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Retraction

Retracted: Multiobjective Optimization of Airport Ferry Vehicle Scheduling during Peak Hours Based on NSGA-II

Security and Communication Networks

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Security and Communication Networks has retracted the article titled "Multiobjective Optimization of Airport Ferry Vehicle Scheduling during Peak Hours Based on NSGA-II" [1] due to concerns that the peer review process has been compromised.

Following an investigation conducted by the Hindawi Research Integrity team [2], significant concerns were identified with the peer reviewers assigned to this article; the investigation has concluded that the peer review process was compromised. We therefore can no longer trust the peer review process, and the article is being retracted with the agreement of the Chief Editor.

The authors do not agree to the retraction.

References

[1] J. Bi, C. Ding, D. Xie, and Y. Li, "Multiobjective Optimization of Airport Ferry Vehicle Scheduling during Peak Hours Based on NSGA-II," *Security and Communication Networks*, vol. 2022, Article ID 7388406, 12 pages, 2022.

[2] L. Ferguson, "Advancing Research Integrity Collaboratively and with Vigour," 2022, https://www.hindawi.com/post/advancing-research-integrity-collaboratively-and-vigour/.

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Research Article

Multiobjective Optimization of Airport Ferry Vehicle Scheduling during Peak Hours Based on NSGA-II

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Airport ferry vehicles are used to transport passengers between the far apron and terminals. During the peak hours of flight arrival or departure, the demand for ferry vehicles will increase, and improper scheduling will result in significant delays. In this study, we construct a 0–1 integer programming scheduling model for ferry vehicles with multiple objectives: minimize flight delays and vehicle travel distances and balance vehicle workloads when there is an insufficient number of ferry vehicles. To solve the multiobjective model, this study selects the second version of the nondominated sorting genetic algorithm-II as the main framework and designs a modified coding and decoding scheme to solve the constraint problem in the model. The proposed model and algorithm are verified using actual data from Kunming Changshui International Airport, China. Compared with the scheduling method of manual first come first serve, the total delay time of the proposed model is reduced by 24.52%, the transit distance by 6.63%, and the balance index by 24.05%, which helps the airport solve the problem of insufficient ferry vehicles during peak hours. Comparison results show that the proposed model has a shorter calculation time and better distribution of solution sets than three state-of-the-art multiobjective optimization algorithms: MOPSO, MOACO, and SPEA-II. This research can help airports reduce flight delays, vehicle purchases, and operation costs.

1. Introduction

With the rapid advancement of civil aviation, the supply and demand mismatch between the increasing number of flights and the limited ground service facilities has become prevalent. Many scholars have explored efficient methods for optimizing the use of existing resources, such as runway assignment [1, 2], gate assignment [3, 4], and ground service vehicle scheduling [5–7]. As one of the ground service vehicles, a ferry vehicle is responsible for transporting passengers between the terminal and aircraft parked at the far apron. Flight arrival and departure times at large airports are typically short and dense during peak hours. A large number of flights can only park at the far apron because of the limited number of terminal gates, significantly limiting ferry vehicle scheduling. At present, the efficiency of scheduling ferry vehicles in many airports mainly depends on experienced staff. High scheduling efficiency is difficult to ensure, which can easily lead to flight delays. Therefore, establishing an optimal scheduling model for ferry vehicles using scientific methods and improving the service level of airports are very critical.

Scheduling airport ground service vehicles can be a challenge; vehicle scheduling in some studies is modeled as vehicle routing problems with time windows (VRPTW). For example, Du et al. [8] investigated a trailer scheduling problem in flight transit services and constructed an integer programming model with minimizing trailer operation costs as the optimization objective. Padrón et al. [9] modeled each support vehicle scheduling problem as a VRPTW subproblem and ensured the consistency of each subsolution using a constraint propagation mechanism. Other studies have also used heuristic algorithms. Ip et al. [10] proposed a novel generic algorithm to minimize the total flight delay

caused by ground support services. Wang et al. [11] proposed a scheduling algorithm based on the greedy strategy to deal with the dynamic scheduling problem of airport refueling vehicles. For ferry vehicle scheduling, Zhao et al. [12] constructed a ferry vehicle sharing network, where the model was transformed into the problem of maximum network flow. Han et al. [13] also proposed a ferry capacity network model, where the directed edge indicates that the two associated nodes may be continuously served by the same ferry. Li et al. [14] investigated the ferry vehicle scheduling problem and established a quadratic programming model to minimize the variance in the number of flights per ferry vehicle serving. These studies aim to find a sufficient number of ferry vehicles to meet flight service needs. However, in practice, due to the high cost of the ferry vehicles and airport space constraints, the number of ferry vehicles is typically very limited, and purchasing excess vehicles will lead to vehicle idleness and waste during the normal period. In addition, how to reduce the transfer distance of vehicles and balance the workload of vehicles has not been considered. Therefore, to bridge the research gap mentioned above, we propose a new model to facilitate multiobjective optimization of ferry vehicle scheduling.

The primary contributions of this study include three aspects. First, we construct a 0–1 integer programming scheduling model for ferry vehicles to minimize flight delay and vehicle travel distances and balance vehicle workloads when there is an insufficient number of ferry vehicles. Then, we proposed and designed a nondominated sorting genetic algorithm (NSGA-II) to develop a multiobjective model with a modified coding and decoding scheme to handle the constraints in the model. Finally, the proposed model and algorithm are verified by the actual flight and ferry vehicle data of Kunming Changshui International Airport, China. This research can help the airport reduce flight delays, vehicle purchases, and operation costs.

The rest of this paper is organized as follows: Section 2 describes the ferry vehicle scheduling problem and model. Section 3 presents the detailed design steps of the NSGA-II algorithm. Section 4 demonstrates the calculation process using actual data from Kunming Changshui International Airport, China, validates the accuracy and the efficiency of the method, and performs correlation analysis. Finally, conclusions are drawn in Section 5.

