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CIRCLE LINE OPTIMIZATION OF SHUTTLE BUS IN CENTRAL BUSINESS DISTRICT WITHOUT TRANSIT HUB

ABSTRACT

The building density of Central Business District (CBD) is usually high. Land for a bus terminal is insufficient. In this situation, passengers in CBD have to walk far to take a bus, or take a long time to wait for a taxi. To solve this problem, this paper proposes an indirect approach: the design of a circle line of shuttle bus as a dynamic bus terminal in CBD. The shuttle bus can deliver people to the bus station through a circle line. This approach not only reduces the traffic pressure in CBD, but also saves travel time of the passenger. A bi-objective model is proposed to design a circle line of a shuttle bus for CBD. The problem is solved by non-dominated sorting genetic algorithm (NSGA-II). Furthermore, the Dalian city in China has been chosen as the case study to test the proposed method. The results indicate that the method is effective for circle line optimization of shuttle bus in central business district without a bus terminal.

KEY WORDS

Central Business District; shuttle bus; transfer; genetic algorithm; bi-objective model;

1. INTRODUCTION

1.1 Background

Central Business District (CBD) is an important area of traffic attraction. With the development of a city, the traffic congestion has become a serious problem now and the conflict between traffic demand and traffic supply of traffic facilities has become increasingly prominent. During peak hours, the bus line and intersection congestion are common. For most cities, a bus terminal in CBD can improve the traffic condition. Because of the scarce and expensive land resources in CBD, many cities do not have bus terminals in CBD. Thus, it is feasible to design a circle line of a shuttle bus that makes use of the existing important

bus stops. People can get to the bus stops by shuttle bus instead of walking. The shuttle bus has many outstanding features, such as short stop spacing, short interval, low fare and good service. The shuttle bus can achieve the functions of transfer as a dynamic bus terminal. Dynamic bus terminal indicates that a shuttle bus can pass through bus stations or bus terminals of different buses in CBD by a circle line. Moreover, a shuttle bus can deliver passengers to different bus stations or bus terminals which they want to reach in CBD.

The shuttle bus line design is introduced in this paper to solve the transfer in CBD, especially for the ones that lack land resources. The line can also provide convenient transfer services for passengers when the bus terminal is unavailable. The shuttle bus reduces the traffic congestion by lowering the car or taxi travel. Therefore, the optimization of the stop selection of a shuttle bus and the operation strategies proposed in this paper are of significance for the traffic congestion in CBDs.

1.2 Literature review

Some studies have focused on the circle rail transit. Warade [1] proposed a circle line in Chicago which would serve the urban core of the Chicago region, and was likely to significantly affect both land use and travel patterns. The paper developed the frameworks and models for the Circle Line project and applied it to quantify the accessibility and development impacts of the Circle Line project. Zhibin et al. [2] studied the circle rail transit line timetable scheduling, and they discussed the definition of circle line topology structure, time-space structure, and transfer schemes.

Due to the limited studies of circle line of shuttle bus, studies about transfer from bus to other modes of transport can be referenced in this paper. Chen et

al. [3] proposed a spatiotemporal data model for time geographic entities, which include space-time path, station, prism, and lifeline, in road networks. Wirasinghe [4] presented an approximate analytical model of a rail plus feeder bus system. The system served a peak-period many-to-one type demand. Bookbinder and Desilets [5] minimized the overall inconvenience to passengers for transfer optimization. Martins and Pato [6] focused on establishing a model. A two-phase method was used to solve the feeder bus network design problem (FBDP). The objective was to minimize the cost function, where interests of both passenger and operator were considered. Quadrifoglio and Li [7] proposed an analytical model and solution to the problem, and verified the validity of the analytical modelling approach by comparing to the values generated from simulation. Proper design and operations are becoming increasingly important to enhance the performance of the public transportation system network. Ceder [8] designed an integrated smart feeder/shuttle service established to overcome the problem of using an excessive number of cars arriving and parking at the train station within the same time span. This work developed a new idea of an integrated and innovative feeder/shuttle system with new operating and routing concepts. Dikas and Minis [9] modelled a design problem by a mixed integer-linear program. Such a system may offer higher quality of transport to clients with disability without increasing significantly the public transport expenditure. Braekers et al. [10] presented a meta-heuristic algorithm which is an excellent and efficient tool for solving larger problems comparing to branch-and-cut algorithm. Lai et al. [11], Saka [12], Chien and Qin [13] focused on the optimization of bus stop location and spacing.

Large numbers of studies are available on problems related to feeder bus scheduling or departure frequency that is in accordance with the main transit. Shafahi and Khani [14] represented two models with the aim of minimizing the transfer waiting time in transit networks. Sivakumaran et al. [15] used continuum models to analyze cases in which the trunk-line vehicle schedule was given exogenously. In the model, coordination could be Pareto improving and operator and user costs both diminished, when the frequencies of trunk and feeder services could be established jointly. Sumalee et al. [16] proposed a multi-modal transport network assignment model considering uncertainties in both demand and supply of the network. Zhibin and Qixiang [17] arranged the service-based shuttle bus timetable in accordance with the rail transit. The model achieved a seamless connection from the rail transit station to the living community. Fu et al. [18] presented a reliability-based user equilibrium traffic assignment model for congested multi-modal transport networks under demand uncertainty. Liu et al. [19] studied transit users' route choice in the context of transit assignment

in three groups: static transit assignment, within-day dynamic transit assignment, and emerging approaches. The bus frequency or bus scheduling for transfer can be found in literature [20-25].

