role in improving operational efficiency and reducing costs. Through literature review and case studies, the practical effectiveness of linear programming methods has been confirmed. Despite some limitations, research has shown that adopting advanced mathematical models can significantly improve the picking path of logistics centers and enhance overall performance. Future research should continue to improve these models and explore their integrated applications to better respond to the constantly changing logistics demands

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