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Human Resource Scheduling in Urban Rail Stations Considering Multi-Personnel Skills

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Abstract: The rapid development of urban rail systems and the growing number of passengers brought significant challenges to the operation of urban rail system. Scientific and reasonable human resource scheduling at urban rail stations plays a vital role in ensuring efficient operation and management of urban rail system. Traditional human resource scheduling methods often concentrated in a single station, and adopts the scheduling mode of fixed time posts, and there are some problems such as managers using the mode of experience scheduling, neglects the characteristic of operation tasks and the skill characteristics of personnel at urban rail stations. To address this problem, this study combines the reality of skill matching between employees with different levels and skills, so as to propose a multi-objective human resource scheduling model that takes into account the characteristics of multi-skill of personnel. Meanwhile, in order to be able to guide the actual production activities, three different scenarios are considered for this purpose, and the validity of the model is verified by analyzing the variables. The results indicate that by incorporating employee skill factors into the human resource scheduling of subway stations, the utilization of skills can be effectively optimized, thereby improving service quality and operational efficiency, and at the same time, the adaptability of the system to cope with different passenger demands can be enhanced, and the system has stronger resilience to interference. The outcome of the present work is significant for improving human resource utilization and operation efficiency of urban rail stations, further facilitates the promotion and sustainable development of urban rail systems.

Keywords: human resource management; urban rail stations; tabu search; multi-skill

1. Introduction

In the context of global urbanization, transportation is undoubtedly a key force in promoting social development. Urban rail, as the main body of passenger flow in urban rail polis, its contribution to urban development is not to be underestimated [1]. By the end of 2021, more than 50 cities in China have opened urban rail transportation, with an operation history of up to 9192.62 km, of which the urban rail operation mileage accounts for 78.9% [2]. Similarly, urban rail still accounts for the majority of passenger traffic in the Washington area, with an average of 600,000 weekday trips [3]. As the core of urban rail operation and management, station personnel can only ensure the normal operation of stations and urban rail network by reasonably arranging the tasks of station personnel. In the past, human resource scheduling mainly relied on experienced scheduling to draw spreadsheets, which was not only time-consuming and laborious, but also prone to errors, resulting in a waste of human resources [4]. The productivity of human resources is one of the most important factors in economic decision-making, and efficient and reasonable human resources can effectively promote the improvement of public welfare. The ultimate goal of human resource scheduling in urban rail stations is to improve the operational efficiency of the enterprise, create higher economic benefits for the enterprise as well as ensure the normal operation of society [5–8].

According to an investigation, in the operation of urban rail stations, the organization of passenger transportation is mainly responsible for the station service department. The station service part is the largest personnel base and the most complex business in urban rail operation. The organizational relationship and processing business of station service employees in urban rail stations are relatively complex: on the one hand, the station service center manages the personnel hierarchically with a variety of organizations such as station service, security, electromechanical, cleaning, etc., and different groups have different persons in charge; on the other hand, the station service work is interlocked, and different organizations are responsible for different locations and tasks within the station with a relatively high degree of exclusivity. In addition to having different levels of qualifications, employees in urban rail stations are also multi-skilled. A shift consists of different levels of station personnel, each with all the skills required. Each segment of the task requires at least two employees in the group to perform collaborative tasks, with a relatively large variety of segments and personnel. The current station scheduling is mainly based on the shift as the smallest unit of personnel management, the personnel scheduling of each shift is decided by the team leader according to the actual work situation, the formulation of scheduling program has a large degree of subjectivity and randomness, the lack of macro-integration and coordination, the personnel arrangement of the various tasks have certain problems, prone to redundancy or lack of personnel, thus affecting the overall efficiency of the work [9].

Human resources occupy a unique position among the factors of production, and efficient human resource scheduling is particularly important as a key factor that coordinates other factors and significantly affects productivity [7]. Human resource scheduling itself is a resource-constrained problem, so the acronym: "HRCPSP" (Human Resource-Constrained Project Scheduling Problem) is used. This problem has been studied across a wide range of industries, including railroads [10], mail centers [11], emergency response [12], and healthcare [13], and is particularly critical in labor-intensive industries. When considering human resource scheduling, the central issue is how to maximize the potential of manpower at the lowest cost, while considering the impact of time in special situations [7]. Specifically, human resource scheduling focuses on two main aspects: on the one hand, shift design [14–23]. Shift design is a key aspect to protect employees' rights and interests while meeting production demands. Some studies usually consider employees' rest time [14] by designing the rest time window in order to balance the actual demand and employees' work experience. However, separate studies of rest and work time cannot fully satisfy the actual needs, so some studies have determined the optimal shift time period by setting the start and end times of shifts [15,16]. However, previous studies studied rest time and work time separately and lacked discussion on the continuity of shift design. Hung's studies [17–19], on the other hand, fill the gap in the discussion of shift design continuity. Nonetheless, such studies still lack consideration of the relationship between time and demand. Seckiner [20] and Feng [21], on the other hand, made initial refinements to the shift design process by studying multi-shift design, which integrates demand changes with shift design. In the solution process of shift design, different scholars choose different methods according to different problem characteristics. Seckiner [20] establishes an integer planning model for the hierarchical workforce problem under the compressed workweek and uses the idea of the compressed workweek and the branch-and-bound algorithm to solve the problem. Tang [22] proposes a task replication method under the hierarchical qualification scenario, and uses the tabu search algorithm to reduce the complexity of neighborhood search to solve the problem. Lu et al. [23] address the constraints such as shift type and employee qualification unknown, first generates a feasible solution that satisfies the employee qualification and shift type, and then designs a block Gibbs-based playback sampling algorithm to optimize the shift type as well as the workgroup composition in conjunction with the working hours.

On the other hand, skill matching [24–37]. Considering collaboration among employees in shift design is usually done through skill matching. The challenge of skill matching is how to effectively integrate employees' skills into their work, which is a great challenge for managers [26]. The utilization of human resources and organizational capabilities can be significantly improved through multi-skill matching. However, it also increases the complexity of the quantity demand problem, as the solution needs to focus on the demand for differently skilled personnel across shifts, while considering the time and cost issues associated with different skills [28]. To deal with the Multi-skilled Human Resource Scheduling Problem (MSPSP), researchers have adopted various approaches. Dai et al. [29] proposed the concept of "skill stabilization" to simplify the problem of allocating multi-skilled workers to single-skilled workers. Akbari et al. [30] developed a methodology to maximize employee satisfaction. developed a model with the objective of maximizing employee satisfaction and found the optimal solution through simulated annealing and variable neighborhood search algorithms. Zhu et al. [35] solved the multi-skilled resource-constrained project scheduling problem and constructed the model with the objectives of maximizing the completion time and minimizing the total cost, respectively. A fairly sophisticated system already exists for the multi-skilled worker scheduling problem. However, most of the current studies focus on qualitative analysis and propose a series of scheduling strategies, but these analyses often lack sufficient data support [5,7,13–16].

