Optimising the design of a limited-stop bus service for a branching network

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This paper presents an optimisation model for designing limited-stop lines for a branching bus network composed of several feeder lines and a trunk line. On the basis of the different demand patterns in the feeder lines and the trunk line, passenger assignment in the bus route is considered. The optimisation model is used to calculate the total cost of a transit system in which limited-stop services are implemented on bus routes. The total cost includes the cost of passenger waiting time and in-vehicle time, as well as the operator cost for each bus route. With better service planning of limited-stop lines, based on the demand behaviour in high-demand corridors, the total cost can be reduced (compared with the normal service costs of stopping all buses at all stops). A genetic algorithm is adopted to ascertain the optimal model. This algorithm can determine continuous and discrete optimisation variables: the optimal bus frequencies and the best pattern of limited-stop use for each bus route. Finally, a numerical example is optimised. The results show that a limited-stop service for branching corridors can reduce the total cost of the transit system.

Notation

C	total cost of a branching corridor
C^{l_k}	total cost in the feeder line l_k
F	limited operable fleet size for the branching corridor
$f_A^{L_k}$	frequency of fleet A in the trunk line L_k
$f_A^{l_k}$	frequencies of fleet A
$f_B^{l_k}$	frequencies of fleet B
n_{l_k}	number of stations in the feeder line l_k
R_i	bus running time between stations i and $i+1$
$TD_A^{l_k}$	average dwelling time of fleet A at station i
$TD_B^{l_k}$	average dwelling time of fleet B at station i
$TI_A^{l_k}$	in-vehicle time of passengers riding fleet A
$TI_B^{l_k}$	in-vehicle time of passengers riding fleet B
TR^{l_k}	running time of buses
TW^{l_k}	total waiting time in the feeder line l_k
$V_{A,i}^{l_k+}$	boarding of passengers that can only ride fleet A buses at station i
$V_{A,i}^{l_k-}$	alighting rate of passengers that can only ride fleet A buses at station i
$V_{AB,i}^{l_k+}$	boarding rate of passengers that have the opportunity to select fleet A or fleet B buses
$V_{AB,i}^{l_k-}$	alighting rate of passengers that have the opportunity to select fleet A or fleet B buses
$v_{(i,j)}^{l_k}$	demand from station i in the feeder line l_k to j in the entire bus route
$x_i^{l_k}$	type of station i , which equals 1 if the station is serviced by fleet B and 0 otherwise
ϕ_i	value of in-vehicle time
ϕ_R	value of running time
ϕ_w	value of waiting time

1. Introduction

In public transit systems with high demand levels due to the fluctuating demand patterns and an unbalanced distribution of passengers along the corridor, the use of a normal all-stop service is not adequate and will not guarantee efficient operation. However, by adjusting the frequency of services and by establishing limited stops, these limited-stop services appear to be an efficient alternative operational strategy which could improve the service level of a transit system. By skipping a subset of stops, the limited-stop services can reduce passenger travel time and shorten the running time of buses. This will enable the transit operator to utilise fewer vehicles while still meeting the same demand along the corridor. Given the advantages of limited-stop services in a bus route, similar services should be extended to the design of the transit network, in order to improve the service level of multiple bus lines.

Designing limited-stop services as an optimisation strategy for a bus line or corridor has been studied by a number of authors in an attempt to select the appropriate limited stops and determine the bus frequencies. Afanasiev and Liberman (1982) stated that bus services consist of three types of services: normal, limited stop and express. The authors of this study also addressed the design of skipped-stop lines. The beginning and the end of a limited-stop line are determined based on a model designed to fulfil passenger demand but with frequency constraint. The experience in the city of Chimkent shows that passenger travel time and gasoline consumption both decrease considerably when using a limited-stop service, compared with the equivalent all-stop services. Silverman (1998) analysed the

