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Research Article

A Two-Lane Cellular Automaton Model to Evaluate the Bus Lane with Intermittent Priority

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Bus lanes with intermittent priority (BLIPs) are lanes where general traffic is required to give way to approaching buses. BLIPs can improve the reliability of bus services and help maximize the use of road resources. It can be seen as an innovative sharing mobility, such as carsharing, carpooling, and lane sharing. However, implementation of BLIPs has never been feasible until vehicle communications could accommodate the idea. Vehicle-to-vehicle (V2V) communications have broad application prospects in the deployment of BLIPs. This paper develops a two-lane cellular automaton (CA) model to simulate BLIPs and assesses the benefits of connected vehicles for bus operation. In the model, lane-changings are asymmetric with an improved mandatory BLIP lane-changing rule underlying. The effects of BLIPs are explored through numerical simulations, including BLIPs' impacts on neighboring lanes, travel time saving, fuel consumption, and the punctuality rate of buses. Analysis of traffic flow characteristics of corridors using BLIPs reveals that there is a strong connection among the bus departure interval, clear distance, and road capacity.

1. Introduction

The rate of motorization has outpaced the development of the carrying capacity of urban roads. Traffic congestion causes delays for buses operating in mixed traffic lanes and reduces the attractiveness of buses. Although dedicated bus lanes provide right-of-way to vehicles, they also cause a reduction in private vehicle capacity.

Viegas and Lu [1] firstly introduced a bus priority method named the intermittent bus lane (IBL). IBL utilizes real-time information on bus locations and variable message signs (VMSs) on the road to switch the bus lane status between closed and open based on predicted bus arrival times. The system receives the alert from an oncoming bus

and issues a command to switch the lane from a regular lane to a temporary bus lane, while the indicator transmits the lane information to the regular vehicle. When the IBL indicator signals a temporary change in lane status, vehicles in the lane and the arriving bus have the right-of-way, and other vehicles are prohibited from entering. In the process, bus travel time would be reduced, resulting in increased delays in traffic.

To reduce the negative effects of the IBL, Eichler [2] developed a new strategy which is a bus lane with intermittent priority (BLIP). BLIP is reserved for buses, and private vehicles are admitted to enter the lane, although, requires that general vehicles leave the lane when buses are in demand. Flexibility in time and distance is a characteristic

of BLIP, and infrastructure requirements include overhead signs, pavement lights, and bus detection. The original BLIP concept was based on road segments and used variable message signs (VMSs) to provide information on vehicle rights-of-way. The road network geometry and intersection locations determine the length of each road segment [3–6]. If a bus is detected to be moving in the lane, the road segment of BLIP will continue to change to a bus lane one by one. Once the bus passed, the segment will be available to general purpose traffic until the system issues a command again. It provides a compromise between dedicated bus lanes and buses operating in mixed traffic lanes. It provides a trade-off between bus priority and the delay suffered by general traffic.

This study investigates the implementation of BLIPs using connected vehicles. Vehicle-to-Vehicle (V2V) communications provide the necessary means for signaling the presence of an approaching bus to general traffic. Using a numerical simulation, the positive effects of operating BLIP under a connected vehicle environment can be quantified.

2. Literature Review

The implementation of BLIP has been studied in recent research. Eichler and Daganzo [2, 7] study the feasibility, impacts, and benefits of BLIPs using kinematic wave theory. Although BLIP increases the average traffic density and traffic delay, it would not significantly reduce total road capacity. If the traffic volume does not exceed the road capacity of nonBLIP lanes, these delays are more than offset the advantages to public transport travelers. Xie and Leclercq [8] focus on the activation phase of the BLIP strategy also using the kinematic wave model. This research shows that BLIP's activation reduces the capacity and increases the travel time of buses. A simulation by the U.S. Dept. Of Transportation sets two segments in front of the bus as dedicated and off-limits to general purpose traffic. Simulation results indicate that BLIP reduces bus travel time by 14% and improves reliability by 28% [9].

For segment-based BLIP, private cars are restricted from using the lane in the whole segment. Since each roadway segment may not be equal in length, this may cause unequal benefits of BLIP depending on the segment. On one hand, there is a significant loss of road capacity for a long segment; on the other hand, the segment of insufficient length may weaken the effect of clearing general traffic out of the BLIP lane. There would be better performance if general traffic that is following the bus could occupy the BLIP. In light of this, Wu et al. [10] proposed that a connected vehicles environment with frequent information interaction is conducive to BLIP. In connected vehicle environments, all vehicles are assumed to have V2V communication technologies to support car following and lane changing decisions. Vehicles that are both in front of and behind the target bus can better use the BLIP lane. Furthermore, a unified clear distance (dynamic moving segment) for general traffic could be set with minimum road capacity loss.

In a connected vehicle environment, existing studies have explored the implementation of forced lane change rules underlying the CV-based BLIP strategy. A microsimulation analysis shows CV-based BLIP could result in up to 32% benefit compared with a dedicated bus lane [3, 10] in arterial. Recommended clear distance is between 300 and 500 meters. In addition, BLIP implementation is not recommended under a certain saturation degree. Three-lane cellular automaton (CA) models are proposed to evaluate the positive effects of BLIP operation [3, 11]. Research results reveal strong connections among bus departure intervals, clear distance, and road capacity. Lane change behaviors, lane usage, and road capacity loss are investigated by these CA models. The recommended traffic density is between 30 and 90 pcu/km, the recommended clear distance is between 30 and 90 meters and the lower threshold of bus departure interval is 90 seconds.

Although the benefits and impacts of BLIP are investigated in recent research [2, 3, 9–14], a paucity of research considers BLIP under connected vehicle environments. Even if setting conditions have been pointed out by the literature, they are mainly focusing on three-lane or four-lane models. Few works have been dedicated to investigating the performance of BLIP under two-lane arterials. Since there is no implementation of BLIP in the real world, the only similar application is IBL in Lisbon, Portugal in 2005–2006, which is exactly with two lanes. The preliminary conclusion of the case is that IBL will bring a 20% improvement in average bus speed, giving no signal priority at downstream intersections. Especially, during peak traffic congestion, the improvement effect is 50% [15]. Therefore, the benefits of BLIP under two lanes should not be ignored. Furthermore, there is no research paper has studied the advantage of bus fuel saving and bus punctuality rate of BLIPs. In order to fill this gap, this paper develops a two-lane CA model to explore the benefits and impacts of BLIPs.

3. Model

CA models have been widely exploited to simulate various traffic flow scenarios and also have been equal to kinematic waves in traffic flow [7]. The CA model is a powerful tool for characterizing macroscopic and microscopic traffic flows.

