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# Scheduling Combination Optimization Research for Bus Lane Line

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***Abstract***

*Different scheduling forms can be adopted in bus lane system to meet passengers' travel demand well and improve operational efficiency. Therefore, this paper researched the optimal headway and bus scheduling combination of a bus lane line. Bus scheduling combination is composed of a sequence of full-length, express bus and short-turn. We established a model to minimize passengers' waiting cost and vehicles' operation cost and to optimize headway and bus scheduling combination, under the constraint of the headway restriction for each stop, the minimum number of vehicle trips in one hour and the proportion of short-turn and express bus trips in total trips. The model was solved by improved genetic algorithm, and the optimal solution was obtained by repeating the operation of genetic algorithm L times. The results of numerical example show that the whole cost can be saved by 21.77% at most after optimization, which indicate the model and algorithm we presented are reasonable and practicable.*

***Keywords***: *Scheduling Combination, Headway, Bus Lane Line, Genetic Algorithm*



## 1. Introduction

Bus lane system is a bus form between ordinary buses and bus rapid transit, speed and priority higher than the former, lower than the latter. Bus scheduling is the bus organization forms in vehicles operation. As shown in Figure 1, full-length bus is a basic scheduling form. Short-turn buses only travel in the large passenger flow section of bus lines, and express buses drive the entire route and only stop at certain stations with large passenger volume [1].

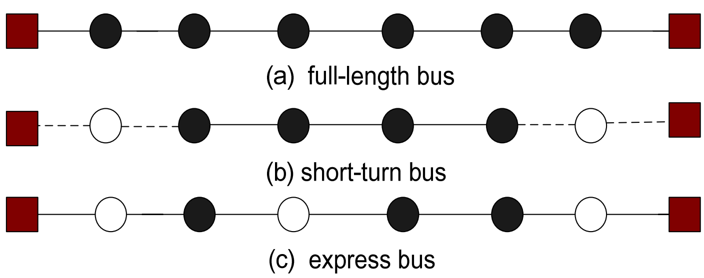


Figure 1. Stops of three scheduling forms

Some related literature is as follows. Jiang first put forward the idea of combination scheduling and made a preliminary discussion on vehicle scheduling combination problem [2]. With the shortest bus operation turnover time for the target and known headways, Zhang et al. researched the vehicles' combination scheduling order [3]. Zou proposed a regional scheduling model to optimize vehicle scheduling mode and dispatch schedule simultaneously, but she

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didn't give a specific algorithm for that model [4]. Xu et al. put forward the express bus scheduling model and applied it to practice [5]. Bai et al. optimized the combination frequency of BRT line and standard line by simulation of tabu simulated annealing algorithm [6]. Sun et al built the optimization model based on minimizing passenger travel time costs and transit vehicles operation time costs, and studied and determined the headway and scheduling combination form of Bus Rapid Transit [7]; however, she didn't take into account the number constraints of short-turn and express bus, and the restrictions on maximum waiting time of passenger at the middle bus stop, which makes the obtained optimization results impracticable. The current bus scheduling researches are mostly concentrated in timetable and frequency optimization of traditional bus lines [8-9]; moreover, scheduling researches on BRT are not many. Furthermore, scheduling researches on bus lane lines is rare, and the literature studying vehicle scheduling combinations and headway optimization simultaneously is also considerably less. Thus, this article intends to study the vehicle scheduling combination and headway optimization of bus lane lines.

## 2. Optimization Model of a Bus Lane Scheduling

### 2.1. Problem Description and Assumption

Bus lane line runs smoothly with special lanes, therefore, different scheduling forms can be adopted to meet bus passengers' travel demand well in various sections and at the same time to increase operational revenue of bus companies. In summary, the key to optimize the bus scheduling programs and improve the service level of bus transit is to establish a rational and effective optimization model on headways and bus scheduling combinations. Considering the passenger flow uneven with the time, under reasonable assumptions, an optimization model will be built to research headway and scheduling form combination of bus lane lines in a certain period in this paper, whose objective is to minimize the sum of bus company operation costs and passengers waiting costs.