2. Model Construction

In this study, we consider a case in which the number of airport ferry vehicles is fixed. The existing ferry vehicles cannot complete the ferry task of all flights without delay during the peak hours of flight arrival and departure. One option is to purchase additional ferry vehicles to meet the demand. However, this will increase the cost, and the additional vehicles will be idle during normal operating periods. Another option is to make some flights wait for ferry vehicles, which will result in a small waiting time but no major delays. We opt for the second scheme for modeling. The optimization goal is to minimize the total delay time of all flights. In addition, we consider reducing the total travel time of all ferry vehicles to reduce fuel consumption and balance the workload of each ferry vehicle.

Due to the diversity of actual situations, to simplify and standardize the process of vehicle scheduling, make the model applicable to most scenarios and ensure a satisfactory solution, the following assumptions are made for the ferry vehicle scheduling problem: (1) the proposed model is based on the basic information about flights and the gate assignment results, which can be known in advance. (2) We assumed that the number of ferry vehicles is known, and the driving time between the starting and ending points of the same ferry task remains unchanged, regardless of the rest or refueling time. (3) Flights to be served are of equal importance. Then, the ferry vehicle scheduling problem can be described as follows:

During a peak period at the airport, there are I flights parked at the apron waiting for ferry services. The set of ferry vehicles is K. The service times for arrival and departure flights are different, as shown in Figure 1. If flight i is an arrival flight, a ferry vehicle needs to arrive at the remote stand in an advance time t_{adv}^{A}. After the flight arrives at ETA (estimated time of arrival), passengers need t_{wait} time to alight and board. The time for ferry vehicles to travel from the stand P_i to the entrance of the terminal is t_i^{ferry}. After the passengers alight, this service is completed. If flight i is a departure flight, the ferry vehicle needs to arrive at the corresponding boarding gate of the terminal in advance. The time to travel from the boarding gate to the parking position P_i is t_i^{ferry}. Passengers need t_{wait} time to board after alighting, and they need to arrive t_{adv}^{D} time before the flight departure at ETD (estimated time of departure). If the number of passengers on the flight is greater than the maximum capacity of one ferry vehicle, it will be divided into some virtual flights. The split flights have the same arrival and departure times as the original flight, so only one ferry vehicle is required for each flight. To sum up, for the ferry task of each flight i, there is a task start time TS_i and a task end time TE_i. For arrival flights, $\text{TS}_i = \text{ETA} - t_{\text{adv}}^{A}$ and $\text{TE}_i = \text{ETA} + 2 * t_{\text{wait}} + t_i^{\text{ferry}}$. For departure flight, $\text{TS}_i = \text{ETD} - t_{\text{adv}}^{D} - 2 * t_{\text{wait}} - t_i^{\text{ferry}}$ and $\text{TE}_i = \text{ETD} - t_{\text{adv}}^{D}$.

There is a connection time t_{ij} between two continuous ferry tasks, that is, the ferry vehicle travel time from the service end location of flight i to the service start location of flight j. If the connection time is less than the interval time $(\text{TS}_j - \text{TE}_i)$, one ferry vehicle can continuously perform i and j tasks without delay; otherwise, the delay time will be generated, as shown in Figure 2. We define an upper triangular matrix $\text{D} = (d_{ij})_{I \times I, i < j}$ to represent the delay time:

$$d_{ij} = \begin{cases} 0, & t_{ij} \leq \left(\text{TS}_j - \text{TE}_i\right), \\ t_{ij} - \left(\text{TS}_j - \text{TE}_i\right), & t_{ij} > \left(\text{TS}_j - \text{TE}_i\right). \end{cases} \tag{1}$$

Since the flight and distance information is known, the values of matrix D can be obtained. Moreover, we define a maximum threshold of flight delay $P_{\max}$ to avoid two flights with excessive delays being served by the same ferry vehicle.

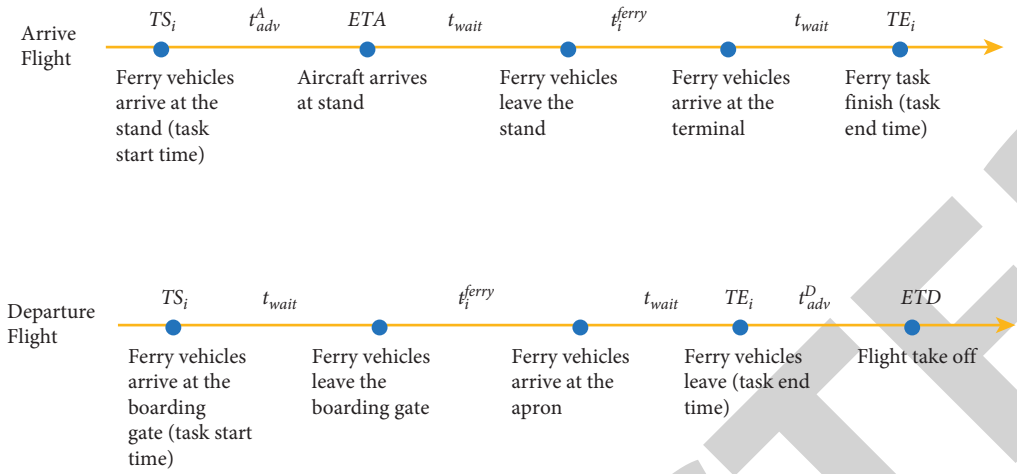

Figure 1: Ferry service process for arrival and departure flights.