The CA model was originally adopted to simulate traffic in a single lane by Kai and Schreckenberg [16], and extended to a two-lane model with a stochastic lane change rule by Rickert et al. [17] and Chowdhury et al. [18]. Daoudia and Moussa (2003) developed an asymmetric lane change rule for the CA model. Nai et al. [19], Qian and Wang [20]; and Luo et al. [21] explored mixed private and public traffic flows using CA models. Research studies have also investigated bus priority strategies by constructing CA models [3, 11, 22, 23]. These studies indicate that the CA model can efficiently characterize some traffic flow phenomena occurring in multilane and mixed traffic flow scenarios for their fast performance. Based on the advantages of CA models, this paper proposes a two-lane CA model underlying the asymmetric lane changing rule to investigate the impact of BLIP on urban traffic flow in connected environments.

3.1. Model Definition. This model is under open boundary conditions, so a private car or bus can only be generated with a certain probability at the left head of the cells chain and can
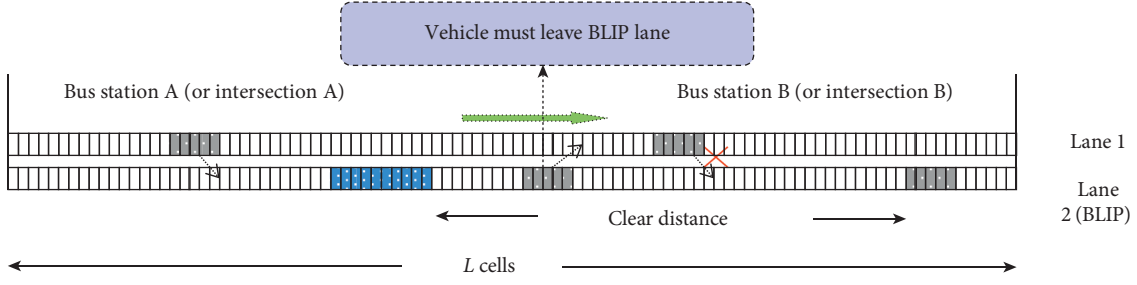
FIGURE 1: Diagram of double-lane traffic using BLIP.

TABLE 1: Summary of the variables and parameters used in the model definition.

Variables and parameters	Description
x_i^j	Coordinate of vehicle. i and j are the index of vehicle and operating lane, respectively
v_i^j	Speed of vehicle. i and j are the index of vehicle and operating lane, respectively
gap_i^j	Available zones in front of vehicle. i and j are the index of vehicle and operating lane, respectively
$gap - front_i^k$	Available zones in front of vehicle. i and k are the index of vehicle and original lane, respectively
$gap - rear_i^k$	Available zones rear of vehicle. i and k are the index of vehicle and target lane, respectively
gap_{safety}	Safety zones for a vehicle
l_{cd}	Length of clear distance
l_i^j	Length of vehicle. i and j are the index of vehicle and operating lane, respectively
v_{max}^c	Maximum speed of private cars
v_{max}^b	Maximum speed of buses
p_{in}	Probability of vehicles generation.
p_{out}	Probability of vehicles removement
p_{rand}	Randomization probability
p	Advancing probability
$C_{passenger}$	Capacity of passenger
t_{depart}	Departure time interval of bus
L	Cells number of each lane

only be removed from the right end of the cells chain with another certain probability [24]. Hence, it is more similar to real urban traffic compared to the periodical boundary CA model and more convenient to set bus departure intervals. Bus stations are generally located near intersections, and buses can use the red-light time to stop. BLIP can be regarded as a significant component in traffic flow in urban areas. Therefore, studies suggest that bus stations and intersections should be considered in the model [21, 23].

The simulation is conducted on two one-dimensional cells chain with L cells, and one cell represents only one private cars or bus at a time (Figure 1). The two cells chains represent two parallel one-way lanes of the hypothetical BLIP system, respectively. In previous CA models, the cell size is 7,5 meters. Evidence suggests that reducing the cell size can more accurately represent the physical features of vehicle movements [25, 26]. In this paper, cells represent a series of 1.5 meters road divisions. The model simulates general purposed traffic and public traffic. For regular cars, the maximum speed is $v_{max}^c = 15$ cell/s ($\approx$81 km/h) and is represented by five cells, which are $v_{max}^b = 10$ cell/s ($\approx$54 km/h) and ten cells for buses. The clear distance ahead of buses can be defined as 150 m, 300 m, 450 m, and 600 m. One time-step corresponds to one second in the real world. The significant variables and parameters are summarized in Table 1.

3.2. Vehicle Movement Rules. Figure 2 describes vehicles' generate and eliminate rules in one time step. If it is empty at the first few cells of each lane and $p \leq p_{in}$, a new vehicle would be generated at the left boundary of the lane and runs forward at maximum speed. If $p > p_{in}$ or the leftmost cells are occupied by another vehicle, the vehicle would not be created. When the vehicle appears at the right end of the cells chain, the elimination mechanism will be triggered: if $p \leq p_{out}$, the vehicle should be removed; otherwise, the vehicle remains its location and it can not pass the right boundary. The parameters p_{in} and p_{out} are used to set traffic flow from the upstream intersection and congestion saturation at the downstream intersection especially, a generate and eliminate procedure in a time interval is as follows: the two ends of the BLIP are the upstream intersection A. And, the downstream intersection B, respectively, when bus i departs from upstream bus intersection A, the bus will be generated at the left of BLIP lane; when the bus i arrives at bus intersection B, it is removed from the system (if $p \leq p_{out}$). Buses are only allowed to utilize the BLIP (right) lane, and lane changes of buses are prohibited.