characteristics of limited-stop services and recognised that such services can improve bus speed and reliability. Passenger response to this limited-stop service strategy is also described in the Silverman (1998) study. Têtreault and Ahmed (2010) proposed a model to determine the skipped stops and estimated the running times for a limited-stop line in parallel with a normal line. The objective of this study was to maximise the running time savings of buses and to reduce the waiting time of passengers that arrive at stops. The numerical results show that implementing limited-stop lines can reduce the running time. Leiva *et al.* (2010) addressed the design of limited-stop services with capacity constraints and determined the optimum frequencies of different types of buses. The methodology of Leiva *et al.* (2010) minimises the sum of wait time, travel time, transfer time and operator costs. Given the effect of vehicle capacity constraints and transfers, the proposed method optimises the frequencies, type of vehicles and serving stations. Cortés *et al.* (2011) proposed integrating short-turning and deadheading services. Short-turning and deadheading services are designed for a specific, single line (in a two-line system), with an all-stop service implemented on the other line. The model determines the frequencies and serving zones of two bus fleets, thus providing a short-turn strategy. Sun *et al.* (2013) analysed the travel time model under mixed traffic conditions and proposed an optimisation model for designing skip-stop services that can minimise the total travel time for both car travellers and bus travellers.

With regard to the bus frequency design aspect of a network, Sun and Mark (2010) analysed the effects of different scheduling alternatives on a branching transit route. The passenger travelling time in the trunk and feeder line is examined under a variety of schedule alternatives that could be implemented. These schedule alternatives are related to the assignment of bus to trunk-feeder lines and bus holding strategies. The objective is to estimate the performance of a branching transit route with different scheduling alternatives. Yu *et al.* (2010) proposed a bi-level model to determine the frequency of an urban public transportation system using a genetic algorithm with fleet size constraint. Passenger assignment in the bus routes was considered. Additionally, the total travel time, integrating waiting time and in-vehicle time of passengers, was minimised. In a real transit network, optimisation can improve the overall service level. Sivakumaran *et al.* (2012) analysed the schedule coordination properties that can save costs in a trunk-feeder transit system. The result is that the total costs of both the user and the operator can be reduced by coordinating the schedules of trunk-feeder vehicles. Dell'Olio *et al.* (2012) optimised the frequency and bus size in a transit network. This study proposed a bi-level optimisation model with capacity constraints, to assign passengers to different bus routes. Then, the model is able to minimise the total cost of the user and the operator by determining the optimised frequency and bus sizes. Along these lines, an

optimisation model with constraints on bus capacity (in terms of bus size and setting frequencies on each route in the system) has been proposed in accordance with the premises detailed below.

In this paper, to implement a limited-stop service on the network, this paper proposes an optimisation method for the design of limited-stop services for a branching corridor. A branching corridor denotes a simple feeder-trunk network. Assume the limited-stop service is implemented on each bus route, and the total cost of the transit system in the feeder lines and trunk line is calculated. By minimising the total cost, the optimal operational scheme in the feeder line and trunk line (and the optimal frequency) can be found. The total cost is calculated in terms of waiting time, in-vehicle travel time and operator cost (Baaj and Mahmassani, 1995; Ceder and Wilson, 1986; LeBlanc (1988); Mauttone and Urquhart, 2009).

2. Optimisation modelling

In this paper, the idealised branching corridor is a tree-shaped network in one direction, as shown in Figure 1. The network consists of a trunk line and several feeder lines. Each feeder line (where only one bus route is provided) connects to the trunk line. The bus route provides service from uptown to downtown (central business district (CBD)), first along the feeder line and then the trunk line. In this approach, suppose now that the trunk line is disconnected from the junction nodes between the feeder lines and trunk line, denoted as $L_1, L_2, \dots$, and the feeder lines are denoted as $I_1, I_2, \dots$. This paper further considers that the single bus route is operated in the feeder line, while buses of different routes flow into the trunk line. Then, limited-stop schemes of the single bus route are determined in both the feeder line and the trunk line, respectively.

