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Campus Bus Network Design and Evaluation Based on the Route Property

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Campus Bus Network Design and Evaluation
Based on the Route Property

Jishiyu Ding, Shuo Feng, Li Li, and Yi Zhang

Abstract: A campus bus network design and evaluation, taking Tsinghua University as an example, is investigated in this paper. To minimize the total cost for both passengers and operator, the campus bus system planning in a sequential approach is discussed, including the route network design, headway (i.e., the inverse of service frequency) optimization, and system evaluation. The improved genetic algorithm is proposed to optimize the route network based on the route property, and the impacts of the fluctuation of passenger demand and average traveling time are analyzed. The identity proportion in the headway optimization is then introduced with full consideration of its impacts. Based on the actual variety of passenger demand, a non-fixed schedule demonstrates its efficiency. VISSIM is finally adopted to simulate the campus bus system and a comprehensive evaluation system for the campus bus is developed. Compared with the current bus network and the one without considering the route property, the evaluation of the proposed approach shows an improvement of 18.7% and 10.1%, respectively. Moreover, the sequential approach shows an efficiency improvement over the alternative method. It is of great significance for the development of public transit systems in large industrial parks to decrease the total cost for both passengers and operator.

Key words: genetic algorithm; transit network design; route property; identity proportion; transit system evaluation

1 Introduction
The expansion of a campus, which always happens in many developed universities, brings much inconvenience for teachers, students, and retired people to move on campus. More often, some campuses and industrial parks have built their own transit systems to provide a solution for transit of the “last-mile”. In April 2015, the “Micro Bus” project was launched in Zhejiang University, in which each micro bus would only carry 1 or 2 persons, so it cannot be considered as public transportation. In 2011, Zhangjiang Hi-Tech Park sets up its own public transportation system for its staff, which brought much more convenience for employees traveling within the large-scaled industrial park. These projects provide an excellent experience and knowledge for the later implementation of a local bus system.

This paper focuses on the campus bus network design, which is not well studied since much more studies focus on the urban transportation network design. Chien et al.[1] determined an optimal feeder bus route using the genetic algorithm by dividing the area into regular rectangle grids. Chakroborty[2] emphasized the efficiency of the genetic algorithm in urban transportation system optimization. Amiripour et al.[3] proposed an optimal modification approach to preserve the existing route network as much as possible. Amiripour and Ceder[4] also conducted research on route design and headway at the same time considering the cost for both the passengers and the company.
Compared with urban transportation systems, the campus bus system has some specific characteristics, which usually have not been investigated sufficiently, as follows: small-scaled, limited occupancy space, larger volatility, and more restrictions. Besides, being lack of consideration of route property, the fluctuation of passenger demand, and the proportion of passenger identity, the existing bus network usually operates in an inefficient manner. On the other hand, the incomplete evaluation for the route network and services cannot guarantee its environmental-friendly and sustained usage without considering criteria, such as energy saving and environmental impacts.

In this paper, a sequential design method for a small-scale campus bus system is discussed, which contains three parts: route design, headway optimization, and evaluation of the bus system. Two newly-defined factors, route property and identity proportion, are introduced in the study to analyze the influence of these factors on route design and headway optimization. The complete evaluation based on comprehensive indicators is developed to assess the level of route network and services quantitatively. The campus bus system implemented recently at Tsinghua University is used as an example to verify the proposed approach.

The remaining parts of this paper are organized as follows: Section 2 specifically describes the problem of the campus bus network design and frequency setting. Section 3 presents the sequential model including route design and headway optimization. The algorithm with the computational results for the route design and headway optimization is presented in Section 4 as well as the analyses for impacts of the route property. Section 5 implements the route network evaluation and simulation. Lastly, Section 6 provides concluding remarks.

2 Problem Descriptions

In this section, the Transit Network Design and Frequency Setting (TNDFS) problem as well as the data preparation are presented. The route design and frequency setting in the campus bus system, which corresponds to the two stages of bus service planning, is related to a TNDFS problem in transit systems\cite{5-11}.