In the CA model, gap_i^j is available cells number in front of a certain vehicle. Given the vehicle's coordinate x_i^j and the length of the vehicle l_i^j then the available zones in front of the vehicle is $gap_i^j = x_{i+1}^j - x_i^j - l_{i+1}^j$. Available zones illustrate
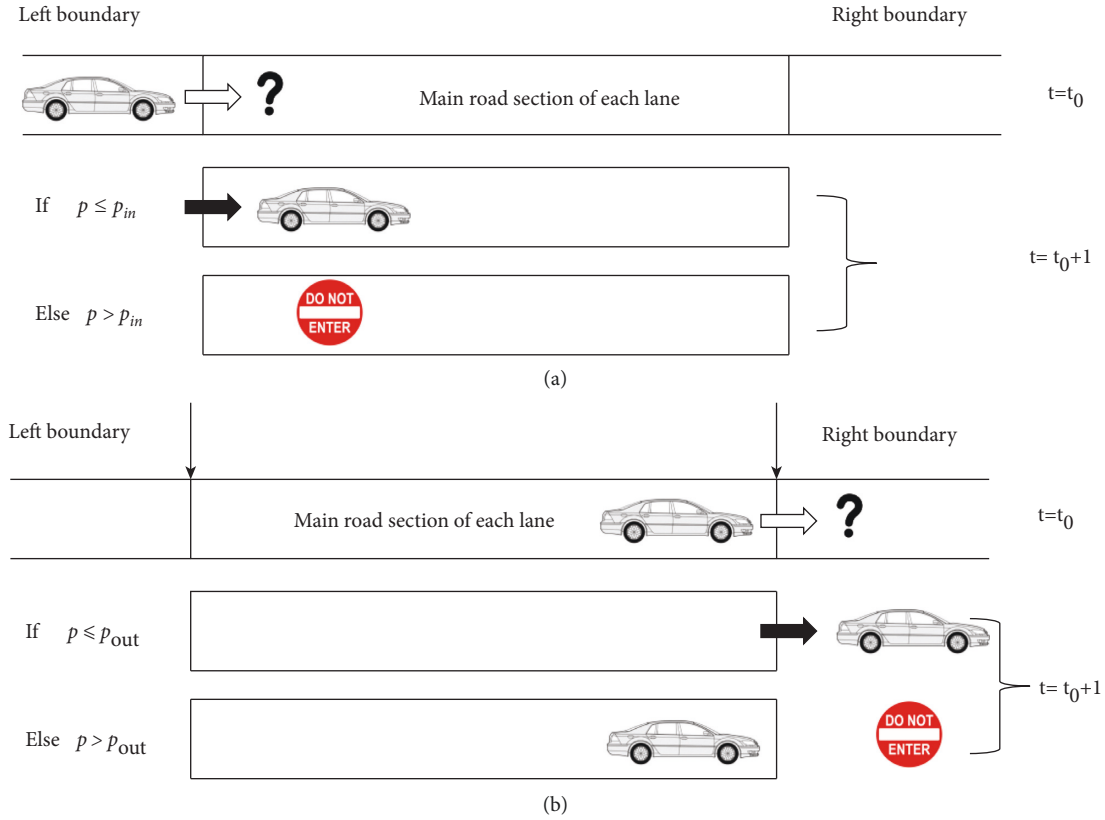
FIGURE 2: Vehicle movements rules. (a) Vehicle movements at the left boundary. (b) Vehicle movements at the right boundary.

the progress of vehicles in simulation. The randomization parameter p_{rand} is 0.25. Vehicles movements updated in each discrete time step should strictly conform to the following four rules:

(1) Acceleration: if vehicle i is traveling in lane j under its maximum speed (v^c_{max} or v^b_{max}), and there is enough free space ahead ($v^j_i < gap^j_i - 1$), the vehicle will increase speed by 1 cell/s (≈ 5.4 km/h), i.e.,

If $v^j_i < gap^j_i - 1$, then $v^j_i = \min[v^c_{max}, v^j_i + 1]$ or $v^j_i = \min[v^b_{max}, v^j_i + 1]$

(2) Deceleration: if vehicle i is unable to maintain a safe distance from the vehicle in front of it ($v^j_i \geq gap^j_i + 1$), vehicle i will be reduced to gap^j_i, i.e.,

If $v^j_i \geq gap^j_i + 1$, then $v^j_i = gap^j_i$

(3) Randomization: for a more realistic simulation of vehicle driving, if the speed is great than zero, it will be reduced by 1 cell/s (≈ 5.4 km/h) with the probability p_{rand}, i.e.,

Given p_{rand}: $v^j_i = \max[v^j_i - 1, 0]$

(4) Coordinate update: each vehicle moves v^j_i cells forward at each time step

3.3. BLIP Lane Changing Rule. Once one vehicle enters the clear distance in front of a bus, it has to change and leave the current lane. Hence, a special asymmetric lane change rule is set for general traffic.

As illustrated in Figure 1, private cars in the left lane are prohibited from moving into the right lane if they would enter the clear section in the temporary bus lane after their lane change. This provides more available spaces for cars merging from the BILP. Private cars in clear segments are then encouraged to exit the temporary bus lane when they satisfy the lane changing criteria. In the premise of safety, the principle of the private car immediately drive away is described in the following:

If $gap - front^k_i \geq gap_{safety}$ and $gap - rear^k_i \geq \min[v^c_{max}, v^j_{i+1} + 1] - \min[v^c_{max}, v^k_{i+1} + 1] + gap_{safety}$

then private car i leaves1 lane j to enter lanes k

Private cars on the BLIP lane out of clear segments are exempt from the mandatory lane changing rule.

4. Numerical Simulations

In this section, simulations of urban roads are performed based on the proposed CA model. The main road includes 1600 cells (2400 meters). We generate one vehicle at the left head of each cell chains as input to the CA model with probability p_{in} ($0 \leq p_{in} \leq 1$), and initialize the input variables as follows: $t_{depart} = 60$ s, $l_{c\ d} = 300$ m, $p_{rand} = 0.25$, $p_{in} = 1$, $p_{out} = 0.7$ [3, 11]. We performed two groups of numerical simulations for a normal urban double-lane road without the implementation of bus priority and BLIP (Group A), and an urban double-lane road with BLIP (Group B).
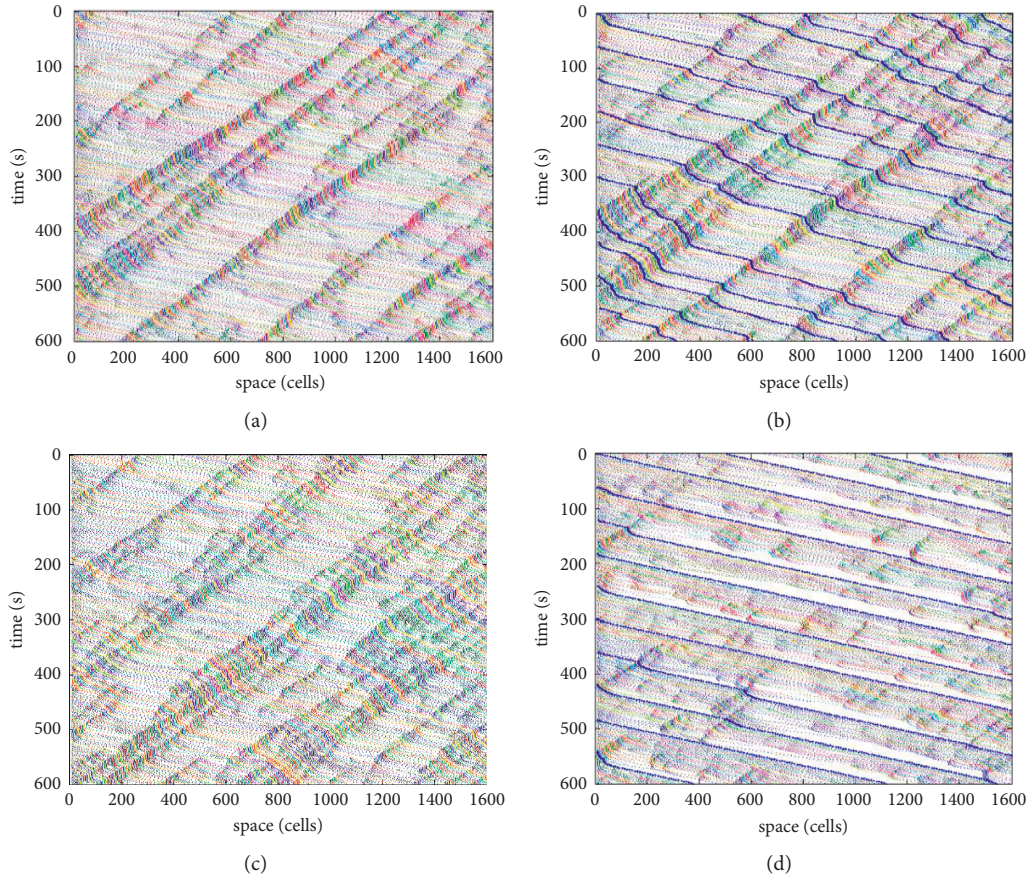
FIGURE 3: Time-space distributions. (a) Time-space distribution of the left lane in Group A. (b) Time-space distribution of the right lane in Group A. (c) Time-space distribution of the left lane in Group B. (d) Time-space distribution of the right lane in Group B.