To summarize, human resource scheduling is a complex and critical management task that combines factors such as shift design, skill matching, and cost time. As an important part of the city's lifeline, the urban rail system plays a vital role in the smooth operation of society. As a crucial factor in operation, human resources, whether its scheduling is reasonable or not, directly affects the operation effect of rail and then affects the society [6]. The human resources of urban rail are usually divided into the scheduling of crew and station employee, the scheduling of crew refers to the scheduling of the employees on the train, while the scheduling of station employee refers to the scheduling of the employees at the rail stations. Although a few studies have explored the scheduling of crews through quantitative analysis, these studies usually do not consider the need for 24/7 work, especially the scheduling of station employees [4,36]. While stations, as nodes of the urban transportation system, often bear the brunt when the system suffers from disturbances or impacts, and the impaired performance of the stations will directly affect the normal operation of the whole system. Therefore, it is particularly important to conduct an in-depth study on Human Resource-Constrained Project Scheduling Problem on Urban Rail Station (HRCPSP-URS). There is a significant difference in the scheduling needs of the crews and station employees: crews usually run with the train and the train does not run 24/7, which means that the crews scheduling can be done without regard to all-day work demands. In contrast, station employees need to meet the needs of all-weather work, not only in the daytime to ensure the normal operation of the station, but also at night to carry out maintenance and overhaul of facilities to ensure the normal operation of the rail station. As a key node of the urban rail transportation network, the station's operation status directly affects the efficiency and safety of the entire rail transportation system [36]. Currently, there is a relative lack of research on human resource scheduling from the perspective of stations. Unlike human resource scheduling in general scenarios, HRCPSP-URS needs to consider the cooperative work of different skills of employees and the scheduling of full-day work schedules, which has not been fully explored in existing studies [38]. This study aims to fill this research gap and propose human resource scheduling strategies suitable for urban rail station scenarios through in-depth analysis and research in order to improve the efficiency and effectiveness of station operations.

While solving the human resource scheduling, there are many choices of algorithms for the human resource scheduling problem. Common heuristic approaches include particle swarm algorithms [34,39,40], ant colony algorithms [11], neural networks [41], and CPLEX [42]. Additionally, some recent studies have discussed the applications of BWR and BMR algorithms in optimization and operational contexts, demonstrating their potential in handling specific constraint types [43,44]. However, considering the complex characteristics of multi-skill, multi-level, and multi-shift scheduling in this study, the most commonly used and effective method remains the tabu search algorithm [38,45–47].The advantage of applying it to the human resource scheduling problem is that it can solve complex problems with a large number of candidate solutions, such as multi-skill, multi-level, and multi-shift scheduling in the employee scheduling problem. Tabu search tends to converge to high-quality solutions more rapidly than other heuristic algorithms, making it particularly valuable for time-sensitive scenarios. Existing studies in relevant fields have widely adopted this algorithm, mainly due to its low sample size requirement and computational simplicity. Compared with heuristic algorithms employed in other literature, tabu search demonstrates superior performance in terms of both speed and accuracy. Therefore, the application of tabu search algorithms to human resource scheduling can serve as an effective optimization tool for urban rail systems, helping them meet professional skill requirements, cut operational costs, and improve overall resource utilization efficiency.

Therefore, this study aims to ensure that all tasks in urban rail operations are efficiently accomplished through effective scheduling of personnel at urban rail stations; at the same time, rational human resource scheduling can also reduce the additional costs associated with over- or underemployment.

Its main contributions can be summarized as follows:

- A multi-objective human resource scheduling optimization model considering the skill factor of the personnel is proposed with the multinomial cost as the objective function and solved using the tabu search algorithm;
- In order to validate the proposed modeling framework, numerical experiments and sensitivity analyses are performed with real data.

The remaining parts of this paper are organized as follows. Section 2 describes and discusses the complexity of the problem. Section 3 presents the results and analysis of the computational experiments. Section 4 concludes and discusses the practical implications, limitations, and future research directions.

2. Model Building

2.1. Problem Description

Based on the field research, this study summarizes some characteristics of HRCPSP-URS:

Although the hourly passenger flow at the station is changing, the station's human resource scheduling is based on a fixed number of shifts and employees. Usually, each station has fixed morning and evening shifts and alternate shifts every day.

Even in an ordinary station there is still an intricate management with different working groups such as security, inspection, electrical maintenance and station management. The staffing of different work groups is determined by their respective leaders. In particular, for station managers, different types of station management tasks require different skill sets. The station management structure is categorized into three levels based on the experience and qualifications of the personnel: Station Area Managers (responsible for multiple stations), Duty Officers (responsible for one station per shift), and Normal employee (members of the shift team).

In urban rail stations, different levels of personnel possess different numbers of skills, and even personnel at the same level may have different skill sets. (See in Table 1.) In general, higher-level personnel have more experience and skills, including skills specific to their level, than lower-level personnel.

In the survey, we found that the daily work of station staff can be roughly divided into several types, namely, unified scheduling in the office, serving passengers in the station, and being responsible for the normal operation of the station and other tasks.

Table 1. Multi-skill human resource scheduling diagram of urban rail station.

	Task A	**Task B**	**Task C**	**Task D**	**Task E**
Employee 1, S: {A, B, C, D, E}	√	√	√	√	√
Employee 2, S: {A, B, D}	√	√	×	√	×
Employee 12, S: {B, D}	×	√	×	√	×
Employee 24, S: {D}	×	×	×	√	×

√: Execute; ×: Can't execute.

2.2. Model Hypothesis

Based on what we know about the station, this is abstracted into the following hypothesis:

- Personnel requirements are divided into time period, with different personnel requirements for different time periods; different in this case means that the amount and type of tasks vary from one time period to the next, and therefore the personnel requirements are different.;
- Station employees have a variety of skills that allow them to perform a variety of tasks in different roles. Although station employees possess a variety of skills, the skills remain stable over time and there are no differences in skill efficiency between employees;
- The cost is divided into two parts, one is the start-up costs, which depend on the type of shift and the level of the employee. The longer the shift and the higher the level of the employee, the higher the salary; the other part is the additional cost, where there is a fixed number of personnel for each shift. When the regular shift size is difficult to cope with, the number of shifts will be increased and additional allowances will be paid to those who exceed the normal shift size.