2.1 TNDFS problem

In the transit network design, a set of transit routes are needed to be searched to form an efficient transit network, passengers’ travel demand represented by an origin-destination matrix to be satisfied with minimum total traveling time, and the transfer penalties to be considered to guarantee the optimization. In the frequency setting, a schedule should be achieved basically to minimize the total cost of the campus bus system. The higher frequencies directly increase the operational cost and in contrary contribute a better service (i.e., less waiting time) to passengers. It is a trade-off problem that makes the TNDFS problem multi-objective in nature\cite{12-16}.

In fact, the TNDFS problem is an NP-hard, multi-constrained combinatorial optimization problem with a vast search space. Its evaluation of route sets for candidate solutions can be both challenging and time-consuming, with many potential solutions rejected due to infeasibility. The routes and corresponding frequencies inference each other to find a solution to the problem. Arbex and Cunha\cite{5} used an alternative objective genetic algorithm to solve the multi-objective optimization problem. Szeto and Wu\cite{6} proposed a simultaneous solution for the bus route design and frequency setting problem for Tin Shui Wai. In this paper, the TNDFS problem is proposed to be solved sequentially, as shown in Fig. 1. Namely, we use a heuristic approach (i.e., the genetic algorithm) to derive the route network first and then optimize the headway for each route. Compared with the alternative method, the sequential method shows an improvement in efficiency of the small-scale route network. Moreover, in the route design, the objective is to satisfy the passenger demand to the maximum extent while in the headway optimization, the objective is to minimize the total cost for both the passengers and the operator.

2.2 Data preparation

Data preparation includes the area’s topology, Origin-Destination (OD) matrix, fleet size, alternative bus

Fig. 1 Framework of the campus bus network design.
stops, and additional information, such as bus operating costs, route length, speed, and so forth. The road network, bus stops, and transfer zones define the area’s topology. The travel times and the distance between bus stops can also be specified by the OD matrix. Sometimes, the geographic information system and various shortest-path algorithms are utilized for calculating the travel time of the OD matrix. Therefore, a survey was performed in June 2016 at Tsinghua University. The OD matrix, acceptable transfer times, walking distance, waiting time, and identity are investigated to be the data used for our method.

3 Problem Modeling

3.1 Route design

The model for the route design is described in Fig. 2, where passenger demand, route efficiency, and public facility are considered as three main factors which will impact on the design of the route network. Some quantifiable variables for each are selected to be included in the calculation of the objective function. Respectively, these represent the passenger demand, traveling cost, identity proportion, traveling time, distance between stations, etc.

Passenger demand represents the number of passengers to take the campus bus at the stations. The service level of one route can be denoted using the traveling time, distance between stations, and so on. Compared with the previous literatures, a newly-defined factor, relative traveling cost, is introduced here to describe the property of a route, where a higher value may be adopted for a commuting route and a lower value for a touring route. The identity proportion indicates the proportion of different groups of passengers, including students, teachers, retired people, and people touring on campus. In our experiment, it shows no influence on the network design results, so it is not considered in the route design. Similarly, some other factors, such as service facilities, shown in Fig. 2, which are unquantifiable, are also not discussed.

3.1.1 Assumptions

With the consideration of the simple conditions and general constrains on campus, the objective function for the route design can be formulated based on the following assumptions:

1. Due to the limitation of numbers of buses and the campus scale, the number of routes is assigned as three and each route has its own property concerning the different characteristics on the small-scaled campus.
2. According to the survey, one transfer is the most acceptable for passengers while two or more transfers are inconvenient on a small-scaled campus. Thus, one transfer with a corresponding penalty in the route network is allowed while two or more transfers are considered as unsatisfied demands.

3.1.2 Notations

The definitions of the variables for the route design are given in Table 1, while the settings of relative traveling cost for the route property is provided empirically in Table 2 (the relative traveling cost ranges from 1 to 2). The route property consists of four types, namely commuting, school, living demand, and entertainment.

