

Research on Personnel Scheduling Optimization in Logistics Sorting Centers Based on Linear Programming and Heuristic Algorithms

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Abstract. With the rapid development of the logistics industry, the efficient operation of logistics sorting centers is crucial to the entire supply chain's efficiency. Staff scheduling, as a key aspect of the daily operations of sorting centers, directly impacts the control of labor costs and the job satisfaction of employees. To address the scheduling problem and enhance operational efficiency, this study proposes a personnel scheduling optimization model for logistics sorting centers based on linear programming and heuristic algorithms. Firstly, this paper analyzes the sorting center's cargo volume data and staffing requirements, clarifying the goal of scheduling optimization to meet workload demands while minimizing the total number of workdays, taking into account the different characteristics of regular and temporary workers, as well as legal regulations on working hours. Subsequently, a standard linear programming model is constructed, with the number of regular and temporary workers for each shift of every day as decision variables, to minimize the total workdays through linear optimization. However, due to the expansion of the problem scale, the solution time for the linear programming model has increased significantly. Therefore, a heuristic search algorithm is introduced to find an approximate optimal solution. Ultimately, through the analysis of actual cases, the effectiveness and practicality of the proposed model and algorithm are verified. This study's research not only provides a new method for personnel scheduling optimization in logistics sorting centers but also offers a reference for other industries requiring personnel scheduling optimization. Future research can further explore the applicability of the model in sorting centers of different scales.

Keywords: Linear Programming; Heuristic Algorithm; Staff Scheduling; Logistics Sorting Center; Scheduling Optimization.

1. Introduction

In the modern logistics industry, sorting centers act as the core hub of the logistics network, and their efficient operation is crucial for the smoothness of the entire supply chain [1]. The operational efficiency of sorting centers not only affects the speed of goods turnover but is also directly related to the control of logistics costs and the quality of customer service experience. Among them, staff scheduling, as an important part of the daily management of sorting centers, has a significant impact on improving work efficiency, reducing labor costs, and protecting the rights and interests of employees [2].

However, due to the fluctuating workload of sorting centers, combined with the differences in cost and efficiency between regular and temporary workers, as well as the legal regulations on working hours, the problem of scheduling optimization becomes complex and challenging. Traditional scheduling methods often rely on experience and intuition, which are difficult to cope with the rapidly changing operational demands and the increasing number of employees. Therefore, how to scientifically carry out staff scheduling to achieve balanced distribution of workload, minimize the total number of workdays, and take into account the balance between work and rest for employees has become an urgent problem to be solved in the field of logistics management [3].

In response to this issue, this paper proposes a study on personnel scheduling optimization based on linear programming and heuristic algorithms [4, 5]. Through the linear programming model, we can develop a reasonable scheduling plan while meeting the workload requirements, taking into account the different characteristics of regular and temporary workers. The introduction of heuristic algorithms aims to solve the computational problems in large-scale scheduling issues, quickly find

approximate optimal solutions, and improve scheduling efficiency and quality. This study not only provides a new method for personnel scheduling optimization in logistics sorting centers but also offers a reference for other industries that require personnel scheduling optimization [6].

Next, this paper will introduce in detail the analysis of the problem and the establishment and solution process of the model, and evaluate the model, in order to provide a feasible solution for practical applications.

2. Establishment of Model

The core objective of this study is to optimize the efficiency of personnel usage while ensuring the fulfillment of cargo volume demands, which is approached from two main aspects: firstly, by ensuring that the cargo volume requirements for each shift are adequately met; secondly, by optimizing the scheduling plan for both regular and temporary workers. Given the differences in cost and efficiency between regular and temporary workers, as well as potential legal or contractual restrictions (such as the maximum number of consecutive working days), we have chosen to employ linear programming or mixed-integer programming methods to address these challenges. Additionally, considering the potential overlap in shift times, we have developed an algorithm that first allocates orders over time to ensure a balanced distribution of orders between shifts, followed by the optimization of personnel scheduling.