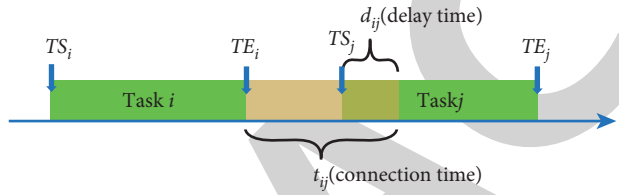

Figure 2: Delay time of two continuous tasks for one ferry vehicle.

Based on the above description, Table 1 summarizes the parameters and variables used in the ferry vehicle scheduling model. The decision variable x_{ik} specifies whether the ferry vehicle k should be assigned to flight i. In the case of a limited number of ferry vehicles, to reduce the delay time of flights and take into account the shortest travel distance of ferry vehicles and the balance of tasks, the established ferry vehicle scheduling model is expressed as follows:

$$\min \sum_{k\in K} \sum_{i,j\in I, i\neq j} \left(x_{ik} * x_{jk}\right) * d_{ij}, \tag{2}$$

$$\min \sum_{k\in K} \sum_{i,j\in I, i\neq j} \left(x_{ik} * x_{jk}\right) * t_{ij}, \tag{3}$$

$$\min \sum_{k\in K} \left(\sum_{i\in I} x_{ik} - \frac{|I|}{|K|} \right)^2, \tag{4}$$

$$\text{St} \sum_{k\in K} x_{ik} = 1, \quad \forall i \in I, k \in K, \tag{5}$$

$$x_{ik} + x_{jk} \leq 1, \quad \forall i, j \in I, d_{ij} > P_{\max}, k \in K, \tag{6}$$

$$x_{ik} + x_{jk} + x_{lk} \leq 2, \quad \forall i, j, l \in I, d_{ij} > t_{jl}, k \in K, \tag{7}$$

$$x_{ik} \in \{0, 1\}, \quad \forall i \in I, k \in K. \tag{8}$$

The objective function (2) is to minimize the total delay time only when flights i and j are assigned to ferry vehicle k simultaneously and there is a delay time between flights i and j. The objective function (3) is to minimize the total connection time of ferry vehicles, which is used to represent the driving cost. The objective function (4) refers to the workload balance of each ferry vehicle. Constraint (5) stipulates that one flight can only be served by one ferry vehicle. Constraint (6) means that two flights with delay times greater than the $P_{\max}$ delay time cannot be served by the same ferry vehicle. Constraint (7) means that the delay of a ferry vehicle cannot be accumulated, that is, when there is a delay between the first two tasks, the delay time cannot be greater than the connection time of the third task. Constraint (8) means that the variable can only take 0 or 1 as a value.

3. Algorithm

The ferry vehicle scheduling model established in the previous section has multiple objective functions, and it is generally difficult to obtain an optimal solution that satisfies these multiple objective functions simultaneously. In the process of optimization, improving the attribute value of one objective will need to be at the expense of the other objectives. Taking the ferry vehicle scheduling problem in this paper as an example, if the optimization direction is to blindly find the shortest travel distance, it may cause a ferry vehicle to only choose the nearest flight, resulting in the sacrifice of flight delay time, and an optimal delay time cannot be guaranteed. Therefore, a reasonable solution set for this problem should be to obtain the Pareto optimal solution [15]. NSGA-II is an improved multiobjective optimization algorithm proposed by Professor Deb [16]. It is widely used by scholars in transportation optimization

Table 1: Parameters and variables used in ferry vehicle scheduling model.

Parameters	
I	The set of flights
K	The set of ferry vehicles
N_i	The number of passengers on flight i, $i \in I$
C_{max}	The maximum capacity of a single ferry vehicle
P_i	The parking stand of flight i, $i \in I$
TS_i	The start time of ferry vehicle service for flight i, $i \in I$
TE_i	The end time of ferry vehicle service for flight i, $i \in I$
t_{ij}	The connection time between ferry task i and ferry task j, i, $j \in I$
d_{ij}	The delay time between ferry task i and ferry task j, i, $j \in I, i < j$
P_{max}	The maximum threshold of flight delay
Decision variable	
x_{ik}	0–1 decision variable, $x_{ik} = \begin{cases} 1, & \text{flight i is served by ferry vehicle } k \\ 0, & \text{flight } i \text{ is not served by ferry vehicle } k \end{cases}$ $i \in I$, $k \in K$

[17, 18] because of its good distribution and fast convergence. The algorithm proposes a fast nondominated sorting operator, introduces the strategy of saving elites, and replaces sharing with "crowding distance." The algorithm can compare the advantages and disadvantages of all individuals in the population and ensure that there are a certain number of Pareto optimal solutions. The ferry vehicle scheduling model in this study has three optimization objectives that can be solved using the NSGA-II algorithm. However, due to the limitation of constraints, infeasible solutions can easily be formed when crossing and mutating chromosomes in the algorithm, which reduces the efficiency of the algorithm. Therefore, taking the NSGA-II algorithm as the framework, this study designs a novel coding and decoding scheme to solve the constraint problem in the model.

3.1. Coding and Decoding Scheme. For the ferry vehicle scheduling problem, the main purpose of coding is to map the ferry vehicle scheduling plan into a chromosome with a certain gene structure to facilitate the operation of various genetic operators. To intuitively represent the ferry scheduling plan, this study adopts the way of real number sorting and coding and numbers the flights as 1, 2, . . ., N according to the service start time. Each chromosome consists of the number of flights to be assigned. Each flight corresponds to a gene on the chromosome and exists uniquely. Chromosomes with different gene sequences correspond to different scheduling plans. Mapping chromosomes into scheduling plans is completed by decoding, as shown in Figure 3. Starting from the flight on the leftmost side of the chromosome, flights 6, 1, and 8 are continuously assigned to ferry vehicle 1 under the condition of meeting the model constraints. When assigning flight 7 to ferry 1, the flight is selected to be ignored because the constraints are not met. If the number of consecutively ignored flights exceeds the maximum search step S_{max}, the flight assignment of ferry 1 is ended. In the flight chain of each ferry vehicle, flights follow the first come first serve (FCFS) principle, that is, they are executed in sequence according to their service times. According to this operation, the service flight chains 1–4–6–8–11, 2–7–9–13, and 5–10–12–14–15 of the three ferry cars can be decoded, respectively. When all ferry vehicles are allocated, a complete dispatching plan can be obtained.