Additionally, some studies have jointly considered the feeder bus network and scheduling. Shrivastava and O'Mahony [26] optimized the feeder routes and frequencies simultaneously using genetic algorithms. Martínez and Eiró [27] designed a minibus feeder service for the Sintra rail line. The formulation was divided into three main steps: the establishment of stops, scheduling and fleet dimensioning. Ibeas et al. [28] developed a bi-level optimization model for locating bus stops to minimize the social cost of the overall transport system. They took into account possible changes in demand due to different bus stop locations considering congestion on buses. They [29] also proposed an optimization model for designing the intervals (headways) and sizes of buses circulating on public transport networks by minimizing the system's operating and user costs. The proposed model takes into account congestion on the public transport system. Szeto and Wu [30] aimed to improve the existing bus services by reducing the number of transfers and users' total travel time. Ruisanchez and Ibeas [31] presented a bi-level optimization model to assign optimal bus sizes and frequencies to public transport routes. The upper level problem of the proposed model minimizes the cost function representing the costs of the users and operators, and the lower level solves a public transport assignment model subject to capacity constraint. An integrated solution method was proposed in which a genetic algorithm would tackle the route design problem and a neighbourhood search heuristics would deal with the frequency setting problem. Besides, Ngamchai and Lovell [32], Chen et al. [33], have also carried out similar studies.

1.3 Contributions

This paper presents a new idea about the shuttle bus through a circle line in CBD. An airport ferry bus can remove the passengers from the lounge to the far seat aircraft they want to go. Similar to the airport ferry bus, the shuttle bus would transfer people to the bus station which they want to reach through a circle line. Because of the high population density and the high degree of congestion in CBD, the design of a shuttle bus can reduce the degree of congestion and provide people with services of convenience. In the shuttle bus line design, there is a conflict of interest between the operator and the passenger. To make passengers more satisfied and the operator costs lower, the stop selection and headway should be weighted at the same time. Therefore, both bus stop selection and headway are important for a successful shuttle bus regular management.

There are two main contributions in this paper. Firstly, a new idea about the shuttle bus as a dynamic bus terminal through a circle line in CBD is presented in this paper. Due to crowded population and expensive land in CBDs, it is very difficult to create a new bus terminal to facilitate passengers. So this paper presents an idea about a shuttle bus as a dynamic bus terminal to deliver people from different locations in CBD to the bus stations to which they want to go. Secondly, the passengers prefer high frequency to reduce their travel time while the bus operators try their best to reduce the operation cost. This paper builds a bi-objective model to balance the benefits of the passengers and the bus operator which improves the implementation probability of the optimal scheme. In addition, real data of Dalian city in China are used to test the optimization model.

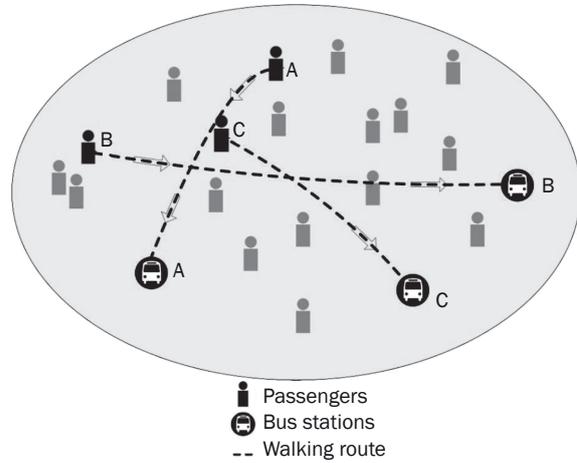
The rest of the paper is organized as follows: Section 2 introduces the bi-objective model of shuttle bus line design for transfer; the NSGA II is described in Section 3; a case study of Dalian city, the convergence of the algorithm and the results analysis are presented in Section 4; and finally, the conclusions and directions for future research are presented in Section 5.

2. THE CIRCLE LINE OF SHUTTLE BUS OPTIMIZATION MODEL FOR TRANSFER

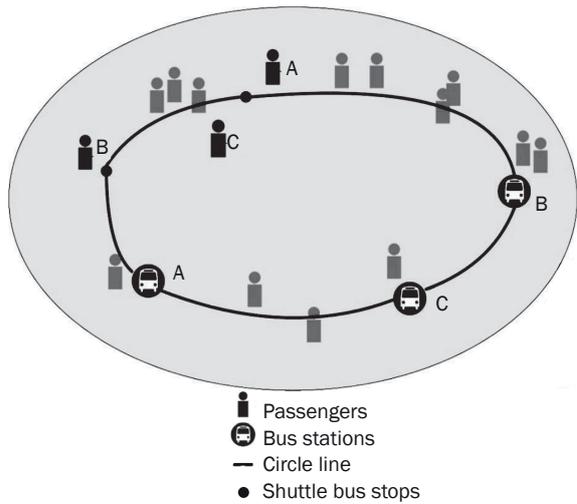
2.1 Problem description

CBD is the meeting-place of pedestrian flows and traffic streams. For a CBD without bus terminals, passengers have to walk far to get to a bus stop. Passengers can also choose to take a taxi, but they have to wait for a long time and spend a lot of money. Lacking a bus terminal causes dissatisfaction of passengers and they lose preference for public transport facilities. However, after opening a shuttle bus, the situation will change. *Figure 1* shows the change of the passenger flow in CBD after opening a circle line of shuttle bus. The shuttle bus runs quickly through the important bus stops which connect the bus routines in other directions. For example, passenger A in *Figure 1a* wants to go to the bus station A for taking bus A. From A's position to the bus station, taking a taxi would cost passenger A a lot and it is also inconvenient for people to take a taxi in CBD which is always congested. Thus, passenger A has to walk a long distance to get to bus station A. There are plenty of people who have a similar situation as passenger A in CBD, such as passenger B, C and grey people (shown in *Figure 1a*), etc. This situation increases the degree of congestion and generates chaos in CBD. The situation would be alleviated after opening a shuttle bus circle line (shown in *Figure 1b*). Passengers can take the shuttle bus at the shuttle bus stop which is close to them. The circle line

