Simulation-based optimization of bus departure scheme for large airport considering passenger evacuation

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Abstract

Purpose – This study aims to optimize the traffic capacity allocation to solve the problem of low share of public transit in the landside system so as to get rid of the congestion trouble in landside traffic. The optimal timetable for airport buses can be searched by changing the departure interval of each line and evaluating the corresponding performance continuously.

Design/methodology/approach – This paper constructs a simulation model based on the real-world situation in Beijing Capital International Airport (BCIA), which simulates the whole process of airport bus schedules and analyzes the connections among multiple steps for transferring. The evaluation system is constructed by considering the benefits of passengers, airports and companies comprehensively. The optimal timetable for airport buses can be searched by changing the departure interval of each line and evaluating the corresponding performance continuously.

Findings – According to the experimental results, an excellent evacuation effect can only be achieved when the majority of departure intervals of airport buses are shortened to 50% of their original values, and some busy routes such as the Beijing Station line are supposed to be reduced to one-third of their original fixed intervals. As the airport bus passenger flow presents an obviously periodic variation over days, the timetable of the airport bus is supposed to be redesigned every day. A flexible bus timetable can not only meet the dynamic passenger flow but also enhance the attractiveness of public transit.

Originality/value – This paper constructs a simulation model based on the real-world situation in BCIA, which can not only model the complex scenes in the whole process of airport bus schedules but also reflect the intricate interaction between transferring passengers and vehicles caused by dense streamlines.

Keywords Passenger evacuation, Timetable, Landside, Transfer simulation, Airport shuttle bus

Paper type Research paper

1. Introduction

Air transportation, featured with flexibility, safety and comfort, has competitive advantages in long-distance travel (Song and Yang, 2006). Airport hubs are also crucial nodes

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connecting ground and air transportation. Recent years have seen the rapid growth of air passenger volume and the worsening congestion of landside traffic (Di *et al.*, 2019). The common issue, low share of public transit in the landside traffic system, troubles a series of international airports. According to the survey in 2019, the proportions of bus mode in Beijing Capital International Airport (BCIA), Guangzhou Baiyun International Airport and Shanghai Hongqiao International Airport in China are 36.3%, 40% and 49%, which are still far behind those of developed countries such as Tokyo Narita Airport (80%) and Incheon Airport in South Korea (64%). Because of the obvious gap concerning the split rate of bus, it is necessary to optimize the traffic capacity allocation so as to get rid of the congestion trouble in landside traffic (Di *et al.*, 2019).

The air passenger flow in large airport hubs always arrives densely with the characteristic of a surge, which is supposed to be evacuated in a short time (Chen *et al.*, 2020). The timetable optimization of airport buses can not only improve evacuation efficiency but also the travel experience of passengers leaving the airport. Most of the existing studies optimize the timetable of airport buses based on the theory of urban bus optimization. Wu and Ma (2022) built an airport bus timetable optimization model, considering the interests of passengers and the airport comprehensively. Aiming at reducing the schedule cost and passenger waiting time, Jia (2018) proposed a timetable optimization model integrating metro and airport buses. Lu *et al.* (2013) tried to capture the correlation between departure interval and the volume of passengers and constructed a timetable optimization model to maximize the profit of companies. Lu *et al.* (2016) formulated a bus schedule optimization model with the objective of maximizing the split rate of airport buses. Lia (2013) focused on the transfer efficiency of passengers leaving the airport and built a fuzzy bi-level and multiobjective model. Liu and Bao (2020) predicted the potential passenger flow based on taxi and riding-hailing data and designed a multiobjective optimization model to estimate the departure interval of airport bus, which is solved by an improved genetic algorithm. Salicrú *et al.* (2011) designed an algorithm aiming at searching for the optimal bus timetable with the objective of minimizing the travel time of passengers. Shi *et al.* (2022) considered the dynamics of passenger flow and built a bus timetable optimization model according to the volume in different periods. Zhou *et al.* (2012) aimed to minimize passenger travel time and formulated an airport bus schedule optimization model solved by a genetic algorithm.

In addition to establishing mathematical models to optimize airport bus timetable, the simulation methods for designing bus schedules have also attracted more and more attention from researchers. Liu and Zhang (2021) shortened the departure interval of one bus line to relieve station congestion and reduce transfer time, according to the analysis of the effect of the departure interval on transfer efficiency based on AnyLogic. Ni and Yang (2002) developed a simulation system to capture the characteristics of passenger flow using Visual C++6.0. Xing *et al.* (2021) built a simulation model for the operation time of airport buses. Liu *et al.* (2023) proposed a simulation-based optimization modeling framework. Yan and Ma (2020) designed a metro timetable coordination evaluation method for multi-line coupling states based on AnyLogic. However, most of the current simulation-based studies focus on airport metro instead of airport buses.