To keep the workload of vehicles as balanced as possible, we set the maximum task threshold $\gamma = \text{Ceil}(|I|/|K|)$, where $|I|$ and $|K|$ represent the number of flights and ferry vehicles, respectively, and Ceil is the upward rounding function. If there are still flights unassigned to ferry vehicles after the flight assignment task, such as flight 3 in Figure 3, these flights will be assigned to virtual ferry vehicles. For virtual ferry vehicles, when calculating the value of each objective function, a sufficiently large penalty value should be added to reduce the adaptability of the corresponding individual. According to the previous model constraints, algorithm 1 provides the pseudo-code of the decoding algorithm.

3.2. Crossover, Mutation, and Selection Operators. The crossover operator replaces and reorganizes the partial structures of two parent individuals to generate new individuals, to improve the searchability of the genetic algorithm. For different coding methods, the implementation of the crossover operator is also very different. According to the characteristics of sequencing coding, it can be divided into the crossover mode in which a single chromosome determines the selection position, and the crossover mode in which both chromosomes participate in position selection. The former includes cycle crossover (CX) [19], and the latter includes order crossover (OX) [20] with gene fragments as the exchange object. From the developed decoding algorithm, we can know that chromosome information about excellent individuals is based on the specific order of gene fragments. To preserve the excellent gene fragments, OX is used as the crossover mode of the genetic algorithm. The specific operation of the OX mode is shown in Figure 4. Taking the structure of one offspring as an example, first, randomly select two gene loci in a pair of chromosomes as the starting and ending positions of crossover gene fragments. Then, the progeny individual 1 is generated to ensure that the selected gene position in the progeny is the same as that in the parent individual 1. Then, the location of these selected genes is found in the parent individual 2. Finally, the

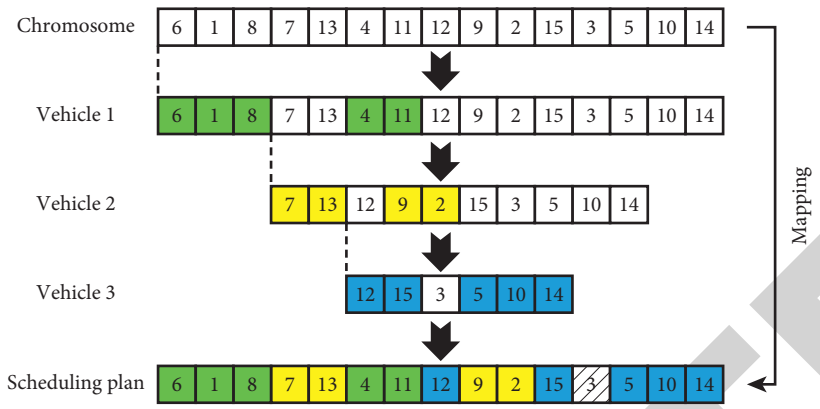

Figure 3: Decoding scheme of chromosome.

```
Input:
  Chromosome chromo
  Flights set I
  Ferry vehicles set K
  Maximum search step S_max
  Maximum task threshold γ = Ceil(|I|/|K|)
Output:
  Ferry vehicle scheduling plan vehicle.flights
  for vehicle in vehicles_set K:
    vehicle.flights =# Create an empty set to store allocated flights
    for i in chromo:
      if vehicle.flights ==:
        vehicle.flights.append(I[i])
        chromo.remove(i)
      elif I[i] does not conflict with any flight in vehicle.flights:
        vehicle.flights.append(I[i])
        chromo.remove(i)
      if len(vehicle.flights) > γ:
        break
      if chromo.index(i) − chromo.index(vehicle.flights[−1]) > S_max:
        break
      if len(chromosome) > 0:
        virtual_ferry.flights = chromo
```

Algorithm 1: Decoding algorithm

remaining genes in the parent individual 2 are put into the offspring individual 1 to produce a complete offspring individual 1. The generation process of the other offspring is the same. Only the positions of the two parents need to be exchanged while keeping the randomly selected loci the same. The coding sequence of the other offspring in the figure is 6–7–13–11–9–14–8–1–12–4–2–15–3–5–10.

The term mutation means to introduce new gene information to individuals to improve the diversity of the population. It is also a supplement to cross-operation to ensure that each gene can reach the entire search range of alleles. Similar to the crossover process, to ensure the completeness and uniqueness of chromosome genes during mutation, this study designs a mutation mode based on gene exchange, as shown in Figure 5. A new chromosome can be obtained by randomly selecting two different loci on the original chromosome and then exchanging the genes on the two loci.