will reduce the passengers' walking distance greatly and increase the convenience of passengers. The lack of a bus terminal in CBD can be solved by a shuttle bus transfer. It not only alleviates the traffic pressure, but it also reduces the travel time and costs of passengers.



a) Passenger flow before opening the shuttle bus circle line



b) Passenger flow after opening the shuttle bus circle line

Figure 1 – The changes of passenger flows after opening the shuttle bus circle line

2.2 Assumptions

The following assumptions are introduced to simplify the building and calculation of the optimization model:

- When the shuttle bus departs from the bus stop, it accelerates uniformly to normal operating speed; when the shuttle bus reaches the bus stop, it decelerates the normal operating speed to rest uniformly;

- All passengers near the bus stop of circle lines will walk to the bus stop;
- Passengers arriving at the bus stop submit to uniform distribution and the average waiting time is half the headway (the number of people in CBD is large, so the average was used for calculation);
- The first shuttle bus passengers encounter at the bus stop still has space, supposing the shuttle bus can carry 60 people.

2.3 The shuttle bus line optimization model

This model sets up multiple alternative stops near each demand point in CBD. Then the appropriate stops are selected as shuttle bus stops to form the circle line of the shuttle bus as shown in Figure 2. At the same time, the model optimizes the bus headway in order to achieve the requirements of both passengers and the operator. In this paper, the interests of both passengers and bus operators are balanced, corresponding to the minimum cost of passengers and the minimum cost of the operators, respectively. The cost of passengers is reflected on the total travel time, including the walking time from the origin to the bus stop, waiting time at the bus stop, time on the bus and walking time from the bus stop to the destination. The interest of the operator embodied in the operating costs, including the depreciation and maintenance cost of the bus stops and the cost of the fuel consumption and bus wear.

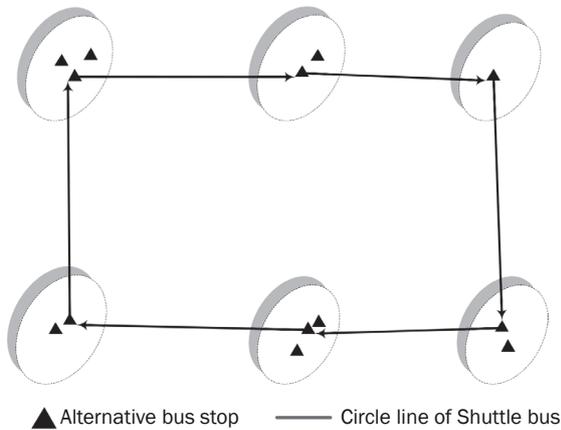


Figure 2 – Schematic diagram of shuttle bus line optimization model

2.3.1 First objective: minimum passenger travel cost

The first objective is to minimize the passenger travel cost, which includes the walking time cost from origin to bus stop, the waiting time cost at the bus stop, the time cost on the bus and walking time cost from the bus stop to the destination. The specific formulas are shown as follows:

$$\text{Min } PC_1 + PC_2 + PC_3 + PC_4 \quad (1)$$

- Walking time cost from origin to bus stop and walking time cost from bus stop to destination

$$PC_1 = \eta \cdot \sum_{i=1}^n \frac{l_i}{v} \cdot O_i \cdot x_i \quad (2)$$

$$PC_2 = \eta \cdot \sum_{i=1}^n \frac{l_i}{v} \cdot D_i \cdot x_i \quad (3)$$

where PC_1 is the walking time cost from origin to bus stop; PC_2 is the walking time cost from bus stop to destination; n is the set of bus stops; η represents the value of unit time; O_i is the trip generation at bus stop i ; D_i is the trip attraction at bus stop i ; l_i is passenger's walking distance to bus stop i ; v is the passenger walking speed; x_i is 0-1 variable; if the alternative bus stop is chosen, the value of x_i is 1, otherwise it is 0.

- Waiting time cost at bus stop and time cost on the bus

$$PC_3 = \eta \cdot \sum_{i=1}^n \left(O_i \cdot \frac{H}{2} + \lambda_1 \cdot n_i \right) \cdot x_i \quad (4)$$

$$PC_4 = \eta \cdot \sum_{i=1}^n \sum_{j=1}^n \left(\theta_{ij} \cdot \left(\frac{l_{ij} \cdot x_i \cdot x_j}{u} - \frac{ub + 3ua}{2ab} \right) \cdot \left(\sum_{k=1}^i O_k - \sum_{m=2}^j D_m \right) \right) \quad (5)$$

where PC_3 is the waiting time cost at the bus stop; PC_4 is the time cost on the shuttle bus; H is the headway; λ_1 represents the time of one passenger getting on or off a bus; n_i represents the max number of people getting on or off the bus at bus stop i ; θ_{ij} is 0-1 variable; if i and j are two adjacent bus stops, the value of θ_{ij} is 1, otherwise 0. l_{ij} is the length of arcs i, j ; u, a, b represent normal speed, acceleration and deceleration, respectively; $\frac{l_{ij} \cdot x_i \cdot x_j}{u} - \frac{ub + 3ua}{2ab}$ is the time on shuttle bus from stop i to j , consisting of acceleration time, running time at normal speed and deceleration time; $\sum_{k=1}^i O_k - \sum_{m=2}^j D_m$ is the passenger trip flow between stops i and j .