To analyze the functions of BLIP, six aspects are explored: time-space distributions, average travel time, average speed, fuel consumption, bus punctuality, and passenger capacity.

4.1. Time-Space Distributions. Figure 3 is the time-space distributions of traffic flow of the right lane under both Group A and Group B. The blue lines in Figures 3(b) and 3(d) represent the trajectory of buses.

Figure 3(b) illustrates that in Group A, the rear vehicle will choose to follow the bus or change lanes and overtake the bus. This may lead to congestion in downstream which reduces the bus speed. This problem is significantly solved by introducing the BLIP strategy. Private cars in the clear segment in front of the bus are dispersed away from the BILIP lane (Figure 3(d)). This leads to a vacuum in front of the bus and a significantly lower traffic density of the BILP.

Therefore, in Group B, the headway of the two buses is more consistent with their departure intervals after introducing the BLIP strategy. This results in more consistent high speeds, better fuel efficiency, and shorter delays for buses.

However, the mandatory lane change leads to more complex merging behaviors in the right lane. It may also induce greater traffic density and more disturbance in the left lane (Figure 3(c)).

The simulation results (Figure 4) additionally show that in Group B, the vehicle density in the left lane expands by at least 15%, with the most extreme increase being 25%, due to the forced lane change criterion. Comparatively, the vehicle density in the right lane diminishes by at least 16%, with the most extreme decrease being half.

4.2. Average Travel Time. The BLIP strategy is developed to mainly ensure the stability of the bus (Figure 5). Lane changing of general traffic flow disturb bus traffic, increasing the number of brakes and travel time. Here, the stability is measured by the average travel time given different traffic densities. As presented in Figure 5, when the density $\rho < 0.3$, the traffic flow can be considered as a free flow which is the same between the travel time of Group A and Group B. Given $0.3 \leq \rho \leq 1$, in the Group B scenario, the bus performs better in terms of average travel time even during the peak period. BLIP strategy decreases bus travel time by providing buses with a dedicated bus lane temporarily. The average bus travel time is reduced by more than 25% given $0.5 \leq \rho \leq 0.8$.

As presented in Figure 6, the average car travel time is very close in both lanes in Group A, but it differs in Group B. The average car travel time of lane 2 is less than the average car travel time of lane 1 when the traffic density $\rho \geq 0.3$. The average car travel time of lane 2 in Group B

(a)   (b)
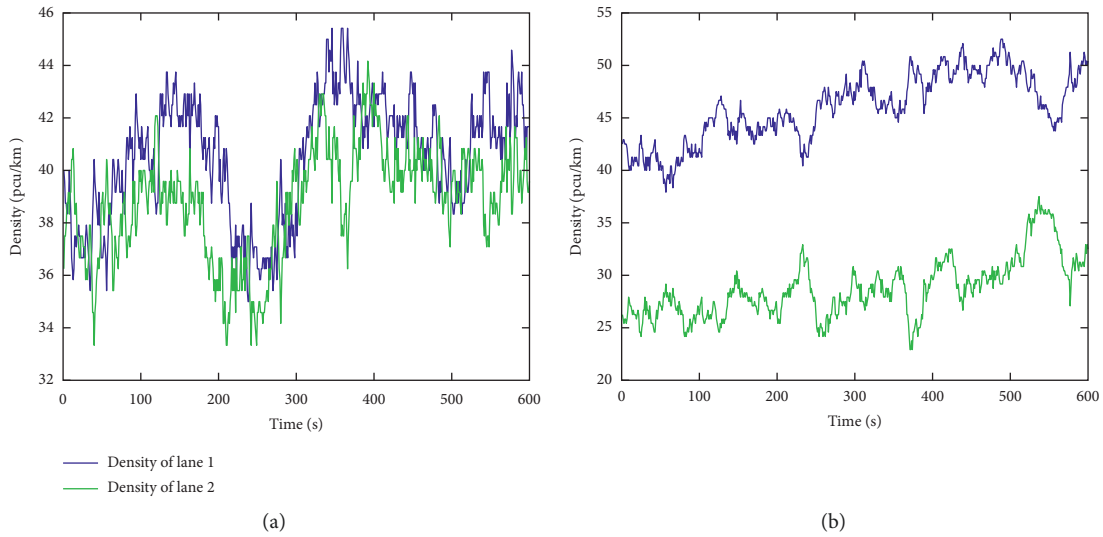
Figure 4: (a) Traffic density of two lanes in Group A. (b) Traffic density of two lanes in Group B.
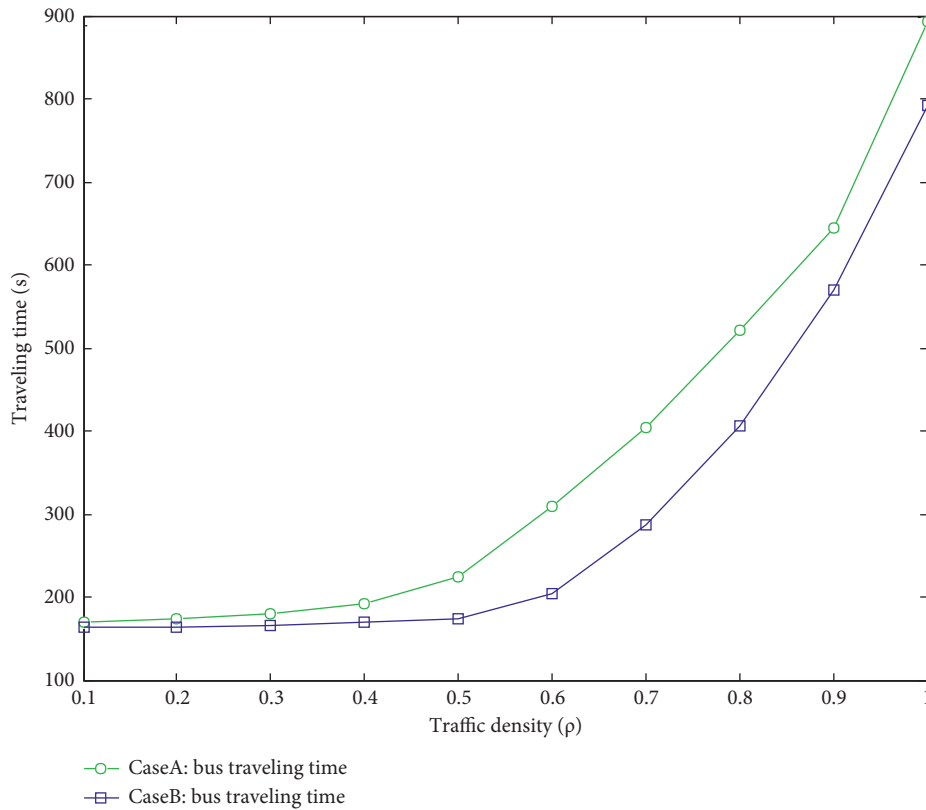