However, there remain limitations in the existing research. On the one hand, because of the strict constraints and model assumptions in model construction, there are always discrepancies between the situation modeled by mathematical models and reality in airport hubs with complex interactions between vehicles and passengers (Bian *et al.*, 2022), resulting in the optimized results that may not contribute to improve the reality. On the other hand, though simulation-based method, with the ability in simulating the complex situation in reality, is able to obtain apparent effects (Zou, 2010) and reliable results in an intuitive approach, most of simulation studies focus on the timetable optimization of airport metro instead of airport bus. Motivated by the above limitations and to overcome these problems, this paper constructs a simulation model based on the real-world situation in BCIA, which can not only model the complex scenes in the whole process of airport bus schedules but also reflect the intricate interaction between transferring passengers and vehicles caused by dense streamlines. Moreover, the optimal timetable of airport buses can be searched by changing the departure interval of each line and evaluating the corresponding performance continuously, which improves passenger waiting time, vehicle occupancy rate and evacuation efficiency of airport buses simultaneously. A case study of BCIA is conducted, and optimization suggestions are concluded, which are also references for timetable optimization of airport buses in other large-scale airports.

2. Analysis of airport buses in Beijing Capital International Airport

BCIA, as a mega airport, undertakes the important responsibility of international communication for the Beijing–Tianjin–Hebei region. The landside traffic system of BCIA is highly representative among airport hubs in China, integrating five travel modes: metro, airport bus, taxi, riding-hailing service and private car. In addition, the road networks, surrounding BCIA are well established for arriving at or leaving the airport conveniently, including four expressways and two first-class roads. Although the existing road network is already dense, the operation conditions of surrounding roads are supposed to be improved because of troubles such as insufficient road capacity resources and low traffic efficiency.

As shown in Figure 1, regardless of the impact of Covid-19, the passenger volume in BCIA has continued to rise in the past decade, exerting pressure on landside traffic. At present, the capacity of public transit in the landside traffic system can serve a proportion of passengers of no more than 40%. More than half of the passengers served by cars not only worsen traffic conditions but also pose great challenges to environmental protection (Zhong *et al.*, 2020). Therefore, it is important to raise the utilization of landside traffic capacity resources, especially in peak hours for passenger evacuation and waiting time reduction. This paper focuses on airport buses.

As shown in Table 1, there were 15 airport bus lines departing from BCIA in 2019, including two night routes. All the destinations of the lines are in urban areas. The coverage

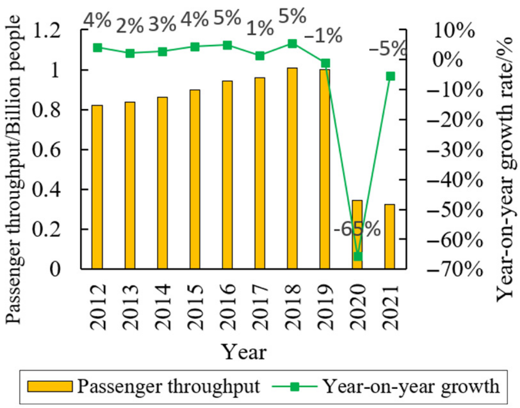

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Figure 1.
Passenger volume of BCIA during 2012–2021

No.	Line name	Starting time	Ending time	Distance (km)	Travel time (min)	Interval (min)
1	Beijingnan Railway Station Line	9:00	0:00	45	90	30
2	Beijing Station Line	7:00	0:00	37	70	30
3	Wangfujing Line	9:00	21:00	37	60	60
4	Fangzhuang Line	11:00	21:00	52	90	30
5	Beijing Station Line (Night Route)	0:00	The time of last flight arriving	50	90	30
6	Gongzhufen Line	6:30	0:00	49	90	30
7	Gongzhufen Line (Night Route)	0:00	The time of last flight arriving	49	90	60
8	Beijingxi Railway Station Line	9:00	11:00	50	100	30
9	Changping Line	7:30	17:30	60	90	60
10	Huilongguan Line	8:00	18:00	57	100	60
11	Shangdi Line	7:40	21:40	46	90	60
12	Zhongguancun Line	6:50	0:00	41	70	30
13	Shijingshan Line	7:30	22:00	57	100	30
14	Tongzhou Line	8:30	0:00	38	70	30
15	Yanjiao Line	7:40	23:00	45	90	40

Source: Author's own work

Table 1. Airport bus routes of BCIA in 2019

area and demand of stations within the fifth ring road are 64% and 92%, respectively, with a radius of 3 km. Currently, airport buses depart from BCIA with fixed departure intervals, and only a few lines adjust the intervals to adapt to the fluctuation of passenger flow during peak hours.

This paper compares the bus routes at several large international airports. As shown in Table 2, the bus routes, with their relatively small number and fixed intervals at New York's Kennedy Airport, are in line with the obvious travel characteristic that most of passengers arrive or leave airports by private car in the USA, leading to a low share of airport buses.