2.3.2 Second objective: minimum operating cost of operator

The second objective is to minimize the operating cost of the operator, which includes depreciation and maintenance cost of bus stops, cost of fuel consumption and bus wear, fixed costs of the circle line. The specific formulas are shown as follows:

$$\text{Min } OC_1 + OC_2 + OC_3 \quad (6)$$

- Depreciation and maintenance cost

$$OC_1 = \sum_{i=1}^n x_i \cdot \lambda_2 \quad (7)$$

where OC_1 is depreciation and maintenance cost of bus stops; λ_2 represents the daily maintenance and depreciation expenses of each bus stop.

- Cost of fuel consumption and bus wear

$$OC_2 = \sum_{i=1}^n \sum_{j=1}^n \frac{T}{H} \cdot \theta_{ij} \left[\lambda_3 \cdot \left(\frac{l_{ij} \cdot x_i \cdot x_j}{u} - \left(\frac{u}{2a} + \frac{u}{2b} \right) \right) + \lambda_4 \left(\frac{u}{a} + \frac{u}{b} \right) + \sum_{i=1}^n \lambda_5 \cdot n_i \right] \quad (8)$$

where OC_2 is the cost of fuel consumption and shuttle bus wear; T is bus operating time; $\frac{T}{H}$ are the running times of buses in T hours a day; λ_3 represents the average fuel consumption and loss per unit time under normal speed; λ_4 represents the average fuel consumption and loss per unit time when accelerating or decelerating; λ_5 represents the average fuel consumption and loss when each person gets on or off the bus; n_i represents the max number of people getting on or off the bus at bus stop i .

- Fixed costs of the circle line

$$OC_3 = \frac{L}{u \cdot H} (\lambda_6 + \lambda_7) \quad (9)$$

where OC_3 are fixed costs of the circle line; L is the total length of shuttle bus regular management; u is the average speed of a bus in a shuttle bus routine; $\frac{L}{u \cdot H}$ is the total number of shuttle buses; λ_6 represents the depreciable cost of a shuttle bus one day; λ_7 represents the stuff cost of a shuttle bus one day.

2.3.3 Constraints

In this paper, the shuttle bus stop spacing, headway, total length of line and ensuring circle line are restricted. The specific formulas are shown as follows:

$$l_{\min} \leq l_{ij} \cdot \theta_{ij} \cdot x_i \cdot x_j \leq l_{\max} \quad (10)$$

$$H_{\min} \leq H \leq H_{\max} \quad (11)$$

$$l_i \cdot x_i \leq D_w \quad (12)$$

$$L_{\min} \leq \sum_{i=1}^n \sum_{j=1}^n l_{ij} \cdot \theta_{ij} \cdot x_i \cdot x_j \leq L_{\max} \quad (13)$$

$$\sum_{i=1}^n \delta_{ki} \cdot x_i = 1 \quad (14)$$

$$\sum_{j=1}^n \theta_{ij} = \sum_{k=1}^n \theta_{ki}, \forall i \quad (15)$$

$$\sum_{i=1}^n x_i = \sum_{i=1}^n \sum_{j=1}^n \theta_{ij}, \forall i \quad (16)$$

where, l_{\min} and l_{\max} are the shortest and longest bus spacing; H_{\max} , H_{\min} represent the upper and lower bound of headway; L_{\min} and L_{\max} are the shortest and

longest total length of shuttle bus regular management; D_w is the maximum tolerance of passengers walking distance; δ_{ki} is a 0-1 variable; if stop i is within the demand point k , the value of δ_{ki} is 1, otherwise it is 0.

Constraint 9 restricts the bus stop spacing; *Constraint 10* restricts the bus headway; *Constraint 11* indicates that passenger walking distance cannot exceed the maximum tolerance; *Constraint 12* stands for the range of the total line length; *Constraint 13* represents that only one stop is the selection for one demand point. *Constraints 14* and *15* ensure the shuttle bus regular management to be a circle line: The left side of *Equation 15* represents the total number of bus stops. The right side represents the total number of road links in a circle line. In addition, x_i and H are the decision variables in this paper.

3. ELITIST NON-DOMINATED SORTING GENETIC ALGORITHM

A large part of literature suggested that heuristic algorithm was often the first choice to solve this kind of complicated problems. To optimize the circle line of a shuttle bus and its corresponding headway, a heuristic algorithm, Elitist Non-dominated Sorting Genetic Algorithm (NSGA- II), F was introduced. The non-dominated sorting GA (NSGA) was proposed by Srinivasan and Deb [34]. Then, Deb et al. [35] improved it to be NSGA-II which had been applied to various problems. Shimamoto et al. [36] proposed a method for evaluating the effect of transit fare systems on passengers' behaviour. Both total cost and connection reliability were adopted as the evaluation index of the problem. NSGA-II was used to solve this problem. Kwan and Chang [37] improved NSGA- II for timetable synchronization. Lau et al. [38] used NSGA- II to solve the transportation problem. Song et al. [39] suggested a multi-objective model to plan the regional bus timetable. The Elitist Non-Dominated Sorted Genetic Algorithm- II was employed to search a group of Pareto optimal solutions for the model. Khoo et al. [40] solved the problems of selection and scheduling of the exclusive bus lane with NSGA-II. Compared with NSGA, NSGA-II could reduce the complexity. NSGA-II can also increase the diversity and avoid the algorithm prematurely converging to local optimal, and the algorithm mutates the superposition individuals in the objective space and adds some new individuals to every generation.