Figure 5: Average bus travel time in Group A and Group B given traffic density.

performs better than that of Group A due to reduced traffic density. Overall, private cars in Group B have an average 13% lower travel time on lane 2.

4.3. Average Speed Distributions. This section discusses the impact of the average speed by the BLIP strategy, with the same input variables as in Section 4.1. Figure 7 shows that there is no significant difference in the range of average

speed between lanes if BLIP is not implemented. Buses in groups A and B use only lane 2. Before introducing the BLIP strategy, normal vehicles will make lane changes to obtain higher speeds, which is the reason why the average speeds of the two lanes are similar. In Group B, the average speed of the BLIP lane increased by 50% compared to Group A. When a bus passes, the average speeds on the BLIP lane and the regular lane reach their peaks and troughs simultaneously, respectively. In addition, numerical simulations
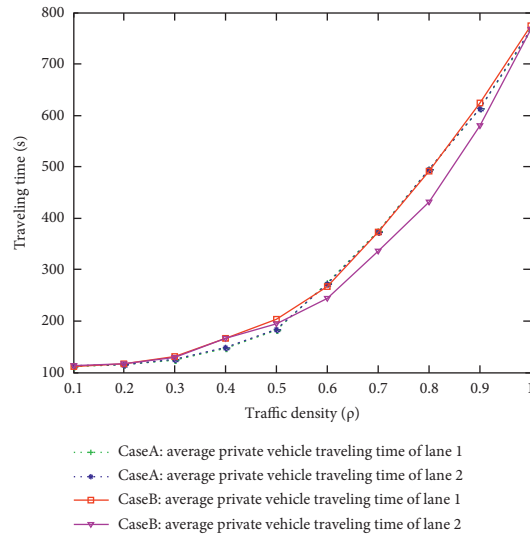
Figure 6: Average car travel time in Group A and Group B given traffic density.
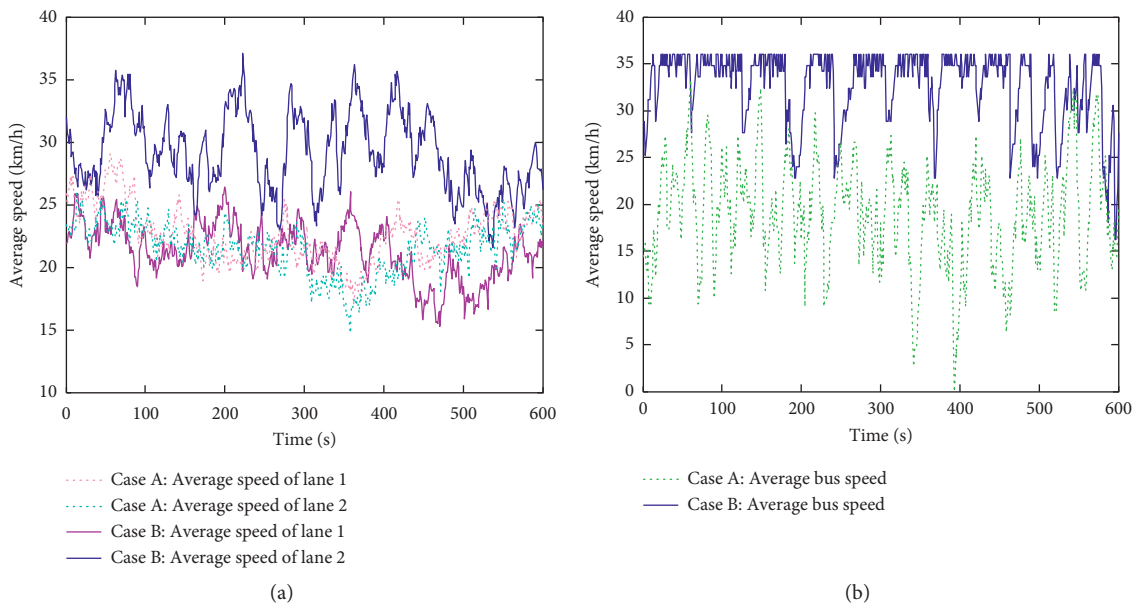

(a)

(b)

Figure 7: Average speed distributions of Group A and Group B.

indicate that the BLIP strategy enables buses to show outstanding speed performance even at high traffic flow density. BLIP gives higher priority to buses, therefore the average speed of buses on lane 2 is higher. At the same time, the BLIP strategy provides a clear segment for the bus in front, which results in a lower Lane2 flow density and achieves a higher average speed.

Figure 7(b) shows that the average bus speed fluctuation is more severe in Group A than in Group B. The histogram shown in Figure 8 further demonstrates this phenomenon. The skewed and centralized distribution of average speed and high average speed provide passengers with a smooth experience, increases the fuel efficiency of the bus high, and improves the quality of bus service.