Airport name	The no. of bus routes	Starting time	Ending time	Night routes	Maximum interval	Minimum interval
John Fitzgerald Kennedy International Airport	3	5:00	23:30	–	30 min	30 min
Paris Charles de Gaulle Airport	1	5:15	0:30	–	30 min	15 min
Munich International Airport	1	6:25	22:25	–	20 min	20 min
Narita International Airport	23	6:30	The time of last flight arriving	5	60 min	20 min
Hong Kong International Airport	64	5:15	4:40	23	60 min	10 min
Beijing Capital International Airport	13	6:30	The time of last flight arriving	2	60 min	30 min

Source: Author's own work

Table 2. Comparison of airport bus routes among large airports

Similarly, the number of bus routes at European airports is still small and few lines operate at night. The characteristics of European countries, such as small land area, well-established road networks and railway networks, result in the low utilization of airport buses. Large airports in Asia focus more on the construction of multi-mode landside traffic systems, especially the airport bus system at Hong Kong Airport, with a split rate of 50%. By contrast, the number of airport bus routes operating both daytime and nighttime is not enough, and the departure interval is relatively high in BCIA.

In 2019, the proportion of passengers evacuated by airport bus was 16.3% in BCIA. Figure 2 shows the daily passenger flow of arriving flights at different hours of the day, indicating a strong imbalance in passenger traffic throughout the day, ranging from a peak of 8,308 passengers per hour to a low of 1,054 passengers per hour. As shown in Table 1, the bus departure intervals for each route at BCIA remain relatively fixed during different time periods, which cannot adapt to the fluctuation of passenger flows during high and low peak periods. It not only reduces the level of service of airport buses during peak hours but also wastes capacity resources during off-peak hours. Therefore, it is necessary to redesign an airport bus schedule so as to improve the level of service of bus, interests of airport bus companies and efficiency of passenger evacuation.

In summary, the main problems in the landside traffic system of BCIA are as follows:

- The traffic structure of landside traffic is imbalanced, where the share of airport buses is less than 20%. Generally, the low share of public transit and the high share of private cars exert huge pressure on the surrounding road networks of BCIA, leading to congestion and a low level of service, even affecting the competitiveness of BCIA.
- The fixed departure interval is unable to deal with the fluctuation of arriving passenger volumes. The time-varying passenger flow causes capacity waste in off-peak hours and capacity shortages in peak hours when buses operate according to a fixed departure interval. Meanwhile, most of the current timetables with longer intervals tend to damage travel experience of passengers.

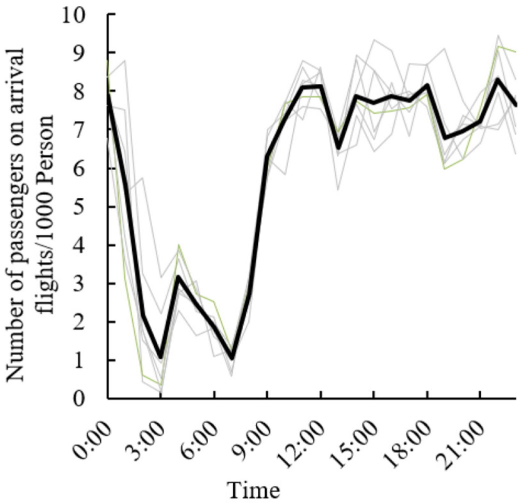

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Figure 2. Number of passengers arriving at BCIA in different time periods

- The traffic organization among transferring passengers, private cars and airport buses is unclear, resulting in low transfer and evacuation efficiency. The streamlines weaving between passengers and vehicles have great influences on the experiences and efficiency of transfer and evacuation. Meanwhile, the coordination among multi-modes is not enough.

3. Simulation model of airport bus based on AnyLogic

3.1 Construction of simulation model

The first step is environmental modeling. Specifically, the elements used to construct the simulation environment for buses departing from airports include walls, elevators, roads, areas, services, queues and so forth. This section loads the layout drawing of Terminal 3 at BCIA into the model and aligns it to scale. Then, the concerned elements are imported in turn according to the layout drawing.

The next step is process modeling. The walking paths of transfer passengers taking different bus routes are roughly the same, but the waiting areas of different buses are distinct. All the buses depart from the P7 parking lot situated in the east of the T3 terminal, with relatively fixed driving routes consisting of stations located on both sides of lanes. There are 247 parking spaces in the P7 parking lot, which only serves airport buses instead of private vehicles. The general logic of the entire process is shown in Figure 3.

The final step is parameter setting. As shown in Table 3, the parameters that need to be assigned include:

- fixed parameters: passenger arrival rate, passenger walking speed and service time of service facility; and
- parameters concerning transportation capacity allocation: the split rate and departure schedule of different bus lines.

