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Coordinated Control Strategy for Multi-Line Bus Bunching in Common Corridors

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Abstract: Improving the sharing rate of public transportation is an important content for the sustainable development of urban transportation. However, bus bunching, a common phenomenon during transit operation, makes negative effects on reliability and service level of the bus system. In most urban centers in China, many bus lines usually serve in a corridor. Different buses may interact with each other in the corridor, which may aggravate the bus bunching. However, previous studies on bus bunching focused on single bus service. In addition, with the popularization of bus data acquisition and the maturity of data processing methods, the accuracy of bus bunching research meets more opportunities. In this paper, we proposed a holding strategy based on two-bus cooperative control. A simulation was carried out after preliminarily processing and analyzing the bus operation data of Foshan, Guangdong City. In the simulation, we compared the performance of three different scenarios, which are before control strategy, under the strategy for a single bus line and under the coordinated strategy for multiple bus lines. We contrastively analyze the results of the two strategies from different aspects. The results show that in aspects, such as holding a frequency, holding time, the total running time and the influence on the other bus line, the cooperative holding strategy manifests better. It illustrates that it is meaningful to do such a research on the effect of corridor service on bus bunching and add this effect into traditional holding strategy to build a multi-bus cooperative control strategy. The results have important theoretical significance for enriching and completing existing theory and methods of transit system and practical value for improving the service level and attractiveness of buses, increasing the share rate of public transportation, and thus, promoting the sustainable development of cities.

Keywords: bus bunching; common line; coordinated control strategy; bus big data

1. Introduction

With the acceleration of China's urbanization process, the urban population and the number of cars increase rapidly. The problem of urban traffic becomes increasingly prominent. Traffic congestion has gradually become a major bottleneck restricting the development of cities. Giving priority to the development of public transport has been an important strategy for sustainable development. However, the share rate of regular buses is decreasing year by year. This is because there are more interference factors during the operation of regular buses, resulting in its poor stability, poor punctuality, and as a result, the phenomenon of bus bunching. Many researchers have studied the occurrence mechanism and improvement strategies of bus bunching, most of which are based on a single bus line. While the fact is that in most cities of China, the bus network is complex and there are many common bus segments (that is, sections of the road passing by multiple bus lines at the same time). Buses of different bus routes interact with each other in the common corridor, which may affect the implementation effect of the improvement strategy for a single bus line. Therefore, it is necessary to propose a coordinated improvement strategy for multi-line buses.

With the application of on-board GPS device and communication technology in buses, a large number of data related to bus operation can be collected and stored, such as real-time GPS data, IC card (Integrated Circuit Card) records, video recording in buses, etc. Compared with the traditional bus survey data, such information is more comprehensive, accurate, less limited and of great application value. Now public transport informatization has been deeply involved in the management, operation and other aspects of public transport enterprises. It has brought more abundant basic information to the research of bus bunching, and made the research on the influence mechanism and improvement strategy for bus bunching more accurate. In addition, with the popularity of big data in recent years, data mining technology has become increasingly diversified and mature, bringing more opportunities for researchers to process data. Therefore, based on the big data of public transport, this paper will study the influence of the common corridor on bus bunching and the improvement strategy for it.

Based on the summary of relevant research, a coordinated holding strategy for multi-line buses in the same corridor was established. Processing and analyzing the bus big data in Foshan, Guangdong City, bus routes with obvious bus bunching and common corridors were selected as the object in this paper. The running performance of the proposed strategy was verified through simulation. Results show that the coordinated holding strategy has a good effect on improving bus bunching.

The research results have important theoretical significance for enriching and improving the existing analysis theories and methods for the public transport system, and have important practical value for improving the service level of public transport, and thus, developing the intelligent management decision support system for public transport.

In the second part of this paper, the existing improvement strategy models for bus bunching is summarized. In the third part, a coordinated holding strategy based on collaborative control for two bus lines is proposed. Finally, the improvement effect of this strategy is verified by simulation, and the comparison of two scenarios on the improvement effect proves that the coordinated holding control has advantages when multiple bus lines have a common corridor

2. Literature Review

There are many methods to improve the reliability of public transport services and effectively improve the phenomenon of bus bunching, such as adjusting timetable, dynamic scheduling of buses, the priority of traffic signals, bus lane planning, route design, etc. They are summarized and classified in Table 1:

Table 1. Strategies for improving bus bunching.

Strategy	Description	Classification
Adjust timetable [1–3]	Establish a reasonable bus operation schedule according to passenger demand.	Scheduling
Bus dynamic scheduling [4–7]	According to real-time monitoring of the bus station, holding and skipping are adopted to keep the headway stable.	
Bus signal priority [8–11]	When the bus arrives at the intersection, it gives priority to the signal, so that the bus can pass through the intersection quickly and reduce the waiting time at the intersection.	Bus priority
Bus lane [12,13]	Planning a bus lane to reduce the interference of social vehicles.	

Table 1. *Cont.*

Strategy	Description	Classification
Route design [14–16]	Change the length or the direction of the bus line.	Others
Bus station design [17,18]	Change the number of bus stations, the layout of bus stations and other characteristics.	
Bus driver training [19,20]	By training bus drivers, the instability of running time caused by driver operation can be reduced.	
Spare bus and driver [21,22]	Arrange the spare driver and bus reasonably in case of emergency.	

Although bus priority has always been the hot topic of research, they are often focused on the improvement of bus running speed and the reduction of the impact of other traffic flows, rather than the direct improvement of bus bunching. At present, most strategies improving bus bunching still focus on dispatching. Therefore, the following sections combine bus priority with other strategies, and mainly review the literature on bus dispatching and some other advanced strategies.

2.1. Bus Dispatching Strategy

The dispatching strategy is one of the most extensive strategies to study the improvement strategy of bus bunching. There are mainly two kinds of dispatching strategies for improving bus bunching: One is a planning strategy, the other is a real-time strategy.

2.1.1. Planning Strategy

Planning strategy is a long-term strategy that needs to be made based on existing timetable. According to different goals, the researchers put forward different timetable optimization scheme. Based on the analysis of bus bunching phenomenon and its causes, Zhou et al. studied the minimum departure interval of the bus with the goal of minimizing the operating cost of bus enterprises and maximizing the benefits of passengers under the constraint of easing bus bunching [23]. With the goal of minimizing the cost of waiting for passengers and maximizing the benefits of public transportation companies, Liang established an intelligent bus dispatching model based on the improved genetic algorithm, which can reduce the occurrence of bus bunching [24]. Xiao processed the historical GPS of the bus, analyzed the running characteristics of the bus, and established the bus departure time model to alleviate the phenomenon of bus bunching and large interval [25]. Wu et al. aim to minimize the total waiting time of transfer passengers, waiting for passengers and direct passengers, and add redundant time in the bus timetable to adapt to the randomness of bus travel time [26]. A reasonable timetable can effectively improve the stability of the bus system from the root and reduce the trouble of later dispatching. However, due to the randomness of the bus system, the static dispatching measures are difficult to deal with emergencies. Therefore, more research is now focused on real-time strategies.

2.1.2. Real-Time Strategy

Real-time strategy is a short-term strategy, such as bus-skipping, bus-holding, etc. Bus skipping is that when the bus falls behind the schedule in the running process, the bus can skip several stops without stopping, so that it can catch up with the scheduled time. Vuchic et al., the earliest scholar who described and evaluated the strategy of skipping at the level of operation, believed that compared with normal operation, bus-skipping could improve the speed of bus operation and maintain a high frequency of bus service [27]. Ercolano et al., through the comparison of bus-skipping and normal operation on the same bus line, found that bus-skipping could reduce the travel time, improve the bus operation speed and save the operating cost [28]. The researchers discussed bus-skipping from different goals, including the minimum waiting time of passengers [29], the minimum of passenger travel time (the sum of waiting and boarding time) [30], the minimum passenger expense [31], evenly spaced fleet [32], and the minimum operating cost of vehicles [33].

The bus-skipping is simple and effective, which can quickly restore the stability of the headway of bus, but it will also lead to a very adverse impact on passengers boarding, causing inconvenience to some passengers. Therefore, the implementation of this strategy is very cautious. In order to study the applicability of bus-skipping, Fu et al. conducted a sensitivity analysis on the bus line and found that the bus-skipping strategy had a good effect when the bus headway was small, and it could only be used when the bus running time fluctuated appropriately [34].

Compared with the bus-skipping strategy, the bus-holding strategy has better practicability and is the most widely studied bus bunching improvement strategy. The holding strategy enables the bus to stay at the station for an appropriate period in order to stabilize the headway. The simplest holding strategy is based on the planned timetable or headway [35]. This kind of strategy implements a holding strategy based on the actual arrival time of the bus, causing the bus to leave the station at the time planned by the timetable or to maintain the planned headway with the front car.

These holding strategies set the holding time based on the actual arrival time. With the development of automatic vehicle positioning system, automatic vehicle identification system and other advanced technologies, researchers can obtain the real-time location data of buses. So, a lot of prediction-based holding strategies are beginning to emerge. Bartholdi [36] and Daganzo et al. [37] used the real-time data of bus vehicles to predict the arrival time of the next bus, and to control the middle bus at the station, taking into account the headway of the previous bus and that of the next bus, so as to avoid the phenomenon of bus bunching with the next bus after holding at the station.