4.4. Fuel Consumption. The strong correlation between fuel consumption and average speed has been demonstrated by the Clean Urban Transport in Europe (CUTE) project [27]. The discussion of the fuel consumption of buses in this section is based on setting the maximum speed as 7.72 cell/s and the minimum speed as 1.05 cell/s. Since BLIP can increase the average bus speed, which will certainly affect the bus fuel consumption. Here, we define y (average fuel consumption, liter diesel equivalents per 100 km) as a function of x (average bus speed, km per hour). Figure 9 shows the correlation between bus fuel consumption and average bus speed [27, 28]. The maximum and minimum values of speed are fixed and therefore the maximum and minimum values of fuel consumption are fixed. The lower
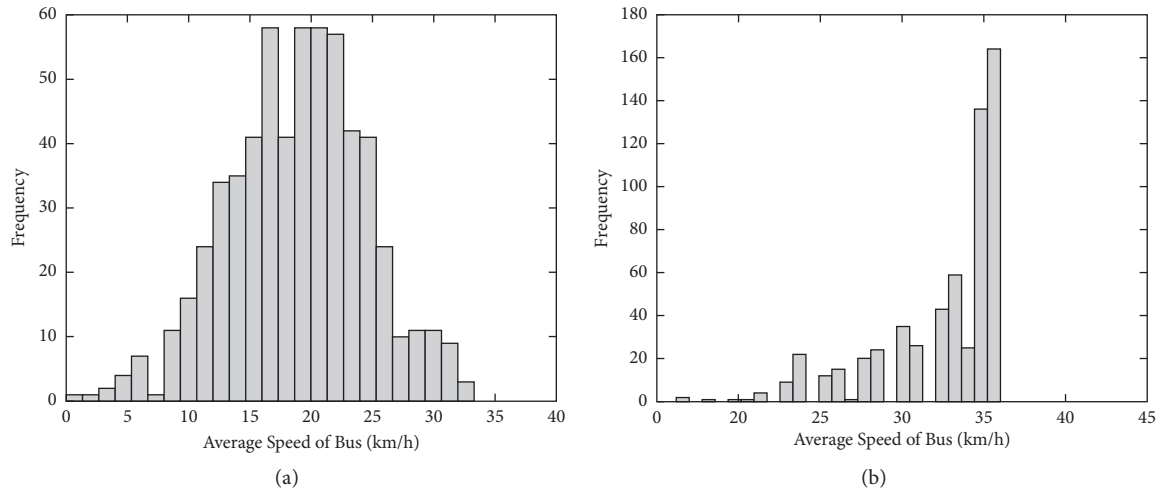
(a)

(b)

FIGURE 8: Histograms of average bus speed. (a) Histograms of average bus speed in Group A. (b) Histograms of average bus speed in Group B.
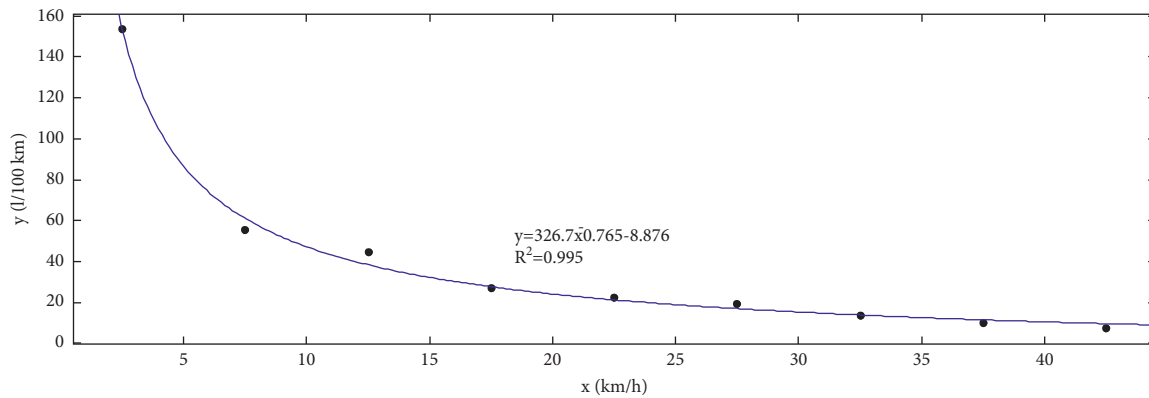

FIGURE 9: The correlation between average bus fuel consumption and average bus speed.

the average bus speed, the greater the fuel consumption [27–34]. We use the results of Li [35] on the relationship between fuel consumption and speed:

$$y = 326.7x^{-0.765} - 8.876,$$
$$R^2 = 0.995. \tag{1}$$

In this study, function (1) is used in the CA model to evaluate fuel consumption in both cases. Figures 10 and 11 and Table 2 investigate the average bus instantaneous fuel consumption in Group A and Group B. As shown in Figure 10(a), due to frequent acceleration and deceleration of buses, bus instantaneous fuel consumption changes dramatically. The maximum average bus fuel consumption is more than 77 liters/100 km. According to the cumulative curve in Figure 11(a), about 80% of the average bus fuel consumption exceeds 10 L/100 km, and close to 40% of the average bus fuel consumption is more than 20 L/100 km. The mean of average bus fuel consumption for Group A is 24.3034 L/100 km. Numerical simulations support that BLIP creates an excellent energy saving effect. The relatively stable high speed well ensures the bus has a smooth ride and high

fuel efficiency (Figure 10(b)). There are more than 60% of the average bus fuel consumption maintains at 10 L/100 km (Figure 11(b)). Besides, there are more than 20% of the average bus fuel consumption is only slightly larger than 10 L/100 km. The mean of the average bus fuel consumption is 11.8046 L/100 km and is less than half of which in Group A.