The selection operator is responsible for selecting excellent individuals from the previous generation population and eliminating inferior individuals to keep the population developing toward environmental adaptation. The selection operator is based on the fitness evaluation of individuals in the group. The comparison of individual fitness in the NSGA-II algorithm is based on a dominance relationship, so this study selects the binary tournament selection method [21] as the crossover operator, and its specific operation is shown in Figure 6. First, two individuals are randomly selected from the parent population (each individual in the population has the same probability of being selected), and then, the better individual is selected to join the offspring population according to the congestion comparison

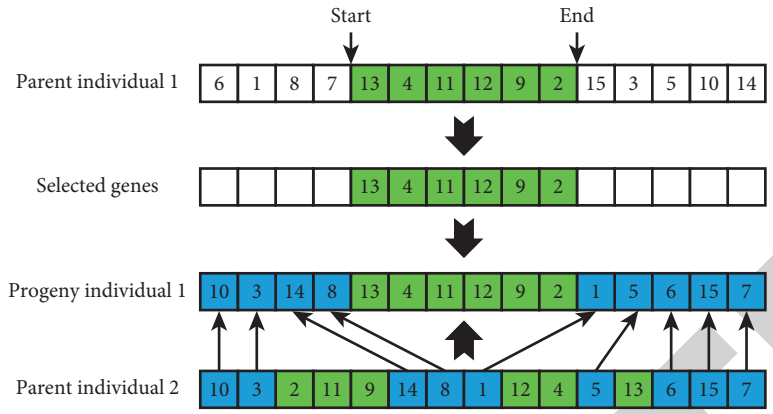

Figure 4: Diagram of OX cross.

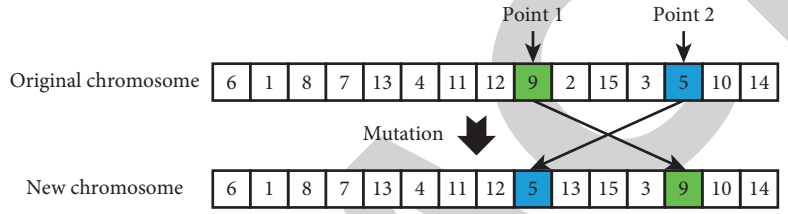

Figure 5: Diagram of mutation operator.

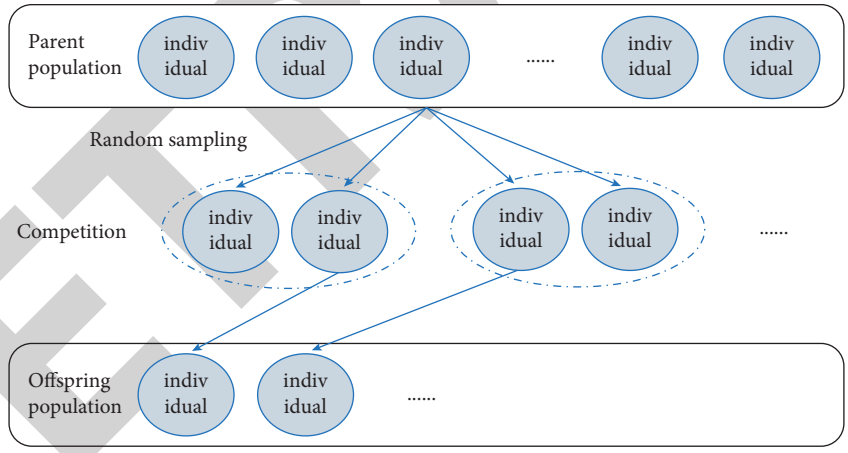

Figure 6: Binary tournament selection method.

operator. Finally, the previous process is repeated until the size of the offspring population is the same as that of the parent.

3.3. Ferry Vehicle Scheduling Algorithm Based on NSGA-II. Based on the NSGA-II optimization strategy and the design of operators, the algorithm steps for the ferry vehicle scheduling model are as follows:

Step 1. Initialize the algorithm parameters, including the population size, the maximum number of iterations, and the maximum search step.

Step 2. According to flight information, a flight is numbered according to the task time of the ferry vehicle, and the initial population with population size N is randomly generated. Each chromosome in the population represents a different allocation order. According to the decoding algorithm, the chromosome is decoded into a scheduling plan, and three target values of each individual are calculated. According to the target value, the population can be rapidly non-dominated sorted, and the crowding distance can be calculated.

Step 3. The binary tournament selection is performed according to the calculation results, and then, the screened

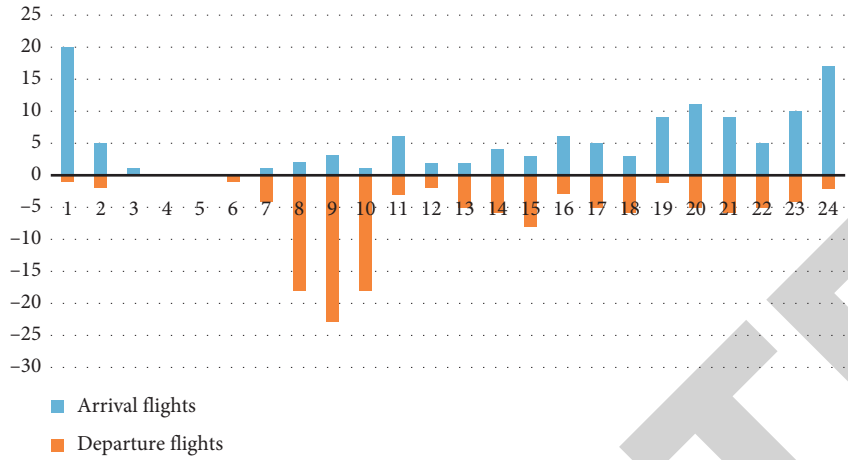

Figure 7: Average number of arrival and departure flights in different periods.

population is subjected to OX crossover and mutation based on gene exchange to produce an offspring population with the population size N.

Step 4. If the number of iterations exceeds the maximum number of iterations, the algorithm ends. Otherwise, proceed to Step 5.

Step 5. Combine the parent and child populations to generate a temporary population with a scale of $2N$, calculate the three target values of each individual, rapidly nondominated sort the temporary population and calculate the crowding distance according to the target value, then select N individuals using the elite strategy to form a new parent population, and jump back to Step 3.

4. Experiment and Analysis

In the previous section, the modeling research on the ferry vehicle scheduling problem in the peak hours of large airports is conducted, and a heuristic algorithm based on NSGA-II is designed to solve the model. This section uses the actual operation data of Kunming Changshui International Airport, the fifth largest airport in China, to verify the effectiveness and feasibility of the proposed model and algorithm.