Table 1 Definitions of the variables used for the route design.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z$</td>
<td>Objective function value</td>
</tr>
<tr>
<td>$S$</td>
<td>Set of alternative stations</td>
</tr>
<tr>
<td>$q_{ij}$</td>
<td>Demand from stop $i$ to $j$</td>
</tr>
<tr>
<td>$t_{q_{ij}}$</td>
<td>Transfer demand from stop $i$ to $j$</td>
</tr>
<tr>
<td>$u_{q_{ij}}$</td>
<td>Unsatisfied demand from stop $i$ to $j$</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Transfer penalty coefficient</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Unsatisfied demand penalty coefficient</td>
</tr>
<tr>
<td>$d_{ij}$</td>
<td>Distance from stop $i$ to $j$</td>
</tr>
<tr>
<td>$t_{ij}$</td>
<td>Travel time from stop $i$ to $j$</td>
</tr>
<tr>
<td>$c_k$</td>
<td>Route traveling cost of route $k$</td>
</tr>
<tr>
<td>$l_k$</td>
<td>Length of route $k$</td>
</tr>
<tr>
<td>$l_{\text{min}}(l_{\text{max}})$</td>
<td>Minimum (maximum) length of route $k$</td>
</tr>
<tr>
<td>$u_{q_{ij}}^\text{max}$</td>
<td>Maximum unsatisfied demand</td>
</tr>
</tbody>
</table>

Table 2 Relative traveling cost for different route properties.

<table>
<thead>
<tr>
<th>Route property</th>
<th>Relative traveling cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td>1.25</td>
</tr>
<tr>
<td>School</td>
<td>1.20</td>
</tr>
<tr>
<td>Living demand</td>
<td>1.15</td>
</tr>
<tr>
<td>Entertainment</td>
<td>1.00</td>
</tr>
</tbody>
</table>
on campus. According to the characteristics of the campus, the importance of the route type decreases in the order listed above. It is important to note that different values can be assigned for different considerations. For example, a high value such as 1.5 for traveling cost of school may specifically emphasize its importance.

### 3.1.3 Objective function and constraints

Based on the definition above, the objective function to be adopted to evaluate the route design from the passengers’ viewpoint can be summarized in Eq. (1). It can be optimized to satisfy the passenger demand as much as possible under the limited route network on campus. Equation (2) lists the limitation for the route length in an acceptable range while Eq. (3) gives the total tolerance of the maximum unsatisfied demand. The total number of routes implemented on campus is given in Eq. (4).

$$Z = \sum_{(i,j) \in S} \left( q_{ij} + \alpha \times t_{ij} + \beta \times u_{ij} \right) \times \frac{d_{ij}}{t_{ij} \times c_k}$$  \hspace{1cm} (1)

$$l_{\text{min}} \leq l_k \leq l_{\text{max}}$$  \hspace{1cm} (2)

$$\sum_{(i,j) \in S} u_{ij} \leq u_{\text{max}}$$  \hspace{1cm} (3)

$$|L_{\text{route}}| = 3$$  \hspace{1cm} (4)

### 3.2 Headway optimization

Based on the initial designed route network, an optimal headway (also called a departure interval) can be calculated to provide the full operation of the campus bus system. To achieve the headway optimization, the model shown in Fig. 3 is summarized to minimize total cost for passengers and operator. Some main relative reference factors are listed here to help understand the impacts of different sources.

#### 3.2.1 Assumptions

With the same principle used for the route network design, the objective function to minimize the total cost can be formulated based on the following assumptions:

1. The bus delay induced from acceleration and deceleration at each stop is assumed as constant.
2. The costs for arriving, waiting, and in-vehicle traveling time are assumed to be equal. Actually, the costs for arriving, waiting, and in-vehicle traveling can be set unequally for different considerations.
3. According to the survey, the average distance from the origin to the stations is assumed to be a quarter of the average distance between the stations.
4. The passenger demand follows a many-to-many pattern and is fixed roughly over a period. In addition, the influence of passenger demand will be analyzed in Section 4.2.2.