Taking into account the time overlap between shifts, we initially allocate the cargo volume for each hour to the respective shifts, with the aim of maintaining a relative balance of cargo volume for each shift. This step facilitates a balanced distribution of personnel in subsequent scheduling optimization. In terms of scheduling optimization, we consider the number of regular and temporary workers for each shift of each day as variables and use a linear optimization model to seek a solution that minimizes the total number of workdays.

2.1. Balanced distribution order optimization

Because of the time overlap between different shifts, simply assigning an hourly load to one shift can cause balance issues. In order to avoid this situation, we introduce order balanced allocation method for optimization. In this method, we first set O_t to the order quantity in the t hour. Let S represent the set of all shifts, and each shift $s \in S$ is represented by $s = (\text{start}, \text{end})$, i.e. its start and end times. Let C_s be the order count in shift s .

For each hour t , we first find the set of shifts $A_t \subseteq S$ that can process orders for the t hour, defined as $A_t = \{s \in S | \text{start} \leq t < \text{end}\}$. Then, the shift s^* with the lowest order count is found in the set A_t , defined as $s^* = \arg\min_{s \in A_t} C_s$, and the order quantity in the t hour is added to C_{s^*} , that is, update $C_{s^*} = C_{s^*} + O_t$. This way, we can ensure a balanced shift allocation for all hours of order volume.

2.2. Personnel scheduling optimization

In this study, we treated the number of permanent and temporary employees per shift per day as a decision variable, with the goal of minimizing the total number of days worked while ensuring that the volume of goods per shift was handled. This scheduling optimization problem is then constructed as a linear optimization problem to be solved.

By defining the number of official labor assigned to shift s on day d as X_{regds} , and X_{tempds} as the number of temporary workers assigned to shift s on day d , we can get the number of days that the objective function minimizes the total population as follows.

$$\text{Minimize } \sum_{d=1}^D \sum_{s=1}^S (x_{regds} + x_{tempds}). \quad (1)$$

For constraints, we need to ensure that the quantity of goods per shift is handled as follows.

$$\forall d \in \{1, \dots, D\}, \forall s \in \{1, \dots, S\}, E_{reg} \cdot x_{regds} + E_{temp} \cdot x_{tempds} \geq L_{ds}. \quad (2)$$

It is also necessary to ensure that the number of regular workers per day does not exceed the total number and that each person is only allowed to work one shift per day.

$$\forall d \in \{1, \dots, D\}, \sum_{s=1}^S x_{reg_{ds}} \leq R. \quad (3)$$

In addition, it is also necessary to prioritize the use of regular employees and ensure the priority of regular employees.

$$\forall d \in \{1, \dots, D\}, \sum_{s=1}^S x_{reg_{di}} = R. \quad (4)$$

2.3. Specific scheduling optimization problem

Based on the above balanced order allocation and scheduling optimization problems, we get the specific number of regular and temporary employees in each sorting center every day, and these results are shown in Table 1.

Table 1. Results of personnel assignment in some sorting centers.

Sorting Center	Date	Classes	Number of Permanent Workers	Number of Temporary Workers
SC54	2023/12/1	00:00-08:00	10	10
SC54	2023/12/1	05:00-13:00	7	7
SC54	2023/12/1	08:00-16:00	32	32
SC54	2023/12/1	12:00-20:00	6	6
SC54	2023/12/1	14:00-22:00	2	2
SC54	2023/12/1	16:00-14:00	3	3
SC54	2023/12/2	00:00-08:00	7	7
SC54	2023/12/2	05:00-13:00	25	25
SC54	2023/12/2	08:00-16:00	8	8
SC54	2023/12/2	12:00-20:00	7	7
SC54	2023/12/2	14:00-22:00	6	6
SC54	2023/12/2	16:00-24:00	7	7
SC54	2023/12/3	00:00-08:00	0	0
SC54	2023/12/3	05:00-13:00	0	0

3. Model Optimization

Schedule a detailed schedule for each permanent employee and handle the increase in the number of employees. Considering the constraints of attendance and continuous working days, the solving time of linear optimization problems is greatly extended. In order to solve this problem, a heuristic search algorithm is proposed to solve this optimization problem effectively.