Lucas et al. found that the implementation of the skipping strategy could lead to an increase in the total delay, while making the headway stable through a comparison between the implementation of holding strategy and the strictly punctual bus service. This indicates that the optimal control strategy should not aim at obtaining uniform headway [38]. Therefore, many researchers set different objective functions and constraints to optimize the holding time. These models are complex and take many factors into consideration comprehensively. It is usually necessary to solve the holding time through heuristic search and other algorithms. Based on the predicted arrival time of the buses, Yu et al. established a model aiming at the minimum cost of the user from the perspective of the user, and used a genetic algorithm to solve the optimal holding time [39]. Zhang established a bus line model aiming at minimizing the average of additional travel time for passengers and discussed the relationship between different bus holding strategies and the stability of the headway. In order to determine the threshold affecting the stability of headway, she made an investigation on passenger travel choice behavior under the influence of the stability of headway [40]. In order to achieve a more ideal effect of holding control, Chen et al. considered the boarding behavior of passengers, took the shortest waiting time of passengers on the bus and at the station as the optimization objective, and extended the single control point problem into multiple control points to reduce the deviation of the headway of downstream stations [41]. Berrebi et al. proposed a global approach to deal with public transportation dispatching problem, making a large interval of buses can be absorbed by some or all the subsequent buses. Its goal is to keep the departure frequency as large as possible and make the passengers' waiting time shortest at the same time [42]. Lizana et al. calculated the optimal holding time and the minimum passenger waiting time through mathematical programming model and developed a real-time application to convey the control command to the bus driver [43].

Some researchers combine the holding strategy with other techniques to make it more effective. While carrying out dynamic holding dispatching, Han coordinated with the intersection signal priority technology to achieve uniform distribution of buses on the road and stable departure interval of each station on the premise of not affecting bus operation of the same station and other bus lines at the intersection [44].

With the development of relevant advanced technologies, the research on bus control is not limited to bus stations, but can also control the speed of buses in the process of bus operation. Because of its wide control range, the theoretical effect is better than the traditional holding control strategy. The strategy proposed by He can adaptively determine the actual holding time and running speed of the bus on the road, and take into account the non-linear boarding process of passengers [45]. Daganzo proposes a speed control scheme that can adjust the bus in real time, assuming that the bus in front is given enough information to interact with the bus behind [37]. Estrada et al., based on real-time data of the bus at the station, controlled the running speed of buses and extended the green light phase at the intersection when there facing a large delay [46]. John et al. proposed a bus operation scheme of automatic adjustment, in which the headway between vehicles can be dynamically self-regulated. Its goal is to reduce the average time headway and the deviation of headway. This scheme gives up the traditional method of considering timetable or preset headway [36]. However, in the actual situation, the frequent change of speed will make the driver always in a state of high tension, and the real-time speed adjustment is not easy to achieve, due to the driver's driving skills, the traffic situation at that time and other factors. These methods are more suitable for automatic buses with bus lanes.

2.2. Other Strategies

Bus priority can improve the bus running speed, reduce the bus operation delays caused by traffic congestion and red lights at the intersections. It has a positive significance to improve the phenomenon of bus bunching. Bus lane can set up to isolate buses from social vehicles, reduce the interference of them, improve the running speed of buses, and thus, improve the reliability of bus operation [47]. Bus signal priority is a common bus priority strategy. It provides red light advance, green light delay, phase insertion and other methods for specific buses detected, so as to reduce the bus delay at the intersection. In order to reduce the influence of bus signal priority on social vehicles, the priority of the bus signal should be conditional. Only when the bus is late can the priority request of bus signal priority be triggered [48]. Wanjing et al. presented a group of coordination based on the intersection of conditional bus priority strategy. The method considers the bus arrival time of downstream intersection when awarding the priorities, which significantly reduces the deviation of bus headway, improve the reliability of bus and at the same time, does not significantly affect other motor vehicle delays [8]. Chow et al. proposed a multi-objective optimization control framework based on bus timetable and headway deviation and additional delays caused by surrounding traffic to buses, calculated the optimal control formula for bus signal priority, and verified the rationality of this method through a case analysis of real scenes in London [9]. Larry used the priority diagram model to optimize the bus priority signal control scheme and reduce the bus delay [49]. Yang et al. predicted the time of vehicle arrival at the main intersection, coordinated and controlled main intersection and its signal timing, reducing the headway variation coefficient [10]. Anderson did not consider the influence of bus signal priority on other traffic in the model. He believed that fewer bus priority requests would have less influence on other traffic. Therefore, he directly took the reduction of headway deviation as the objective function and proposed a mathematical model on Brownian motion to solve the bus priority strategy [11].

In addition, bus arrival time can be predicted, and bus arrival time and full load rate can be released to passengers through electronic station signs, which can regulate passengers' transfer behavior, effectively improve the stability of bus operation and significantly reduce the number of bus transits [50]. Xia analyzed and clustered various abnormal situations in the daily operation of public transport vehicles, quantified them based on the practical experience of dispatchers, applied the knowledge base technology of expert system and proposed the idea of establishing the transport capacity configuration system [51]. A bus route length model based on headway stability was established to determine the optimal length of the bus route. When the bus route was higher than the optimal length, it should be arranged in the section with low saturation as far as possible to reduce the occurrence of bus bunching [18]. Shi, based on the study of the phenomenon of multi-line bus bunching, believes that the section repetition coefficient should be limited in the layout of the bus network, and suggests that the collinear stations of different lines should not exceed 1/3 of the total stations [52]. Furthermore, the development of autonomous buses can make up for the restrictions of drivers and improve the stability of bus operation.

3. Methodology

3.1. Notation

The symbols and meanings used in the model are shown below.

- i—index of bus line A (i = 1,2, 3 . . .).
- k—index of bus line B (k = 1,2,3 . . .).
- $g_{i,j}$—holding time [sec] of bus i (bus line A) at the stop j.
- $h_{i-1,i}$—planned headway [sec] between bus i (bus line A) and bus $i-1$ (bus line A).
- $d_{i,j}$—the original departure time of bus i (bus line A) at the stop j (before the implementation of holding control) [time units].
- $\overline{d}_{i,j}$—the actual departure time of bus i (bus line A) at the stop j (after the implementation of holding control) [time units].
- d_j—the departure time of the latest bus of bus line A at stop j (updates when every bus leaves the stop with an initial value of 0) [time units].
- $G_{k,j}$—holding time [sec] of bus k (bus line B) at the stop j.
- $H_{k-1,k}$—planned headway [sec] between bus k (bus line B) and bus $k-1$ (bus line B).
- $D_{k,j}$—the original departure time of bus k (bus line B) at the stop j (before the implementation of holding control) [time units].
- $\overline{D}_{k,j}$—the actual departure time of bus k (bus line B) at the stop j (after the implementation of holding control) [time units].
- D_j—the departure time of the latest bus of bus line B at stop j (updates when every bus leaves the stop with an initial value of 0) [time units].
- g_{max}—the maximum allowable holding time, set $g_{max} = 90$s.
- β—a coefficient for holding time, set $\beta = 0.7$.
- c—the minimum headway that judges whether two buses will encounter at the station, set $c = 60$ s.

3.2. Network Configuration

In this paper, we only consider the common corridor with two bus lines. The bus network is simplified into the model shown below (Figure 1). When two bus lines are in a common corridor, the number of common stops is n, and the stops are marked as $S+1,\ S+2,\ \ldots,\ S+n$.

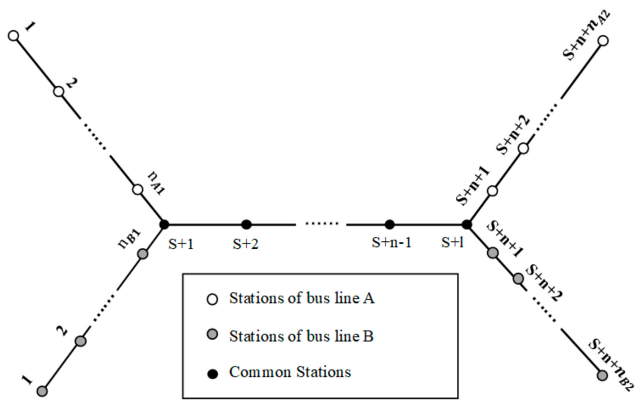

Figure 1. Station number of bus lines.

3.3. Problem Formulation

When solving the problem of bus bunching, most of the studies take the passenger waiting time or the total travel cost as the objective function to optimize the solution. However, the research difficulty and solution complexity of these goals are relatively high, and they are often used for one bus line and single control point. In this paper, we implemented a coordinated holding control for all buses departing from 07:00 to 09:00 during peak hour to reduce the occurrence of bus bunching. There are more than one bus line, and coordinated holding control is carried out not only at one point. So, the holding strategy is based on the traditional target of stabilizing the headway of buses. This method is relatively simple and can be solved fast. The main goal of the headway-based holding control is to adjust the headway between buses by station holding. The average passenger waiting time is related to the average headway and variance of headway, as shown in the following equation [53]:

$$E(W) = E(H)/2 + var(H)/[2 \cdot E(H)] \tag{1}$$

In which
$E(W)$ is the average waiting time [sec] of passengers;
$E(H)$ is the mean headway [sec];
$var(H)$ is the variance of headway.