#### 3.2.2 Notations

Definitions for the variables for the headway optimization are given in Table 3.

#### 3.2.3 Objective function and constrains

The total cost to be considered for the operation of the campus bus system contains two parts: passenger cost and operation cost, which is described in Eq. (5) with a weighted coefficient $C$:

$$TC = C \times c_p + (1 - C) \times c_o$$  \hspace{1cm} (5)

where $TC$ represents the total cost of the bus system, $c_p$ represents the cost of the passengers, $c_o$ represents the cost of the company operation. The calculation for the two costs is explored in detail here.

1. **Passenger cost**

The passenger cost can be represented equivalently using total travel time which usually consists of three parts: the arriving time, waiting time, and in-vehicle traveling time. The arriving time, denoted by $t_a$, is the time for a passenger to arrive at a station from an original destination. The waiting time, denoted by $t_w$, is the time for a passenger waiting for a bus at the station. The in-vehicle traveling time, $t_i$, represents the time for a passenger to ride in the bus. Equation (6) can then be used to calculate the total traveling time for a passenger as:

$$t_p = t_a + t_w + t_i$$  \hspace{1cm} (6)

Equation (7) denotes the total equivalent cost for traveling corresponding to the arriving time, waiting time, and in-vehicle traveling time.

$$c_p = c_a + c_w + c_i = u_a \times t_a + u_w \times t_w + u_i \times t_i$$  \hspace{1cm} (7)

where $c_a$ represents the cost for arriving, $c_w$ the cost for waiting, and $c_i$ the in-vehicle cost.
According to the study of Zhao and Chien\[8\], the passenger cost can be finally outlined as Eq. (8).

\[
c_p = u_w \times q \times H \sum_{i=0}^{n-1} \left( 1 + \frac{t_{var}}{H^2} \right) + \
\]

\[
u_a \times q \times \frac{l}{v_p} + u_i \times \left( q \frac{n}{2} \times a + \sum_{i=0}^{n-1} i \times \frac{q^2}{n^2} \times \right) \\
\rho \times H \times \left( 1 + \frac{t_{var}}{H^2} \times \frac{q l}{2v_b} \right)
\]

(8)

Moreover, the identity proportion of passenger is introduced in Eqs. (9)-(11).

\[
u_w \times q = q \times (u_{w,old} \times p_{old} + u_{w,stu} \times \\
p_{stu} + u_{w,other} \times p_{other}) \]

(9)

\[
u_a \times q = q \times (u_{a,old} \times p_{old} + u_{a,stu} \times \\
p_{stu} + u_{a,other} \times p_{other}) \]

(10)

\[
u_i \times q = q \times (u_{i,old} \times p_{old} + u_{i,stu} \times \\
p_{stu} + u_{i,other} \times p_{other}) \]

(11)

where \( p_{old} \) represents the proportion of retired people to take the campus bus system and \( u_{w,old} \) is the equivalent value for waiting time of retired people. Consequently, \( p_{stu}, u_{w,stu}, p_{other}, \) and \( u_{w,other} \) have similar meanings for students and other people.

(2) Operational cost

The operational cost mainly depends on the headway and the total number of buses which can be used in the campus bus systems. The operational cost can be calculated by Eq. (12):

\[
c_o = u_o \times \left( \frac{l}{v_b} + n a + q \rho H \right) + \frac{l}{v_b} \]

(12)

where \( H \) represents the headway, \( l \) represents the route length, \( v_b \) represents the velocity of bus, \( n \) represents the total number of stops, \( q \) represents the travel demand, and \( \rho \) represents the average time for passengers to board the buses.
(3) Total cost
Based on the calculation above, the total cost can be outlined as Eq. (13).