In order to facilitate research, the following assumptions are given: (a)The article studies headway and scheduling combinations only in the single direction at a bus lane line; (b)Passenger demand is stable with the headway and bus scheduling combination changing; (c)The running time between stations is certain. Specifically, taking the average running time; (d)In the study period, the passengers are uniformly arrived; (e)The station dwell time of vehicles is fixed, obtained by continuous observation; (f)There are enough vehicles in every fleet; (g)The lane transit vehicles have a uniform departure interval at the origin station.

### 2.2. Symbol Definition

In the paper, the variables involved are defined as follows: $i$ - vehicle trip of a bus lane line at the origin station, $i=1,2,\cdots,j_s, i\in I$; $k$ - stops on the bus line, $k=1,2,\cdots,N$; $K_a$ - stop set of full-length buses; $K_e$ - stop set of express buses; These stops are selected from all stops according to passenger flow volume, and they maybe discontinuous sites. To show the difference, with $k'$ denotes them, $k'=1,2,...,n$; $K_s$ - stop set of short-turn buses; $K_g$ - intersection of set of full-length stops, express stops and short-turn stops, $K_g=K_a\cap K_e\cap K_s$; $j$ - scheduling form, $j=1$ means full-length bus, $j=2$ is express bus, $j=3$ means short-turn bus; $j_s$ - the total number of bus trips, $j_s=j_1+j_2+j_3$; $j_1$ - the number of full-length bus trips; $j_2$ - the number of express bus trips; $j_3$ - the number of short-turn bus trips; $r_k$ - passenger average arrival rate at stop $k$ during the study period (per/min); $t_0$ - departure time of the first bus trip at the origin station in the given period; $a_{i,k}$ - the arrival time of bus trip $i$ at stop $k$; $a'_{i,k}$ - the arrival time of bus trip $i$ at stop $k$, obtained by sorting $a_{i,k}$ ascending; $d_{i,k}$ - the departure time of bus trip $i$ at stop $k$; $d'_{i,k}$ - the departure time of bus trip $i$ at stop $k$, obtained by sorting $d_{i,k}$ ascending; $h$ - headway between bus trips at the origin station; $h_{i,k}$ - headway between bus trip $i-1$ and $i$ at stop $k$, when stop belonging to the set $K_g$, and $h_{i,k}=d'_{i,k}-d'_{i-1,k}$; $h_{i',k}$ - headway between vehicle trip $i'-1$ and $i'$ at stop $k$,when stop $k$ not belonging to the set $K_g$, and

$h_{i',k} = d'_{i',k} - d'_{i'-1,k}$ , $i' \in I$ , $k \notin K_g, k \in K_a$ ; $t_{k-1,k}$ - vehicle running time between stop $k-1$ and $k$ ; $b_0$ - vehicle dwelling time at stops; $\delta$ - outbound acceleration and inbound deceleration time, and the time will be saved when vehicles don't stop at some stations; $S_{i,k}, S_{i',k}$ - remaining passengers at stop $k$ when bus $i$ or $i'$ leaving stop $k$ . In subsequent calculations, the number of passenger left at stops is generated by a random number generator in the above-mentioned ranges. $x_i^j$ - scheduling form of bus trip $i$ ; Although the variable $x_i^j$ doesn't appear in the model, the value of $x_{i,k}^j$ is determined by $x_i^j$. $x_{i,k}^j$ - "0-1" variable, for the scheduling form $j$ , when vehicle trip $i$ stops at station $k$ , the value is 1, otherwise is 0; $h_{\min}, h_{\max}$ - the given minimum and maximum headway (min); $v_w$ - passenger waiting cost (yuan/min); $v_o$ - vehicle operating cost (yuan/min); $\alpha, \beta$ - in the objective function, the respective weights of passenger waiting costs and vehicles operating costs; $Q_t$ - during the $tth$ hour, passenger flow of the highest section; $Q_0$ - vehicle rated passenger capacity; $r_t^0$ - during the $tth$ hour, vehicle actual load rate quota; $\mu$ - the endurance time when passengers waiting for vehicles at station. Generally, it is 10 to 15 minutes for peak period, flat period to take 15 to 20 minutes; $\gamma$ - the proportion of short-turn and express bus trips in total trips; $T$ - the study period (min);

