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Original Research Paper

Timetable optimization for single bus line based on hybrid vehicle size model

Daniel(Jian) Sun [a,b,c,*], Ya Xu [c], Zhong-Ren Peng [c,d]

[a] State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
[b] Key Laboratory of Highway Engineering of Ministry of Education, Changsha University of Science & Technology, Changsha 410004, China
[c] Transportation Research Center, Shanghai Jiao Tong University, Shanghai 200240, China
[d] Department of Urban and Regional Planning, University of Florida, Gainesville 32611, USA

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ABSTRACT

This study proposes a flexible timetable optimization method based on hybrid vehicle size model to tackle the bus demand fluctuations in transit operation. Three different models for hybrid vehicle, large vehicle and small vehicle are built in this study, respectively. With the operation data of Shanghai Transit Route 55 at peak and off-peak hours, a heuristic algorithm was proposed to solve the problem. The results indicate that the hybrid vehicle size model excels the other two modes both in the total time and total cost. The study verifies the rationality of the strategy of hybrid vehicle size model and highlights the importance of the adaptive vehicle size in dealing with the bus demand fluctuation. The main innovation of the study is that unlike traditional timetables, the arrangement of the scheduling interval and the corresponding bus type or size are both involved in the timetable of hybrid vehicle size bus mode, which will be more effective to solve the problem of passenger demand fluctuation. Findings from this research would provide a new perspective to improve the level of regular bus service.

1. Introduction

As one of the most troublesome problems in urban transit operation research, bus demand fluctuation at different periods is widespread, seriously challenging the bus operating efficiency (Ahmed, 2014; Doust, 2014). Bus resource waste at off-peak time is a common phenomenon, which generally leads doubts to the rationality of the bus timetable (Sun et al., 2011; Xue et al., 2015). Consequently, timetable optimization is an important task for transportation researchers to tackle the problem.

Determining an appropriate schedule interval for a bus line is the main method to adjust to the demand fluctuation. In the previous works of bus operation optimization, microeconomic model was proposed, considering passenger waiting time, in-vehicle time and access time, and the total cost was a function

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* *Corresponding author*. State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China. Tel.: +86 21 34206674.
E-mail address: danielsun@sjtu.edu.cn (D. J. Sun).

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of bus schedule frequency, where the fittest frequency could be easily calculated (Mohring, 1972). Hurdle (1973) devised a schedule to minimize the total cost, including passenger waiting time, and vehicle operation cost using fluid flow model and found the optimal solutions for a number of hypothetical frequency. Since the demand for high quality bus service increased, Marques et al. (1996) introduced a notion of flexible and dynamic public transport schedule, and the system comprehensively analyzed service supply, demand and network data to reschedule the so-called SUPERBUS. Feasibility evaluation of the technology, user-acceptance and socioeconomics for SUPERBUS was also included in the study. Mekkaoui et al. (2000) used an explicit traveler choice model, which assumed bus riders select the solution to minimize the cost incurred by traveling earlier or later than their ideal schedule time, to obtain the desirable solution. Ceder (2005, 2007) introduced four different methods in determining a timetable based on a range of data collection techniques. Bai et al. (2013) analyzed bus scheduling method including big interval departure, time in coordination, adopted three synchronization methods and obtained inhomogeneous departure intervals.

As presented, the majority of previous literature focused on the optimization of schedule interval, while the importance of the adaptive bus size for each bus trip is ignored, although some researchers tried to find the optimal bus size for a single bus line and some literature focused on the estimation of fleet size (Ceder, 2005; Oldfield and Bly, 1988). As referred, vehicle waste is common and the existence of low-loading bus will seriously lower the operation efficiency. In fact, some scholars indicated that in this condition, the merits of public transport were significantly reduced (Potter, 2003). Hybrid-vehicle-type bus was considered in some vehicle scheduling research, while the types of bus in these studies were arbitrary, which influenced its application (Kliewer et al., 2006; Site and Filippi, 1998). Unlike the former literature, Ceder et al. (2013a, 2013b) dealt with the creation of bus timetables using several fixed types bus to improve urban public transport service, concluded that the implementation of the mixed vehicle size bus fleet was promising. Unfortunately, their study is mainly limited to traditional timetabling strategies, with the deficiency of reasonable modes to reveal the systematic relationship between passenger time cost and operational cost with the changing of vehicle size for the bus trip.