2.3. Model Building

To address the HRCPSP-URS problem, we propose a mathematical model that explicitly distinguishes between time periods, shifts, and employee skills. The notations and the integer programming formulation are defined as follows:

(i) Sets and indices

T: Set of time periods, indexed by $t \in \{1,2,\ldots,|T|\}$. In this study, $|T| = 24$, representing hourly intervals.
I: Set of available employees, indexed by $i \in \{1,2,\ldots,|I|\}$.
J: Set of shift types, indexed by $j \in \{1,2,\ldots,|J|\}$. Each shift covers a specific subset of time periods.
K: Set of skills, indexed by $K \in \{A,B,C,D,E\}$.

L: Set of employee levels, indexed by $l \in \{1,2,\dots,5\}$ (where 1 represents the highest seniority).

(ii) Parameters

R_{tk}: Demand for personnel with skill k during time period t.

A_{jt}: Binary parameter, equals 1 if shift j covers time period t, and 0 otherwise.

S_{ik}: Binary parameter, equals 1 if employee i possesses skill k, and 0 otherwise.

$Level_i$: The level of employee i.

$C_j^{\text{base.}}$: Base cost for scheduling an employee to shift j.

C^{extra}: Additional cost per person when the shift size exceeds the standard capacity.

N_{min}: The standard staffing number (threshold) for a shift.

M_{ratio}: The maximum allowable ratio of junior employees to senior employees.

(iii) Decision Variables

x_{ij}: Binary variable, equals 1 if employee i is assigned to shift j, and 0 otherwise.

y_j: Integer variable, representing the number of excess employees assigned to shift j beyond the standard number N_{min}.

(iv) Objective function

The objective is to minimize the total operational cost, which consists of the base salary cost and the extra allowance cost for over-staffing situations.

$$\text{Minimize} Z = \sum_{i \in I} \sum_{j \in J} C_j^{base} \cdot x_{ij} + \sum_{j \in J} C^{extra} \cdot y_j \tag{1}$$

(v) Constraint

$$\sum_{i \in I} \sum_{j \in J} (x_{ij} \cdot A_{jt} \cdot S_{ik}) \geq R_{tk}, \forall t \in T, \forall k \in K \tag{2}$$

$$\sum_{j \in J} x_{ij} \leq 1, \forall i \in I \tag{3}$$

$$\sum_{i \in I} x_{ij} - N_{min} \leq y_j, y_j \geq 0, \forall j \in J \tag{4}$$

$$\sum_{i \in I, Level_i > 3} x_{ij} \leq M_{ratio} \cdot \sum_{i \in I, Level_i \leq 3} x_{ij}, \forall j \in J \tag{5}$$

$$x_{ij} \in \{0,1\}, y_j \in \mathrm{Z} \geq 0 \tag{6}$$

In this mathematical model, Equation (1) represents the objective function, which aims to minimize the total operational cost. This cost is composed of two parts: the sum of the base employing cost for all assigned personnel (C_j^{base}) and the extra cost (C^{extra}) incurred when the number of employees in a shift exceeds the standard staffing threshold. Equation (2) guarantees that for every time period and every specific skill type, the total number of working employees possessing that skill meets the required demand (R_{tk}). Equation (3) ensures that each employee is assigned to at most one shift per day to comply with labor regulations. Equation (4) defines the auxiliary variabley_j, calculating the number of excess employees per shift beyond the standard capacity(N_{min}). Equation (5) represents the team composition constraint to ensure safety: the number of junior-level employees (Level > 3) in any shift must not exceed a specific ratio (M_{ratio}) of the senior-level employees (Level ≤ 3), ensuring that juniors are always supervised. Finally, Equation (6) specifies the domains of the decision variables, requiring x_{ij} to be binary and y_j to be a non-negative integer.

3. Algorithm Building

3.1. Parameter Settings

The algorithmic structure of the tabu search algorithm is relatively simple, but needs to be adapted to the specifics of the optimization problem. One important feature is the neighborhood structure, which determines how the neighborhood is obtained; another important parameter is the list length.

The design divides the day into 24 periods, with a total of five levels of tasks, and several tasks for each level. (See in Table 2.)

Table 2. Different types of tasks at different times of the station.

Period	Task A	Task B	Task C	Task D	Task E
1	1	5	4	8	5
2	2	4	5	1	2
3	4	7	2	4	5
4	5	2	1	3	4
...	...	...	...	...	...
24	2	4	5	6	2

In station work, the level of station employee is generally divided into three levels, and each level has a different number of levels. Level 1 employees are senior managers, Level 2 employees are general managers, and Level 3 employees are ordinary employees. The number of skills of senior employees is higher than that of junior employees, and they have skills that junior employees do not have. For details, see Table 3.

Table 3. Station personnel information.

Employee ID	Employee Level	Employ Skill	Cost	Extra Cost
1	1	A, B, C, D, E	400	
2	1	A, B, C, D, E	400	
3	1	A, B, C, D, E	400	
4	1	A, B, C, D, E	200	
...	...	...		200
14	2	A, D	200	
15	2	A, B, C	200	
...	...	...		
49	3	B	100	
50	3	E	100	

3.2. Domain Construction Settings

Randomly generate the tasks for the duration of each shift. Import the basic personnel information obtained from on-station investigations of subway stations. Based on this, generate random initial solutions that meet the tasks.

Neighborhood actions are a commonly used method in optimization problems, typically employed to improve the current solution in search of a better one. These actions involve exploring potential improvements in the vicinity of the current solution. By making small-scale changes and adjustments in the solution space, the quality of neighboring solutions is evaluated. This aids in finding better solutions within the local region of the problem. In this study, two neighborhood actions, namely replacement and reduction, were utilized based on the specific circumstances. These two actions are the most commonly used methods in real-life scenarios, and according to the survey, the choice between them is made by leaders. Therefore, we believe that these two actions are considered at the same level of consideration. Please refer to Figure 1 for specific examples.