### 2.3. Model Formulation

This paper researches morning peak hour passenger flow in upstream direction of a certain bus lane line. The numbers of boarding passengers at each stop can be obtained by dealing with the data of reading bus cards times during the given period, and the numbers of alighting passengers can be also acquired. When knowing the numbers of boarding and alighting passengers at each stop, we can determine the stops for short-turn and express buses. This article assumes that all vehicles depart from the origin station due to the land utilization restriction of middle stops. We build the optimization model to minimize passenger's waiting fees and vehicles' operating costs in this paper. However, both these costs are in opposite relation. Namely, bus companies always want to provide as large departure interval and reduce the bus trips to decrease operation costs; however, passengers hope to get high frequency bus services to reduce the costs of waiting and transferring. Thus, there is a benefit inconsistency between passengers and bus companies. The bus scheduling combination optimization is a typical multi-objective optimization problem, and this problem can use weight coefficient transformation method; that is to say, we can transform the multi-objective problem into a single-objective one by assigning different weight coefficients to each sub-goal and making a linear weighted summation of all sub-goals. The mathematical model is formulated as follows:

$$Z_1 = v_w\{\sum_{i=1,i'\in I}^{j_s}[\sum_{k\in K_g}^{N}(\frac{1}{2}r_k \cdot h_{i,k}{}^2 + S_{i,k} \cdot h_{i,k}) + \sum_{k\notin K_g, k\in K_a}(\frac{1}{2}r_k \cdot h_{i',k}{}^2 + S_{i',k} \cdot h_{i',k})]\} \quad (1)$$

$$Z_2 = v_o\{j_1\sum_{k=2}^{N}(t_{k-1,k} + 2\delta + x_{i,k}^j \cdot b_0) + j_2\sum_{k'\in K_e}[t_{k'-1,k'} + (x_{i,k'-1}^j + x_{i,k'}^j)\delta + x_{i,k'}^j b_0] + j_3\sum_{k\in K_s}(t_{k-1,k} + 2\delta + x_{i,k}^j \cdot b_0)\} \quad (2)$$

$$\min\ Z = \alpha \cdot Z_1 + \beta \cdot Z_2 \quad (3)$$

$s.t.$

$$h_{\min} \le h \le h_{\max} \quad (4)$$

$$h_{i',k} = d'_{i',k} - d'_{i'-1,k} \le \mu, \quad \forall i', k \quad (5)$$

$$h_{i,k} = d'_{i,k} - d'_{i-1,k} \le \mu\ , \quad \forall i', k \quad (6)$$

$$j_1 + j_2 + j_3 \geq \frac{Q_t}{Q_0 \cdot r_t^0} \tag{7}$$

$$j_2 + j_3 \leq \gamma(j_1 + j_2 + j_3) \tag{8}$$

$$a_{i,k} = t_0 + h \cdot (i-1) + \sum_{k=2}^{k} [t_{k-1,k} + (x_{i,k-1}^j + x_{i,k}^j) \cdot \delta + x_{i,k}^j \cdot b_0] \tag{9}$$

$$d_{i,k} = a_{i,k} + x_{i,k}^j \cdot b_0 \tag{10}$$

$$j_s \cdot h = T \tag{11}$$

$$x_{i,k}^j \in \{0, 1\}, \quad j = 1,2,3, \quad \forall i,k \tag{12}$$

Equations (1) and (2) indicate passenger waiting costs and vehicle operating costs respectively. Equation (1) consist of two parts, the first part denotes passengers' waiting cost when stop $k$ belonging to the set of $K_g$, the second part denotes passengers' waiting cost of other stops. Passenger waiting costs include the passenger average waiting cost and the extra waiting cost of passengers left by previous trip. From equation (2), the vehicles' operation cost includes the operation cost of full-length, express and short-turn buses.