The average number of flights in each period of the airport in June 2021 is shown in Figure 7. The figure shows that 7 : 00–11 : 00 a.m. is the morning peak period at the airport. We chose the specific flight data on June 26, 2021, as the sample data to evaluate the model and algorithm. The total number of flights at the airport was 1,083, of which 272 were parked at far stands. Seventy-nine flights in this period are selected as the research object. The original information about the flights, including arrival and departure times, flight attributes, number of ticket reservations, and other information about the flight, is presented in Table 2. According to the ferry vehicle scheduling model constructed in Section 2, the relevant constant parameters are shown in Table 3. From these parameters, we can successively calculate the start and end times and place of the service of inbound and outbound flights in the set of flights to be served, disassemble flights with the number of flight bookings exceeding the maximum passenger capacity of ferry vehicles, and construct the corresponding virtual flights. After the above operations, 118 flights (including virtual flights) to be served are obtained, as shown in Table 4. The starting point of the ferry service includes a boarding gate, port of entry, and parking stand. Based on the actual situation of the airport, these locations are divided into 8 regions. Table 5 presents the travel time information between different regions. Based on the ferry task data, the relative delay time d_{ij} of any two flights in the flight set and the connection time t_{ij} between the two flights can be calculated. The calculation results are shown in Table 6.

Table 2: Flight raw data (partial).

Flight number	ETA/ETD	I/O	Aircraft type	Passengers	Gate	Boarding gate
DR6521	2021/6/26 7 : 00	O	B738	189	716	22
DR6509	2021/6/26 7 : 00	O	B737	144	325	23
8L9863	2021/6/26 7 : 00	O	B738	189	522L	5
8L9801	2021/6/26 7 : 00	O	A320	183	323	20
8L9849	2021/6/26 7 : 05	O	B737	104	522R	24
MU5823	2021/6/26 7 : 15	O	B737	116	318	3

Table 3: Setting of model parameters.

Model parameters	Symbol	Value
Number of ferry vehicles	$\|K\|$	23
Advanced time (arrival)	t^A_{adv}	5 min
Advanced time (departure)	t^D_{adv}	20 min
Board/get off time	t_{wait}	5 min
Maximum passenger capacity	$C_{\max}$	120
Maximum delay threshold	$P_{\max}$	30 min

Table 4: List of flight service requirements.

Flight number	Start location	End location	Start time	End time
DR6521(1)	22	716	6:12	6:40
DR6521(2)	22	716	6:12	6:40
8L9801(1)	20	323	6:22	6:40
8L9801(2)	20	323	6:22	6:40
DR6509(1)	23	325	6:20	6:40
DR6509(2)	23	325	6:20	6:40
8L9863(1)	5	522L	6:20	6:40
8L9863(2)	5	522L	6:20	6:40
8L9849	24	522R	6:25	6:45
MU5823	3	318	6:37	6:55

Table 5: The distance matrix between the points of the ferry.

Region	1	2	3	4	5	6	7	8
1	—	—	10	—	18	—	18	18
2	—	—	13	—	18	—	18	18
3	10	13	0	8	5	8	10	5
4	5	5	8	—	15	—	18	15
5	18	18	5	15	0	15	5	0
6	5	0	8	—	15	—	18	15
7	18	18	10	18	5	18	0	5
8	18	18	5	15	0	15	5	0

Table 6: List of relative delay times and connection times (partial).

Flight i	Flight j	Delay time d_{ij} (min)	Connection time t_{ij} (min)
8L9801(2)	MU767(2)	−72	13
UW9947(1)	DR6505R	96	18
UW9930(2)	GX7881	−27	8
ZH9456	CA4171(2)	139	18
MU2589(2)	MU5953	78	15
CA4171(2)	MU5971(2)	−75	11
8L9833	8L9849	171	13
MU2249	O36944(1)	156	9

After calculating the start and end times of the ferry task and the relative delay and connection times between all ferry tasks, the fitness value of a chromosome can be calculated according to the decoding scheme designed in Section 3, and all solution processes of the model can be completed using various operators designed. The algorithm is implemented using Python 3, the integrated development tool is PyCharm, and the running environment is Intel (R) Core (TM) i5-3210 m CPU @ 2.50 GHz ram 8.00 GB. Set the population size of the NSGA-II algorithm to 200, the maximum number of iterations to 200, and the maximum search step size to 3, and optimize the configuration of all 23 ferry vehicles in the airport. The Pareto front of the calculation results is shown in Figure 8. The figure shows that the calculated solution set is evenly distributed in the solution space, and most points are concentrated in ideal positions. Because the primary purpose of the ferry scheduling plan during peak hours is to ensure the normal operation of flights and reduce the delay time, the five best solutions are selected according to the ascending order of delay time (the first target value), as shown in Table 7.

With an increase in the target delay time, the target transit distance gradually decreases, but the reduction range is small, and the corresponding buffer time keeps increasing. Under the condition that the delay time is not significantly different, the third solution can best maintain the task balance of the ferry scheduling plan. Therefore, No. 3 is selected as the final satisfactory solution. Table 8 shows flight sequence information about each ferry service. The Gantt chart of the scheduling plan is shown in Figure 9. Among all 79 original flights, 41 flights are in normal operation, 29 flights have delay times but no more than 15 min, and the maximum delay time is no more than 23 min.