2.1 Cost of feeder-line service

In a branching corridor, a limited-stop service for a bus line is provided by buses of fleet A and fleet B. The fleet A buses serve every station along the bus route, while the fleet B buses serve specifically designated stations where the passengers can

Figure 1. Sketch of branching corridors

$$7. \quad TD_{A,i}^{l_k} = \max \left[a \cdot \left(\frac{1}{f_A^{l_k}} V_{A,i}^{l_k+} + \frac{1}{f_A^{l_k} + f_B^{l_k}} V_{AB,i}^{l_k+} \right), \right. \\ \left. b \cdot \left(\frac{1}{f_A^{l_k}} V_{A,i}^{l_k-} + \frac{1}{f_A^{l_k} + f_B^{l_k}} V_{AB,i}^{l_k-} \right) \right]$$

Here, a and b are the average passenger boarding and alighting times; R_i is the bus running time between stations i and $i+1$. Similarly, the in-vehicle time of passengers riding fleet B can be expressed by

$$8. \quad TI_B^{l_k} = \sum_{i=2}^{n_{l_k}} \left\{ \left(\frac{f_B^{l_k}}{f_A^{l_k} + f_B^{l_k}} V_{AB,i-1}^{l_k+} - \frac{f_B^{l_k}}{f_A^{l_k} + f_B^{l_k}} V_{AB,i}^{l_k-} \right) \cdot TD_{B,i}^{l_k} \right\} \\ + \sum_{i=1}^{n_{l_k}} \left\{ \left(\frac{f_B^{l_k}}{f_A^{l_k} + f_B^{l_k}} V_{AB,i}^{l_k+} - \frac{f_B^{l_k}}{f_A^{l_k} + f_B^{l_k}} V_{AB,i}^{l_k-} \right) \cdot R_i \right\}$$

Note that since the dwelling time at a skipped station is equal to 0, the average dwelling time of fleet B can be expressed by

$$9. \quad TD_{B,i}^{l_k} = x_i \cdot \max \left[a \cdot \frac{1}{f_A^{l_k} + f_B^{l_k}} V_{B,i}^{l_k+}, b \cdot \frac{1}{f_A^{l_k} + f_B^{l_k}} V_{B,i}^{l_k-} \right]$$

The above formulae calculate the time that passengers spend on travel. For the operator, this paper considers the running time of buses, which is similar to the in-vehicle time of passengers. Operator running time can be calculated as follows

$$10. \quad TR^{l_k} = f_A^{l_k} \sum_{i=1}^{n_{l_k}} (R_i + TD_{A,i}^{l_k}) + f_B^{l_k} \sum_{i=1}^{n_{l_k}} (R_i + TD_{B,i}^{l_k})$$

Finally, the total cost of feeder line l_k is the variable time items multiplied by the value of time, accordingly

$$11. \quad C^{l_k} = \phi_w \cdot TW^{l_k} + \phi_i \cdot (TI_A^{l_k} + TI_B^{l_k}) + \phi_R \cdot TR^{l_k}$$

Here, ϕ_w , ϕ_i and ϕ_R are the value of waiting time, in-vehicle time and running time, respectively.

2.2 Cost of a trunk-line service

In a trunk line, multiple routes normally operate at the same stations (i.e. there are k bus routes which serve the trunk line L_k). Passengers have more chances to select alternative bus routes in the trunk line than they have in the feeder line. Figure 3 shows a simple trunk-feeder transit system.

In the trunk line L_k , passenger boarding and alighting rates at station i can be shown as follows

$$12. \quad V_{A,i}^{L_k+} = \sum_j v_{(i,j)}^{l_k} \cdot \prod_{m=1}^{k-1} \max \left[(1 - x_i^{l_m}), (1 - x_j^{l_m}) \right] \\ \text{for } i = 1, 2, \dots, n_{l_k}$$

Figure 3. Scheme of limited-stop service in trunk line

$$13. \quad V_{A,i}^{L_k-} = \sum_i v_{(j,i)}^{l_k} \cdot \prod_{m=1}^{k-1} \max \left[(1 - x_i^{l_m}), (1 - x_j^{l_m}) \right] \\ \text{for } i = 1, 2, \dots, n_{l_k}$$

$$14. \quad V_{L_k,AB,i}^{L_k+} = \sum_j \left[\frac{f_A^{l_k}}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(i,j)}^{l_k} \cdot x_i^{l_r} x_j^{l_r} \right] \\ \text{for } i = 1, 2, \dots, n_{l_k}$$

$$15. \quad V_{L_k,AB,i}^{L_k-} = \sum_i \frac{f_A^{l_k}}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(j,i)}^{l_k} \cdot x_i^{l_r} x_j^{l_r} \\ \text{for } i = 1, 2, \dots, n_{l_k}$$