Constraint (4) ensures headway of the origin station in a reasonable range, namely, greater than or equal to the $h_{\min}$, and less than or equal to the $h_{\max}$. Constraints (5)-(6) assure that headway of intermediate station should be no more than passenger waiting endurance time $\mu$. Constraint (7) assures that the total number of bus trips should be greater than or equal to the minimum number of configured vehicles in given period to meet the requirement of actual load rate. Constraint (8) guarantees the number of short-turn and express vehicle trips can't exceed a certain proportion of the total. Constraints (9)-(10) express how to respectively calculate vehicles' arrival time and departure time. Constraint (11) indicates that the studied period is divided into $j_s$ intervals by uniform headway. Constraint (12) shows that variable $x_{i,k}^j$ is a "0-1" variable.

## 3. Improved Genetic Algorithm for Bus Scheduling Combination Problem

The genetic algorithm which simulates the evolution laws of mechanism of being survival of the fittest in biological world is a robust search and optimization methods. Practice has proved that the genetic algorithm can quickly solve large-scale combination optimization problems which the traditional methods can't solve. In this paper, the bus scheduling combination problem is a typical NP combination optimization problem, therefore, this paper uses the genetic algorithm to solve this problem. However, in the application of basic genetic algorithm, some unsatisfactory issues also appear, such as its premature phenomenon and poor local search ability. Thus, this paper makes some improvement in coding and genetic operators of basic genetic algorithm. The core of an improved genetic algorithm for solving the bus scheduling combination problem is to determine the coding mode, initial population, fitness function and the design of genetic operators [10-14].

### 3.1. Determination of Coding Mode

The model contains two decision variables: headway and bus scheduling form combinations, and these variables are interrelated. Therefore, considering two variables together, chromosome length is variable. Namely, according to the number of bus trips, encoding the scheduling forms. If chromosome length is variable, and there will produce many invalid and infeasible solutions, which will greatly lower the efficiency of algorithm. Therefore, this paper aims at headways which divide study period into integer trips, and respectively adopts genetic algorithm in solving the optimal scheduling combination. Finally, comparison and analyses of these optimal vehicle scheduling form combinations are presented. Within [$h_{min}$ , $h_{max}$ ] interval and the number of bus trips being integer, valid headway will be finite number $L$ . Therefore, we need to repeat the operation of genetic algorithm $L$ times. For three different vehicle scheduling forms, 00 is represented as full-length bus, 01 as express bus, and 10 as short-turn bus. For example, when the headway is in the interval [3,15], to take the headway 10min, the number of bus trips is six, and the possible coding is [00 01 00 10 00 00], which gives one of the bus scheduling form combination.

### 3.2. Determination of Decoding Method and Initial Population

Besides combinations described above, 0 and 1 can also produce another combination 11. For 11, when decoding, and it is designed for each randomly assigned in this paper. Namely, when 11 appears, there will produce a random number $\lambda$ in [0,1], and if $0 \le \lambda < 0.5$ , 11 is decoded into full-length bus; if $0.5 \le \lambda < 0.75$ , 11 is decoded into express bus; if $0.75 \le \lambda \le 1$ , 11 is decoded into short-turn bus.

The initial population should be more widely representative and have enough chromosomes in order to avoid falling into local optimum and premature phenomenon. For bus scheduling optimization problem, the initial population consists of part of chromosomes by random and part of the feasible solution chromosomes.

### 3.3. Construction of Fitness Function

In genetic algorithm, we use fitness function to evaluate the extent of the pros and cons of each individual; if individual fitness is greater, the individual is inherited to the next generation with higher probability. The goal of this bus scheduling combination model is to get minimum value, therefore, we can determine its fitness function by finitude construction method. The fitness function is expressed as:

$$F(x) = \begin{cases} c_{max} - f(x) & f(x) < c_{max} \\ 0 & f(x) \ge c_{max} \end{cases} \quad (13)$$

Where $c_{max}$ represents the current generation's maximum objective function value $f(x)$ and it will vary with generations.