The core strategy is to first ensure that there are enough regular employees per shift to complete the required workload. If there is a shortage of regular staff, temporary staff will be brought in to

supplement the necessary workload. When assigning work, priority is given to those regular employees with fewer schedules, with the aim of balancing the workload among employees as much as possible. This approach not only simplifies the complexity of the problem, but also quickly finds the approximate optimal solution on the basis of maintaining the optimization quality, in order to reduce the total labor cost, while ensuring the uniformity of employee work arrangements.

3.1. Linear optimization model

In the process of solving the scheduling optimization problem, this study takes the number of regular and temporary workers in each shift of each day as the decision variable, and adopts linear optimization to minimize the total working days on the basis of ensuring that the cargo volume of each shift is processed.

Define a binary variable X_{rds} that takes a value of 1 if and only if the regular worker r works on shift s on day d , and 0 otherwise. At the same time, the variable Y_{ds} is defined to represent the number of temporary workers required for shift s on day d .

$$\min \sum_{d=1}^D \sum_{s=1}^S (\sum_{r=1}^R x_{rds} + y_{ds}). \quad (5)$$

For constraints, we need to ensure that the quantity of goods per shift is handled as follows.

$$\sum_{r=1}^R x_{rds} \cdot E_{reg} + y_{ds} \cdot E_{temp} \geq P_{ds} \quad \forall d \in \{1, \dots, D\}, s \in \{1, \dots, S\}. \quad (6)$$

It is also necessary to ensure that the total number of days of attendance per regular employee does not exceed 85%.

$$\sum_{d=1}^D \sum_{s=1}^S x_{rds} \leq C_{max} \quad \forall r \in \{1, \dots, R\}. \quad (7)$$

In addition, it is also necessary to ensure that the consecutive days of attendance of each regular worker cannot exceed 7 days.

$$\sum_{i=0}^7 \sum_{s=1}^S x_{r,d+i,s} \leq 7 \quad \forall r \in \{1, \dots, R\}, d \in \{1, \dots, D-7\}. \quad (8)$$

We know that the number of decision variables and constraints reaches hundreds, which makes it impossible to seek the global optimal solution from the perspective of optimal chemistry. Therefore, we also need to employ heuristic search methods to find solutions.

3.2. Heuristic allocation algorithm

In addressing the complexity of the personnel scheduling optimization problem, particularly when the number of employees increases and the constraints on attendance rates and consecutive working days are considered, the traditional linear programming approach may become computationally intensive and time-consuming. To circumvent this challenge, this study introduces a heuristic allocation algorithm designed to efficiently navigate the solution space and identify near-optimal solutions in a reasonable timeframe.

The heuristic algorithm is initialized with parameters defining the scheduling horizon, the number of shifts per day, and the total number of regular workers. The algorithm also takes into account the efficiency rates of both regular and temporary workers, as well as the predicted cargo volume for each shift. The decision variables are binary indicators for regular worker assignments and integer counts for temporary worker allocations.

The algorithm proceeds by iterating through each day and shift, attempting to allocate sufficient regular workers to meet the cargo volume requirements. Should the available regular workers fall short of meeting the demand, the algorithm calculates the necessary number of temporary workers to cover the remaining workload. This process ensures that each shift is adequately staffed while prioritizing the scheduling of under-allocated regular workers to balance the workload among employees.

The heuristic allocation algorithm operates under the following steps:

1. Initialization: Set the scheduling period ($D=30$), the number of shifts per day ($S=6$), the total number of regular workers ($R=200$), as well as the efficiency of regular workers ($E_{reg} = 25$), unit cargo volume/shift) and the efficiency of temporary workers ($E_{temp} = 25$), the predicted cargo volume of shift s on day d (P_{ds}).

2. Constraint setting: Establish constraints to ensure that the total attendance of each regular worker does not exceed 85% of the schedule period, and that no regular worker works more than 7 consecutive days.

3. Algorithm allocation: go through every day d and every shift s . For each shift, try to assign enough regular workers to meet it. If regular work is not sufficient, calculate the number of temporary workers required.