The above equation shows that the holding strategy based on headway can not only improve the stability of headway, but also reduce the average waiting time of passengers. The main principle of this holding strategy is that, when the headway between two buses is less than a planned number, the latter bus will be held at the station to adjust the headway.

In order to reduce the unnecessary long time of holding, a coefficient β ($0 < \beta \leq 1$) is introduced and βh is the minimum allowable headway. Only when the distance between two buses is smaller than βh can the holding strategy be implemented. Previous studies show that the β range between 0.6 and 0.8 is relatively appropriate [54]. So, a medium value of 0.7 is taken for β in this paper. The holding strategy means the extension of the bus stopping time at the station, leading to the prolonging of passenger waiting time in the cars. However, the waiting time that passengers can endure in the car is limited. Therefore, a maximum allowable holding time g_{max} is set in this paper. The value of g_{max} is set as 90 s according to Reference [55].

3.4. Assumptions

- The capacity limit of the bus is not considered, that is, all the passengers waiting at the station can get on the bus when a bus arrives.
- The transfer within the common corridor is not considered.
- Passengers data at each station for every bus line is calculated from the historical data, and is not a variable.
- In the corridor, only the interactions between two buses are considered.

3.5. Formulation of the Holding Criteria

3.5.1. Single Line Holding Strategy

The holding time in this paper refers to the additional time that bus stays at the station under the implementation of holding strategy. Figure 2 is a simplified diagram of single line bus operation. Assuming that the number of bus station is n, the holding time is calculated as follows:

$$g_{i,j} = \begin{cases} \min\left[\max\left[0, \beta h_{i-1,i} - \left(d_{i,j} - \overline{d}_{i-1,j}\right)\right], g_{max}\right], & \mathrm{i} \neq 1 \\ 0, & \mathrm{i} = 1 \end{cases} \tag{2}$$

$$\overline{d}_{i,j} = d_{i,j} + g_{i,j} \tag{3}$$

$\beta h_{i-1,i} - \left(d_{i,j} - \overline{d}_{i-1,j}\right)$ is the holding time considering the headway when holding strategy is not implemented, and the minimum allowed headway. When the value is less than zero, the value of $g_{i,j}$ will be zero. That is, the bus normally leaves the bus station without holding. When the value is greater than g_{max} (the maximum allowed holding time), the holding time will $g_{i,j}$ be set as g_{max} so that passengers will not wait too long in the bus. When the value is between 0 and g_{max}, the holding time will be the calculated value of $\beta h_{i-1,i} - \left(d_{i,j} - \overline{d}_{i-1,j}\right)$.

The first bus departing from the starting station will not be held, and the holding strategy will be carried out from the second bus. Buses at the first and last station and the penultimate station will not be held too. The effect of the bus holding at the penultimate station is meaningless, because the implementation of the station directly affects the arrival time of the next station, which is the terminal, and there will be no passengers waiting. In a word, the holding strategy is carried out from the second station to the third from the bottom.

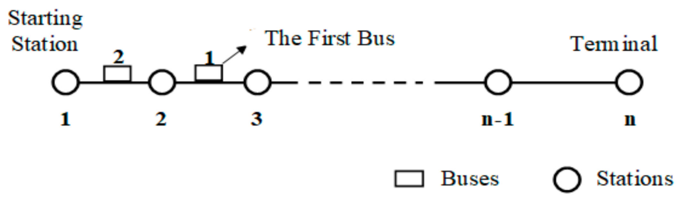

Figure 2. Operation of the single bus line.

3.5.2. Holding Strategy Outside the Common Corridor

When buses of bus line A and bus line B are outside the common corridor, the buses of two lines will not interfere with each other, so the control method as that of a single line.

For bus line A

$$g_{i,p} = \begin{cases} \min\left[\max\left[0, \beta h_{i-1,i} - \left(d_{i,j} - \overline{d}_{i-1,p}\right)\right], g_{max}\right], & \mathrm{i} \neq 1 \\ 0, & \mathrm{i} = 1 \end{cases} \tag{4}$$

$$\overline{d}_{i,p} = d_{i,p} + g_{i,p} \tag{5}$$

For bus line B

$$G_{k,q} = \begin{cases} \min\left[\max\left[0, \beta H_{k-1,k} - \left(D_{k,j} - \overline{D}_{k-1,q}\right)\right], g_{max}\right], & \mathrm{i} \neq 1 \\ 0, & \mathrm{i} = 1 \end{cases} \tag{6}$$

$$\overline{D}_{i,q} = D_{i,q} + G_{i,q} \tag{7}$$

3.5.3. Holding Strategy Within the Common Corridor

When two bus lines are running in a common line segment, they will interfere with each other and aggravate the phenomenon of bus bunching. Therefore, the influence of another bus line in the common corridor should be taken into consideration when carrying out the bus control strategy. Since it is difficult to control the running speed of buses between stations, this paper carries out collaborative control on the stopping time of buses at the station in order to reduce the occurrence of bus bunching between different bus lines. Therefore, within and without the common corridor, the calculation of holding time is different. The influence of other lines should be considered in the common corridor.

For the two bus lines in the common corridor, the holding time can be calculated, respectively, as follows:

For bus line A:

$$g_{i,j} = \begin{cases} min\left\{ \begin{array}{c} max\left[\begin{array}{c} min\left[max\left[0, \beta h_{i-1.i} - \left(d_{i,j} - \overline{d}_{i-1,j}\right)\right], g_{max}\right], \\ max\left[0, c - \left(d_{i,j} - D_j\right)\right] \end{array} \right], \\ min\left[max\left[0, h_{i-1,i} - \left(d_{i,j} - \overline{d}_{i-1,j}\right)\right], g_{max}\right] \end{array} \right\}, \left(D_j \neq 0, i \neq 1\right) \\ min\left[max\left[0, \beta h_{i-1,i} - \left(d_{i,j} - \overline{d}_{i-1,j}\right)\right], g_{max}\right], \left(D_j = 0, i \neq 1\right) \\ 0, \ (i = 1) \end{cases} \tag{8}$$

$$\overline{d}_{i,j} = d_{i,j} + g_{i,j} \tag{9}$$

$$d_j = \overline{d}_{i,j} \tag{10}$$

For bus line B:

$$G_{k,j} = \begin{cases} min\left\{ \begin{array}{c} max\left[\begin{array}{c} min\left[max\left[0, \beta H_{k-1.k} - \left(D_{k,j} - \overline{D}_{k-1,j}\right)\right], g_{max}\right], \\ max\left[0, c - \left(D_{k,j} - d_j\right)\right] \end{array} \right], \\ min\left[max\left[0, H_{k-1,k} - \left(D_{k,j} - \overline{D}_{k-1,j}\right)\right], g_{max}\right] \end{array} \right\}, \left(d_j \neq 0, k \neq 1\right) \\ min\left[max\left[0, \beta H_{k-1,k} - \left(D_{k,j} - \overline{D}_{k-1,j}\right)\right], g_{max}\right], \left(d_j = 0, k \neq 1\right) \\ 0, (k = 1) \end{cases} \tag{11}$$

$$\overline{D}_{k,j} = D_{k,j} + G_{k,j} \tag{12}$$

$$D_j = \overline{D}_{k,j} \tag{13}$$

For the last station in the common corridor, that is, station $S + n$, it is also treated as the station outside the common corridor. This is because no matter whether the strategy is carried out at this station, the two bus lines will never meet at the next stop.

When the buses of bus line A and bus line B are running along the common corridor, the two lines may meet in the station or section to affect each other. So, when implementing a holding strategy, the interaction of the two bus lines should be taken into consideration. The principle of this model is to avoid the meeting of different bus lines. When the headway between the bus of line A and the bus of line B is less than c, it is considered that the buses of the two lines are too close. So that control strategy needed to be carried out and the holding time is $\max\left[0,\ c - \left(d_{i,j} - D_j\right)\right]$. At the same time, it should also satisfy the stabilization of the headway between buses of the same bus line. Make it the bigger one of the two bus lines. As the ultimate goal is to ensure the headway remain stable, not to avoid the two bus lines meeting, the maximum allowable holding time $\min\left[\max\left[0, H_{k-1,k} - \left(D_{k,j} - \overline{D}_{k-1,j}\right)\right], g_{max}\right]$ is set to prevent the situation that buses waiting too long at the station and make the headway of the front bus too large.

4. Simulation Experiments

The experiment data in this paper are derived from the bus operation data of Foshan, Guangdong City. The cases of bus no. 391 and bus no. 378 with a common line segment and the obvious phenomenon of bus bunching are selected as the object in this paper. The direction and common route sections of bus no. 391 and bus no. 378 are shown in Figure 3.