$$16. \quad V_{L_k,AB,i}^{L_r+} = \sum_j \left[\frac{f_B^{l_r}}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(i,j)}^{l_k} \cdot x_i^{l_r} x_j^{l_r} \right] \\ \text{for } i = 1, 2, \dots, n_{l_k}$$

$$17. \quad V_{L_k,AB,i}^{L_r-} = \sum_i \frac{f_B^{l_r}}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(j,i)}^{l_k} \cdot x_i^{l_r} x_j^{l_r} \\ \text{for } i = 1, 2, \dots, n_{l_k}$$

Also

$$18. \quad f_A^{l_k} = \sum_m^{k+1} f_A^{l_m}$$

Here, $f_A^{l_k}$, $f_A^{l_r}$ and $f_B^{l_r}$ are the frequencies of fleet A in trunk line L_k , fleet A and fleet B on route l_m starting in the feeder line l_r ; $V_{A,i}^{L_k+}$ and $V_{A,i}^{L_k-}$ are the boarding and alighting rates of passengers that can only ride the fleet A buses at station i , while $V_{L_k, \bar{A}B,i}^{l_r+}$ and $V_{L_k, \bar{A}B,i}^{l_r-}$ are the boarding and alighting rates of passengers that select fleet A; $V_{L_k, \bar{A}B,i}^{l_r+}$ and $V_{L_k, \bar{A}B,i}^{l_r-}$ are the boarding and alighting rates of passengers that select the fleet B buses of route l_r ; n_{l_k} is the number of stations in trunk line L_k ; $v_{(i,j)}^{l_k}$ is the demand from station i in trunk line L_k to j in the rest of the bus route along trunk line L_k .

With regard to waiting time, for the stations that are serviced by fleet A, the average waiting time is $1/f_A^{l_k}$, while for the stations that are served by both fleets A and B, the average waiting time is $1/(f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r})$ at station i . The total waiting time in the trunk line L_k is

$$19. \quad TW^{l_k} = \sum_i^{n_{l_k}} \left\{ \frac{1}{f_A^{l_k}} V_{A,i}^{l_k+} + \sum_r \sum_j \left[\frac{1}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(j,i)}^{l_k} x_i^{l_r} x_j^{l_r} \right] \right\}$$

With regard to the in-vehicle time of passengers, based on the number of boarding and alighting passengers, the average dwelling time of fleet A, denoted as $TD_{A,i}^{l_k}$, and fleet B on route l_r , denoted as $TD_{B,i}^{l_r}$, can be expressed at station i by

$$20. \quad TD_{A,i}^{l_k} = \max \left\{ a \cdot \left(\frac{1}{f_A^{l_k}} V_{A,i}^{l_k+} + \sum_r \sum_j \left[\frac{1}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(j,i)}^{l_k} x_i^{l_r} x_j^{l_r} \right] \right), \right. \\ \left. b \cdot \left(\frac{1}{f_A^{l_k}} V_{A,i}^{l_k+} + \sum_r \sum_j \left[\frac{1}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(j,i)}^{l_k} x_i^{l_r} x_j^{l_r} \right] \right) \right\}$$

$$21. \quad TD_{B,i}^{l_r} = x_i^{l_r} \cdot \max \left\{ a \cdot \sum_r \sum_j \left[\frac{1}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(j,i)}^{l_k} x_i^{l_r} x_j^{l_r} \right], \right. \\ \left. b \cdot \sum_r \sum_j \left[\frac{1}{f_A^{l_k} + \sum_{r=1}^{k-1} f_B^{l_r} x_i^{l_r} x_j^{l_r}} v_{(j,i)}^{l_k} x_i^{l_r} x_j^{l_r} \right] \right\}$$