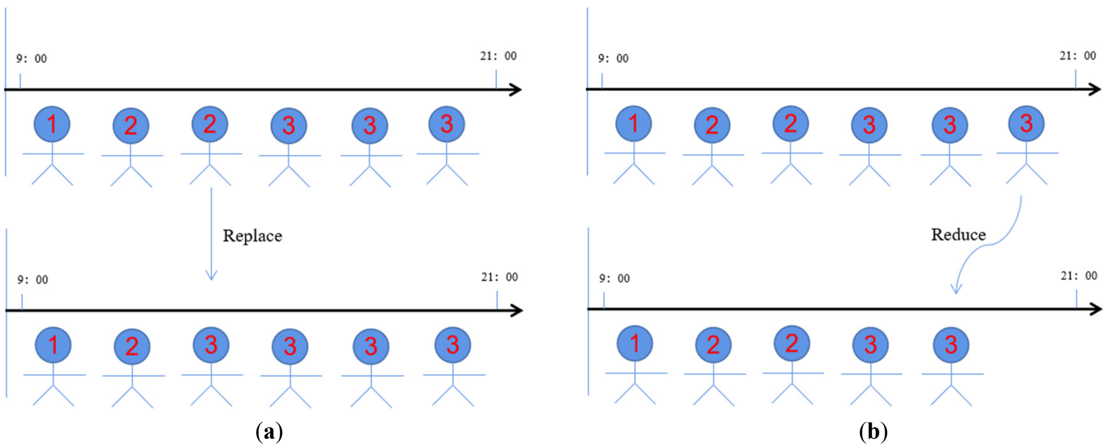

Figure 1. Neighborhood actions: (**a**) Replace; (**b**) Reduce.

3.3. Calculation of Objective Function Values

The fitness function chosen in this paper is the weighted sum of the cost. The size of each target value is used as the final objective function value, and the minimum value of the objective function is considered the optimal solution.

3.4. Update of the Tabu List with Unbanning Rules

The tabu list is set to store the updated scheduling solution using neighborhood actions. In the case of random solutions, a sensitivity analysis of the tabu list length was conducted, and it was found that setting the length of the tabu list to 10 resulted in the best convergence speed and sought solutions.

If during the process of updating a solution, it is found that the solution being updated is already in the tabu list, it will not be included in the tabu list. After executing the update strategy, if a solution with a lower cost is obtained, it is added to the tabu list, and the solution with the highest fitness in the tabu list is removed.

The maximum number of iterations is used as the stopping condition, and the iteration process stops when the number of iterations reaches the set maximum value. Otherwise, update the tabu list and repeat the above steps.

The flowchart for the tabu search algorithm is shown in Figure 2.

The solution method of this paper is to generate randomly generated event types according to the personnel information of the station, and to determine the personnel scheduling of the station and arrange the scheduling plan of each employee. The final output of the program is a personnel scheduling scheme for 24 periods. The tabu search algorithm can be used to recalculate the calculation by changing the person information or entering the identified requirements.

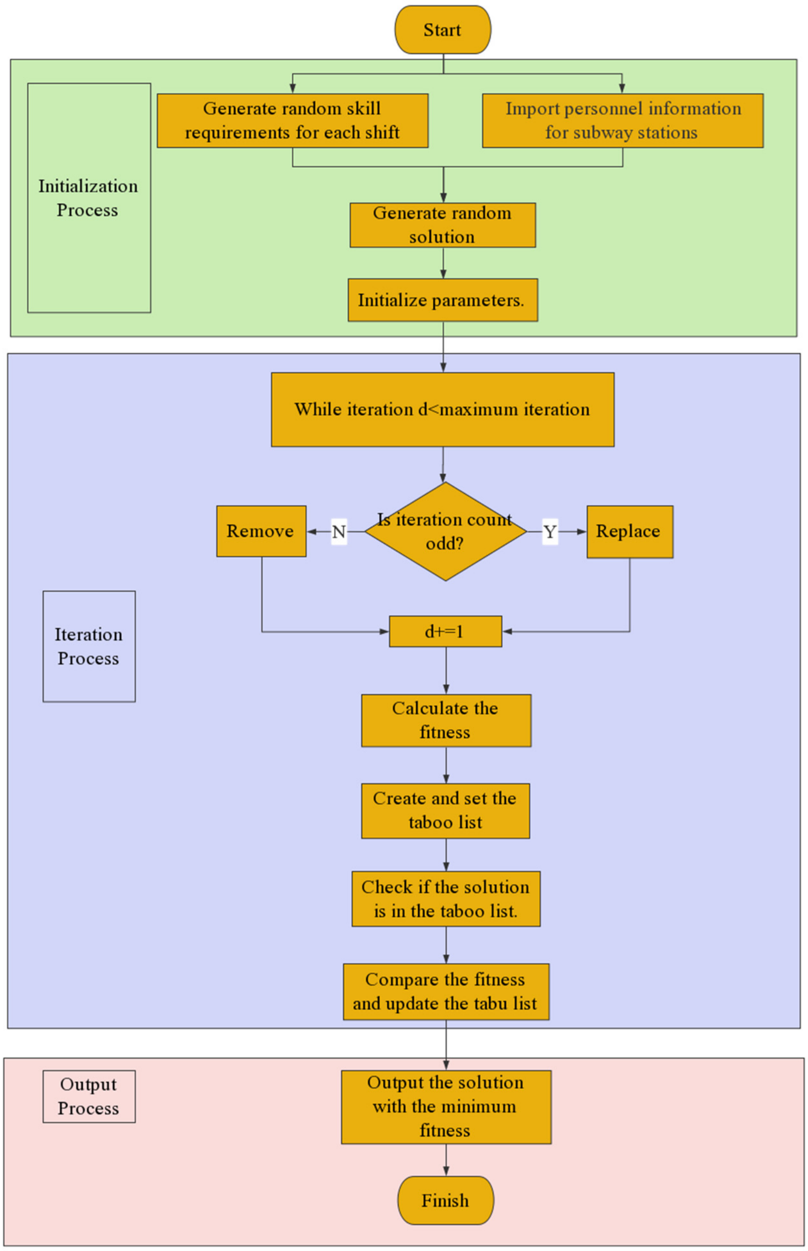

Figure 2. Flowchart for the tabu search algorithm.

4. Analysis of HRCPSP-URS

In this section, three different scenarios of multi-skill human resource scheduling are discussed and based on that the human resource scheduling for that scenarios are obtained and analyzed.

4.1. Scenario 1

In this scenario, with limited human resources on each shift, how to rationally schedule employees for skill matching to accomplish the corresponding tasks and minimize the scheduling cost is the research objective discussed in this subsection. In this case, employees are divided into shifts, in which senior and junior personnel are reasonably matched.

In the multi-skill employee scheduling model, the station needs to be manned 24 h a day. The obtained scheduling plan is shown in the figures, ensuring that the number of people in each time slot is around 7~8 people. Every employee is on duty every day. The shift plan is shown in Figures 3 and 4, where different colors represent different levels of the employees, and because of different skills of the employees, it ensures that human resources are fully utilized, and that the working hours of each employee can be maintained at around 8 h. Figure 5 shows the number of employees on each shift.