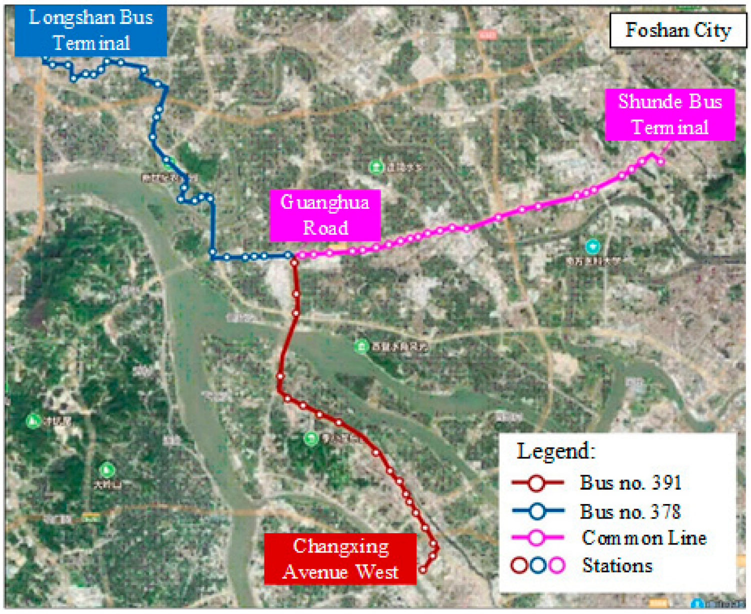

Figure 3. Bus route map of bus no. 391 and bus no. 378.

Through the statistical analysis of historical data and simulation, it is proved that buses running in the same corridor will influence each other, making bus bunching more common. Therefore, the simulation experiment is carried out to verify the effectiveness of the collaborative control strategy proposed in this paper to solve the problem of the bus lines running in the common corridor.

4.1. The Performance of the Proposed Strategy

The simulation environment was built by Vissim based on the current situation of bus no. 378 and bus no. 391. Under the simulation condition, the operation data of bus no. 391, with the implementation of the proposed strategy, were obtained. It is then calculated and compared with the original operation data without any control strategy. The departure and arrival time at each station is extracted and drawn into the bus running trajectory diagram, as shown in Figures 4 and 5.

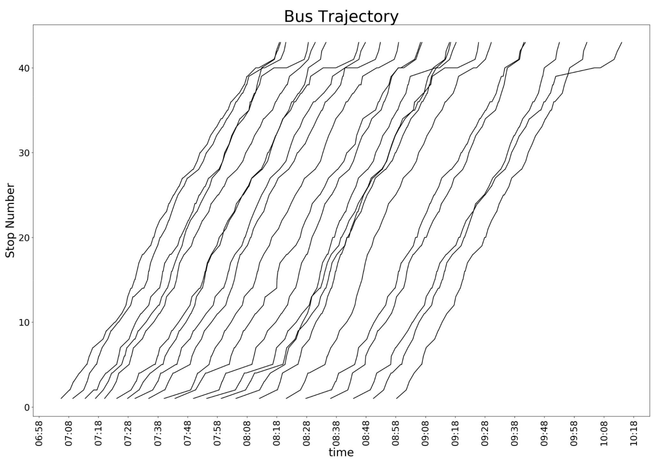

Figure 4. Bus running trajectory of bus no. 391(before control strategy).

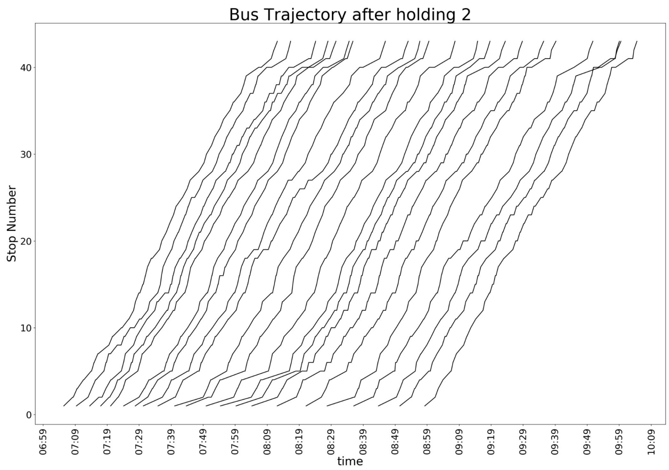

Figure 5. Bus running trajectory of bus no. 391(after control strategy).

From the comparative figure above, it can be clearly seen that after the implementation of the strategy, the interval between the two adjacent buses becomes more even.

Calculate the headway of the buses and the distribution of headway is shown in Figures 6 and 7.

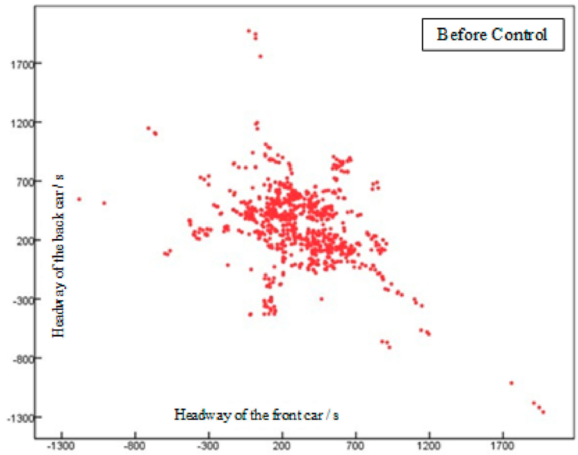

Figure 6. The distribution of headway before control strategy.

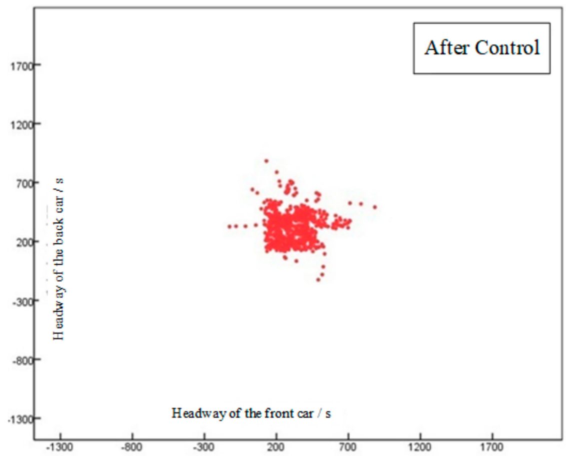

Figure 7. The distribution of headway after control strategy.

The headway of the original data shows a scattered state in Figure 6, indicating that the headway greatly deviates, and the bus operation is very unstable. While after the implementation of the holding strategy, headway converges towards the center (Figure 7), indicating that the headway becomes stable.

Calculate the time headway variation coefficient of each station (Table 2) and a comparison diagram is shown in Figure 8. It can be seen from the figure that after the implementation of strategy, the headway variation has been significantly reduced, which indicates that the probability of bus bunching is reduced.

Table 2. Headway Variation Coefficient of Bus no. 391 before and after S2 implemented.

Station Number	Before	After	Station Number	Before	After	Station Number	Before	After
2	0.33542	0.33542	**16**	0.66405	0.34674	**30**	0.94128	0.46917
3	0.34644	0.32562	**17**	0.68118	0.34925	**31**	0.96914	0.46697
4	0.35375	0.32309	**18**	0.73276	0.36878	**32**	0.96255	0.46979
5	0.47092	0.40193	**19**	0.78133	0.37848	**33**	0.94588	0.46908
6	0.48254	0.39156	**20**	0.78978	0.37240	**34**	0.94812	0.47679
7	0.44699	0.36211	**21**	0.79991	0.36622	**35**	0.99950	0.45800
8	0.50515	0.37850	**22**	0.78921	0.36887	**36**	1.02260	0.48445
9	0.52741	0.36828	**23**	0.81225	0.37209	**37**	1.07164	0.47845
10	0.51524	0.37468	**24**	0.83981	0.37775	**38**	1.11700	0.46139
11	0.52402	0.37089	**25**	0.8241	0.42168	**39**	1.13477	0.64522
12	0.58781	0.36637	**26**	0.83851	0.47405	**40**	1.69743	0.59404
13	0.59309	0.35567	**27**	0.85388	0.46738	**41**	2.15718	0.51007
14	0.64604	0.38590	**28**	0.87571	0.46836	**42**	2.20790	0.50792
15	0.65685	0.37230	**29**	0.92892	0.46315	**43**	2.18257	0.41818

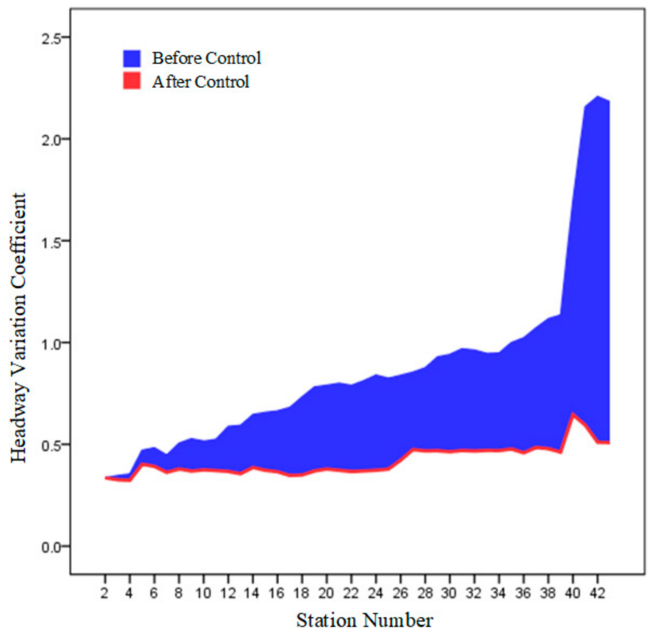

Figure 8. Headway variation coefficient before and after S2 implemented.