Based on the achievements of literature, three different models for hybrid vehicle size bus, large vehicle size bus and small vehicle size bus are built, respectively in the study. The operation mode is defined by the vehicle type. In the study, vehicle bus is used in hybrid vehicle sizes model, only large vehicle bus is used in large vehicle size model and only small vehicle bus is used in small vehicle size model. The bus type is determined by the number of seats in the vehicle. As to be mentioned in Section 4.2, the seats numbers in large vehicle bus and small vehicle bus are 29 and 19 respectively. The result comparisons are conducted to verify whether the hybrid vehicle size model is suitable to real world bus operation. In additional to the description of background and literature review, problem formulation is presented in Section 2. Three different models are introduced in Section 3 and Section 4, schedule schemes for the three models were obtained and compared. Conclusions and future research are summarized in Section 5.

2. Problem formulation

For a single vehicle size model (large vehicle size model or small vehicle size model), the operation arrangement is to determine the schedule interval, while it needs to determine both the schedule interval and the type of bus for the hybrid vehicle size model. The schedule interval and the type of vehicle affect both the level of service, represented by the total time cost of passengers and the operational cost (Xue et al., 2014). The object of the study is a bus line with several bus tops in which the passenger's OD matrices can be calculated from the data of IC card and GPS (Zhao et al., 2007; Sun et al., 2014). The task of the study is to determine the operation arrangement for each bus trip at the condition of travel demand fluctuation. To determine the main factors in the study, assumptions were proposed to simplify the process as follows:

1. The travel time between two stops will be calculated by the average speed of the bus;
2. The operation parameters (i.e., speed, acceleration, etc.) are assumed to be equal for all vehicle size buses in the study;
3. No capacity constraint, meaning all passengers arriving at the stop can be loaded by the next vehicle;
4. No quantity restrictions in the use of any vehicle size buses.

Based on the assumptions, the main factors are determined as time periods and vehicle size. The application of

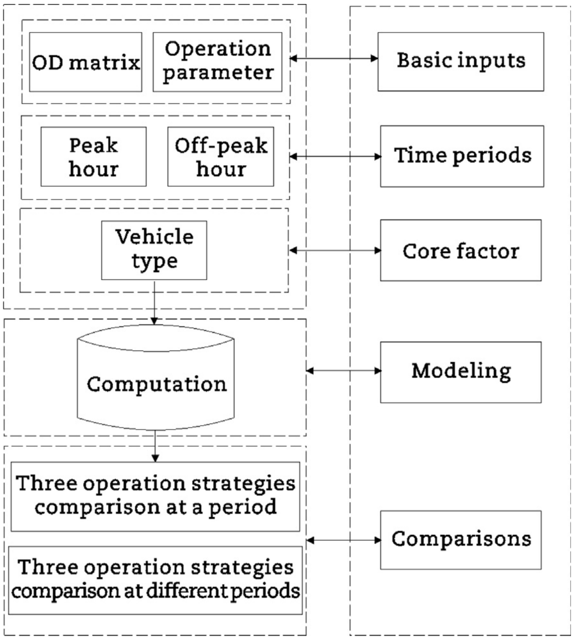

Fig. 1 – Framework of problem formulation.

hybrid vehicle size bus for every trip is the key of the research. It leads to three different operation strategies, including strategies of scheduling only with large vehicle size bus, only with small vehicle size bus, and with hybrid vehicle size bus respectively. The objective of the paper is to verify whether the hybrid vehicle size bus strategy is economically feasible.

As emphasized, the study aims to come up a rational timetable using hybrid vehicle size bus to tackle demand fluctuation. As the fluctuation lies not only in a single time period but also among different time periods, the study will compare the total time and total cost of the three operation strategies both at a single time period and among different time periods, such as peak hours and off-peak hours.

The framework of the problem formulation is presented in Fig. 1.

Fig. 1 shows the study is divided into three steps:

Step 1: Determining the inputs, including basic inputs, time periods inputs and vehicle type inputs;
Step 2: Modeling and computation;
Step 3: Analyzing the results, and concluding whether the hybrid vehicle size model is suitable for operating based on the results comparison of the three models.