√ On × Off	Day/Month/Year																							
Employee ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√
2	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×
3	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
4	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×
5	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
6	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√
7	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×
8	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√
9	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
10	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×
11	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
12	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	×	×	×	×
13	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×
14	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
15	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
16	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√
17	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√
18	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
19	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×
20	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√
21	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×
22	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
23	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√
24	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×
25	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×

Figure 3. Employee shifts schedule in first scenario.

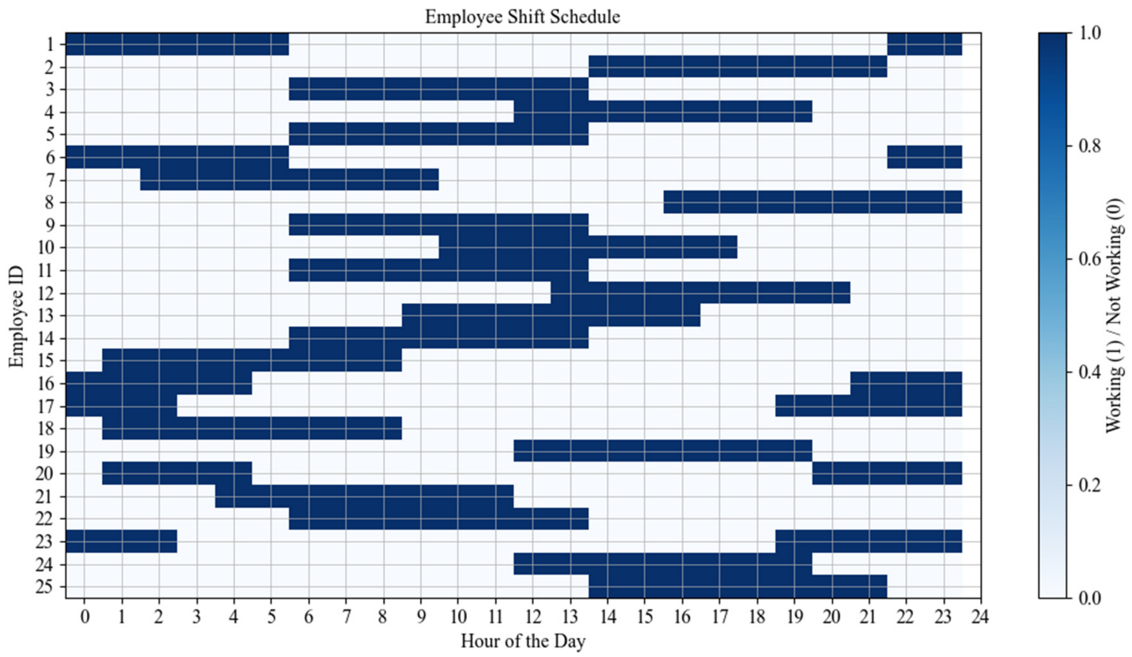

Figure 4. Shifts assigned to each employee during 24 period in first scenario.

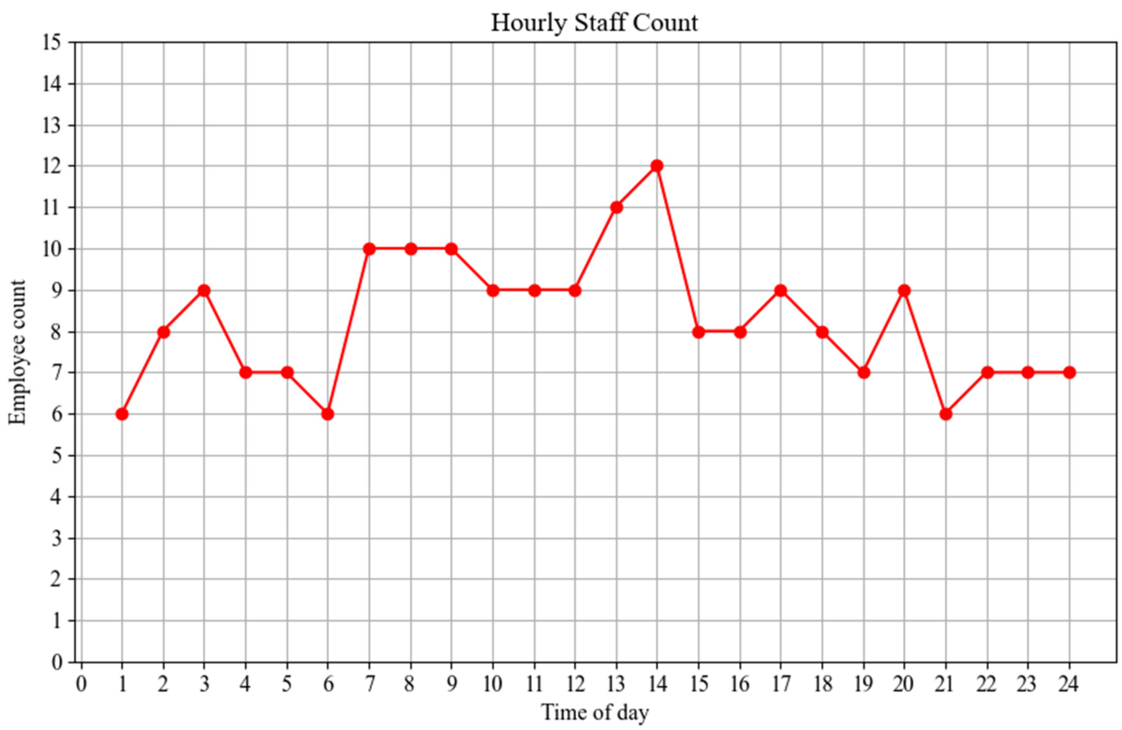

Figure 5. Number of employees in first scenario.

4.2. Scenario 2

The problem transforms into a single-skill human resource scheduling when all employees have a skill number of 1. Consider the tasks generated at the station and the number of people to be dispatched when single-skill multi-level personnel scheduling is performed. A schematic of single-skill personnel scheduling is shown in Figure 6. Table 4 shows the skills possessed by different employees in the single-skill scenario. The different colors in Figure 7 represent different levels of the employees. As shown in Figures 7 and 8, it can be obtained that in the single-skill scenario, the working time of the personnel carries on increasing to different degrees. It may be due to the shortage of human resources caused by the single-skill. It requires longer working time to deal with the same demand. Meanwhile, it can be obtained the number of employees in second scenario shown in Figure 9.