In addition, relevant indicators were calculated to quantify the difference before and after the implementation of the strategy, as shown in Table 3.

Table 3. Indicators before and after S2 implemented.

Indicators	Before	After	Relative Difference
Average headway variation coefficient	0.870491	0.41818029	−51.96%
Standard deviation of headway	314.6746	137.4170	−56.33%
Total time of bus operation/s	97586	96915	−0.69%
Total time of bus stopping/s	5649	10074	78.33%
Total time of bus travelling/s	91937	86841	−5.54%
Total number of bus bunching	125	5	−96.00%

* Note: '-' means that the results calculated after S2 implemented are smaller than before. The same below.

As can be seen from the above table, after the implementation of the holding control, the average headway variation coefficient decreased by 51.96%, and the standard deviation of headway decreased by 56.33%, which indicates that the holding control significantly improved the stability of headway. Furthermore, the total number of bus bunching dropped from 125 times to five times, and the five times of bus bunching occurs in the last four stops, basically solving the problem of bus bunching. Although the total bus dwell time increased by 78.33%, due to the holding control, the overall running time during the common corridor decreased by 5.54%. It also proves that the holding control is very effective.

4.2. Comparison

The main objective of our work is to study the impacts of single-line control strategy versus coordinated control strategy in the common corridor. In order to achieve this, we compared three scenarios:

- Single-line control strategy (S1): All the buses in the corridor are controlled independently without considering the interference of other bus lines.
- Coordinated control strategy (S2): The control strategy is carried out considering the interaction between different bus lines as described in Section 3.
- No control: In this scenario, all the buses are allowed to operate without any intervention or control strategy. This scenario serves as a base line for the comparison of the other scenarios.

Figure 9 is a comparison diagram of headway distribution for S1 and S2. It can be seen from the figure that the headway after the implementation of the two strategies is similar to a high degree of overlap. That is, the improvement effect of both strategies on bus bunching is similar as well.

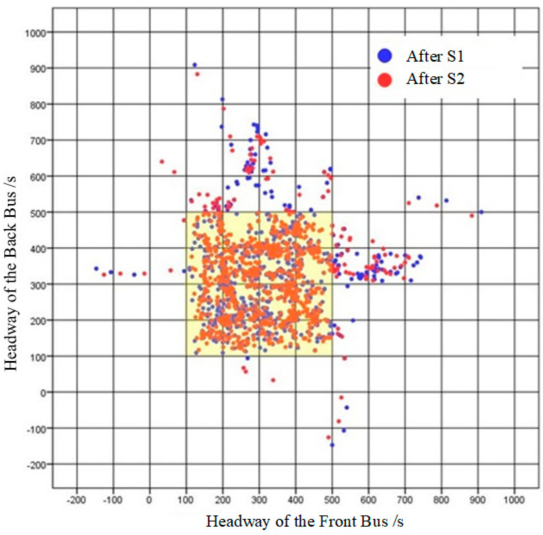

Figure 9. The distribution of headway after S1 and S2 implemented.

In order to further illustrate the advantages of the coordinated control strategy (S2) over single-line based control strategy (S1), the improvement effects of the two strategies are compared and analyzed in the following aspects.

4.2.1. Number of Holding

Figure 10 is a schematic diagram of whether the bus no. 391 is held at the station. The dark square means that the bus is held at the station, while the light square means not. According to the comparison of the two strategies, the dark area of S1 is obviously larger than that of S2, meaning that S1 implemented more times of holding than S2.

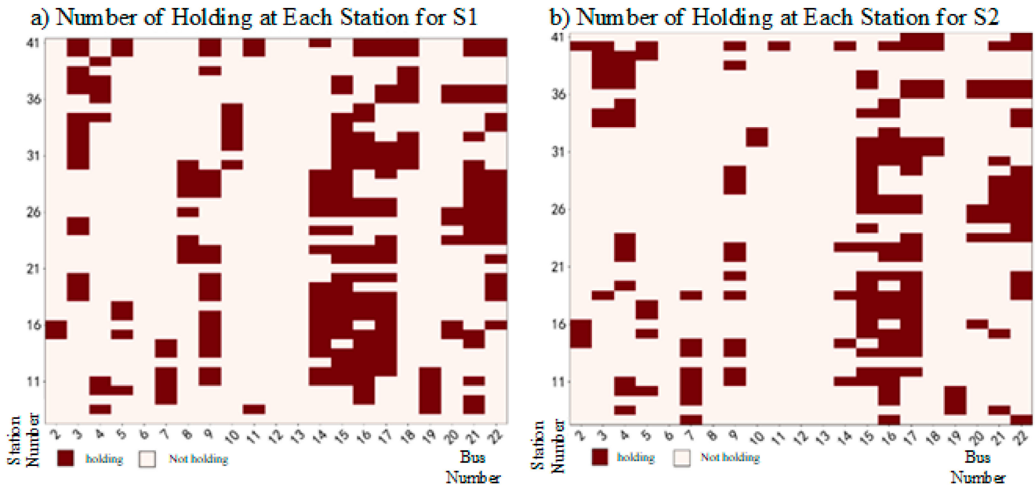

Figure 10. Number of holding at each station after S1 (**a**) and S2 (**b**) implemented.

In addition, most of the buses are held at more than one station. It shows that choosing only one or two stations to carry out holding control will not effectively improve bus bunching. It is because various factors leading to the phenomenon of bus bunching still exist after holding control and will continue to affect the bus operation, causing the instability of headway.

The total number of holding control at each station is calculated, as shown in Table 4. the total number of holding in S1 was 225, while that in S2 was 175, which was 50 times less than that in S1. The increase of the number of holding will add to the complexity of the bus driver's work. That is why previous studies usually select only one or two stations to avoid repeated stops in the process of bus operation. Therefore, S2 is superior to S1 in terms of the number of holding.

Table 4. Total number of holding at each station for S1 and S2.

Station Number	S1	S2	Station Number	S1	S2	Station Number	S1	S2
1	0	3	**15**	5	4	**29**	5	4
2	4	3	**16**	6	5	**30**	6	5
3	4	3	**17**	0	0	**31**	6	2
4	5	5	**18**	6	4	**32**	4	3
5	8	6	**19**	6	6	**33**	6	5
6	7	5	**20**	5	5	**34**	2	2
7	3	0	**21**	5	2	**35**	6	5
8	6	5	**22**	4	3	**36**	8	8

Table 4. *Cont.*

Station Number	S1	S2	Station Number	S1	S2	Station Number	S1	S2
9	6	6	**23**	8	6	**37**	4	3
10	9	6	**24**	6	5	**38**	3	3
11	7	4	**25**	6	4	**39**	1	3
12	6	4	**26**	6	4	**40**	9	11
13	5	4	**27**	7	4	**41**	10	3
14	7	8	**28**	8	4	**TOTAL**	**225**	**175**

4.2.2. Holding Time

The figure below (Figure 11) shows the thermal map of holding time at each station. The darker the color, the longer the bus stays at the station. Comparing the two figures, the dark blocks of S1 are more than that of S2, which indicates that most of the holding time of S1 is longer than S2.

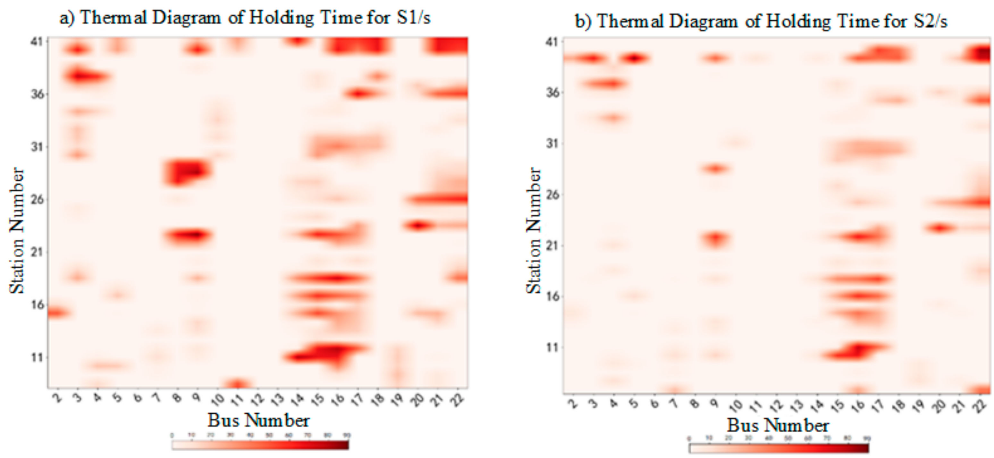

Figure 11. Thermal diagram of holding time at each station for S1(**a**) and S2(**b**).

The total holding time is calculated in Table 5. The holding time at most stations in S1 is larger than that in S2. From the perspective of the whole period, the total holding time of S1 is 5231 seconds, while that of S2 is 3051 seconds. The total holding time of S2 is 41.67% less than that of S1. The holding at the station leads to the extension of the bus running time. Therefore, the longer the bus is held at the station, the greater the impact on bus bunching. To sum up, S2 is superior to S1 in terms of holding time.