3. Models

3.1. *Notations for the models*

Considering a bus line consists of *N* stops and different vehicle size buses will serve all of the bus stops. According to the assumptions mentioned in Section 2, the variables and constants used in the models are summarized as follows:

i: bus stop of the line, $i = 1,2,\cdots,N-1$;
k: the k-th bus trip, $k = 1,2,\cdots$;
S_d: the decelerating distance;
S_a: the accelerating distance;
S_i: the distance between stops i and $i+1$;
a: average alighting time per passenger;
b: average boarding time per passenger;
v: the operation speed of bus;
T_i^d: decelerating time when a bus approaching stop i;
T_i^a: accelerating time when a bus departing stop i;
T_i^{i+1}: travel time from stop i to $i+1$;
$T_i^{k,s}$: stopping time at stop i for the k-th bus trip;
$T_{i,k}$: travel time from stop i to $i+1$ for the k-th bus trip;
$B_{i,k}$: the number of boarding passengers at stop i for the k-th bus trip;
$A_{i,k}$: the number of alighting passengers at stop i for the k-th bus trip;
$P_{i,k}$: the number of passengers in the vehicle when a vehicle driving from stop i to $i+1$ for the k-th bus trip;
$W_{i,k}$: the average waiting time at stop i for the k-th bus trip;
cap_s: total-seat number of a small vehicle size bus;
cap_b: total-seat number of a large vehicle size bus;
δ: the threshold for the crowdedness in a vehicle;
$\Delta t_{\min}$: the minimum schedule interval;
$\Delta t_{\max}$: the maximum schedule interval;
c_1: unit in-vehicle time value;
c_2: unit waiting time value;
c_3: unit personnel cost;
c_4: unit operational cost for small vehicle size bus;
c_5: unit operational cost for large vehicle size bus.

3.2. *Optimization for hybrid vehicle size*

3.2.1. *In-vehicle time cost*

In-vehicle time from stop i to $i+1$ consists of the accelerating time when the bus departs stop i, the decelerating time when the bus approaches stop $i+1$, the stopping time at stop i and the travel time when the speed remains constant. The decelerating time and the accelerating time depend on the acceleration and the operation speed if we assume the accelerating process to be uniform accelerating motion. The decelerating time and the accelerating time can be calculated by Eqs. (1) and (2):

$$T_i^a = \frac{2S_a}{v} \tag{1}$$

$$T_i^d = \frac{2S_d}{v} \tag{2}$$

The stopping time at every stop is related to the number of boarding and alighting passengers. Eq. (3) is used to calculate the stopping time. Combined with the IC and GPS data, $B_{i,k}$ and $A_{i,k}$ can be easily obtained, related to the decision variable Δt_k When the speed remains constant, the travel time can be calculated by Eq. (4).

$$T_i^{k,s} = \max\{aA_{i,k}, bB_{i,k}\} \tag{3}$$

$$T_i^{i+1} = \frac{S_i - S_a - S_d}{v} \tag{4}$$

Thus, the in-vehicle time from stop i to $i+1$ for the k-th bus trip can be obtained by Eq. (5) easily.

$$T_{i,k} = T_i^{k,s} + T_i^a + T_i^{i+1} + T_{i+1}^d \tag{5}$$

In addition, the number of passengers within the vehicle after bus departures from stop i can be calculated by a recursion formula of the boarding and alighting passengers at stop i and the passenger number when the vehicle approaches stop i.

$$P_{i,k} = P_{i-1,k} + B_{i,k} - A_{i,k} \tag{6}$$

Then, the total in-vehicle time cost V_k for the k-th bus trip can be denoted as follow:

$$V_k = c_1 \sum_{i=1}^{N-1} P_{i,k} T_{i,k} \tag{7}$$

3.2.2. *Waiting time cost*

Passengers are assumed to arrive randomly, regardless of the arrival time of the bus. A specific arrival time was assigned to every passenger randomly. We assume the passenger's arrival distribution is Poisson distribution. Thus, if the schedule interval is Δt, the average waiting time is computed as