4.5. Bus Punctuality. Buses are operated on the basis of the scheduled timetable. Punctuality is the key criterion for timetable-based bus services, where passengers arrive at bus stops according to the scheduled time of bus departure. The improvement of punctuality can reduce bus delays and reduce average passenger waiting time. Figure 12 presents the travel time of each bus in Group A and Group B. It shows that the data of travel time in Group A are more discrete than which is in Group B. The fixed bus headway is disrupted by downstream traffic flow. And, this leads to the unequal travel time of each bus. It takes some buses more than 150 s to pass the road section. Meanwhile, it only takes some other buses slightly more than 80 s to pass the same road section. Table 3 further supports this view. The mean and median of bus
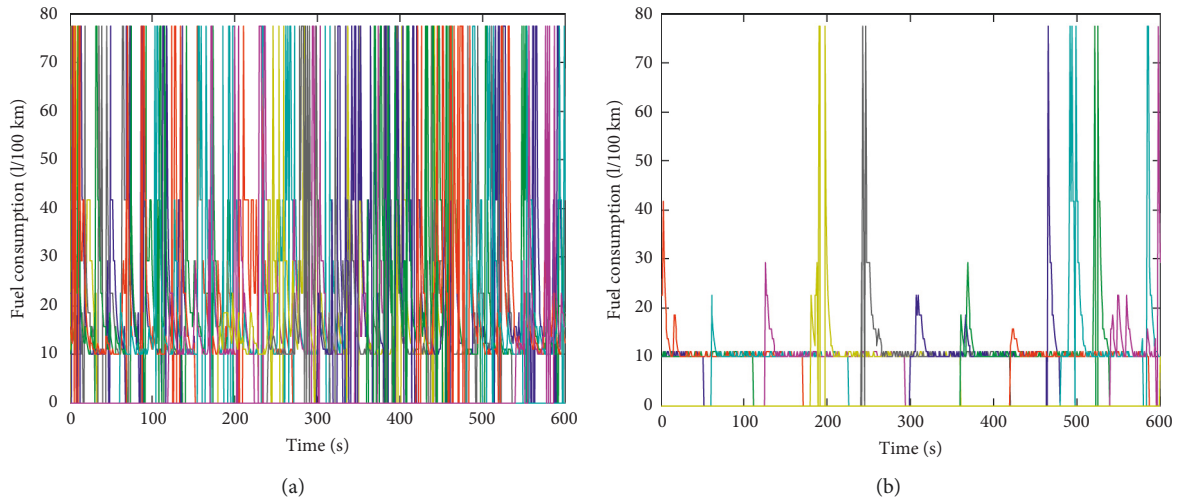
FIGURE 10: Average bus fuel consumption. (a) Average bus fuel consumption in Group A. (b) Average bus fuel consumption in Group B.
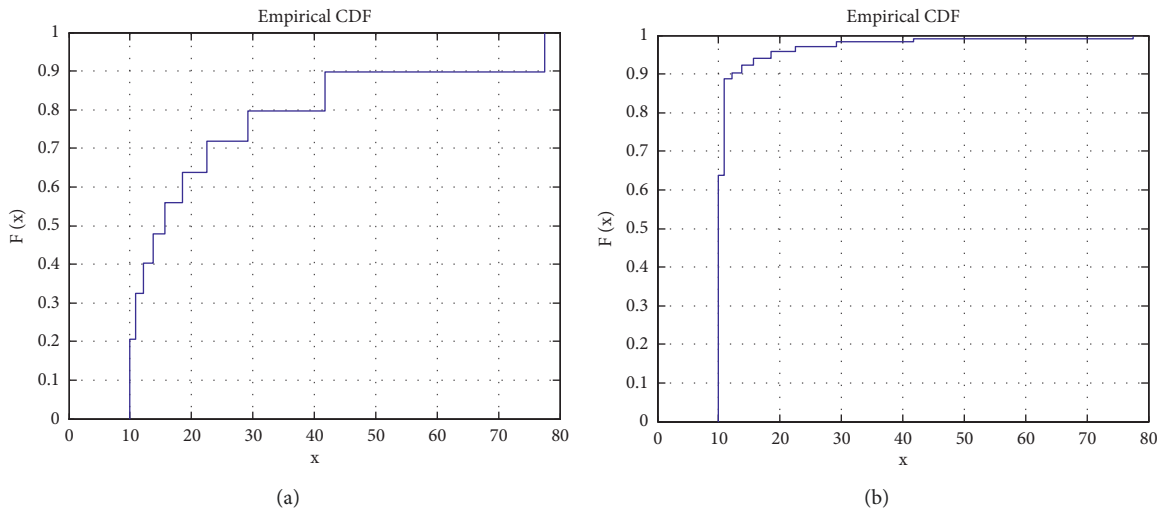

FIGURE 11: Cumulative curve of average bus fuel consumption. (a) Cumulative curve of average bus fuel consumption in Group A. (b) Cumulative curve of average bus fuel consumption in Group B.

TABLE 2: Average bus fuel consumption in Group A and Group B.

Fuel consumption	Min (L/100 km)	Max (L/100 km)	Mean (L/100 km)	Median (L/100 km)	Std
Group A	9.9535	77.5486	24.3034	15.6955	20.3969
Group B	9.9535	77.5486	11.8046	9.9535	7.3366

travel time in Group B is a bit less than which is in Group A. But the variance and mean square error of bus travel time in Group A are much greater than are in Group B. To explore the bus punctuality in both cases, the difference between bus arrival time and timetable is shown in Figure 13. Approximately 34.5% of the difference is less than 10 seconds and 75.9% of the difference is less than 29 seconds in Group A. In contrast, there are 67.85% the difference is less than 12 seconds and 93.2% of the difference is less than 23 seconds in Group B. It is clear that the BLIP could reduce the difference between bus arrival time and timetable and improve the reliability of bus operation.

4.6. Passenger Capacity. Buses Simulation above reveals that the BLIP has several benefits in travel time saving and fuel consumption saving. However, the challenge to this result arises from the fact that some studies have concluded that BLIP has a negative contribution to road capacity. Most of the existing studies believe that the BLIP reduces the road capacity for private cars while improving the stability and efficiency of bus operation [3, 8, 9, 11]. Hence, passenger capacity as another evaluation metric is used in this study. Passenger capacity means the number of passengers passing through a road section. To measure this indicator, average car occupancy is set to 1.3 passengers [36, 37], and average
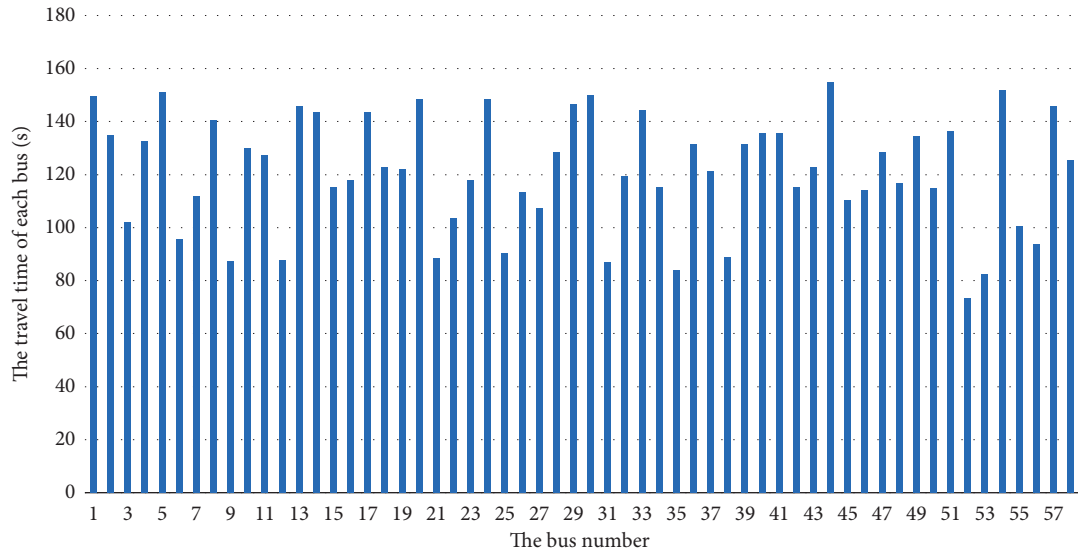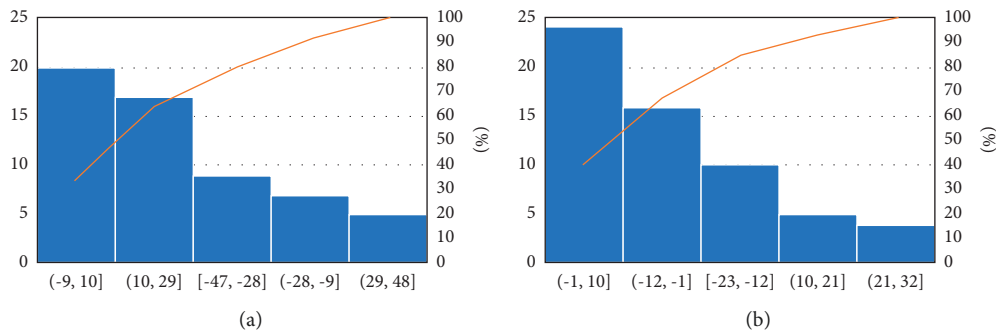
(a)
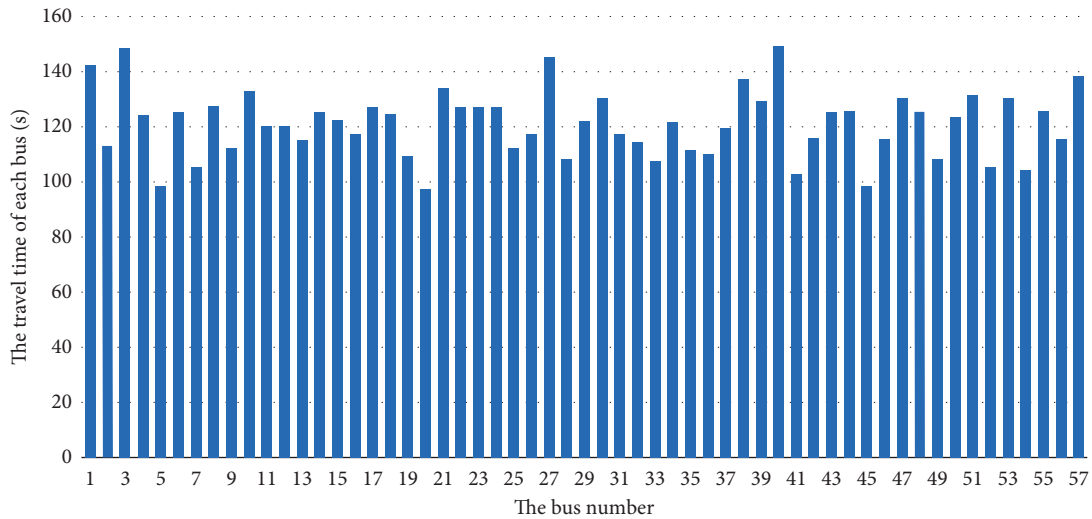
(b)