Then, considering the travel time between stations, the in-vehicle time of passengers riding fleet A can be expressed by

$$22. \quad TI_A^{l_k} = \sum_{i=2}^{n_{l_k}} \left[\left(V_{A,i-1}^{L_k+} + \sum_r V_{L_k, \bar{A}B,i-1}^{l_r+} - V_{A,i}^{L_k-} - \sum_r V_{L_k, \bar{A}B,i}^{l_r-} \right) \cdot TD_{A,i}^{l_k} \right] \\ + \sum_{i=1}^{n_{l_k}} \left[\left(V_{A,i}^{L_k+} + \sum_r V_{L_k, \bar{A}B,i}^{l_r+} - V_{L_k, \bar{A}B,i}^{l_r+} - \sum_r V_{L_k, \bar{A}B,i}^{l_r-} \right) \cdot R_i \right]$$

The in-vehicle time of passengers riding fleet B on route l_r can be expressed by

$$23. \quad TI_B^{l_r} = \sum_{i=2}^{n_{l_k}} \left[\left(V_{L_k, \bar{A}B,i-1}^{l_r+} - V_{L_k, \bar{A}B,i}^{l_r-} \right) \cdot TD_{B,i}^{l_r} \right] \\ + \sum_{i=1}^{n_{l_k}} \left[\left(V_{L_k, \bar{A}B,i}^{l_r-} - V_{L_k, \bar{A}B,i}^{l_r+} \right) \cdot R_i \right]$$

The total in-vehicle time in trunk line L_k can be as follows

$$24. \quad TI^{l_k} = TI_A^{l_k} + \sum_{r=1}^{k+1} TI_B^{l_r}$$

For the operator, the bus running time can be shown as follows

$$25. \quad TR^{l_k} = f_A^{l_k} \sum_{i=1}^{n_{l_k}} \left(R_i + TD_{A,i}^{l_k} \right) + \sum_r^{k+1} f_B^{l_r} \sum_{i=1}^{n_{l_k}} \left(R_i + TD_{B,i}^{l_r} \right)$$

Finally, the total cost of feeder line L_k is the variable time items multiplied by value of time, accordingly

$$26. \quad C^{l_k} = \phi_w \cdot TW^{l_k} + \phi_1 \cdot TI^{l_k} + \phi_R \cdot TR^{l_k} \quad \text{for } k \geq 2$$

The objective function for the total cost of a branching corridor with h bus routes can be expressed by

$$27. \quad \min C = \sum_{k=1}^h C^{l_k} + \sum_{k=1}^{h-1} C^{l_k}$$

s.t.

$$28. \quad F \geq \sum_{k=1}^h \left\{ f_A^{l_k} \left[\sum_{i=1}^{N_{l_k}^k} (R_i + TD_{A,i}^{l_k}) + \sum_{i=1}^{N_{l_k}^k} (R_i + TD_{A,i}^{l_k}) \right] + f_B^{l_k} \left[\sum_{i=1}^{N_{l_k}^k} (R_i + TD_{B,i}^{l_k}) + \sum_{i=1}^{N_{l_k}^k} (R_i + TD_{B,i}^{l_k}) \right] \right\}$$

$$29. \quad f_A^{l_k} \geq 0$$

$$30. \quad f_B^{l_k} \geq 0$$

$$31. \quad x_i^{l_k} \in (0, 1)$$

Here, F is the limited operable fleet size for the branching corridor. Equation 29 is a fleet size constraint which ensures that the optimal service frequency does not exceed the maximum service frequency.

3. Solution methods

This research now requires a solution algorithm for the objective function described in the previous sections. This solution algorithm will enable us to find the optimum limited stop scheme and the corresponding frequencies of buses.

Determining the optimal scheme of a limited-stop service where the type of station is a zero-one variable is a non-linear programming problem and is difficult to solve. Thus, the genetic algorithm that imitates the process of natural evolution is used to search the fittest chromosome, which is the same as the optimal scheme (see – e.g. Agrawal and Mathew, 2004; Fan and Machemehl, 2006). In this paper, a chromosome consists of the entire schemes of bus routes as

$$32. \quad [x_1^{l_1}, x_2^{l_1}, \dots, x_{N_{l_1}}^{l_1}, x_1^{l_2}, x_2^{l_2}, \dots, x_{N_{l_2}}^{l_2}, \dots, x_1^{l_h}, x_2^{l_h}, \dots, x_{N_{l_h}}^{l_h}]$$

Here, h is the number of bus routes in a branching corridor; $x_i^{l_k}$ is a zero-one variable that indicates a possible limited-stop type of station i on route l_k ; N_{l_k} is the number of stations on route l_k that includes the stations in the feeder and trunk lines.