$\Delta t - (1 - e^{-\lambda t})/\lambda$, where λ is average arrival rate of the passengers. Consequently, the total waiting time cost F_k for the k-th bus trip can be calculated as:

$$F_k = c_2 \sum_{i=1}^{N} B_{i,k} W_{i,k} \tag{8}$$

3.2.3. Operation cost

According to studies of Oldfield and Bly (1988), the operational cost consists of time cost, personnel cost and space cost, including vehicle operational cost, such as fuel cost, maintenance cost. With the calculation results of the operating time, the operational cost of large vehicle size bus O_k^b and small vehicle size bus O_k^s for the k-th bus trip can be calculated as follows:

$$O_k^b = c_3 \sum_{i=1}^{N-1} T_{i,k} + c_4 \sum_{i=1}^{N-1} S_i \tag{9}$$

$$O_k^s = c_3 \sum_{i=1}^{N-1} T_{i,k} + c_5 \sum_{i=1}^{N-1} S_i \tag{10}$$

Then, the optimization model for hybrid vehicle size bus is described as follows:

$$\min Z = \sum_{k} \left(s_k C_k^s + b_k C_k^b \right) \tag{11}$$

s. t.

$$C_k^b = V_k + F_k + O_k^b \tag{12}$$

$$C_k^s = V_k + F_k + O_k^s \tag{13}$$

$$T - \Delta t_{\min} \le \sum_{k} \Delta t_k \le T \tag{14}$$

$$\frac{P_{i,k}}{b_k cap_b + s_k cap_s} \le \delta \tag{15}$$

$$\Delta t_k \in \{\Delta t_{\min}, \Delta t_{\min} + 1, \cdots, \Delta t_{\max}\} \tag{16}$$

$$b_k + s_k = 1 \tag{17}$$

$$b_k s_k = 0 \tag{18}$$

Eq. (11) is the objective function, in which C_k^b is the total cost for the k-th trip executed by a large vehicle size bus and C_k^s is the total cost for the k-th trip executed by a small vehicle size bus. Eqs. (12) and (13) are the calculation of C_k^b and C_k^s based on the analysis above. Eq. (14) is used to restrict the number of bus trips by controlling the sum of interval not to exceed the length of time period. Eq. (15) ensures the vehicle between two adjacent stops will not be too crowded. Eq. (16) guarantees the schedule interval should be an integer which lies among the shortest and longest interval. b_k and s_k are the dummy variable to indicate which vehicle size bus is selected to execute the bus trip. Eqs. (17) and (18) ensure that one and only one bus, no matter what the vehicle size is, would complete the bus trip and if the k-th trip is conducted by a large vehicle bus, then $b_k = 1$, else $b_k = 0$.

3.3. Optimization model for large vehicle size

As to the optimization model for the large vehicle size bus, the modeling process is similar. Only the factors of small vehicle size bus are eliminated, which is presented as follows:

$$\min Z = C_k^b \tag{19}$$

s. t.

$$C_k^b = V_k + F_k + O_k^b \tag{20}$$

$$T - \Delta t_{\min} \le \sum_{k} \Delta t_k \le T \tag{21}$$

$$\frac{P_{i,k}}{cap_b} \le \delta \tag{22}$$

$$\Delta t_k \in \{\Delta t_{\min}, \Delta t_{\min} + 1, \cdots, \Delta t_{\max}\} \tag{23}$$

Compared with the model for the hybrid vehicle sizes, the dummy variable b_k is set to 1 while s_k is 0 and the decision variable of the model for the large vehicle size model is Δt_k only.

3.4. Optimization model for small vehicle size

It is easy to understand that the difference between the model for small vehicle size and the model for large vehicle size is that the dummy variable s_k is set to 1 while b_k is 0. The model for small vehicle size model is presented below:

$$\min Z = C_k^s \tag{24}$$

s. t.

$$C_k^s = V_k + F_k + O_k^s \tag{25}$$

$$T - \Delta t_{\min} \le \sum_{k} \Delta t_k \le T \tag{26}$$

$$\frac{P_{i,k}}{cap_s} \le \delta \tag{27}$$

$$\Delta t_k \in \{\Delta t_{\min}, \Delta t_{\min} + 1, \cdots, \Delta t_{\max}\} \tag{28}$$

4. Case study

4.1. Data description

The field data were obtained from Shanghai Public Transportation Company, including the IC card and GPS data for a specific line (Route 55) from July 4–8, 2011. Transit Route 55 in Shanghai is an excellent subject in studying urban bus operation, which the service area of the bus is prosperous, including business districts (Wujiaochang and the Bund), educational districts (Fudan University and Tongji University). The route connects with multiple rail transit lines (Line 2, Line 8, Line 10 and Line 4). Then, it is reasonable to choose Transit Route 55 as the representative and the time period is determined as follows: peak hour (8:00 AM to 9:00 AM) and off-peak hour (1:00 PM to 2:00 PM) on July 4. The conclusions could be widely applicable for urban transit operation.