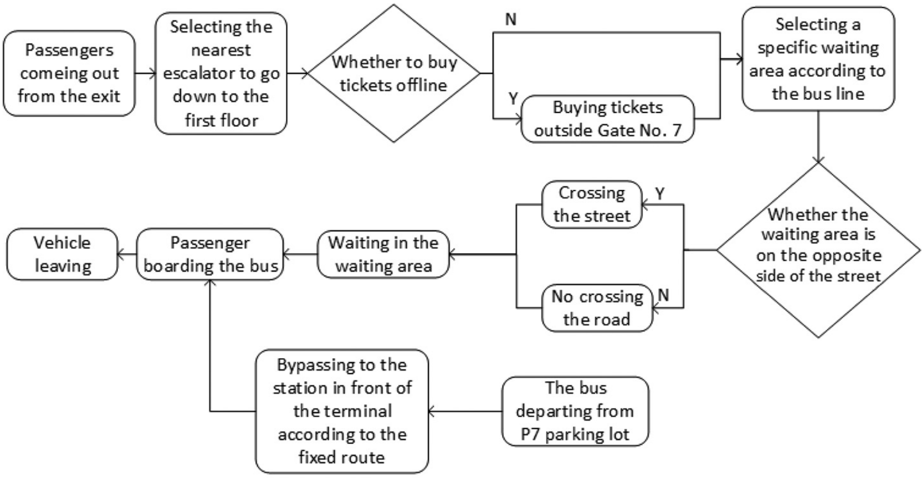

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Figure 3. Logic of airport bus passenger transfer

3.2 Simulation design of passenger transferring to airport bus

The boarding point for airport buses is located on the lane outside the arrival hall. Therefore, the process of transferring passengers to the airport buses includes taking the escalator to the first floor, choosing the pedestrian crossing, crossing the road and boarding the airport bus:

- Design of escalators selection.

The rule for arriving passengers for escalator selection is that passengers choose the nearest escalator. The implementation of the rule in simulation contains four steps. First, number each exit, find the nearest escalator to the exit and assign the number of the exit to the nearest escalator. Then, when passengers pass through one exit, the number of the exit is assigned to the passenger's attribute parameter. Finally, passengers walk toward the escalator, which is assigned with the same number as themselves.

- Design of crossing the road.

Whether passengers need to cross the road mainly depends on the location of the boarding stop for the line they choose. As an example shown in Figure 4, when the destinations of passengers are Zhongguancun, Haidian and Changping, they need to cross the road and wait on the other side. Therefore, the parameters concerning lines and destinations in the agent of AnyLogic determine whether passengers are necessary to cross the road.

If passengers choose to cross the road, it is necessary to control the vehicles traveling on the road to ensure the safety of pedestrians. This function is designed as follows. Area control and parking lines are set in the area of pedestrian crossings. Vehicles traveling on the road are controlled by traffic lights. When the vehicle headway is longer than the time for passengers to safely cross the road, the pedestrian crossing area is open to passengers. Once a passenger enters the pedestrian crossing area, the parking lines on both sides are set a red signal to prohibit vehicles from passing.

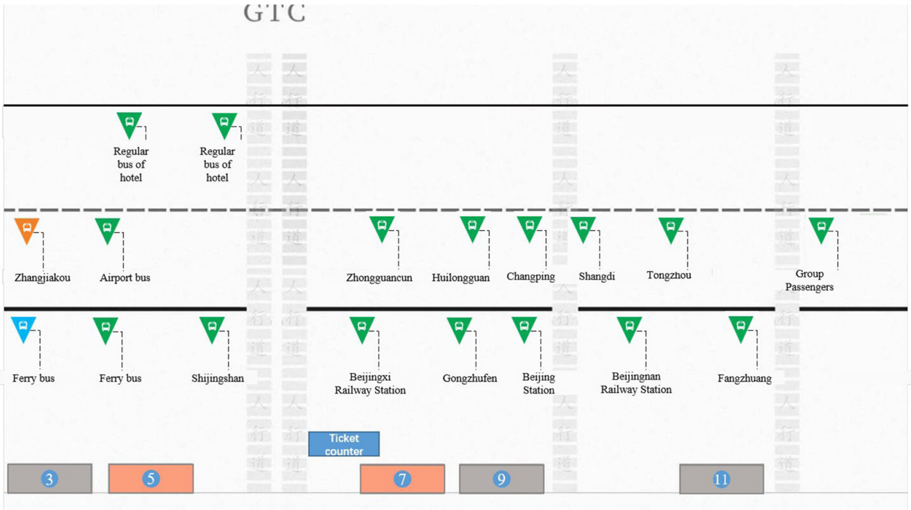
- Design of boarding bus.

Boarding a bus is the final step of passenger transfer, which involves the interaction between passengers and vehicles. This aspect is designed as follows. When a passenger arrives at the corresponding bus waiting area, the function addLast() is used to add the passenger to the ordered set containing waiting travelers on the bus line. When a passenger boards a bus and leaves, the function removeFirst() is used to remove the traveler from the waiting passenger set according to the principle of first in and first out. When the airport bus arrives, passengers whose line parameter is the same as that of the vehicle are removed from the waiting passenger set of the line and board the bus. The other passengers have to wait for the next bus until the line parameter is the same as the arriving bus.