3.1 Fast non-dominated sorting approach

As there is conflict of interests between passengers and the operator, we need to strike a balance between the two goals made. NSGA II is used in this paper. The main features of NSGA II are low computational requirements, elitist approach, and parameter-less

sharing approach. For each solution two entities should be calculated: n_i is the number of solutions which dominate solution i , and S_i is a set of solutions in which solution i dominates. First, we identify all those points which have $n_i=0$ and put them in a list F_1 called the current front. Second, for each solution in the current front we visit each member (j) in its set S_i and reduce its n_j count by one. By doing so, for any member j if the count becomes zero, it is put in a separate list H . When all members of the current front have been checked, the members in the list F_1 are declared as members of the first front. Then we continue this process using the newly identified front H as our current front. This process continues till all fronts have been identified. The overall complexity of the algorithm is $O(mN^2)$. N is the size of population; m is the number of objectives.

3.2 Density estimation

To get an estimate of the density of solutions surrounding a particular point in the population, we take the average distance between the two points on either side of this point along each of the objectives. This quantity $i_{distance}$ serves as an estimate of the size of the largest cuboid enclosing point i without including any other point in the population called crowding distance. In Figure 3, the crowding distance of the i -th solution in its front (marked with solid circles) is the average side-length of the cuboid (shown with a dashed box).

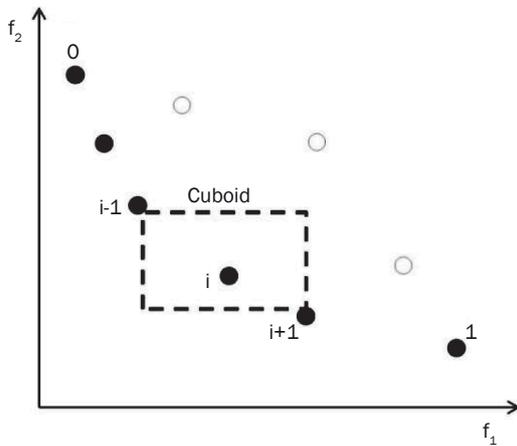


Figure 3 – The crowding distance calculation

3.3 Crowded comparison operator

The crowded comparison operator ($>n$) guides the selection process at various stages of the algorithm towards a uniformly spread-out Pareto-optimal front. Assume that each individual in the population has two attributes: (1) Non-domination rank (i_{rank}) and (2) Local crowding distance ($i_{distance}$).

Define a partial order $\geq n$ as: $i > n_j$, if ($i_{rank} < j_{rank}$) or ($i_{rank} = j_{rank}$ and ($i_{distance} > j_{distance}$)). That is to say that if

non-dominated sorting of two individuals is different, the one with smaller sorting number is taken; if the two individuals are at the same level, the less crowded one is taken.

3.4 Coding

In this paper, real number coding is used. Each coding is on behalf of a stop or headway of the shuttle. Specific process is as follows: demand point, alternative stops of each demand point and headway range should be made sure first. Then, it is supposed that P is the number of demand points and Q is the number of alternative bus stops in CBD. The coding length of each chromosome is $Q+1$. The last one is a representative of the headway.

3.5 The process of algorithm

The flow chart of the optimization for the bi-objective model is shown in Figure 4. And the concrete steps of the NSGA-II algorithm in this paper are as follows:

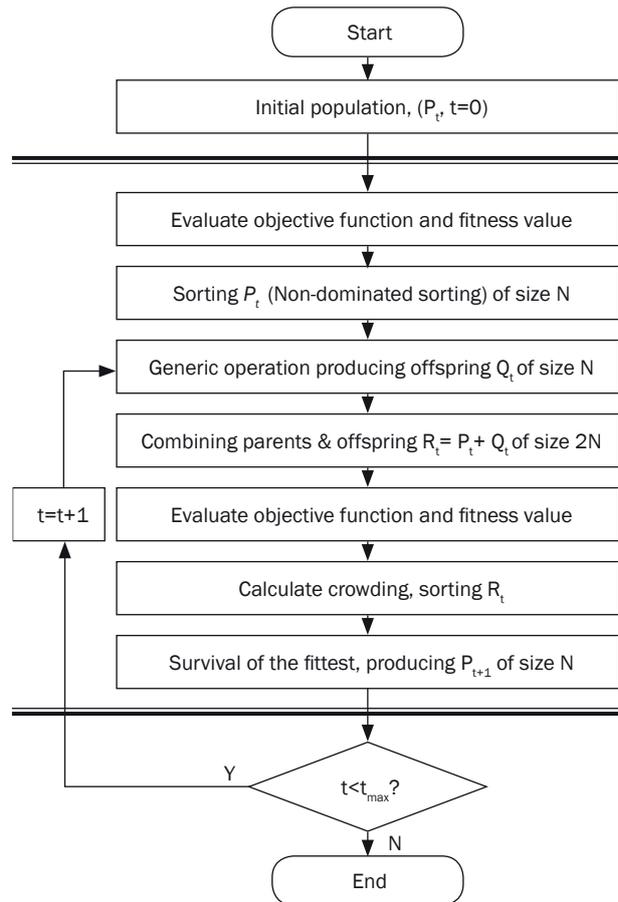


Figure 4 – Flow chart of NSGA-II optimization procedure in this work

Step 1: Generating an initial population of chromosomes. A random parent population P_0 of size N is created. Evaluating the objective function and the