4.2. *Determination of parameters*

Before solving the models, it is necessary to assign a value to every parameter involved in the models. The study determines the parameters used in the study by three ways:

(1) Some parameters are obtained from the website of the bus corporation, which include cap_s and cap_b. These parameters are the most reliable.
(2) A number of literature studied the determination of the value of some parameters, such as c_1, c_2 (Jin and Wu, 2014; Qi et al., 2008). For these parameters, the time and districts difference should be considered, for example: a related literature studied the unit operational cost in 2013. The values should be redefined based on the literature.
(3) As to the rest parameters, some are obtained by a survey from public transit corporation, such as Δt_{min} and Δt_{max}, and the others are quantified by actual measurement on public bus.

Among these parameters, cap_s and cap_b are obtained from the website of the bus corporation, where there is the detailed information of all types of buses. Thus cap_s and cap_b can be determined as 19, 29 respectively. The crowdedness parameter, δ, Δt_{max} and Δt_{min} are determined by the bus corporation. For Transit Route 55, the maximum schedule interval is 20 min and minimum schedule interval is 5 min. c_3, c_4, c_5 are the financial data of the bus corporation, which can be also obtained after the survey. We can obtain the operating speed, the average alighting time and boarding time per passenger by an in-vehicle survey. S_d and S_a are determined according to the experience of the drivers. c_1 and c_2 are assumed to be the same and can be calculated from the following Eq. (29) according to the literature:

$$c_1 = \frac{1}{24} \times \frac{\text{income}}{30} \tag{29}$$

The detailed information of the parameters are shown in Table 1.

4.3. *Solution methods*

The three models in the previous section can be formulated as an integer programming problem. It is unrealistic to be solved by an exhaustive search method. Since the model needs to determine the type of bus and schedule interval for every trip, an exhaustive search method should select the optimal scheme from 16^{24} candidates if we encountered the worst case. We propose a heuristic algorithm to find an optimal or sub-optimal solution. The algorithm is depicted in Fig. 2.

4.4. *Result analysis*

Tables 2 and 3 present the timetables for hybrid vehicle size bus, large vehicle size bus and small vehicle size bus at peak and off-peak hours, respectively. What should be noted is that the sum of the interval may be unequal to the time span of the period; for example, the sum of the schedule interval for hybrid vehicle size bus in Table 2 is 59 min. For the rest of the passengers, the waiting time can be calculated by subtracting their arrival time, and the study does not consider the in-vehicle time.

Table 1 – Parameter values used in the study.

Parameter	Value	Unit
S_d	50	m
S_a	50	m
a	2	s
b	2	s
v	20	km/h
cap_s	19	seat
cap_b	29	seat
δ	3	
Δt_{min}	5	min
Δt_{max}	20	min
c_1	8.6	RMB/h
c_2	8.6	RMB/h
c_3	20	RMB/(veh·h)
c_4	10	RMB/(veh·km)
c_5	15	RMB/(veh·km)

The cumulative time and costs under different trips which the passengers spent during the peak and off-peak hours are depicted in Figs. 3 and 4, respectively.

At peak hours, as shown in Table 2, for the hybrid vehicle size model, the total trip number is five, including two large vehicles and three small vehicles. The average headway of the large vehicle size bus is larger than the small vehicle size bus. As to the timetable of the large vehicle size model, four large vehicle size buses are dispatched at the period. The mean schedule interval is much longer than the hybrid vehicle size bus and the small vehicle size bus. For the small vehicle size model, it can be seen that six small vehicles are used, with the smallest mean schedule interval among the three operation models. When the cumulative times including the waiting time and the in-vehicle time are compared, it is found that the cumulative time of the large vehicle size model increases fast. Finally, the total time is much larger than the other two modes at the peak hours although the trips number is the minimum, as shown in Fig. 3(a). In comparison with the cumulative time of the hybrid vehicle size model and the small vehicle size model, we find a phenomenon that when a large vehicle size bus is deployed, the gap between the two models is widened. However, unlike the large vehicle size model, the gap is controllable and the difference of total time is very small for the trip number of small vehicle size is larger. According to the analysis in previous section, the total cost consists of time cost and operational cost. At the peak hour, the change curve of the total cost is presented in Fig. 3(b). From the figure, it can be seen that the large vehicle size model is obviously inferior compared with the other two models. But, the comparison between the cumulative costs of the small vehicle size model and hybrid vehicle size model is more complex. The gap between the two curves is not significant from the second to the fifth bus trip. But, the advantage of requiring fewer bus trips number brings considerable benefit