Block	Agent	Parameter	Value	Unit
pedSource	Arriving passenger	Arrival rate	1,318	person/h
		Normal walking speed	Uniform (0.5,1)	m/s
		Initial walking speed	Uniform (0.3,0.7)	m/s
pedEscalator	Escalator group	Operation speed	0.5	m/s
pedService	Ticket purchase	Service time	Uniform (7,20)	s
carSource	Arriving vehicle	Interval	30–120	min

Source: Author's own work

Table 3.
Parameters setting



Source: Author's own work

Figure 4. Distribution of bus stops in front of T3 terminal

3.3 Design of airport bus simulation

The simulation concerning airport buses is relatively simple and only controls vehicles to stop at different stations because of the fixed routes within the airport hub. The parking lines are marked on the road according to the stations of each route, which are further used as the unique number of bus routes. When a bus arrives at the corresponding numbered station, it stops in front of the parking line and conducts the delay module to wait for passengers to board. After the process of boarding the bus, the bus continues to travel on the road and leaves the airport. The number of passengers only needs to meet the constraint of vehicle capacity because BCIA is the origin for all the airport bus routes.

4. Design of simulation indicators

This study constructs a multi-level evaluation system for airport bus simulation, considering passengers, bus operation companies and airports comprehensively. The evaluation indicators are passenger waiting time, vehicle occupancy rate and evacuation efficiency of airport buses:

- Passenger waiting time.

From the perspective of air passengers, the duration of waiting time is an important indicator for the service evaluation of airport buses. Therefore, the passenger waiting time for each bus line obtained by each simulation is analyzed statistically, and the average waiting time for each route is calculated as follows:

$$T_k = \frac{\sum_{i=1}^{n_k} O_i - I_i}{n_k} \tag{1}$$

where T_k is the average waiting time of bus route k; n_k is the total number of passengers waiting for boarding bus; O_i is the time when passenger i leaves the waiting area; I_i is the time when passenger i enters the waiting area.

- Vehicle occupancy rate.

The vehicle occupancy rate can reflect the utilization of vehicle capacity and service level of airport buses, which is the key indicator to adjust airport bus schedules. The vehicle occupancy rate is used to measure the match between passenger demand and the capacity of airport buses. To ensure service quality, the maximum capacity of one airport bus is equal to the number of seats on it. The vehicle occupancy rate for one line is formulated as follows:

$$L_k = \frac{P_k}{C_k} \tag{2}$$

where L_k is the vehicle occupancy rate of line k, P_k is the passengers on board of line k and C_k is the number of seats of line k.

- Evacuation efficiency of airport bus.

The passenger volume of large airports in China is more than 100 million passengers per year, with daily passenger volumes exceeding 100,000. Therefore, a large number of passengers may gather at the airport during peak hours. Efficient passenger evacuation is crucial for preventing safety accidents and improving airport service quality. This paper regards the hourly evacuation capacity of airport buses as an indicator to reflect the efficiency of passenger evacuation. The evacuation efficiency of airport buss is calculated as follows:

$$E = \frac{\sum_{k=1}^{n} P_k}{R} \tag{3}$$

where E is the evacuation efficiency and R is the simulation duration.

5. Analysis of simulation results

To reflect the passenger flow unaffected by Covid-19, data from BCIA in 2019 is selected for the case study. The data analysis shows that the daily passenger volume is 129,500. Three hours, 10:00 to 12:00, are selected as the simulation period according to the volume peaks of bus passengers in urban areas. Departure intervals are changed in each simulation. Meanwhile, passenger waiting time, vehicle occupancy rate and evacuation efficiency are calculated after each simulation. The departure intervals for each experiment are shown in Table 4.

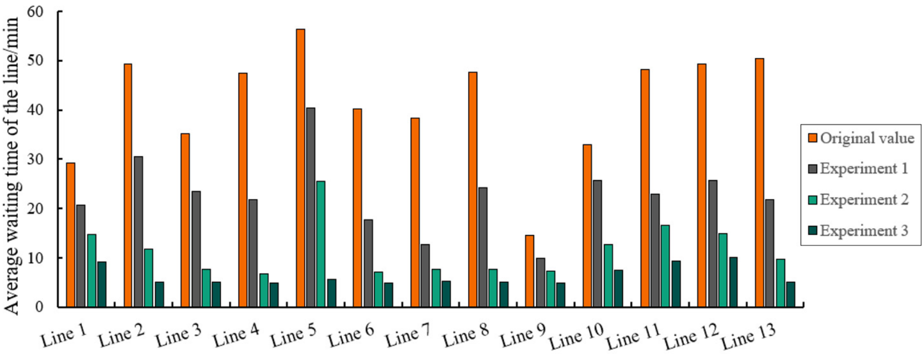
The results obtained by each simulation are shown in Figures 5–7. As shown in Figure 5, when departure intervals are equal to their original value, the average waiting time for bus lines is relatively long except for the Changping Line and the Huilongguan Line. Compared with the results of the following experiments, it is obvious that when the departure intervals are set to the values used in Experiment 2, the average waiting time for each route significantly decreases. However, when the departure intervals are set to the values used in Experiment 3, the average waiting time for other routes decreases slightly except for the Beijing Station Line. The average waiting time for the Huilongguan Line and the Changping Line is insensitive to the changes in the departure intervals in all experiments.