\[ TC = C \times u_0 \times \left( \frac{\frac{1}{v_p} + q_0 + q_0 H}{H} \right) + \frac{1}{v_p} + (1 - C) \times \left( u_w \times \frac{q}{n} \times \sum_{i=0}^{n-1} \frac{H}{2} \times \left( 1 + \frac{t_{\text{var}}}{H^2} \right) + u_a \times q \times \frac{1}{v_p} + u_i \times \left( \frac{q}{2} \times a + \sum_{i=0}^{n-1} \frac{q_i^2}{n^2} \times \rho \times H \times \left( 1 + \frac{t_{\text{var}}}{H^2} \times \frac{q_0}{2v_p} \right) \right) \right) \]  

(13)

(4) Constraints
Besides the trade-off between the costs for passengers and the operator, the capacity constraint described in Eq. (14) should be considered and applied to ensure the service of the campus bus system satisfies the passenger demand on campus.

\[ q \leq \frac{\text{Capacity}}{H} \]  

(14)

4 Route Network Design and Analysis

4.1 Genetic algorithm for route design
The Genetic Algorithm (GA) is applied here to derive the optimal route network and the general definition of GA can be summarized as follows:

\[ \text{GA} = (P_0, M, \Omega, \tau, \Delta, t) \]  

(15)

where \( P_0 \) is the initial population, \( M \) is the whole volume, \( \Omega \) is the selection operator, \( \tau \) is the crossover operator, \( \Delta \) is the mutation operator, and \( t \) is the termination condition.

For clarity, the process of GA applied to search a solution for the campus bus system is presented in Fig. 4.

4.1.1 Alternative route generation
According to the survey for passenger demand on campus, 16 places are selected to be the alternative stations at Tsinghua University as shown in Fig. 5.

All alternative routes are described using a set \( R \), consisting of three parts: \( R_C \), \( R_{DSP} \), and \( R_E \). Here \( R_C \) represents the current routes, \( R_{DSP} \) represents the routes generated by the Dijkstra algorithm, and \( R_E \) represents the empirical routes. Thus, the final alternative route set \( R \) is generated by Eq. (16).

\[ R = R_C \cup R_{DSP} \cup R_E \]  

(16)

4.1.2 Route design results
Based on the proposed model, the iteration progress of the GA is shown in Fig. 6. After several iterations, the final optimal route network designed by the GA for the campus bus system at Tsinghua University is achieved as shown in Fig. 7, where the campus bus
network consists of three routes. One route, from Place 1 to Place 7, covers the upper route in blue, another one, from Place 1 to Place 9, covers the lower route in green while the route in red, from Place 1 to Place 7, goes through the campus from the west to the east.

### 4.1.3 Results without the route property

Without the consideration of route property as discussed before, the route network generated by GA is presented in Fig. 8. It shows that some routes overlap each other and thus it is not the optimal design we expect. The route network without considering the route property will be evaluated and compared with that considering the route property.

### 4.1.4 Influence analysis

In general cases, the travel distance and empirical traveling time are fixed all the time for daily life. However, due to the different traffic conditions, the passenger demand and traveling time among stations are time-varying. It requires more analyses to disclosure the impacts of the fluctuation of passenger demand and traveling time. Obviously, the passenger demand and traveling time may increase in peak hours, while in contrary, they may decrease in non-peak hours.

Take the passenger demand varying from half of normal amount to its 3 times and the traveling time varying from 0.8 to double its normal time. The route network can be generated using the GA in the same progress. The results show that the route network is kept the same indeed, while the average number of iterations is changed. The probable reason is that the small-scale campus bus system provides a solution in limited solution space without any large change to the route network. Figure 9 shows

![Fig. 6 Iteration of the genetic algorithm for route design.](image)

![Fig. 7 Optimal network considering the route property.](image)

![Fig. 8 Optimal network without the route property.](image)

![Fig. 9 Iteration times as a function of demand and traveling time.](image)
the relationship between iteration times, passenger demand, and average traveling time among the stations. The average number of iterations increases as the average traveling time increases. With the existing randomness of the GA, the average number of iterations does not increase monotonously. Figure 10 shows the relationship between fitness, passenger demand, and average traveling time. It is obvious that when the passenger demand and average traveling time among stations increase, the fitness value decreases.