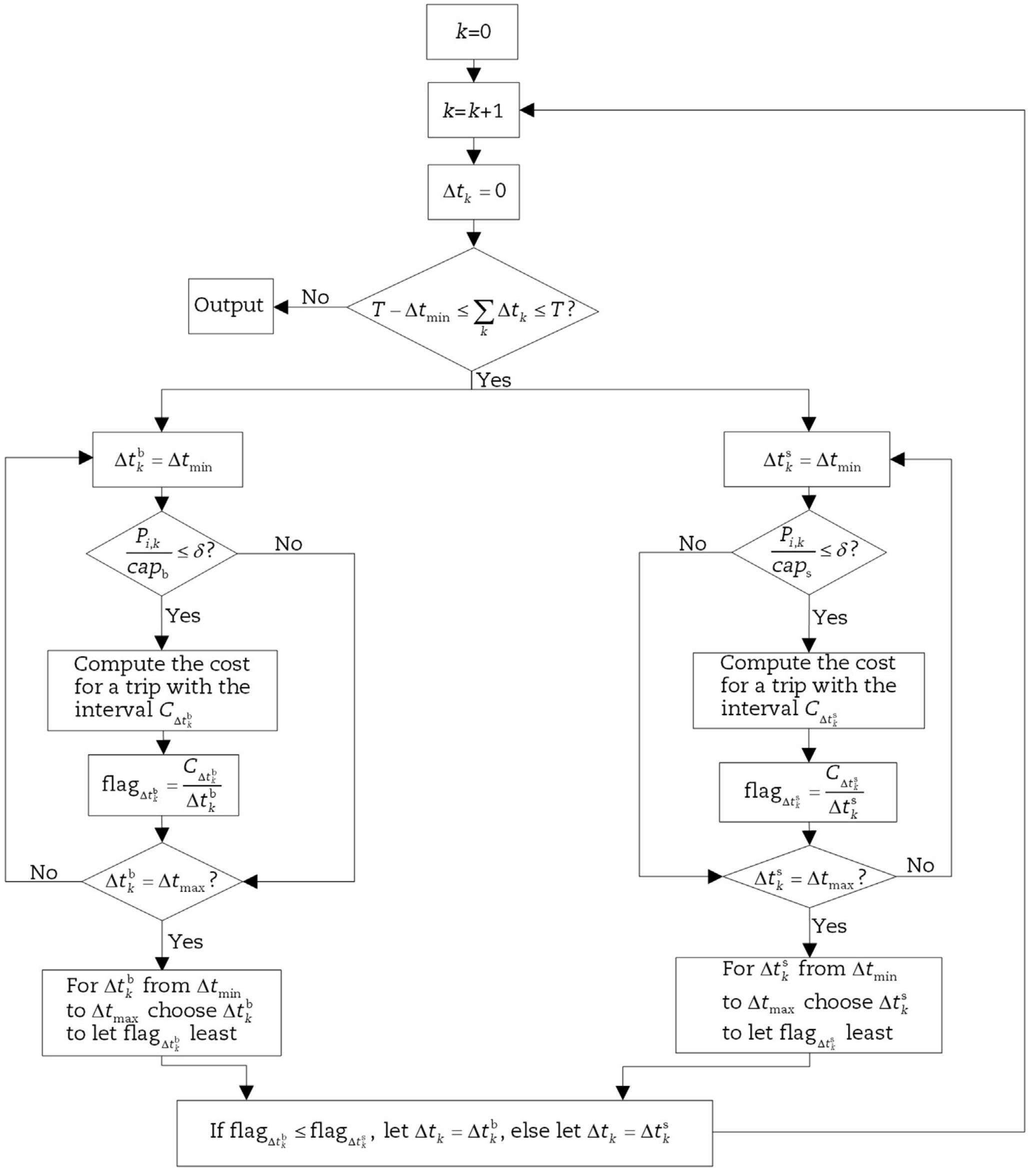

Fig. 2 – Implementation framework for model.

for the hybrid vehicle size, which indicates it is better to adopt hybrid vehicle size model at peak hour.