As shown in Figure 6, the number of passengers evacuated by airport buses presents a step-wise upward trend with the passing of time. Moreover, the plateau period of the

No.	Line name	Departure interval Original value	Experiment 1	Experiment 2	Experiment 3
1	Huilongguan Line	60 min	40 min	30 min	20 min
2	Shijingshan Line	30 min	20 min	15 min	10 min
3	Beijingxi Railway Station Line	30 min	20 min	15 min	10 min
4	Gongzhufen Line	30 min	20 min	15 min	10 min
5	Beijing Station Line	30 min	20 min	15 min	10 min
6	Beijingnan Railway Station Line	30 min	20 min	15 min	10 min
7	Fangzhuang Line	30 min	20 min	15 min	10 min
8	Zhongguancun Line	30 min	20 min	15 min	10 min
9	Changping Line	60 min	40 min	20 min	15 min
10	Yanjiao Line	40 min	30 min	15 min	10 min
11	Shangdi Line	60 min	40 min	30 min	20 min
12	Wangfujing Line	60 min	40 min	30 min	20 min
13	Tongzhou Line	30 min	20 min	15 min	10 min

Source: Author's own work

Table 4. Interval setting in experiments



Source: Author's own work

Figure 5. Average waiting time of each line in different experiments

evacuation curve is also shortened as the departure intervals decrease. When the departure intervals are set to the value used in Experiment 3, there is no obvious plateau period in the evacuation curve. Furthermore, the difference in the cumulative number of evacuated passengers among different experiments becomes larger. As shown in Figure 7, when conducting simulation according to the original value of departure intervals, the number of passengers evacuated by buses within three hours is less than half of the demand, accounting for only 46.8%. As the departure intervals decreased, the number of evacuated passengers in different experiments continued to increase. The departure schedule of Experiment 1 can evacuate 70.4% of the total demand within three peak hours, while Experiment 2 can evacuate 84.1% within the same period. When the departure intervals are set at the values used in Experiment 3, the number of evacuated passengers can reach 93.2% of total demand. As the departure intervals are continually shortened in the experiments, the difference in the total number of evacuated passengers becomes smaller. Therefore, the departure interval

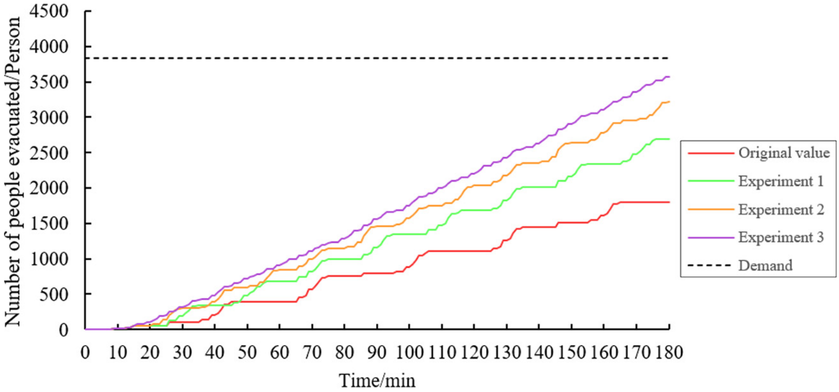


Figure 6. Number of passengers evacuated by the airport bus during different experiments