To further evaluate the effectiveness of the developed model and algorithm, we compare them with the scheduling method of manual FCFS and three advanced multiobjective optimization algorithms, including multiobjective particle swarm optimization (MOPSO) [22], multiobjective ant colony optimization (MOACO) [23], and improved strength Pareto evolutionary algorithm (SPEA-II) [24]. For manual scheduling, a dispatcher will give priority to the currently idle vehicles to serve a flight. If there are no currently idle

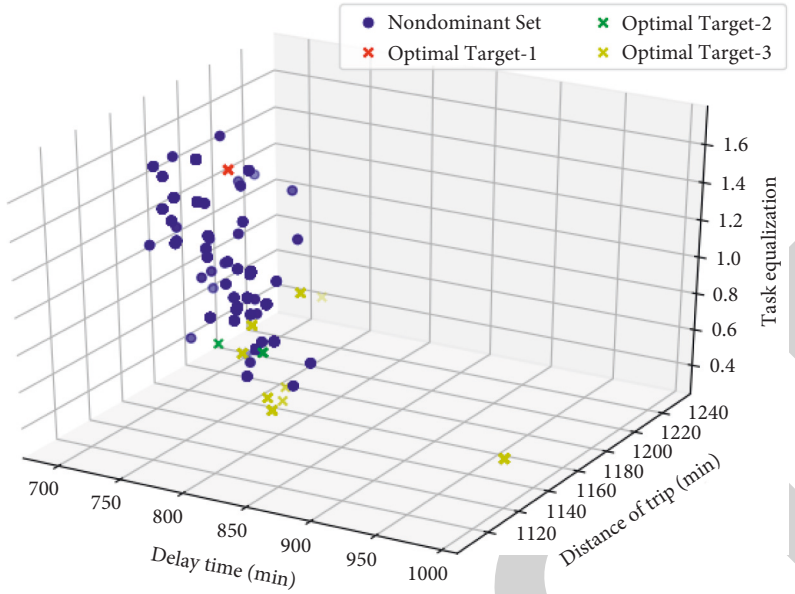

Figure 8: Pareto front obtained by the NSGA-II algorithm.

Table 7: Pareto solution set calculated during peak hours.

Nondominated solution	Total delay time (min)	Total connection time	Balance target	Maximum/minimum workload
1	693	1230	1.19	7,4
2	710	1196	1.57	8,3
3	711	1183	0.34	6,5
4	718	1169	0.61	6,4
5	725	1141	1.26	8,3

Table 8: Ferry scheduling plan calculated by the model.

Ferry vehicle	Flight sequence served	Delay time	Connection time
1	A67107(1)-KY8227-MU767(1)-8L9841-MU5735(2)	20	56
2	DR6521(1)-MU5801(1)-ZH9440(1)-MU5875(2)-MU2249	26	59
3	KY8255(1)-MU2706-O36944(2)-CA4418-8L9957(2)	24	34
4	8L9995-CZ8535(1)-GJ8871(2)-GX7881-3U8129(2)	42	34
5	CA4175-8L9887(1)-KY8297(2)-MU5747(1)-MU5735(1)	44	72
6	DR6509(2)-3U8807-MU2589(1)-ZH9794-MU2250-MU9082	28	65
7	3U8669(1)-MU5801(2)-GJ8871(1)-MU5829(2)-MU5843(1)	24	64
8	8L9863(2)-MU5953-DR6505R-3U8129(1)-UW9945(2)	33	72
9	KY8255(2)-O36944(1)-8L9887(2)-8L9957(1)-DR6505R-1	25	29
10	HO1094(1)-UW9930(1)-MU2027(2)-MU5767-MU5707	30	20
11	DR6579(1)-MU5937-KY8205(1)-CF9018(1)-MU5957	17	38
12	8L9863(1)-MF8430-MU5981(2)-MU5875(1)-KY8253(1)	40	64
13	CA4171(1)-HO1094(2)-UW9930(2)-KY8297(1)-MU5744-GX7882	24	26
14	DR6521(2)-MU5893-ZH9440(2)-MU5705-DR5337	31	46
15	3U8669(2)-MU2027(1)-MU2595-MU5747(2)-MU5655(1)	51	55
16	8L9801(1)-A67107(2)-MU5961-MU767(2)-MU5965-MU5938	24	49
17	MU5879-MU783-MU5971(1)-KY8253(2)-MU5655(2)	39	55
18	HU7768(1)-MU5821-MU5829(1)-UW9947(2)-MU5809	37	59
19	8L9849-MU5941-MU2589(2)-MU5971(2)-UW9945(1)	28	72
20	DR6509(1)-DR6579(2)-MU5981(1)-KY8205(2)-UW9947(1)	41	48
21	8L9801(2)-HU7768(2)-CZ8535(2)-ZH9456-CF9018(2)	35	51
22	CA4171(2)-HO1632(2)-MU5939(2)-MU5885-MU5843(2)	25	64
23	MU5823- HO1632(1)- MU5939(1)-8L9833-8L844	23	51