### 3.4. Genetic Operators' Realization

For selecting operation, this paper adopts the roulette wheel selection method. The specific operation is as follows: first, calculate the sum of the fitness of all individuals in the group; second, calculate the relative fitness value of each individual, and it is each individual's probability inherited to the next generation populations; finally, simulated gambling disk operation to determine the times of each individual selected. In addition, this article also uses elitist strategy to ensure that the best individual obtained so far is not been destroyed by crossover and mutation operators. Crossover operation is a major operation to generate new individuals in the genetic algorithm, and it is an exchange of two individual's part of chromosomes with certain probability. This paper adopts one-point crossover, and the specific operation is as follows: first, pair individuals of groups randomly; secondly, in the individual encoded string, select randomly a crossover point location according to the probability $P_c$ ; finally, exchange parts of the chromosomes of the two paired individuals. Mutation operation also can produce new individuals. In this paper we use simple mutation, namely, for gene value in one or a few locus assigned randomly in the individual encoded string doing mutation operation with mutation probability $P_m$ . For binary coded individuals, mutation operation means that the gene values of the variation points are inverted, with 0 replacing 1, or 1 replacing 0.

### 3.5. Algorithm Steps

Step 1: parameter settings, including population size $M$ , crossover probability $P_c$ , mutation probability $P_m$ , cycle numbers, maximum and minimum value of bus trips $f$ ;

Step 2: initialization, take a valid integer from bus trips and encode the scheduling forms with binary system. By random generation and the supplementary part of the feasible solution, we can produce an initial population made up of $M$ chromosomes;

Step 3: for each individual of the population decoding, we can get the specific bus scheduling forms sequence, and then calculate the objective function value and fitness value of each individual, combined with the given data and statistical data;

Step 4: selection operation, generating new population with roulette selection; First, calculate the selected probability $P_i$ and cumulative probability $q_k$. Next, produce a uniformly distributed random number $r$ in [0, 1]. If $r \le q_1$, then select the first chromosome to replicate; If $q_{k-1} < r \le q_k$, then select the $kth$ chromosome to replicate. Finally, circulate step for $M$ times to produce the next population;

Step 5: crossover operation, for chromosomes of new population making one-point crossover with the crossover probability $P_c$;

Step 6: mutation operation, for the chromosomes of new population generated by crossover operator doing mutation operation with mutation probability $P_m$;

Step 7: repeat 3~6 steps until it meets preset evolution generations, namely, complete the optimization of bus scheduling form combination, under a specific number of bus trips;

Step 8: select new valid value of bus trips, and repeat 2~6 steps, and obtain the optimal bus scheduling form combination under each valid bus trip. Finally, contrast these optimal values obtained by each cycle, and get the final optimal solution of the present model.

## 4. Numerical Example

### 4.1. Parameter Value

In this paper, parameter values are identified as follow: the passenger waiting value is determined to be 0.25yuan/min, and the bus operation cost value is defined to be 1.5yuan/min. With the survey in stops, the vehicle dwelling time is 1min, the average value of the acceleration and deceleration time is 30s. The running speed is 25km/h during morning peak. There are 20 stops and the studied period is 1 hour. Passenger waiting costs share a weight of 0.5, and the vehicle operation costs account for 0.5. Passenger waiting endurance time $\mu$ is 15mins. The proportion of short-turn and express vehicle trips in total trips is 0.4. According to other relevant researches [12-16], the crossover probability $P_c$ is 0.65, the mutation probability $P_m$ is 0.005, the population size is 20, and cycle number is 100. Stops of express buses include site 1,3,5,8,10,11,12,15,17,20, and the short-turn buses run between 1-12 sites. Passengers' volumes and the route parameters are shown in Figure 2 and Tables 1.