Source: Author's own work

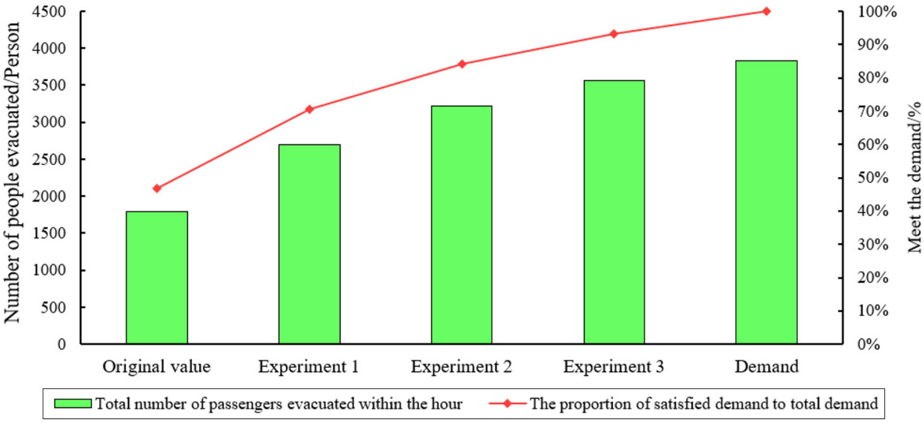


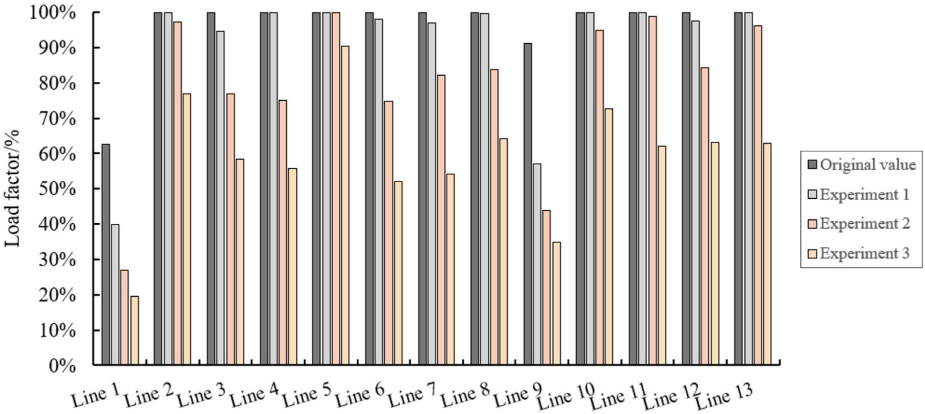
Figure 7. Total amount of evacuated passengers in different experiments

Source: Author's own work

setting in Experiment 2 is optimal when considering evacuation efficiency and the operating cost simultaneously.

Aiming to ensure service quality, the maximum vehicle capacity is equal to the number of seats in it. Therefore, the maximum vehicle occupancy rate for each vehicle is 1. As shown in Figure 8, when departure intervals are set to their original values, the vehicle occupancy rate of almost all the routes is close to 1, except for the Hui Long Guan line and Changping line. The vehicles on each route achieve high utilization but low service levels. When departure intervals are set to the values used in Experiment 2, the vehicle occupancy rate of most routes decreases to around 0.8. The indicators of the Yanjiao line, Shangdi line and Tongzhou line are slightly higher than those of other routes, with a value of 0.9. However, the indicator of the Beijing Station line is still 1 under Experiment 2, and it drops to around 0.9 when the departure intervals are changed to the setting of Experiment 3.

According to the above analysis, the original values are set as the departure intervals of the Changping and Huilongguan lines, while the departure intervals for the Beijing Station line are set according to Experiment 3. The departure intervals of other lines are set



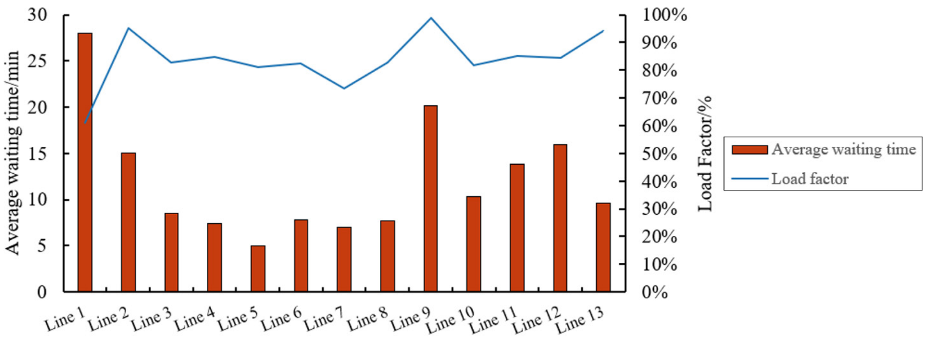
Source: Author's own work

Figure 8. Vehicle occupancy rate of each line in different experiments

according to Experiment 2. The results are shown in Figure 9. It is obvious that the longest average waiting time for each line is less than 30 min, and the average vehicle occupancy rate is around 0.8, ranging from 0.62 for the Huilongguan line to 0.95 for the Beijing Station line. The number of passengers evacuated within three hours is 85.7% of the total demand, with only 14.3% of the bus passengers unable to leave at the current stage.

6. Conclusion

In this study, we propose a simulation-based method for the timetable optimization of airport buses by adjusting the departure interval and comparing the effects on passenger waiting time, vehicle occupancy rate and evacuation efficiency of airport buses. By simulation-based analysis, this paper uncovers the key problem that the current airport bus system at BCIA is difficult to adapt to the dynamic passenger demand without flexible timetable design, especially during peak hours. According to the experimental results, an excellent evacuation effect can only be achieved when the majority of departure intervals of airport buses are shortened to 50% of their original values, and some busy routes such as the Beijing Station line are supposed to be reduced to one-third of their original fixed intervals. In addition, both passenger waiting time and vehicle occupancy rate are improved,



Source: Author's own work

Figure 9. Average waiting time and vehicle occupancy rate when the optimal departure interval set

with the longest average waiting time being less than 30 min and the average vehicle occupancy rate around 0.8. The results of case study demonstrate the effectiveness of proposed simulation-based timetable optimization method. Corresponding optimization suggestions are concluded as follows. First, as the airport bus passenger flow presents an obviously periodic variation over days, the timetable of the airport bus is supposed to be redesigned every day. A flexible bus timetable can not only meet the dynamic passenger flow but also enhance the attractiveness of public transit. Furthermore, the airport can continuously promote the renovation of bus routes based on passenger demand, which can attract more passenger flows from surrounding areas, diversify the source structure of passengers and consolidate the central position of airport buses in the integrated landside traffic system of the airport.