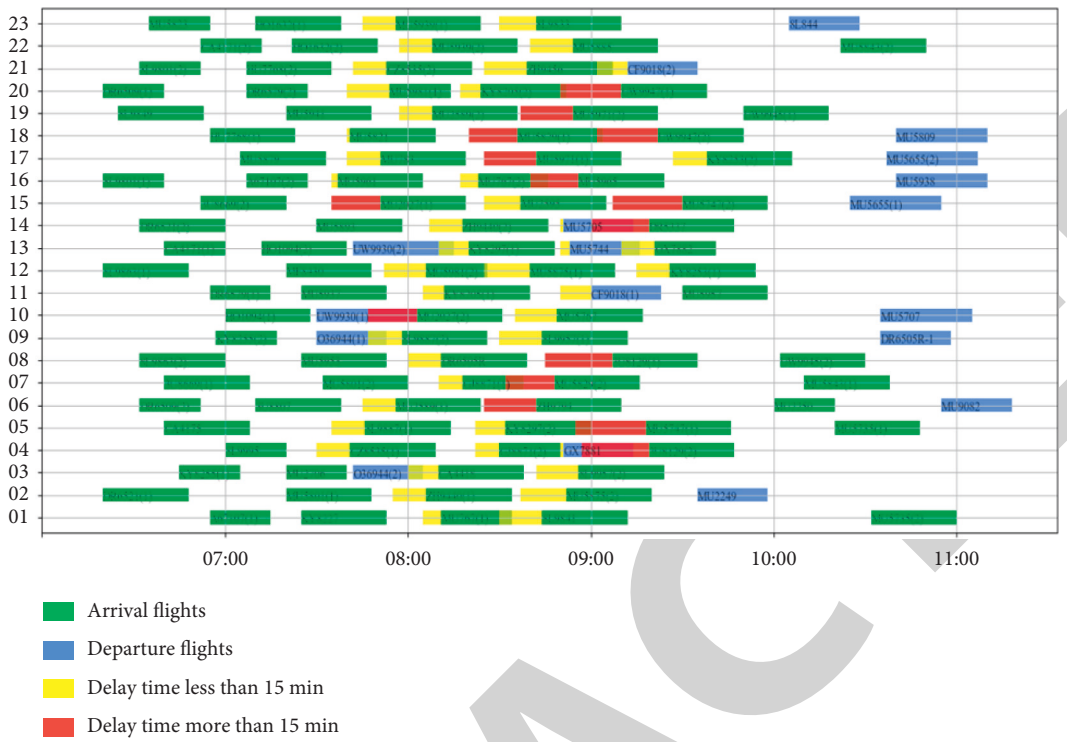

Figure 9: Gantt chart of vehicle scheduling calculated by the model.

Table 9: Comparison of target values between different algorithms.

	Delay time (min)	Connection time (min)	Balance target	Computing time (s)	SP	DM
Proposed algorithm	711	1183	0.34	8.61	0.31	0.68
Manual FCFS	942	1267	0.45	—	—	—
MOPSO	752	1092	0.55	10.25	0.35	0.42
MOACO	735	1125	0.38	50.2	0.43	0.42
SPEA-II	718	1169	0.61	8.82	0.31	0.65

vehicles, the dispatcher will consider vehicles that enter the idle state first to serve the flight and arrange these vehicles one by one according to the arrival of the flight. Based on the concept of manual allocation, this study simulates the process of manual scheduling to compare the optimization effect of the model. For other multiobjective optimization algorithms, we additionally compare the computing time, spread performance (SP), and diversity metric (DM). SP reflects the degree of even distribution of solutions in the search space. The measure is obtained from the standard deviation of the distance from each solution to the nearest solution, with a lower value indicating that the obtained solution is more organized. DM measures the extent to which the approximation set covers the real Pareto front by summarizing the Euclidean distance between each solution and other solutions. The comparison results are shown in Table 9, indicating that the results of the proposed model and algorithm are better than manual scheduling in terms of all indicators. The total delay time is reduced by 24.52%, the transit distance by 6.63%, and the balance index by 24.05%. The proposed algorithm based on NSGA-II has a shorter calculation time and better distribution of solution sets than the other three latest algorithms. Among them, the delay time index has been significantly improved, and it is now exactly in line with the needs of large airports to improve punctuality and effectively reduce the generation of abnormal flights.

Finally, we discuss the influence of these parameters on the model results. The number of ferry vehicles is the key parameter affecting the total delay time of the scheduling. Increasing the number of ferry vehicles can reduce the delay, but it will increase the purchase cost. We gradually increase the number of vehicles on the basis of the original 23 ferry vehicles in the airport and observe changes in the delay target in the model. The results are shown in Figure 10. The figure shows that the number of vehicles needs to be increased to 37 to complete all ferry tasks in peak hours without delay. However, the cost of purchasing an additional 14 ferry vehicles will be millions of dollars, which is not worth it for the airport. Therefore, our model can help the airport schedule the existing ferry vehicle resources, reduce the occurrence of delays, or further help evaluate the balance between the number of vehicles and the total delay.

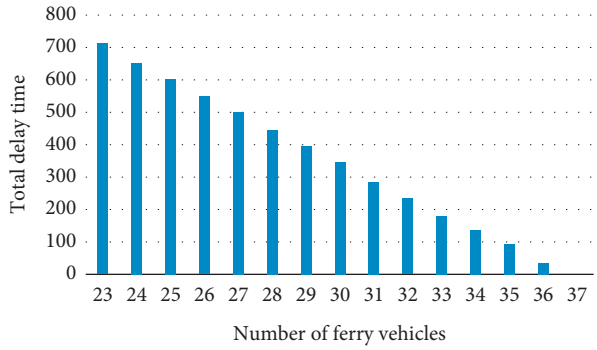

Figure 10: Relationship between total delay time and the number of ferry vehicles.

5. Conclusion

Ferry vehicle resources in the peak hours at large airports are difficult to meet the needs of several flight services, resulting in flight delays. This study constructs a multiobjective optimization model with the main objective of minimizing flight delay time and considering the minimization of transfer distance and vehicle workload balance. Based on the original NSGA-II algorithm framework, a new coding and decoding scheme suitable for the ferry vehicle scheduling problem is designed to solve the constraint problem of the model. Finally, experiments show the effectiveness of the proposed ferry vehicle scheduling algorithm. The calculation results are improved in terms of multiple target values. Among them, the delay time index increased by 24.52%, which is the most obvious and in line with the needs of large airports. In addition, our model can help airports analyze the balance between the number of ferry vehicles and the total delay time and provide decision support for determining whether to delay some flights according to existing resources to achieve scheduling or purchase additional ferry vehicles to reduce the delay. Moreover, the operation of ferry vehicles is related to gate assignment and the scheduling of drivers, where there is certain randomness. Consideration of randomness and multiresource joint scheduling in this regard is the direction of future research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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