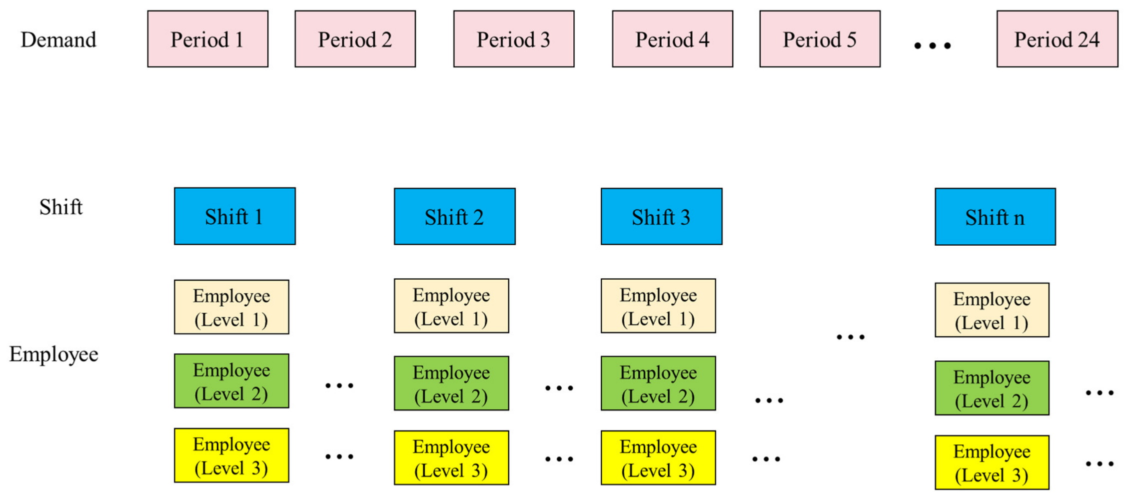

Figure 6. Single-skill human resource scheduling diagram of urban rail station.

Table 4. Single-skill human resource information.

Employee ID	Employee Level	Employ Skill
1	1	A
2	1	A
3	1	A
4	2	B/C
...	...	...
10	2	B/C
11	3	D/E
...	...	...
24	3	D/E
25	3	D/E

√ On × Off	Day/Month/Year																							
Employee ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√
2	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√
3	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×
4	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√
5	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×
6	√	√	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√
7	×	×	√	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×
8	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√
9	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
10	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√
11	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√
12	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	√	×	×	×	×
13	×	√	√	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×
14	√	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×
15	√	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×
16	×	×	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	√	√	√
17	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√
18	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×
19	×	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×
20	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√
21	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√
22	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
23	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	√	√	√	√
24	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×
25	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×

Figure 7. Employee shifts schedule in second scenario.

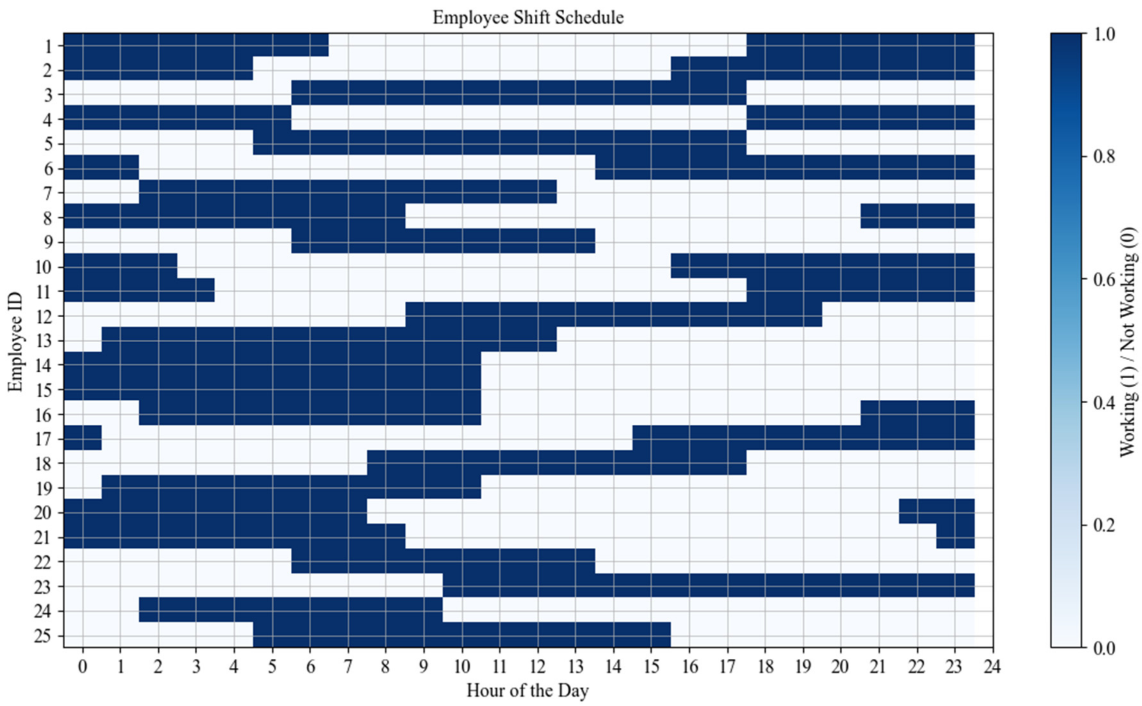

Figure 8. Shifts assigned to each employee during 24 period in second scenario.