fitness value. (Min $PC_1+PC_2+PC_3+PC_4$ and Min $OC_1+OC_2+OC_3$). The population is sorted based on the non-domination. Each solution is assigned a fitness equal to its non-domination level (1 is the best level).

Step 2: Binary tournament selection, recombination, and mutation operators are used to create a child population produce an offspring Q_0 of size N .

Step 3: Performing the elite strategy of NSGA-II. A combined population $R_t = P_t + Q_t$ is formed. The population R_t will be of size $2N$. The population R_t is sorted according to non-domination. Then, the crowding distance in the current front is calculated, producing population P_{t+1} based on crowding distance comparison.

Step 4: Judging whether to continue calculation or not. If iteration reaches maximum times then terminate calculation and output the maximum fitness; otherwise, return to Step 2 to continue the calculation.

4. CASE STUDY

4.1 Essential data

In this paper, about 5 square kilometres of area around the Dalian Railway Station were taken as the research object. This region covers the Dalian Railway Station, Qingniwa Bridge CBD and many hotels and shopping centres. It is the most prosperous area in Dalian. According to actual road network and land use, the research object is divided into 11 demand points (A - K), including 30 alternate stops as shown in Figure 5. The demand points are the bus stations which the passengers want to reach most. The CBD is divided into traffic zones. The demand points are obtained through the investigation based on the actual location of bus stations and passengers' travelling needs in CBD. Several alternate stops are chosen for each demand point separately, and the best points of the alternate stops are chosen as the final demand points.

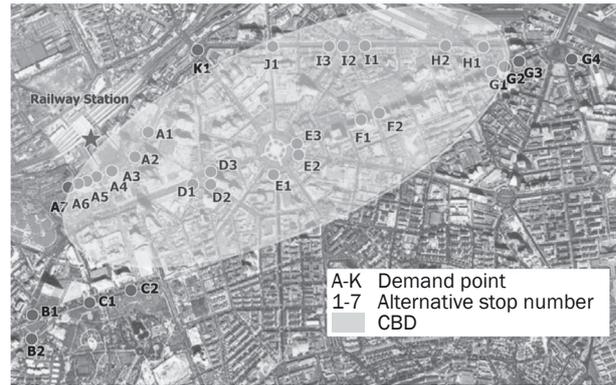


Figure 5 - Distribution of alternative bus stops

The case is based on the public transportation system planning. The basic data are obtained by typical traffic surveys on the bus. The traffic survey was conducted during April 8-10, 2013. It is observed that most passengers travel during 7-9 a.m. and 5-7 p.m. Therefore, the two time periods are identified as the peak hours. In addition, it assumes that the operating time (T) of shuttle bus is sixteen hours. There are four hours of peak time and twelve hours of off-peak time. Due to the higher passenger trip flow per hour at the peak time, different headways corresponding to the peak time and off-peak time are optimized. The numbers of passengers getting on and off at bus stops are shown in Table 1 and Table 2, respectively. Then the passenger trip flows on the road segment can be calculated. The purpose of establishing this circle line is to make the trips of people who want to go to the bus stops nearby more convenient. So there is no need to establish new bus stops for the circle line. One just chooses the already existing points in the CBD, and make them be a circle line.

More than one parameter is involved in this paper, so the specific values will be determined on the base of the specification of the urban traffic planning, as shown in Table 3.

4.2 The results of the circle line of shuttle bus optimization

Table 1 - The numbers of passengers getting on and off at bus stop during the peak hours of a day (person/day)

	A	B	C	D	E	F	G	H	I	J	K
ON	2,570	802	1,012	884	739	945	713	307	1,708	151	222
OFF	2,554	250	865	1,312	1,115	832	1,335	267	1,062	301	160

Table 2 - The numbers of passengers getting on and off at bus stop during the off-peak hours of a day (person/day)

	A	B	C	D	E	F	G	H	I	J	K
ON	4,570	1,426	1,800	1,572	1,313	1,679	1,267	545	3,036	269	394
OFF	4,540	444	1,537	2,332	1,982	1,480	2,373	474	1,889	535	285

Table 3 – Parameter and value of the model

Parameter	Parameter specification	Value
η	the value of unit time [yuan/h]	15
u	normal speed [m/s]	12
a	acceleration [m/s^2]	0.6
b	deceleration [m/s^2]	2
H_{min}	lower bound of headway [min]	1
H_{max}	upper bound of headway [min]	10
D_w	the maximum tolerance of walking distance [m]	100
V	the passenger walking speed [km/h]	5
T_p	the peak hour [h]	4
T_o	the off-peak hour [h]	12
λ_1	the time of one passenger get on or off a bus at bus stop [min]	0.1
λ_2	daily maintenance and depreciation expense of each bus stop [yuan/day]	20
λ_3	average fuel consumption and loss per unit time under normal speed [yuan/s]	0.08
λ_4	average fuel consumption and loss per unit time when accelerating or decelerating [yuan/s]	0.12
λ_5	average fuel consumption and loss when each person get on or off the bus [yuan]	1
λ_6	the depreciable cost of a shuttle bus one day [yuan/day]	135
λ_7	the stuff cost of a shuttle bus one day [yuan/day]	165