Table 5. Total holding time at each station after S1 and S2 implemented.

Station Number	Holding Time/s		Station Number	Holding Time/s		Station Number	Holding Time/s	
	S1	S2		S1	S2		S1	S2
2	63	41	9	452	245	16	728	587
3	392	130	10	65	13	17	554	527
4	130	169	11	99	9	18	273	163
5	102	107	12	0	0	19	83	24
6	0	0	13	0	0	20	199	112
7	28	49	14	320	29	21	401	96
8	304	0	15	583	293	22	455	457
TOTAL	**S1**		**5231**	**S2**		**3051**	**Relative Difference**	**41.67%**

4.2.3. Bus Running Time

After the implementation of control strategy, the bus stop time, running time, and other indicators will change. Therefore, S1 and S2 are compared from these aspects.

In order to better compare the stopping time of the bus at each station, subtracting the stopping of S2 from that of S1 as a stop time difference. The values are drawn into the figure below. In Figure 12, white indicates that the stop time of S1 and S2 is equal, red indicates that the stop time of S2 is longer and blue indicates that the stop time of S1 is longer. The darker the color is, the larger the stop time difference is. There are more blue blocks in the figure than red, indicating that the stop time of S1 is longer than that of S2 at more stations. It is also related to the fact that the holding time of S1 is longer than S2 at most stations. Although there are many blue blocks, most of them are lighter, indicating that although the stop time of S1 is longer, the difference is not significant. In Table 6, the total stop time of S2 is 13.06% less than that of S2, which is consistent with the results presented in the thermal map.

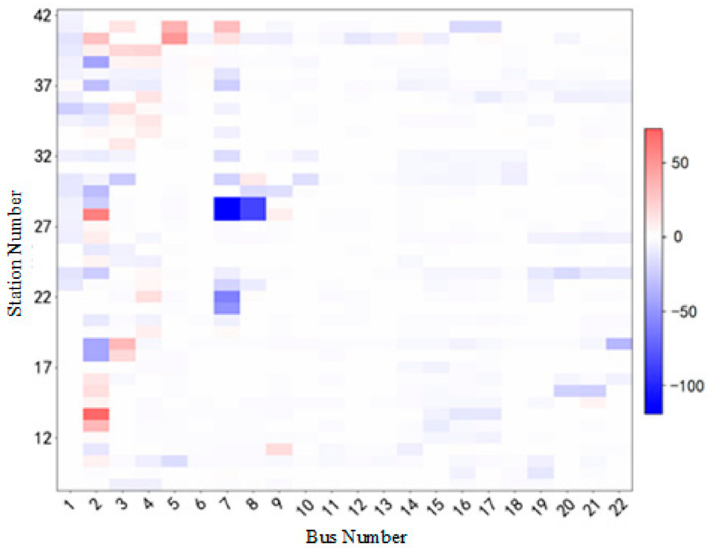

Figure 12. The difference in stopping time between S1 and S2.

Table 6. Indicators of bus operation time.

Indicators	S1	S2	Relative Difference
Total Time of Bus Operation /s	103009	96915	−5.91%
Total Time of Bus Stopping /s	11587	10074	−13.06%
Total Time of Bus Travelling /s	91422	86841	−5.01%

The total running time of S2 is 86841 seconds, which is 5.01% less than that of S1. After the implementation of S2, bus no. 391 was less likely to be affected by bus no. 378 and the speed of bus no. 391 was slightly improved.

In a word, S2 is superior to S1 in terms of the total bus operation time, the total stop time and the total bus section running time.

4.2.4. The Influence of Other Bus Lines in the Same Corridor

S1 only controls bus no. 391, but changes in the running state of bus no. 391 may affect the running state of bus no. 378 in the same corridor. S2 not only controls bus no. 391, but also bus no. 378. Therefore, the running state of bus no. 378 will change after the implementation of S2. In a word, it is necessary to analyze the running state of bus no. 378 after the implementation of the two strategies. The operation state of bus no. 378 in the common corridor is analyzed below. The following three pictures show the bus running trajectory of bus no. 378 before and after the implementation of the two strategies.

Through the comparison between the running trajectory before and after the implementation of S1, as shown in Figures 13 and 14, we can see that although S1 did not adopt any control over bus no.378, the running state of it changed because of the change of bus no. 391. this also shows from the side that buses of different lines in the common corridor will interact with each other.

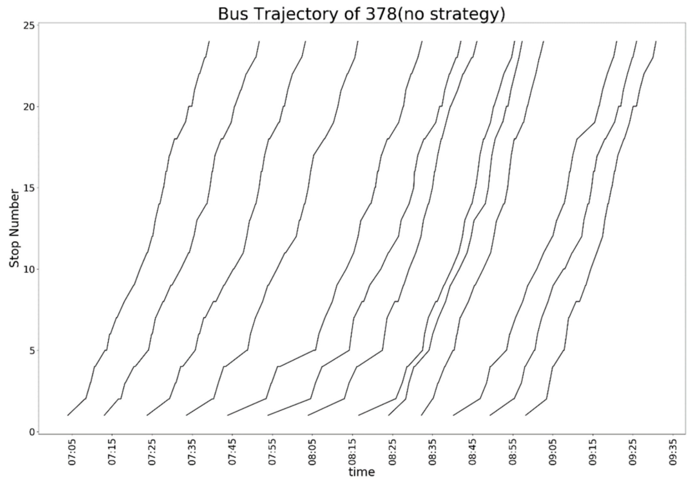

Figure 13. Bus running trajectory of bus no. 378(before control strategy).

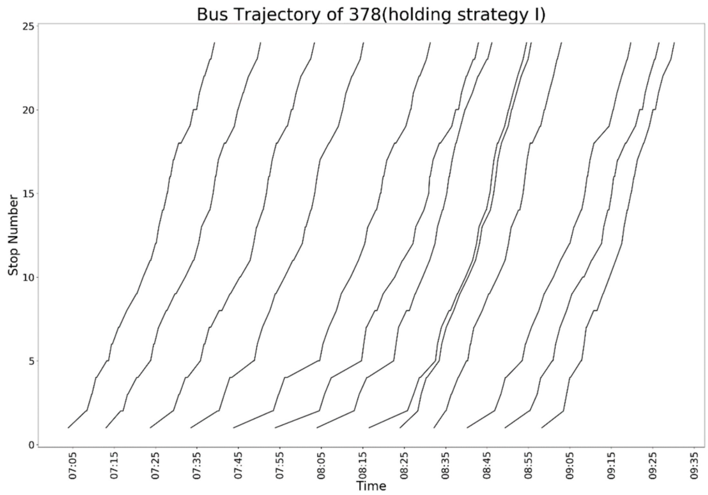

Figure 14. Bus running trajectory of bus no. 378(after S1 implemented).

Through the comparison between the running trajectory after the implementation of S1 and S2, as shown in Figures 14 and 15, we can see that the bus trajectory of S2 is more even. This is because that S2 aims at stabilizing the headway of bus no. 378 as well.

According to Figure 16, after the implementation of S2, the headway variation coefficient of bus no. 378 decreased significantly, indicating that the reliability of bus no. 378 increased. It proves that the implementation of S2 not only improves the phenomenon of bus bunching of bus no. 391, but also increases the operational reliability of bus no. 378.

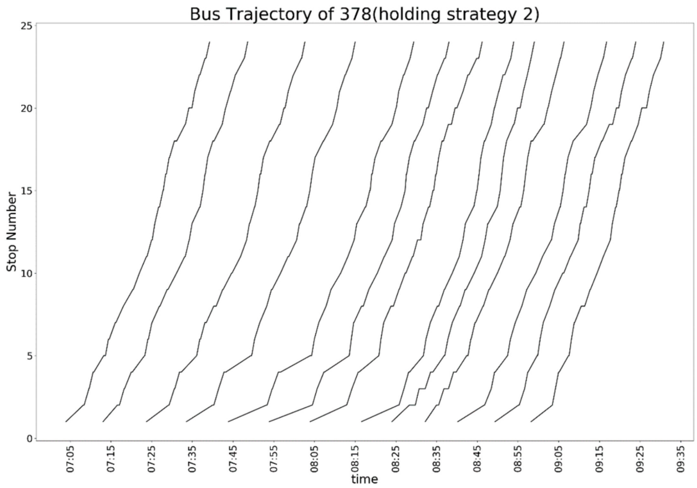

Figure 15. Bus running trajectory of bus no. 378(after S2 implemented).