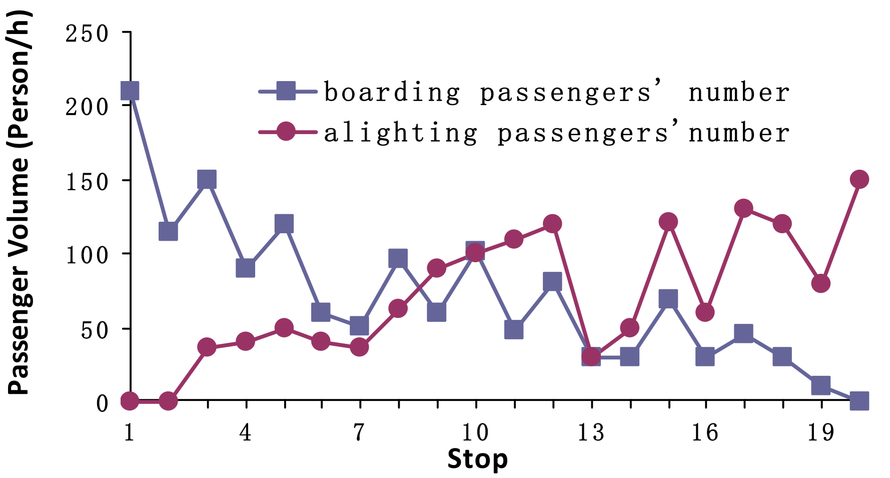


Figure 2. Numbers of boarding and alighting passenger at stops

Table 1. Parameters of bus lane line

| Stops | Distances(m) | Running time (min) |
|---|---|---|
| 1~2 | 600 | 1.44 |
| 2~3 | 550 | 1.32 |
| 3~4 | 650 | 1.56 |
| 4~5 | 500 | 1.2 |
| 5~6 | 650 | 1.56 |
| 6~7 | 600 | 1.44 |
| 7~8 | 500 | 1.2 |
| 8~9 | 600 | 1.44 |
| 9~10 | 650 | 1.56 |
| 10~11 | 550 | 1.32 |
| 11~12 | 800 | 1.92 |
| 12~13 | 600 | 1.44 |
| 13~14 | 650 | 1.56 |
| 14~15 | 700 | 1.68 |
| 15~16 | 800 | 1.92 |
| 16~17 | 650 | 1.56 |
| 17~18 | 550 | 1.32 |
| 18~19 | 650 | 1.56 |
| 19~20 | 650 | 1.56 |

### 4.2. Results Analysis

The genetic algorithm parameters, passenger flow data and parameters of the bus lane line were set into the program, and the calculation results of the numerical example are shown in Table 2. In the optimal bus scheduling form combination, 1 represents full-length bus, 2 represents express bus, and 3 represents short-turn bus. From the results, with the headway decreasing, the objective function values un-optimized decreased gradually because of the reduced waiting time of passengers. For the optimized bus scheduling form combinations, with the number of bus trips, express and short-turn bus increasing, the passenger waiting time at the main stops and overall vehicle operation time decreased, thus the whole system costs have been reduced in different degree. When the headway was 5min and specific bus scheduling form combination was 1 3 1 1 2 1 1 3 1 1 3 1, the optimal solution of the model is obtained and it was 1183.31, which was save by 14.18% after optimization. When the headway is 6min, after optimization, the optimal solution was saved by 21.77% at most. Therefore, this model and algorithm to optimize the headway and bus scheduling form combinations of a bus lane line are reasonable and feasible, and they will save the whole system costs greatly.

Table 2. Optimal scheduling form combination under each headway

| Headway （min） | Vehicle trips | Bus scheduling form combination | Objective values | Objective values (not optimized) | Saved cost（%） |
|---|---|---|---|---|---|
| 12 | 5 | 1 1 1 1 1 | 1704.60 | 1704.60 | 0 |
| 10 | 6 | 1 1 1 1 1 1 | 1635.77 | 1635.77 | 0 |
| 7.5 | 8 | 1 1 3 1 3 1 2 1 | 1477.18 | 1598.73 | 8.23 |
| 6 | 10 | 1 3 1 2 1 1 3 1 3 1 | 1262.82 | 1537.71 | 21.77 |
| 5 | 12 | 1 3 1 1 2 1 1 3 1 1 3 1 | 1183.31 | 1351.11 | 14.18 |
| 4 | 15 | 1 3 1 1 2 1 3 1 3 1 2 1 1 3 1 | 1213.40 | 1315.25 | 8.43 |

### 4.3. Sensitivity Analysis

When the proportion of passenger waiting cost is 0.3~0.7, the changes of optimal values are showed in Figure 3. For the same headway, with the proportion of passenger waiting cost increasing, we can see that the objective values increase, except the headway of 4 minutes, and headway is bigger, the objective value increase quickly. More important, for the same proportion of passenger waiting cost, the optimal objective value corresponds to the different headway. Therefore, we should carefully analysis and determine reasonable proportions of passenger waiting cost and bus operation cost.