4.2 Headway optimization

The passenger demand, identity proportion, and station numbers for a campus bus system have close links, which are discussed in detail here to achieve better headways and finally satisfy the design optimization.

4.2.1 Weighted coefficient optimization

In most of the previous literatures, the weighted coefficient $C$ is empirically set as 0.5. Figure 11 shows the relationship of the total cost with coefficient $C$. There is a trade-off between passenger cost and operational cost; thus, different coefficient $C$ corresponds to different optimal headways. As shown in Fig. 11, when $C$ reaches 0.57 and the weighted total cost is optimal. Compared with the previous studies in which $C$ is set as 0.5, the headway decreases from 0.2588 h to 0.2251 h as an optimal solution.

4.2.2 Influence analysis

The passenger demand and proportion of passengers for the campus bus system are time-varying. Thus, the fluctuation has a non-ignorable influence on the headway optimization.

(1) Identity proportion

Generally, the passengers on campus consist of four groups: students, teachers, retired persons, and people touring on campus. The fluctuation of identity proportion may influence the headway optimization. Since the proportion of outside people is nearly fixed about 10% and less students and teachers use the campus bus regularly, the travel demand from retired people is the core of route network design. Figure 12 shows that when the proportion of retired people varies from 0 to 0.8, the total cost increases and the optimal headway decreases in general. From Fig. 13, the optimal headway declines almost linearly when the proportion of retired people increases while the total cost also grows linearly. It seems reasonable because the longer waiting time is uncomfortable and unacceptable for retired people, such that increasing the frequency of bus departures is necessary and the total cost must increase accordingly. According to our analysis, the optimal headway has a nearly linear relationship with the proportion of retired people.
(2) Passenger demand

As described previously, the passenger demand may increase at peak hours. The parameter $q$ is introduced here to represent the normal demand at each station and is set as 10 persons per hour. Figure 14 demonstrates all curves for different passenger demand scenarios, where the total cost increases in general when $q$ varies from 5 to 50. Figure 15 shows the optimal headway inversely proportional to the passenger demand. It provides evidence that the passenger demand is an important factor regarding the impacts on the optimal headway. When the passenger demand increases, the optimal headway must be inversely proportionally shortened to ensure the satisfied service of operation. When the passenger demand is huge enough, the optimal headway tends to be 0.07 h. It implies that to minimize the total cost, it is impossible for the optimal headway to decrease infinitely.

(3) Passenger demand and proportion

As we know, the passenger demand and identity proportion may vary at the same time. Taking the passenger demand varying from 0 to 50 at each station per hour, the identity proportion varying from 0 to 0.8, Figs. 16 and 17 show the relationships of the passenger demand and identity proportion with the optimal headway. It is obvious that when the passenger demand and identity proportion increase, the optimal headway decreases while the total cost increases correspondingly. The increasing passenger demand and identity proportion indicate the increasing of the amount of retired people, which results in the headway shortened to satisfy traveling demand on campus.

Based on the analyses above, it indicates that the passenger demand and identity proportion play important roles and have the main impacts on the optimal headway. At the same time, the passenger demand has a larger impact on the headway than identity proportion.

4.2.3 Schedule results

Based on the survey, the proportion of retired people at Tsinghua can be set as 0.35 for the headway optimization, while the weighted coefficient is 0.57 for general cases. The passenger demand in off-peak hours, normal period, and peak hours can be assigned as 5, 10, and 20 persons at each station per hour, respectively. Therefore, a non-fixed schedule can be achieved as shown in Table 4, which implies different optimal headways to be used for different periods.
Table 4 Non-fixed schedule.