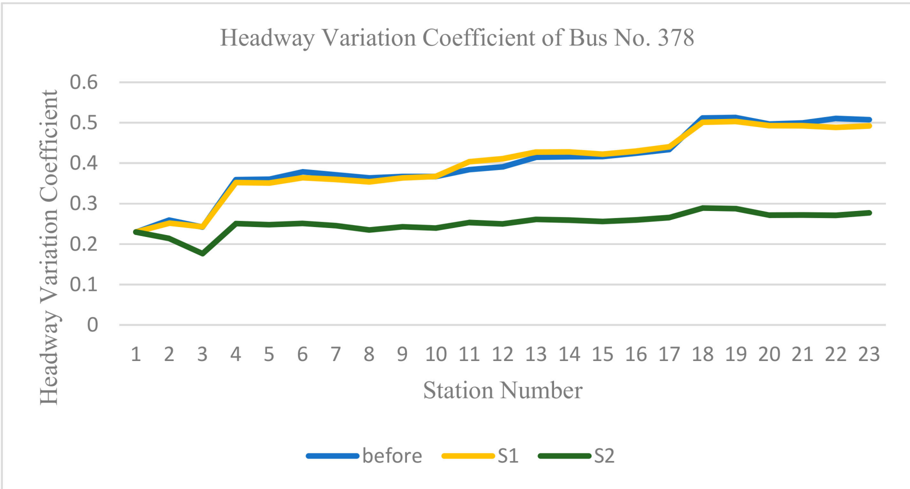

Figure 16. Line chart of headway variation coefficient of bus no. 378 under three scenes.

The following table (Table 7) is the summary table of bus operation indexes of bus no. 378 before and after the implementation of the two strategies. After the implementation of S1, the stop time, the section running time and the total bus running time of no. 378 all decreased to a certain extent. After the implementation of S2, due to holding at some stations, the stop time of bus no. 378 increased. However, due to the reduced interference of bus no. 391, the total running time of bus no. 378 decreased to some extent.

Table 7. Indicators of bus no.378.

Indicators	Before	S1	S2
Total Time of Bus Stopping /s	1810	1711	2301
Total Time of Bus Holding /s			610
Total Time of Bus travelling /s	28533	28371	27295
Total Time of Bus Operation /s	30343	30082	29596

4.2.5. Comprehensive Analysis

Table 8 is a summary of S1 and S2 indicators. Taking the bus no. 391 as the evaluation target, although S1 had a slightly worse improvement effect on bus bunching than the S2, the other indicator

S2 are better than the S1. Taking bus no. 378 as the evaluation target, S2 is better than S1. In addition, taking the system of the common corridor with bus no. 378 and bus no. 391 as the evaluation target, the total number of stops and the total holding time, the total bus operation time, the total stop time and the total section running time of S2 are smaller than the S1. Therefore, after the improvement of S2, the bus bunching phenomenon of bus no. 378 and bus no. 391 has been greatly improved. So, the strategy proposed in this paper is an acceptable better strategy.

Table 8. Summary of indicators for S1 and S2.

Evaluation Object	Category	Indicators	S1	S2	Relative Difference
Bus No. 391	Bus Bunching Improvement	Average Headway Variation Coefficient	0.3993	0.4182	4.73%
		Standard deviation of headway	123.9888	137.417	10.83%
		Total number of bus bunching	4	5	25.00%
	Bus Holding	Total number of bus holding	225	175	−22.22%
		Total time of bus bunching /s	5231	3051	−41.67%
	Bus Operation	Total time of bus operation /s	103009	96915	−5.92%
		Total time of bus stopping /s	11587	10074	−13.06%
		Total time of bus travelling /s	91422	86841	−5.01%
Bus No. 378	Bus Bunching Improvement	Average Headway Variation Coefficient	0.3986	0.2524	−36.68%
		Standard deviation of headway	247.768	171.309	−30.86%
		Total number of bus bunching	0	0	-
	Bus Holding	Total number of bus holding	0	28	-
		Total time of bus bunching /s	0	610	-
	Bus Operation	Total time of bus operation /s	30082	29596	−1.62%
		Total time of bus stopping /s	1711	2301	34.48%
		Total time of bus travelling /s	28371	27295	−3.79%
Bus System	Bus Holding	Total number of bus holding	225	203	−9.78%
		Total time of bus bunching /s	5231	3661	−30.01%
	Bus Operation	Total time of bus operation /s	133091	126511	−4.94%
		Total time of bus stopping /s	13298	12375	−6.94%
		Total time of bus travelling /s	119793	114136	−4.72%

Compared with S1, S2 considers the interaction between buses on different lines within a common corridor. During the implementation of the strategy, not only the single line is controlled, but the multi-lines that have a mutual influence on the common corridor are also controlled coordinately to reduce more delay. By comparing the two strategies, under the premise of better improving the phenomenon of bus bunching, the multi-line cooperative control method reduced the delay caused by the traditional single line control strategy. At the same time, the operating status of other lines in the common corridor is improved.

5. Conclusions

5.1. Key Findings

In this paper, based on the bus big data, this paper conducts a study on bus bunching between two bus lines with a common corridor. The main research results are as follows:

Two bus lines based coordinated control strategy to improve bus bunching is established. The bus running state of the two bus lines are monitored in real time by simulation. Through the analysis of the bus running status before and after the implementation of strategy, it proves that the strategy proposed in this paper has a good effect on the improvement of bus bunching in multi-line corridor.

Compared and analyzed the two different improvement strategies from various aspects. Indicators of the collaborative control strategy are superior to those of the single-line based strategy. It shows that it is meaningful to study the influence of the common corridor on bus bunching and add the factors of the common corridor into the traditional single-line based improvement model.

5.2. Future Work

In this paper, the control strategy is established based on the target of stabilizing the headway of buses. This method is relatively simple. Future research can consider quantifying the mutual influence and coordinated control of different lines in the common line segment into the model, and put the focus on other optimization targets, such as minimizing the total cost of passengers.

To increase the realism of the case study, the bus capacity and passenger data should also be included in the model. In this paper, passenger's data at each station for every bus line is constant and calculated from the historical data. The model can be further improved if stochastic passenger arrivals are considered. To achieve this, a queueing model needs to be added to the model to describe the boarding and alighting process at each station explicitly.

On the other hand, the consideration of bus capacity would amplify the propagation of delays, as crowded buses tend to need more time per passenger to complete boarding and alighting. Consideration of crowding would further possibly lead to a revised queueing model in which passengers might predict that crowded buses require more dwell time at subsequent stops, and hence, prefer to board less congested buses as those buses tend to complete alighting at the next stops faster. Furthermore, if we consider vehicle capacity constraint, the total cost is more likely to increase with regard to the idealized performance with perfect regularity.

In the downtown areas of China's cities, there are many bus lines in some sections, and the number of collinear lines is even as high as 10. The increase in the number of buses lines in the common corridor will lead to more serious interactions with each other. Therefore, this factor can be considered in the research of public transport network planning in future research. Our future study will focus on extending the results and control strategy presented in this paper to the entire bus network. That means a network of different size, branch, corridor lengths should be considered and assessed to decide when and where to carry out the coordinated control strategy. Furthermore, when it comes to the whole network with multiple branching situations, the transferring passengers should also be accounted for.

For different bus lines with a long line segment, future research on timetable optimization can be further improved from the perspective of adjusting the bus departure time to avoid the bus of different lines entering the common line segment at the same time.

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References

1. Ceder, A. Efficient timetabling and vehicle scheduling for public transport. In *Computer-Aided Scheduling of Public Transport*; Springer: Berlin/Heidelberg, Germany, 2001; pp. 37–52.
2. Guihaire, V.; Hao, J.-K. Transit network timetabling and vehicle assignment for regulating authorities. *Comput. Ind. Eng.* **2010**, *59*, 16–23. [CrossRef]
3. Ibarra-Rojas, O.J.; Rios-Solis, Y.A. Synchronization of bus timetabling. *Transp. Res. Part B: Methodol.* **2012**, *46*, 599–614. [CrossRef]
4. Delgado, F.; Munoz, J.C.; Giesen, R. How much can holding and/or limiting boarding improve transit performance? *Transp. Res. Part B: Methodol.* **2012**, *46*, 1202–1217. [CrossRef]
5. Daganzo, C.F. A headway-based approach to eliminate bus bunching: Systematic analysis and comparisons. *Transp. Res. Part B: Methodol.* **2009**, *43*, 913–921. [CrossRef]
6. Xuan, Y.; Argote, J.; Daganzo, C.F. Dynamic bus holding strategies for schedule reliability: Optimal linear control and performance analysis. *Transp. Res. Part B: Methodol.* **2011**, *45*, 1831–1845. [CrossRef]
7. Sidi, M.; Hammadi, S.; Hayat, S.; Borne, P. Urban transport network regulation and evaluation: A fuzzy evolutionary approach. *IEEE Trans. Syst. Man Cybern. Part A Syst. Hum.* **2008**, *38*, 309–318. [CrossRef]
8. Ma, W.; Yang, X.; Liu, Y. Development and Evaluation of a Coordinated and Conditional Bus Priority Approach. *Transp. Res. Rec. J. Transp. Res. Board* **2010**, *2145*, 49–58. [CrossRef]
9. Chow, A.H.F.; Li, S.; Zhong, R. Multi-objective optimal control formulations for bus service reliability with traffic signals. *Transp. Res. Part B: Methodol.* **2017**, *103*, 248–268. [CrossRef]
10. Yang, M.; Sun, G.; Wang, W.; Sun, X.; Ding, J.; Han, J. Evaluation of the pre-detective signal priority for bus rapid transit: Coordinating the primary and secondary intersections. *Transport* **2018**, *33*, 1–11. [CrossRef]
11. Anderson, P.; Daganzo, C.F. Effect of Transit Signal Priority on Bus Service Reliability. *Transp. Res. Part B Methodol.* **2018**. [CrossRef]
12. Eichler, M.; Daganzo, C.F. Bus lanes with intermittent priority: Strategy formulae and an evaluation. *Transp. Res. Part B: Methodol.* **2006**, *40*, 731–744. [CrossRef]
13. Yu, B.; Kong, L.; Sun, Y.; Yao, B.; Gao, Z. A bi-level programming for bus lane network design. *Transp. Res. Part C: Emerg. Technol.* **2015**, *55*, 310–327. [CrossRef]
14. Szeto, W.Y.; Jiang, Y. Transit route and frequency design: Bi-level modeling and hybrid artificial bee colony algorithm approach. *Transp. Res. Part B: Methodol.* **2014**, *67*, 235–263. [CrossRef]
15. Nikolić, M.; Teodorović, D. A simultaneous transit network design and frequency setting: Computing with bees. *Expert Syst. Appl.* **2014**, *41*, 7200–7209. [CrossRef]
16. Nayeem, M.A.; Rahman, M.K.; Rahman, M.S. Transit network design by genetic algorithm with elitism. *Transp. Res. Part C: Emerg. Technol.* **2014**, *46*, 30–45. [CrossRef]
17. Medina, M.; Giesen, R.; Muñoz, J.C. Model for the optimal location of bus stops and its application to a public transport corridor in Santiago, Chile. *Transp. Res. Rec.* **2013**, *2352*, 84–93. [CrossRef]
18. Chew, J.S.C.; Lee, L.S.; Seow, H.V. Genetic algorithm for biobjective urban transit routing problem. *J. Appl. Math.* **2013**, *2013*, 698645. [CrossRef]
19. Sullman, M.J.M.; Dorn, L.; Niemi, P. Eco-driving training of professional bus drivers–Does it work? *Transp. Res. Part C: Emerg. Technol.* **2015**, *58*, 749–759. [CrossRef]