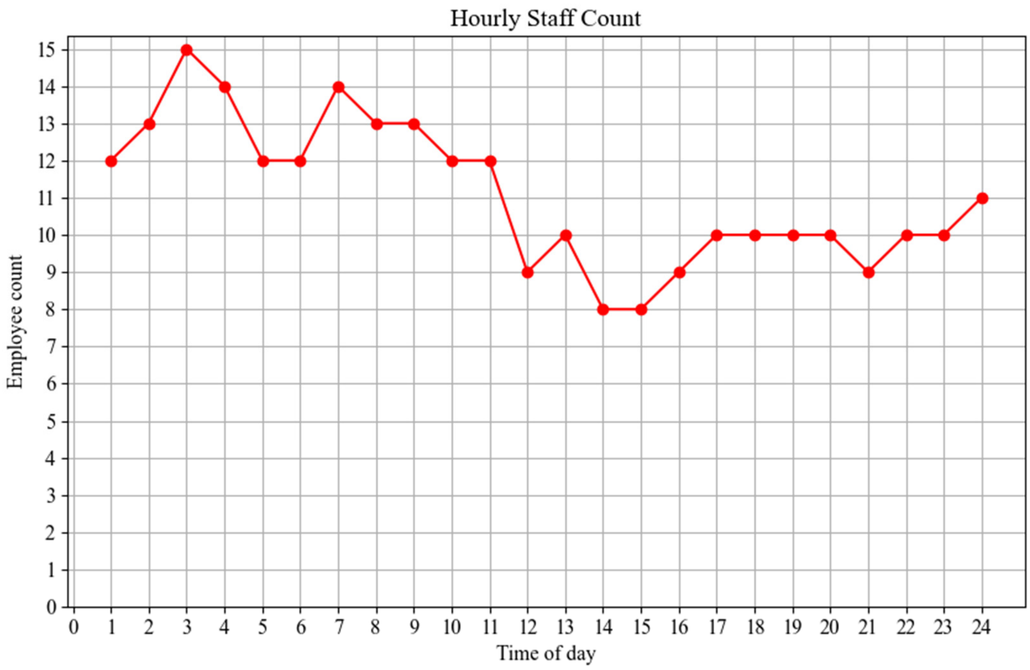

Figure 9. Number of employees in second scenario.

4.3. Scenario 3

In reality, often some of the station's personnel will not be able to arrive at the port properly due to some circumstances, in this case, it is still necessary to keep the number of people in each shift at 7~8 people. In this case get the scheduling planner is shown in Figures 10 and 11, also get the number of employees of every shifts as shown in Figure 12.

√ On × Off	Day/Month/Year																						
Employee ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1	×	×	×	×	×	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
2	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	×	×	×
3	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√
4	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×
5	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	√	×	×	×
6	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√
7	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√
8	×	×	√	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×		×	×	×	×
9	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×
10	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
11	×	×	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×
12	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	×	×	×	×
13	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	√	√	×
14	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√
15	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×
16	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√
17	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
18	×	×	×	×	×	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×
19	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×
20	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√
21	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×
22	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
23	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√	√	×	×	×	×	×
24	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	√	√	√	√
25	×	×	×	×	×	√	√	√	√	√	√	√	√	√	×	×	×	×	×	×	×	×	×	×

Figure 10. Employee shifts schedule in third scenario.

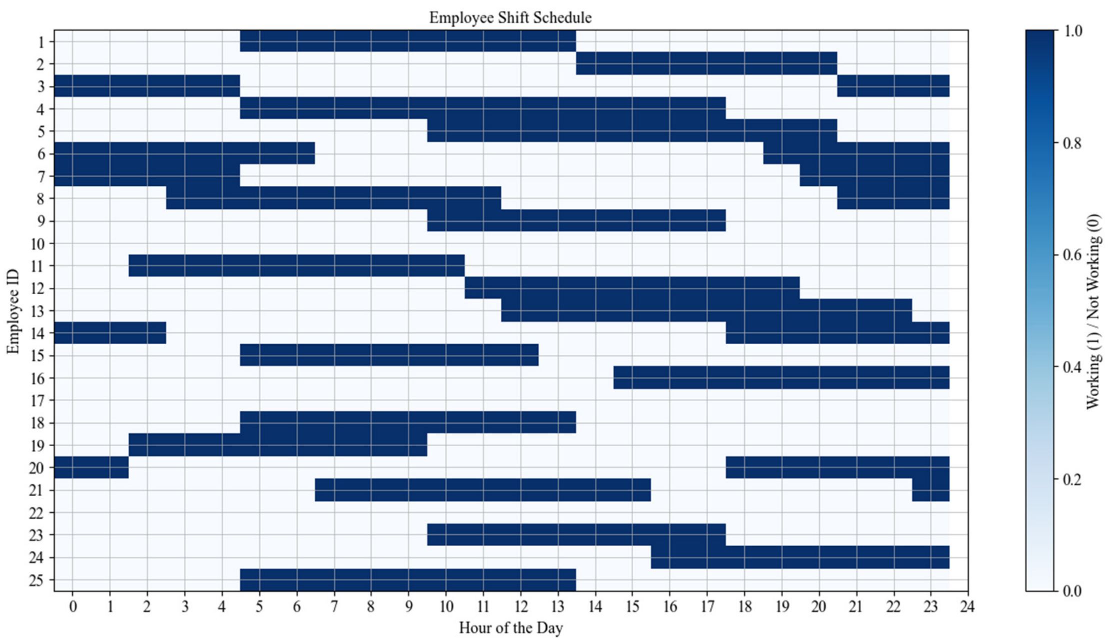

Figure 11. Shifts assigned to each employee during 24 period in third scenario.

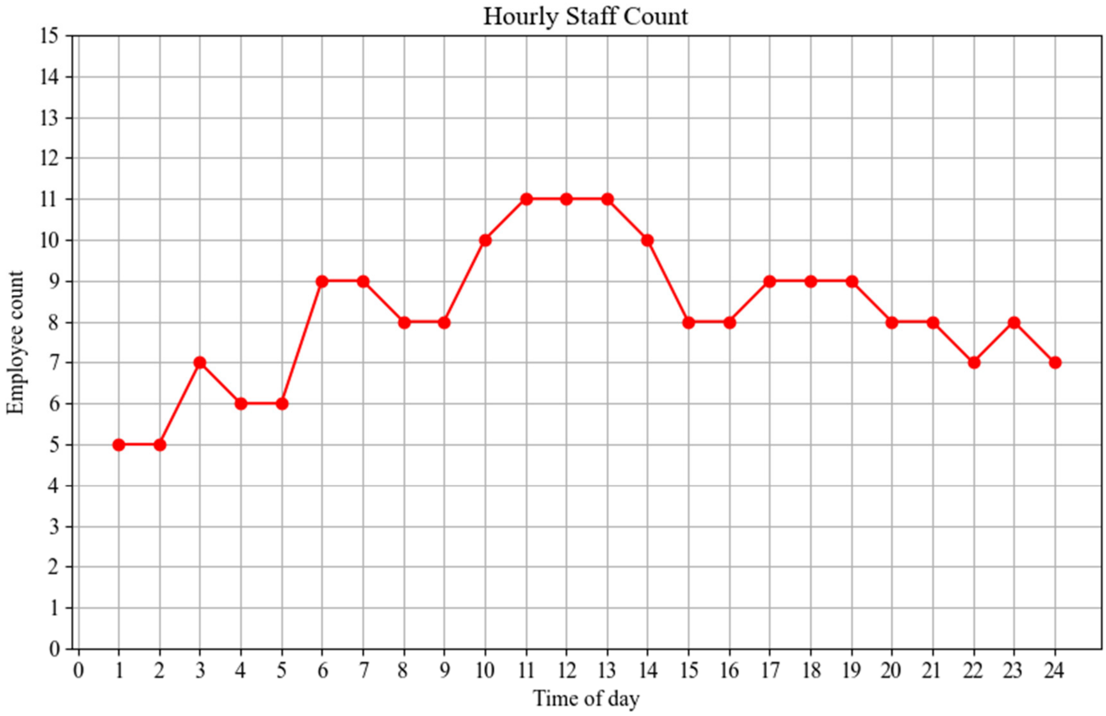

Figure 12. Number of employees in third scenario.