FIGURE 12: The travel time of each bus. (a) The travel time of each bus in Group A. (b) The travel time of each bus in Group B.

(a)

(b)

FIGURE 13: The difference between bus arrival time and timetable. (a) The difference between bus arrival time and timetable in Group A. (b) The difference between bus arrival time and timetable in Group B.

bus occupancy is set to 28 passengers [38, 39]. Initializing inputs for the variables as follows: $t_{depart} = 120$ s, $l_{cd} = 300$ m, $p_{rand} = 0.25$, $p_{in} = 1$, $p_{out} = 0.7$. Figure 14 displays the passenger capacity with different bus operation time in both cases. Despite the reduction of the car through the road section, the number of passengers traveling by car is

TABLE 3: The analysis of bus travel time in Group A and Group B.

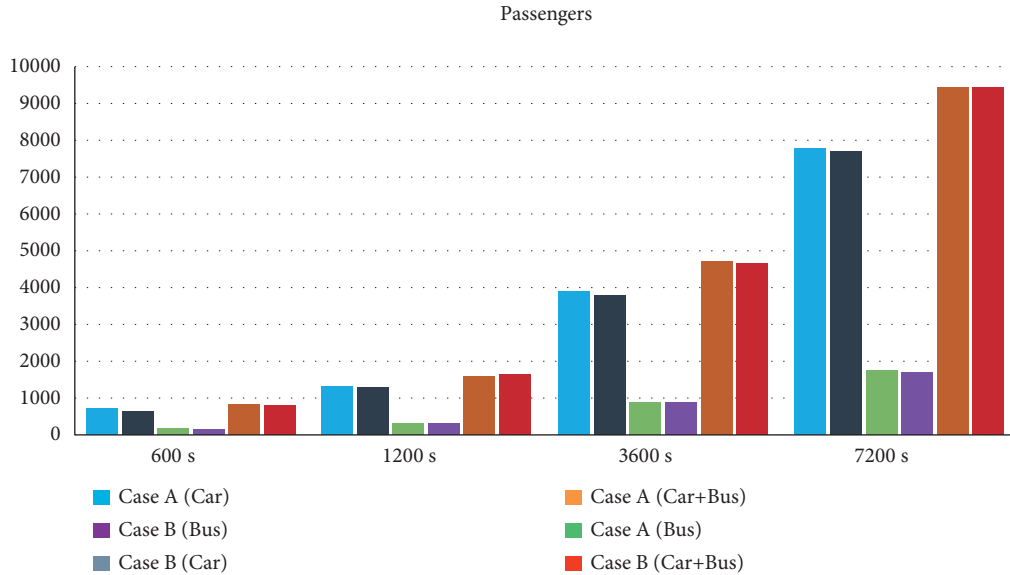| Mean	Median	Variance	Mean square error
121.069	122.5	464.6618	21.55602
120.7797	122	142.4851	11.93671

FIGURE 14: Passenger capacity in Group A and Group B.

reduced. But buses run on duty, and the total passenger capacity does not decrease significantly. In the long-term operation, the total passenger has risen slightly. It illustrates that the BLIP contributes to the improvement of passenger capacity in the long run.

5. Conclusion

This study concentrates on developing an evaluation framework for a double-lane V2V based BLIP system. The main contribution of this article is to evaluate the performance of BLIP under two-lane arterials and connected vehicle environments. A special asymmetric lane change rule for general traffic is set in the CA model to offer a temporary dedicated bus lane. The numerical simulation results show that both average bus speed and bus punctuality are significantly improved by BLIP. Average bus travel time saving is more than 25% at a certain traffic density range and fuel consumption saving is more than 50%. Although BLIP might slightly reduce the road capacity, it shows almost no negative impact on passenger capacity.

The proposed two-lane CA model can accurately and efficiently simulate the implementation of the BLIP strategy and the macroscopic and microscopic characteristics of traffic flow. This model can be further used to evaluate the effectiveness of more complex traffic control strategies. In an automated networked vehicle environment, the model represents specific traffic control strategies in terms of cellular update rules. Since the simulation of more complex control measures can be achieved by adjusting the update rules, the model can be used for more forward-looking studies related to traffic flow control.

Since self-driving and Cooperative Adaptive Cruise Control (CACC) vehicles are fast approaching the practical, the benefits of the BLIP strategy would be more remarkable. And, CACC based BLIP implementation would be easier. More extensive simulation numerical experiments will be conducted to assess the effectiveness of the proposed strategy considering CACC vehicles.

Data Availability

The electronic data used to support the findings of this study are currently under embargo while the research findings are commercialized. Requests for data, 12 months after publication of this article, will be considered by the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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