20. Arnawa, N.M.S.; Putranto, L.S. The influence of driver training on self-regulated and safe driving behavior. case study: Bus driver in Indonesia. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2019; Volume 508, p. 012011.
21. Hassold, S.; Ceder, A.A. Public transport vehicle scheduling featuring multiple vehicle types. *Transp. Res. Part B: Methodol.* **2014**, *67*, 129–143. [CrossRef]
22. Tóth, A.; Krész, M. An efficient solution approach for real-world driver scheduling problems in urban bus transportation. *Cent. Eur. J. Oper. Res.* **2013**, *21*, 75–94. [CrossRef]
23. Zhou, J.; Luo, X.; Huang, Q.; Wei, Q. Research on Minimum Bus Headways Calculating Model Based on Solving High-Frequency of Bus Operation. *J. Chongqing Jiaotong Univ. Nat. Sci. Ed.* **2012**, *31*, 836–841.
24. Liang, J. Research on Bus Intelligent Scheduling Method Based on Genetic Algorithm. Master's Thesis, Lanzhou University of Technology, Lanzhou, China, 2010.
25. Xiao, Q. Research on Bus Driving Plan Based on GPS Data. Master's Thesis, Beijing Jiaotong University, Beijing, China, 2009.
26. Wu, Y.; Tang, J.; Yu, Y.; Pan, Z. A stochastic optimization model for transit network timetable design to mitigate the randomness of traveling time by adding slack time. *Transp. Res. Part C* **2015**, *52*, 15–31. [CrossRef]
27. Vuchic, V.R. Skip-Stop Operation as a Method for Transit Speed Increase. *Traffic Q.* **1973**, *27*, 307–327.
28. Ercolano, J. Limited-Stop Bus Operation: An Evaluation. *Transp. Res. Rec.* **1984**, 24–29.
29. Xu, X.; Xu, D.; Ma, H. Deadheading Scheduling Model in Public Transportation Scheduling. *Comput. Commun.* **2003**, *21*, 19–21.
30. Liu, M. Research on the Reliability of Urban Public Transportation Service Based on the Strategy of the Station. Master's Thesis, Beijing University of Posts and Telecommunications, Beijing, China, 2012.
31. Huang, J.; Zhang, G. Study on the Real-time Deadheading in Transit. *Syst. Eng. Theory Pract.* **2001**, *3*, 107–111.
32. Li, X. Study on Vehicle Dispatching Optimization Model of Bus Lines. Master's Thesis, Huazhong University of Science and Technology, Wuhan, China, 2007.
33. Sun, C. Research on Optimization of Bus Rapid Transit. Ph.D. Thesis, Chang'an University, Xi'an, China, 2008.
34. Fu, L.; Liu, Q.; Calamai, P. Real-Time Optimization Model for Dynamic Scheduling of Transit Operation. *Transp. Res. Rec. J. Transp. Res. Board* **2003**. [CrossRef]
35. Boyle, D.K.; Pappas, J.; Boyle, P.; Nelson, B.; Sharfarz, D.; Benn, H. Controlling System Costs: Basic and Advanced Scheduling Manuals and Contemporary Issues in Transit Scheduling. *Tcrp Rep.* **2009**, *135*, 409.
36. Bartholdi, J.J., III; Eisenstein, D.D. A self-coordinating bus route to resist bus bunching. *Transp. Res. Part B* **2012**, *46*, 481–491. [CrossRef]
37. Daganzo, C.F.; Pilachowski, J. Reducing bunching with bus-to-bus cooperation. *Transp. Res. Part B Methodol.* **2011**, *45*, 267–277. [CrossRef]
38. Zimmermann, L.; Kraus, W., Jr.; Koehler, L.A.; Camponogara, E. Holding Control of Bus Bunching without Explicit Service Headways. *IFAC-Pap. Online* **2016**, *49*, 209–214. [CrossRef]
39. Yu, B.; Yang, Z. A dynamic holding strategy in public transit systems with real-time information. *Appl. Intell.* **2009**, *31*, 69–80. [CrossRef]
40. Zhang, S. Optimization of Conventional Public Transportation System Based on Impact Threshold of Headway Time Stability. Master's Thesis, Chang'an University, Xi'an, China, 2014.
41. Chen, Q.; Adida, E.; Lin, J. Implementation of an iterative headway-based bus holding strategy with real-time information. *Public Transp.* **2013**, *4*, 165–186. [CrossRef]
42. Berrebi, S.J.; Watkins, K.E.; Laval, J.A. A real-time bus dispatching policy to minimize passenger wait on a high frequency route. *Transp. Res. Part B Methodol.* **2015**, *81*, 377–389. [CrossRef]
43. Lizana, P.; Munoz, J.C.; Giesen, R.; Delgado, F. Bus Control Strategy Application: Case Study of Santiago Transit System. *Procedia Comput. Sci.* **2014**, *32*, 397–404. [CrossRef]
44. Han, G. Research on Optimization Model of Bus Operation Scheduling Based on GPS. Master's Thesis, Southwest Jiaotong University, Chengdu, China, 2010.
45. He, S.X. An anti-bunching strategy to improve bus schedule and headway reliability by making use of the available accurate information. *Comput. Ind. Eng.* **2015**, *85*, 17–32. [CrossRef]

46. Estrada, M.; Mensión, J.; Aymamí, J.M.; Torres, L. Bus control strategies in corridors with signalized intersections. *Transp. Res. Part C* **2016**, *71*, 500–520. [CrossRef]
47. Wu, J.; Wang, Y.; Wei, M.; Lin, B. Impact of length of road-side bus lane on bus operational reliability. *J. Jilin Univ. (Eng. Technol. Ed.)* **2017**, *47*, 82–91.
48. Janos, M.; Furth, P. Bus Priority with Highly Interruptible Traffic Signal Control: Simulation of San Juan's Avenida Ponce de Leon. *Transp. Res. Rec. J. Transp. Res. Board* **2002**, *1811*, 157–165. [CrossRef]
49. Head, L.; Gettman, D.; Wei, Z. Decision Model for Priority Control of Traffic Signals. *Transp. Res. Board Natl. Acad.* **2006**, *1978*, 169–177. [CrossRef]
50. Yu, H.; Chen, D.; Wu, Z.; Ma, X.; Wang, Y. Headway-based bus bunching prediction using transit smart card data. *Transp. Res. Part C* **2016**, *72*, 45–59. [CrossRef]
51. Xia, Y. Research on Rational Allocation Method of Urban Bus Line Capacity. Master's Thesis, Southeast University, Nanjing, China, 2006.
52. Shi, Y. Research on the Influencing Factors and Improvement Measures of Multi-Line Bus Series. Master's Thesis, Tongji University, Shanghai, China, 2017.
53. Fu, L.; Yang, X. Design and Implementation of Bus-Holding Control Strategies with Real-Time Information. *Transp. Res. Rec. J. Transp. Res. Board* **2002**, *1791*, 6–12. [CrossRef]
54. Lin, G.; Liang, P.; Shonfield, P.; Larson, R. *Adaptive Control of Transit Operations*; Report No. FTA-MD-26-7002; U.S. Department of Transportation: Washington, DC, USA, 1995.
55. Wu, W.; Liu, R.; Jin, W. Modelling bus bunching and holding control with vehicle overtaking and distributed passenger boarding behavior. *Transp. Res. Part B Methodol.* **2017**, *104*, 175–197. [CrossRef]