Table 3 presents the timetable for the hybrid vehicle size and the corresponding bus type at off-peak hour. Three small vehicles and one large vehicle size bus are dispatched during the period. Like the peak hour, the bus trips number of the large vehicle size model is one bigger than the hybrid vehicle sizes model, and the headways are approximate to. The timetable for the small vehicle size can be also seen in Table 3, which shows five small vehicles are used and the schedule interval for every bus trip is relatively stable and short. As depicted in Fig. 4(a), the difference of the cumulative time among the three models is less significant. The cumulative time of the large vehicle size model is the largest, but the gaps between the large vehicle size model and the other two models are small. Unlike the cumulative time, the cumulative costs are significantly different. As presented in Fig. 4(b), the cumulative cost curve of the large vehicle size model is steep while the curve of the small vehicle size model is relatively flat. However, both end points of the curves are higher than that of the hybrid vehicle size model. It obviously indicates the low-cost advantage of the hybrid vehicle size model at the off-peak hour.

4.5. *Discussions*

As demonstrated, the hybrid vehicle size model is superior to both the large vehicle size model and the small vehicle size model. The small vehicle size model features with small cumulative time for the higher schedule frequency, while the operation cost caused by a larger number of vehicles used during the period may offset the benefit. As to the large vehicle size model, the cumulative time and cumulative cost at peak and off-peak hour are larger than the other two models, meaning that the large vehicle size bus is inefficient for the specific transit line in the study. Different from the

Table 2 – Timetable and corresponding vehicle types at peak hour.

Operation model	Bus trip ID	Departure time	Bus size
Hybrid vehicle size	1	8:14	Large vehicle
	2	8:23	Small vehicle
	3	8:30	Small vehicle
	4	8:50	Large vehicle
	5	8:59	Small vehicle
Large vehicle size	1	8:14	Large vehicle
	2	8:26	
	3	8:45	
	4	8:58	
Small vehicle size	1	8:12	Small vehicle
	2	8:23	
	3	8:30	
	4	8:42	
	5	8:53	
	6	8:59	

small vehicle size bus, the large vehicle size bus can effectively improve the capability of loading the passengers from the original place to the destination, which results in the decrease of the number of bus trips. What's more, the assumption that the unit in-vehicle time cost is irrelevant to the crowdedness in the vehicle results in a preference to the small vehicle size bus.

The hybrid vehicle size model integrates the advantages of small vehicle size bus and large vehicle size bus into a schedule scheme, making the timetable more flexible. Main findings for the model can be summarized as follows:

(1) At peak hour, the small vehicle size bus and the large vehicle size bus are alternative;
(2) At off-peak hour, the large vehicle size bus is acted as a supplement for the small vehicle size bus;
(3) Headway of the small vehicle size bus is significantly smaller at peak hour;
(4) Difference between the headway of the small vehicle size bus and the large vehicle size bus is not significant at off-peak hour;
(5) The specific vehicle size bus dispatched for the trip is significantly related to the passengers demand and needs to be determined according to the passengers demand.

Table 3 – Timetable and corresponding vehicle types at off-peak hour.

Operation model	Bus trip ID	Departure time	Bus size
Hybrid vehicle size	1	13:10	Small vehicle
	2	13:29	Large vehicle
	3	13:42	Small vehicle
	4	13:56	Small vehicle
Large vehicle size	1	13:18	Large vehicle
	2	13:34	
	3	13:54	
Small vehicle size	1	13:10	Small vehicle
	2	13:20	
	3	13:33	
	4	13:46	
	5	13:57	