4.2.1 Calculation results

NSGA- II algorithm is applied in this paper to solve the bi-objective model. The optimized minimum cost is RMB 105,120 during the operating hours. The minimum cost of peak hours is RMB 35,403, while it is RMB 69,717 during off-peak times as shown in Table 4. The actual passenger cost (without taking a shuttle bus), including passengers' walking time cost or taxi fares from origin to destination is also shown in Table 4. Compared with the actual passenger cost, taking a shuttle bus can decrease the cost of passengers. The optimal result of bus stop selection is shown in Table 5.

	Passenger cost	Operator cost	Total cost	Actual passenger cost
Peak	26,430	8,973	35,403	47,210
Off-peak	51,717	18,000	69,717	90,842
Total cost	78,147	26,973	105,120	138,052

There are seven alternative stops near the Dalian Railway Station and the fourth alternative stop is chosen. From the location of the fourth alternative stop, it can be seen that the alternative stop selection should not only consider the passengers' travel distance, but also the length of the road segment. If the length is too long, it will not be convenient for passengers to take a bus. If the length is too short, it will increase fuel consumption. There are four alternative stops near the

Table 4 – Cost breakdown category

Table 5 – Selection plan of alternative bus stops

Sequence number	Selected or not	Sequence number	Selected or not	Sequence number	Selected or not
A1	0	C2	1	G2	0
A2	0	D1	0	G3	1
A3	0	D2	1	G4	0
A4	1	D3	0	H1	0
A5	0	E1	0	H2	1
A6	0	E2	1	I1	1
A7	0	E3	0	I2	0
B1	1	F1	0	I3	0
B2	0	F2	1	J1	1
C1	0	G1	0	K1	1

Note: 1 - selected, 0 - not selected

Harbour Square, and one of the four alternative stops is on the square. The optimization result is to choose the third alternative stop close to the square. This is convenient for passengers to get on or off the shuttle bus and shorten the walking distance. Meanwhile, the shuttle bus does not need to stop in the square and the running speed is relatively uniform.

Headway is another important decision variable in this paper. The optimization results of peak hours and off-peak hours are 5.03 min and 8.45 min, respectively. The shuttle bus circle line should be convenient for passengers to transfer to other bus routes or other modes of transport. So the headway of the shuttle bus cannot be too long. On the other hand, a short headway means the operator has to invest more vehicles. Both fixed cost and variable cost will increase. Considering the demand of transport during the peak time and the off-peak time, the optimization of headway in this paper conforms to the requirements of the interests of passengers and operators. During peak hours, short headway makes the waiting time moderate; during off-peak time, a long headway guarantees that the capacity is not wasted and the cost of operators does not increase much.

After selecting the bus stops, the circle line of the shuttle bus is formed according to the situation on the road and the land use. The shuttle bus runs through Dalian Railway station, Hope Square, Labour Park, Youhao Square, Zhongshan Square, Renmin Road, Bay Bridge, Worker Street, Minsheng Street and Shengli Bridge as shown in Figure 6. The total line length of the shuttle bus is 8.08 km. The cycle time of the shuttle bus in the peak hour is about 34 min. The cycle time of the shuttle bus in the off-peak hour is about 17 min. And there will be seven buses on the line. The shuttle bus can quickly evacuate passengers gathering on the station square to other bus terminals. It is convenient for passengers to transfer to other modes

of transport, and at the same time the phenomenon of waiting long for a taxi is alleviated effectively.

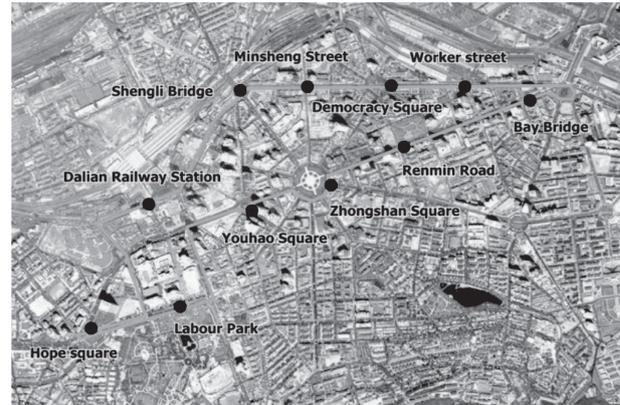


Figure 6 – The shuttle bus circle line

4.2.2 Convergence of the algorithm

In this paper, the crossover rate of NSGA- II is 0.95 and the mutation probability is 0.05. The individual number of initial population is 100. The algorithm evolves 100 iterations. The program runs 10 times to test the convergence of NSGA- II. The Pareto distribution is shown in Figure 7. Pareto solutions are approximate, so the optimal solution is obtained on the principle of minimizing the total cost.

In the initial stage of iteration, the proportion of non-dominated solution is on the rise. Even though in the sixth iteration there comes to a solution degradation, the convergence of the solution is not affected. After 20 iterations, all individuals in each generation are the non-dominated solution (Figure 8). It proves that the algorithm is convergent and reliable.