4. Assign work: For each regular worker r , check whether it is available to work (taking into account attendance and limit of consecutive working days). Prioritize the allocation of less scheduled regular work until volume demands are met or all available regular work is allocated.

5. Temporary worker demand calculation: For each shift, if the surplus volume is not fully processed by the regular workers, the number of temporary workers required is calculated.

3.3. Scheduling results

The heuristic approach allows for a balance between the quality and computational efficiency of the solution, making it suitable for real-world applications where decision makers need actionable insights within a limited time frame. Based on this, we can obtain the final optimization results, as shown in Table 2.

Table 2. Results of personnel assignment in some sorting centers.

Sorting Center	Date	Classes	Number of regular workers
SC25	2023/12/15	16:00-24:00	Permanent worker190
SC25	2023/12/15	16:00-24:00	Permanent worker191
SC25	2023/12/15	16:00-24:00	Permanent worker192
SC25	2023/12/15	16:00-24:00	Permanent worker193
SC25	2023/12/15	16:00-24:00	Permanent worker194
SC25	2023/12/15	16:00-24:00	Permanent worker195
SC25	2023/12/15	16:00-24:00	Permanent worker196
SC25	2023/12/15	16:00-24:00	Permanent worker197
SC25	2023/12/15	16:00-24:00	Permanent worker198
SC25	2023/12/15	16:00-24:00	Permanent worker199
SC25	2023/12/15	16:00-24:00	Permanent worker199
SC25	2023/12/15	16:00-24:00	Permanent worker200
SC25	2023/12/15	16:00-24:00	Temporary workers1
SC25	2023/12/15	16:00-24:00	Temporary workers2
SC25	2023/12/15	16:00-24:00	Temporary workers3
SC25	2023/12/15	16:00-24:00	Temporary workers4
SC25	2023/12/15	16:00-24:00	Temporary workers5
SC25	2023/12/15	16:00-24:00	Temporary workers6
SC25	2023/12/15	16:00-24:00	Temporary workers7
SC25	2023/12/15	16:00-24:00	Temporary workers8
SC25	2023/12/15	16:00-24:00	Temporary workers9
SC25	2023/12/15	16:00-24:00	Temporary workers10

Table 2 shows the specific situation of personnel attendance at the sorting center, which is derived through a heuristic allocation algorithm, taking into account factors such as cargo forecast, employee productivity, legal working hours limits, and employee benefits. Based on the sorting center, the table lists the number of regular and temporary workers per shift by day and shift, ensuring that there are enough people for each shift to handle the expected volume of goods, while also balancing the work and rest time of employees, optimizing the allocation of human resources, and reducing the overall

labor cost. In addition, the results in Table 2 not only provide clear guidance for immediate scheduling at the sorting center, but also provide valuable data support for future HR planning and operational decisions.

4. Conclusion

This study addresses the staff scheduling problem in logistics sorting centers by proposing a scheduling optimization model that integrates linear programming with heuristic algorithms. Through actual case analysis, the model has been validated to effectively minimize the total number of workdays while meeting workload demands, taking into account the different characteristics of regular and temporary workers, as well as legal regulations on working hours. The research findings indicate that the proposed model and algorithm provide a new method for scheduling optimization in logistics sorting centers, with high practical value and reference significance.

The linear programming model can precisely handle scheduling issues, but as the problem size increases, the solution time increases significantly. To address this, the heuristic search algorithm introduced improves solution efficiency while maintaining optimization quality, enabling the rapid identification of near-optimal solutions. The flexibility and efficiency of the heuristic algorithm make it an effective tool for dealing with large-scale scheduling problems. However, every model has its limitations. This model assumes that the cargo volume forecasts for all sorting centers can be conducted independently, neglecting the complex interactions between networks. Additionally, the model has not fully considered other factors that may affect scheduling, such as employee preferences, skill differences, and non-working day demands.

Future research can explore the application of the model to different types of logistics centers and consider personalized employee needs to further enhance the adaptability and satisfaction of the scheduling system. Moreover, studying real-time dynamic scheduling strategies to adapt to the ever-changing operational demands is also a valuable direction.

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