<table>
<thead>
<tr>
<th>Period</th>
<th>Headway (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trough hours</td>
<td>18.8</td>
</tr>
<tr>
<td>Normal period</td>
<td>13.2</td>
</tr>
<tr>
<td>Peak hours</td>
<td>9.3</td>
</tr>
</tbody>
</table>

5 Route Network Evaluation

To evaluate and analyze the designed campus bus system including the route network and the optimal headway proposed in Section 4, VISSIM is adopted here to simulate the operation on the designed route network.

5.1 Evaluation criteria

Traditional evaluation methods\[17–19\] usually compare several selected criteria independently. The evaluation method in this paper covers the performance of the road infrastructure, transport capacity, service level, and benefit level, and combines all the measurable criteria together to evaluate the whole campus bus system. Figure 18 lists the indicator system with all indexes for the route network evaluation. The Analytic Hierarchy Process (AHP) method is adopted here to derive the weights of each criterion. The criteria and corresponding weights for the campus bus system at Tsinghua University are shown in Table 5.

5.2 Simulation and evaluation analysis

VISSIM is adopted to evaluate the designed campus bus system. The simulation parameters are summarized in Table 6. The desired speed distribution is set as 30 km/h because of the speed limitation on campus. The headway is set according to the non-fixed schedule in Table 4. The passenger demand at each station is set as the actual demand according to our survey carried out in 2016 at Tsinghua University. There are a total of six buses operating on working days. The simulation runs for 12 h from 7 a.m. to 7 p.m. and ten repetitions of the experiment are simulated to obtain an average value for each criterion. Thus, the comprehensive evaluation is formulated as Eq. (17). For easier comparison, the value of each criterion must be standardized to lie in [0, 1].

\[
S = \sum_{i=1}^{m} \sum_{j=1}^{n} y_{ij} \times w_{ij}
\]  

where \(S\) is the result of comprehensive evaluation for the designed route network, \(y_{ij}\) represents the value of criterion \(j\) in standard \(i\), and \(w_{ij}\) is defined as the weight of criterion \(j\) with the impacts on standard \(i\) for the whole objective.

Based on the model above and the data collected from VISSIM, the evaluation results are shown in Table 7. Compared with the current bus network and that
without considering the route property, the proposed optimal route network provides an improvement of 18.7% and 10.1%, respectively. Thus, by considering the route property and identity proportion, the campus bus system at Tsinghua University can be operated efficiently.

Moreover, the alternative optimization method is also implemented to compare with the proposed sequential method. The results are summarized in Table 8. The results show that the route network derived by two types of methods is the same; however, the headway is non-fixed, as shown in Table 4, by the sequential method and fixed to 16.8 min by the alternative method. In addition, the computational time of the sequential method is improved 54.7% compared with the alternative method.

## 6 Conclusion

A systematic sequential approach for the design of the campus bus system at Tsinghua University is developed in this paper, including the route network design, headway optimization, and system evaluation. By considering the route property, the GA can provide more optimal and realistic bus routes on campus. The impacts of passenger demand and identity proportion to the optimal headway are then discussed in detail, which show that when the identity proportion of passengers is given, better optimal headway can be derived. Finally, an evaluation system based on the AHP method is developed to evaluate the service level of the bus routes objectively and systematically. Moreover, the sequential method shows an efficiency improvement of 54.7% compared with the alternative method. The proposed evaluation system is practical and convenient for transit agency decision-makers to design the route network and operate the bus system on campus. It also provides good guidance for industrial parks and campuses to save traveling time of passengers and operational cost of the company.

The discussed approach in the paper can also be applied to search a solution considering the existing metro and BRT lines around the campus or industrial park. The design of the bus route with real-time data, such as smart cards and GPS data will be also an interesting issue for future research and application. With the real-time data, passenger demand can be described more precisely, which can facilitate a better solution to the bus route design and optimization problem.

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### References


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