Finally, the NSGA-II is tested 10 times as shown in Figure 9. The total cost of NSGA-II is stable. Therefore, the proposed NSGA-II can improve the optimizing quality, and the algorithm has a good performance.

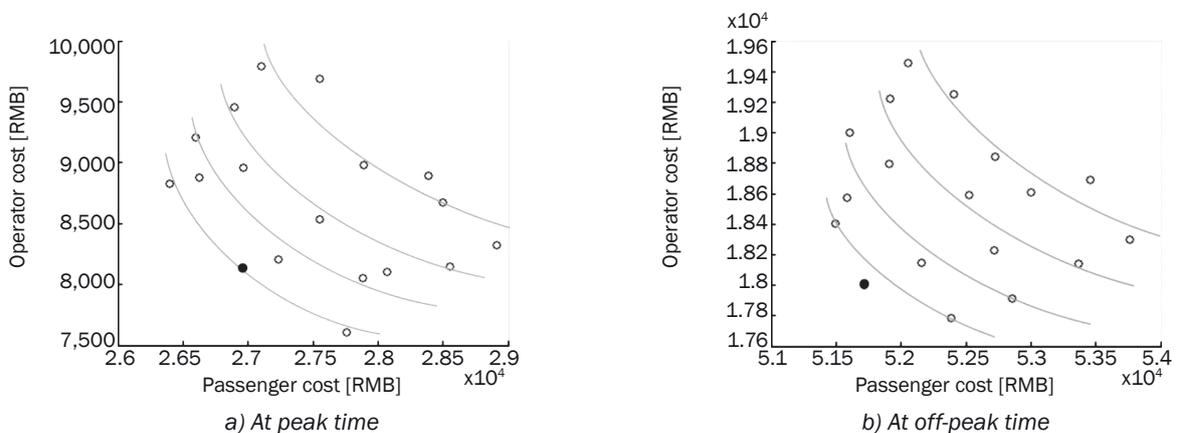


Figure 7 – Pareto distribution

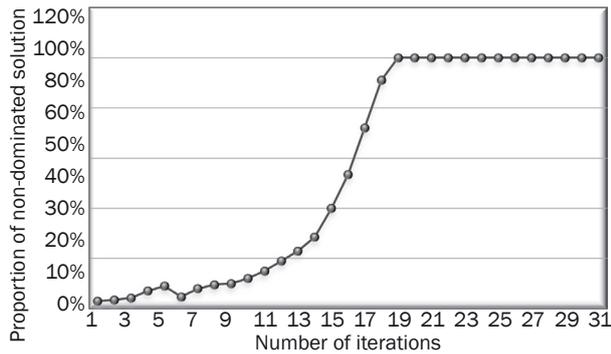


Figure 8 – Proportion of non-dominated solution in each iteration

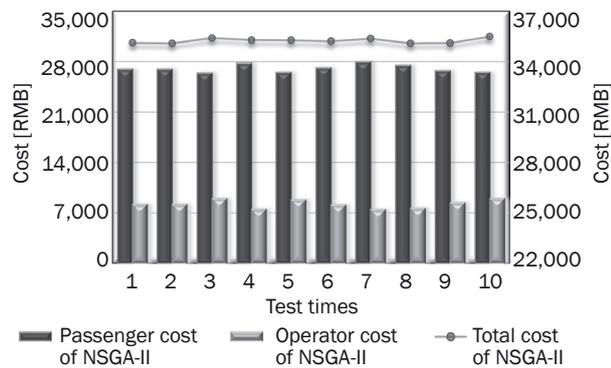


Figure 9 – Test of NSGA-II

5. CONCLUSION

To achieve the goal of relieving traffic congestion and improve the utilization of bus stops in CBD, this paper proposes a design of a circle line of a shuttle bus optimization model for transfer. The model is a bi-objective one. The objectives of this model are minimum passenger travel cost and minimum operator's cost. The interests of both passengers and the operator are taken into account. This paper takes about 5 square kilometres area around Dalian Railway Station as the research object to test the model. And NSGA-II is designed to solve the bus stop selection and determine the headway. The results of the case study show that the model has reliability and validity which can help the operator to make decisions and alleviate traffic pressure in CBD effectively.

For further studies, a new bus stop location and one-way street should be taken into account. The problem will be more complex. Thereby the practicability of the circle line of a shuttle bus can be improved accordingly.

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无公交枢纽背景下中心商业区穿梭巴士环线优化

摘要: 中心商务区 (CBD) 的建筑密度通常较大, 没有充足的空间建设公交枢纽。在这种情况下, 位于中心商务区的乘客必须走很远才能乘坐公共汽车, 或者=花费很长的时间等待出租车。为了解决这个问题, 本文提出了一种间接的解决方案: 在中心商务区设计一条穿梭巴士环线作为动态公交枢纽站。穿梭巴士通过环形路线将乘客疏散到各个公交车站, 这种方式不仅降低了中心商务区的交通压力, 而且节省了乘客的出行时间。本文建立了一个双目标优化模型以设计中心商务区的穿梭巴士环线, 并且运用非支配排序遗传算法 (NSGA-II) 来求解。本文选择中国大连市作为研究案例来检验该优化方法。结果表明, 对于没有公交枢纽的中心商务区来说, 穿梭巴士环线的开通可以解决中心商业区拥堵问题, 并发挥良好的公交枢纽的作用。

关键词:

中心商务区; 穿梭巴士; 换乘; 遗传算法; 双目标

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