References

Bian, Y., Jia, D.Z., Feng, X.F., Zhao, J.J. and Li, J. (2022), "Characteristics of landside passenger flow of Beijing Daxing international airport", *Urban Transport of China*, Vol. 20 No. 4, pp. 63-69+119.

Chen, L., Jian, S. and Tao, A. (2020), "Optimum design and simulation of pedestrian passenger transfer operation in integrated transportation hub", *Systems Engineering*, Vol. 38 No. 3, pp. 84-91.

Di, Z.W., Bao, D.W., Zhang, T.X. and Zhu, T. (2019), "A joint selection model of departure time and travel mode of airport passengers based on agent theory", *Journal of Transport Information and Safety*, Vol. 37 No. 4, pp. 136-144.

Jia, J.H. (2018), *Research on the Emergency Evacuation of Passengers in the Large-Area Flight Delay Situation*, *Nanjing University of Aeronautics and Astronautics*, Nanjing.

Lia, S. (2013), "Improving timetable planning of airport bus stop to enhance seamless transportation of off-shore islands", *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol. 9.

Liu, J. and Bao, Q. (2020), "Investigating airport bus scheduling optimization: a case study of the Beijing capital international airport", *20th COTA International Conference of Transportation Professionals*.

Liu, S.W. and Zhang, Y. (2021), "Functional evaluation of urban rail transit three-line transfer station based on AnyLogic simulation", *Journal of Transportation Engineering and Information*, Vol. 19 No. 1, pp. 135-142.+176.

Liu, Z., Wang, Q., Sigler, D., Kotz, A., Kelly, K.J., Lunacek, M. and Garikapati, V. (2023), "Data-driven simulation-based planning for electric airport shuttle systems: a real-world case study", *Applied Energy*, Vol. 332, p. 120483.

Lu, J., Yang, Z.Z. and Liu, R.J. (2013), "Timetable design of the airport coach based on the relationship between the headway and the passenger volume", *Systems Engineering – Theory and Practice*, Vol. 33 No. 8, pp. 2097-2104.

Lu, J., Yang, Z., Timmermans, H. and Wang, W. (2016), "Optimization of airport bus timetable in cultivation period considering passenger dynamic airport choice under conditions of uncertainty", *Transportation Research Part C: Emerging Technologies*, Vol. 67, pp. 15-30.

Ni, G.M. and Yang, D.Y. (2002), "Computer simulation research on passages flow of airport terminal", *Journal of System Simulation*, Vol. 2002 No. 2, pp. 229-233.

Salicrú, M., Fleurent, C. and Armengol, J.M. (2011), "Timetable-based operation in urban transport: Run-time optimisation and improvements in the operating process", *Transportation Research Part A: Policy and Practice*, Vol. 45 No. 8, pp. 721-740.

Shi, C., Liu, D. and Han, H.F. (2022), "Optimization of departure interval for transfer bus in passenger Air-Rail intermodal transport", *Journal of Dalian Jiaotong University*, Vol. 43 No. 1, pp. 14-20.

Song, W. and Yang, K. (2006), "The impacts of air transportation and airport on regional economic development", *Scientia Geographica Sinica*, Vol. 26 No. 6, pp. 649-657.

Wu, Y.K. and Ma, C.X. (2022), "Timetable optimization of airport shuttle bus based on multi-objective genetic algorithm", *Journal of Lanzhou Jiaotong University*, Vol. 41 No. 04, pp. 35-41.

Xing, Z.W., Gao, Z.W., Luo, X. and Luo, Q. (2021), "Subspace modeling and optimization for airport bus operation process", *Application Research of Computers*, Vol. 38 No. 8, pp. 2344-2348.

Yan, H.Z. and Ma, S. (2020), "Simulation and evaluation of an urban rail transit timetable based on multi-line coupling", *Journal of Transportation Engineering and Information*, Vol. 18 No. 1, pp. 111-119.

Zhong, M., Liu, Y., Guan, H. and Xia, K. (2020), "Restriction factors and experience of the collection and distribution system of the airport comprehensive passenger hub", *Railway Transport and Economy*, Vol. 42 No. 9, pp. 50-56.

Zhou, H.P., Jia, Z.X. and Liu, W.S. (2012), "The optimization method to airport bus routes based on hybrid genetic algorithm", *Journal of Changsha University of Science and Technology: Natural Science*, Vol. 9 No. 4, pp. 12-17.

Zou, Z.J. (2010), "Review on new generation traffic simulation", *Journal of System Simulation*, Vol. 22 No. 9, pp. 2037-2042.

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