4.4. Sensitivity Analysis

The number of skills plays a crucial role in human resource scheduling. In the management of urban rail stations, personnel at different skills have distinct responsibilities and tasks, with varying skills and experience. Setting the number of skills appropriately can impact the flexibility of human resource scheduling, the efficiency of organizational management, and the rationality of task assignments. During our investigation, we found that the skills of personnel at urban rail stations are closely related to the station's grade. For stations with relatively fewer personnel, three hierarchical levels are typically adopted, while larger transfer stations may have four or five hierarchical levels.

Based on this observation, we conducted a sensitivity analysis on the number of hierarchical levels (See in Table 5). Through this sensitivity analysis, we aim to explore the influence of different hierarchical levels on human resource scheduling in urban rail stations. By adjusting the number of levels, we will observe how it affects human resource scheduling strategies. The focus of our analysis will be on the flexibility of task assignments, the efficiency of human resource utilization, and the optimization of organizational management. Additionally, we will investigate how the number of levels affects employee promotion mechanisms and the performance and satisfaction of employees at different levels.

Table 5. The impact of the number of levels on the fitness.

The Number of Levels	Running Time	Fitness	The Total Number of Employees	Maximum Iterations	The Tabu List Length
1	33	3100	25	300	10
2	35	3400			
3	44	3500			
4	55	4100			
5	52	4200			

Through sensitivity analysis of levels, we observe from Table 5 that the fitness value increases significantly as the number of levels increases. This indicates that to some extent, increasing the number of levels negatively affects human resource scheduling. In addition, we also notice a significant increase in the running time, which suggests that the increase in the number of levels leads to an increase in the complexity of the algorithm. Further analysis shows that choosing the appropriate number of levels is crucial for the efficiency and cost of human resource scheduling. In practice, we have found that stations with relatively few personnel usually use a three-level hierarchical structure. This configuration can adequately meet the daily operational needs of the station, and at the same time enable efficient employee collaboration and management. On the other hand, for larger transfer stations, a four- or five-level hierarchical structure is more appropriate. This allows for a more detailed delineation of personnel duties and tasks, further improving flexibility in resource utilization and management efficiency.

However, it must be considered that too many levels may lead to increased costs for the organization and increased complexity in organizational management. Therefore, in concrete implementation, a balance must be struck between efficiency and cost in human resource scheduling, and the most appropriate number of levels must be selected to achieve optimal operational results.

4.5. Evaluation of Indicators

In this section, the scheduling of the above scenarios are analyzed. It is solved using the tabu search algorithm described in the previous section. In order to evaluate the proposed method, three scenarios are identified by changing the variables, as shown in the Table 6 are the average cost of each scenario, the average number of people in each time slot and the average number of hours worked by the personnel. It can be obtained that in the first scenario the cost is the lowest and the advantage of considering multi-skill scheduling can be seen when compared to the second scheduling method. The cost in the third scenario is similar to the cost of the first scheduling, so the operating company can appropriately take some care of the employees based on this. Meanwhile, the working hours of the first scenario are in accordance with the relevant laws and can provide relatively good working experience for the employees, while the working hours of the second scenario are greatly extended due to single skill. In addition, the average working hours of senior managers under the second option are higher than the average working hours of middle and low-level employees, because the special nature of the skills mastered by senior managers makes them irreplaceable and need to work for a long time.

Table 6. The average index of each scenario.

Scenario	Average Fitness	Average Employee Count	Average Work Time
First	3100	8.29	8.00
Second	4200	11.16	10.68
Third	3300	8.20	8.85

5. Conclusions

To carry out human resource scheduling in a system, it is necessary to carry out coordinated planning based on the consideration of many relevant factors, with a view to meeting the needs of the system at the lowest possible cost, while at the same time taking into account the physical health of people who cannot work for a long period of time. Thus, multi-shift scheduling was developed. In this study, we target human resource scheduling at urban rail stations. We choose to solve the most commonly used meta-heuristic algorithm tabu search algorithm, which makes the scheduling cost low to the maximum extent. The contributions of this model are: (1) Constructing a multi-objective planning model based on the multi-skill characteristics of the employee and considering the multiple costs of the employee's work. (2) Validating the model by using the real data of the urban rail transit stations.

For this purpose, this paper designs three scenarios based on whether the employee is on vacation or not, and analyzes the scheduling cost, shift design, shift length, and other variables in its three scenarios. On this basis, the reliability of the model is verified and some insights are obtained. Firstly, it highlights the importance of recognizing the diversity of employee skill sets and levels. By matching tasks to employees' skill proficiencies and hierarchical positions, organizations can utilize their workforce more efficiently and improve productivity and service quality. In addition, this study highlights the need for a systematic approach to human resource scheduling that considers multi-skill factors in combination. By employing advanced algorithms such as the tabu search algorithm, companies can optimize the scheduling process and strike a balance between human resource scheduling and cost-effectiveness. This approach not only improves operational efficiency, but also ensures that stations effectively adapt to changing needs and unforeseen circumstances. In conclusion, this study provides compelling evidence of the benefits of multi-project scheduling that considers multi-skill factors in human resource scheduling. It provides a guiding framework for decision makers at urban rail stations to gain insight into how strategic scheduling practices can drive operational excellence and organizational success. By adopting these insights, organizations can increase their ability to meet customer needs, improve service delivery, and remain competitive in a dynamic urban environment.

However, the study of human resource scheduling at urban rail stations in this paper is limited to a single station. In the context of today's systematic and integrated ITS construction, it will be more effective in responding to emergencies if collaboration among multiple stations is considered. Therefore, the future research direction should still consider the interconnection between different stations and strengthen the ability of regional cooperative scheduling.

Author Contributions

Conceptualization, T.Z. and J.H.; Methodology, T.Z. and J.H.; Investigation, S.B.; Writing—Original Draft preparation, J.H.; Writing & Editing, T.Z. and S.B.; Writing—review and editing, T.L.; Data curation, M.D. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data used to support the findings of the study are available within the article.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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