Figure 4. Solution algorithm

Meanwhile, to yield a minimum cost, an exhaustive search algorithm is used to find the optimal frequencies of different bus routes for each of the chromosomes. The optimal frequencies are subject to Equations 28–30. Figure 4 shows the solution algorithm for the above objective function.

4. Numerical test

Now, the methodology proposed in the above section is applied to a branching corridor in Changchun City, China, as shown in Figure 5. The branching corridor is composed of three bus routes: Route 6, running between Dongguang Group and Changchun Railway Station, Route 66 and Route 306. Both Route 66 and Route 306 run between City Hall and Changchun Railway Station. In this branching corridor, there are three feeder lines, and the trunk line is divided into two sections: L_1 and L_2 . The load profiles of the branching corridor are shown in Figure 6.

According to the study data, when buses serve all stations in a given corridor, the running times of buses operating along routes 66, 306 and 6 are 28, 29 and 25 min, respectively, without considering delay stations. The average passenger boarding and alighting times are, respectively, 5.2 and 4.4 s. Time value is assumed to be \$15/pax-h for waiting time, \$10/pax-h for in-vehicle time and \$500/veh-h for running time.

To test the effect of a limited service on the branching corridor, this research calculated the cost of a transit system operating a limited-stop service compared with an all-stop service ($x_i^k = 1$). Figure 7 shows the operational scheme and frequencies of the limited-stop service. In Figure 7, fleet B buses are required to skip the appropriate stations in the trunk-feeder line (l_1 , l_2 , l_3 , L_1 and L_2), and the frequencies of both fleet A and fleet B are optimised. Table 1 presents the operational results of both the all-stop and limited-stop service. The frequencies and system cost of the all-stop service can be calculated from the above model, if $x_i^k = 1$. From Table 1, it can be seen that the frequencies of buses are readjusted. This causes the running time to increase, because the total frequencies are changed from 52 to 61 veh/h, while both the passenger waiting time and in-vehicle time drop considerably. Therefore, the service level of the transit system can be improved, and the total cost could be reduced, when compared with the original all-stop service for the branching corridor.

5. Conclusions

This paper implements a limited-stop service for a branching corridor to offer optimal bus frequencies. The objective of the paper is to minimise the total cost of a transit system, including the user cost and the operator cost. The objective model can be found by using a trip matrix and the existing data

Figure 5. Branching corridor: (a) street network and (b) existing routes

Figure 6. Load profiles of branching corridor

pertaining to bus routes. Since a limited-stop service is different from a traditional all-stop service, certain stations must be designated as limited stops. These are the stations that need to be determined for fleet B. By skipping those specified stations, the limited-stop strategy can offer a high frequency of service at stations which experience high boarding and alighting demands. Meanwhile, the frequency of buses is also optimised.

By comparing the traditional all-stop service and limited-stop service, it can be seen that the passenger waiting time and the in-vehicle time, and the running time of buses can be changed.

Figure 7. Operational scheme of limited-stop service

Table 1. Test results

Types of service	f_A : veh/h			f_B : veh/h			Waiting time: h	In-vehicle time: h	Running time of buses: h	Total cost: \$/h
	l_1	l_2	l_3	l_1	l_2	l_3				
All-stop service	13	22	17	—	—	—	423-4559	2891	43-6997	57 118
Limited-stop service	12	20	16	5	6	2	381-0035↓	2700↓	47-9403↑	56 691↓
Change	—	—	—	—	—	—	-42-4524	-191	4-2406	-427

↑, rise in value; ↓, decline in value

The waiting time and running time may increase or decrease, based on the optimal frequencies, and the in-vehicle time will be reduced, while the total cost of the transit system will decrease. Therefore, implementing a limited-stop service can reduce the total cost and improve the service level of the transit system. However, because the optimisation method is found using a search algorithm, and because the origin–destination trips of passengers are associated and complicated at different stations, the application ranges of limited-stop services cannot be found. Overcoming this shortcoming would be an interesting project for future research.

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