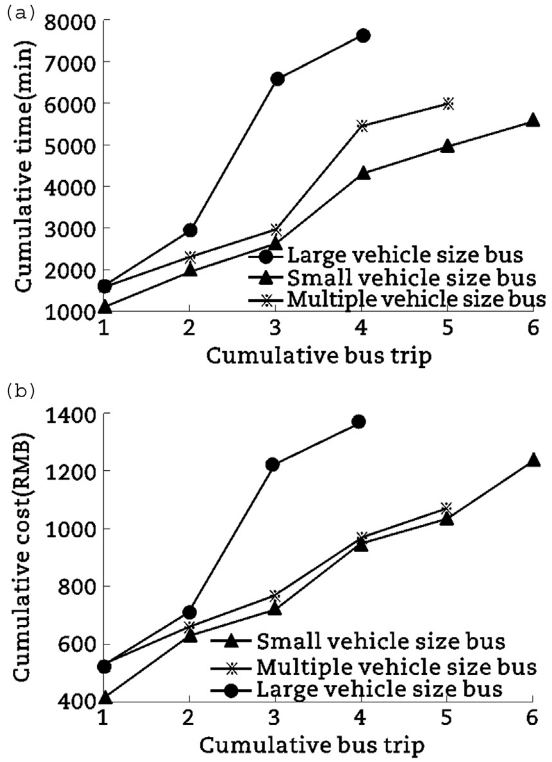

Fig. 3 – Result comparison of three operating modes at peak hour. (a) Cumulative time curve with cumulative bus trip changes. (b) Cumulative cost curve with cumulative bus trip changes.

The results indicate that the hybrid vehicle size model can tackle the passengers demand fluctuation both at peak hour and off-peak hour with a smaller total cost and time cost, perfectly answering the question proposed in Section 2. Characteristics of passengers demand fluctuation at a single period or different periods prove that the hybrid vehicle size model is applicable in transit bus system.

It should also be noted that an important issue of the fleet size determination, namely that the numbers of large vehicle size buses and small vehicle size buses should be purchased for each transit line, is not involved in the study. Some further study may be conducted to solve the problem.

5. Conclusions

This paper proposes a modeling framework for hybrid vehicle size bus and verifies whether the mode is the economically reasonable, providing a new perspective to tackle the demand fluctuation. Three operation strategies, namely hybrid vehicle size bus, large vehicle size bus and small vehicle size bus are proposed and tested, considering the operation cost, in-vehicle time cost and waiting time cost to determine the type vehicle size and headway for every trip. Based on the peak hour and off-peak hour data of Transit Route 55 in Shanghai, we designed the timetable for each operation model at different periods by adopting an adaptive algorithm and the result analysis and discussions followed.

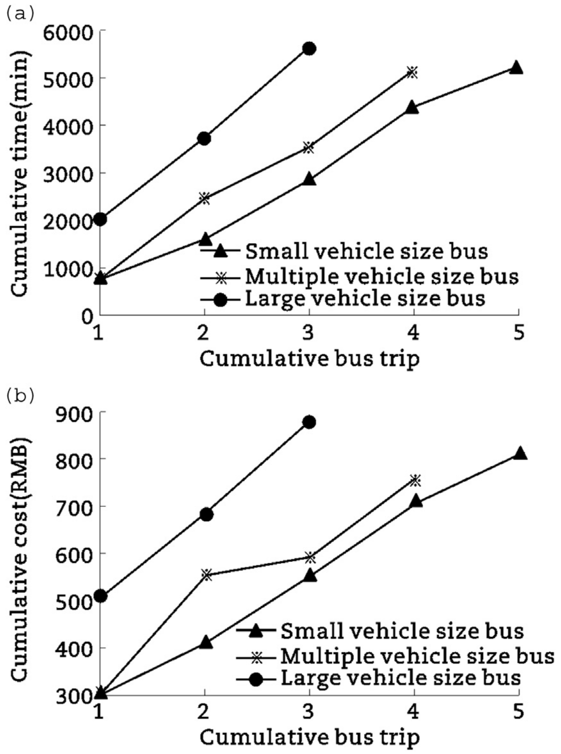

Fig. 4 – Result comparison of three operating modes at off-peak hour. (a) Cumulative time curve with cumulative bus trip changes. (b) Cumulative cost curve with cumulative bus trip changes.

However, due to insufficiency of the data, a number of parameters were obtained from literature and the surveys. For instance, the accelerating and decelerating distances of bus were determined after the conversation with the drivers of Transit Route 55. Moreover, the unit in-vehicle time cost in the study is assumed to be irrelevant to the crowdedness in the vehicle, which may lead to a preference to small vehicle size bus. Further studies should adopt a self-adaptive unit in-vehicle time cost for more objective results.

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