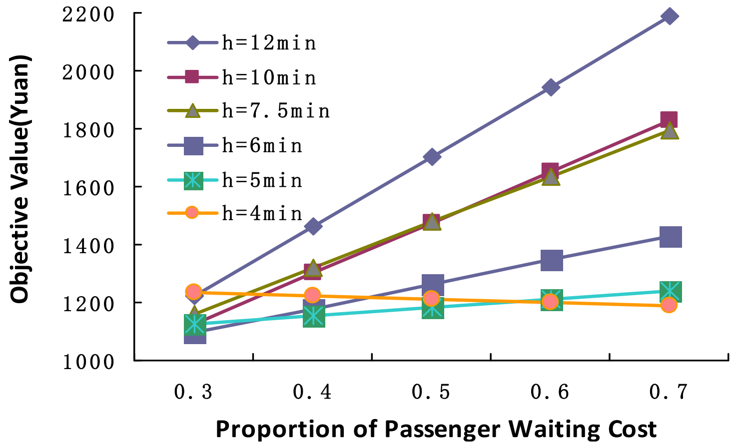


Figure 3. Sensitivity of objective function to proportion of passenger waiting cost

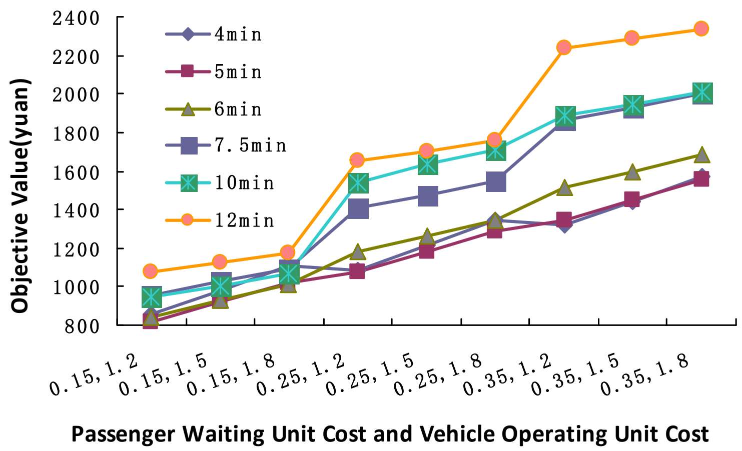


Figure 4. Sensitivity of objective function to passenger waiting and vehicle operating unit cost

From the Figure 4, it can be seen that when the passenger waiting unit cost and bus operation unit cost take nine different combinations, the optimal objective value of the same headway is a broken line, and for the same combination, the optimal objective value corresponds to different headway. Therefore, we should make sufficient investigations on passenger's time cost and bus operation cost, and then determine their reasonable values.

## 5. Conclusion and Discussion

Considering various practical constraints in bus operating process, this paper built the model which aimed at minimizing the linear weighted sum of the passenger waiting cost and vehicle operation cost in order to study the optimal headway and bus scheduling combination for a bus lane line in given period, and solve the model by improve genetic algorithm. The optimal results obtained by numerical example can been saved by 14.18%, compared with the un-optimized value. Therefore, the model and the solving method are practical and effective.

Due to limited space and ability, this study has some defects inevitably, and the following contents need to be deeply explored in further research. First, according to the actual arrival rate of passengers, without equal headway restriction, there can obtain more optimal results. Second, the value of proportion of short-turn and express bus trips in total trips also affects the optimal value of the model, and consequently, there needs careful study to determine the reasonable value in order to reduce passenger waiting time at the main stops and not cause passenger too long waiting time at the rest stops.

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