**Citation:** LIU Haiping, XIAO Yao. Bus Operation and Management During Epidemic Control and Prevention [J]. Urban Transport of China, 2020 (03): 42–45, 92.

# Bus Operation and Management During Epidemic Control and Prevention

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**Abstract:** Since the outbreak of the Coronavirus Disease 2019, the urban public transportation service has encountered unprecedented challenges. As an important part of urban public transportation, bus service must not only provide necessary travel services for urban residents continuously but also effectively control the crowd to minimize virus transmission during the epidemic. By learning the indoor virus transmission through the droplets in the air, this paper analyzes the main influencing factors of virus transmission inside bus. Based on the characteristics of bus operation and management, the paper identifies seven control indicators for bus service during epidemic control and prevention. Finally, the paper proposes the bus service management during the recovery period of epidemic in several aspects: reducing the number of susceptible people on the bus, preventing the occurrence of infected passengers on the bus, shortening the exposure time on the bus, and improving bus ventilation.
**DOI:** 10.13813/j.cn11-5141/ u.2020.0016-en

**Keywords:** bus service; operation and management; COVID-19; virus transmission; epidemic control and prevention; response strategies

Since December 2019, Coronavirus Disease 2019 (hereinafter referred to as “COVID-19”) has spread at an alarming rate, and fighting this pandemic has become a war involving all people. COVID-19 is an acute infectious pneumonia. It can be transmitted from person to person and spreads mainly through droplets and close contact, which poses a huge challenge to urban passenger transportation. Among all passenger transportation modes, public transportation is characterized by crowded passengers and complicated environment, which is a passenger transportation mode with a high risk of virus transmission. As an important part of urban public transportation, bus transportation has played an indispensable role in ensuring the basic travel needs and supporting the economic development of the city during pandemic control and prevention. In the face of the sudden outbreak of the pandemic, the response of bus service has drawn great attention from the government and citizens. However, there is a lack of theoretical research in response strategies, especially during the recovery from the pandemic, which makes it difficult to effectively guide the orderly recovery of urban bus service and support pandemic control and prevention. Therefore, this paper starts with the virus transmission mechanism and analyzes the main influencing factors of virus transmission on buses. In addition, it identifies the control indicators of bus service during pandemic control and prevention and proposes response strategies.

## 1 COVID-19 transmission mechanism

According to the current research, the main modes of transmission for COVID-19 are respiratory droplets and indirect contact. Since aerosol and fecal-oral transmission has not yet to be confirmed by research [1], they are not considered in this paper. Among these modes, droplet transmission is the main mode of virus transmission, and vulnerable people could be infected by inhaling virus-bearing droplets generated by an infected person when he/she coughs or talks. Indirect contact transmission refers to the transmission through indirect contact with an infected person. Virus-containing substances could exist on the surface of an object and infect people who touch them. This paper takes droplet transmission as an example to study the mechanism of indoor virus transmission in the air through droplets and to find out the main influencing factors of virus transmission.

To estimate and model the risk of spreading infectious diseases indoors through the air, Reference [2] proposed the classic Wells-Riley Formula as shown in Formula (1). It used $CO_2$ to track exhaled breath, linked the risk of virus transmission directly to respiration, and calculated the probability of indoor disease transmission through the air based on the continuous monitoring of $CO_2$.

$$P=\frac{D}{S}=1-\exp\left(-\frac{Ipqt}{Q}\right), \quad (1)$$

**Received:** 2020-03-04
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where $P$ is the probability of virus transmission/%; $D$ is the number of people with disease; $S$ is the number of vulnerable people; $I$ is the number of infected people; $p$ is the breathing rate per person/($m^3 \cdot s^{-1}$); $q$ is the generation rate of infectious substance by an infected person/(quanta① $\cdot s^{-1}$); $t$ is the indoor exposure time/s; $Q$ is the outdoor air supply rate/($m^3/s^{-1}$) [3].

Formula (1) shows that when the probability of virus transmission ($P$) is fixed, the number of people with disease ($D$) is directly proportional to the number of vulnerable people ($S$). It also shows that the probability of virus transmission ($P$) is positively correlated with the breathing rate per person ($p$), the generation rate of infectious substance by an infected person ($q$), the number of infected people ($I$), and the indoor exposure time ($t$), and it is inversely correlated with the outdoor air supply rate ($Q$). Therefore, it is of great significance to focusing the study on the interactions between the spread of the virus and these factors to control virus transmission.

## 2 Selection of control indicators for pandemic control and prevention on buses

The indoor virus transmission mechanism described by the Wells-Riley Formula can be applied to bus interior space to identify the main factors that affect the virus transmission on buses. These factors include the breathing rate per person on the bus, the generation rate of infectious substance by an infected person on the bus, the number of vulnerable people on the bus, the number of infected people on the bus, the exposure time on the bus, and the outside air supply rate. The breathing rate per person and the generation rate of infectious substance by an infected person are affected by various factors such as age, physical fitness and living environment. Since both factors are uncontrollable and have little relevance to the pandemic control and prevention on buses, they are not considered in this paper. This paper starts with the other four factors. Referring to the characteristics of bus operation and management, it selects control indicators that are more relevant (Tab. 1) to guide the formulation of the strategies for pandemic control and prevention on buses.

**Tab. 1** Main factors and control indicators for epidemic control and prevention on buses

| Main factor | Control indicator |
|---|---|
| Number of vulnerable people on the bus | Bus load factor |
| | Departure interval |
| Number of infected people on the bus | Hygiene intervention for bus drivers and attendants |
| | Hygiene intervention for buses |
| Exposure time on the bus | Travel distance of passengers |
| | Running speed of the bus |
| Outside air supply rate | Bus ventilation conditions |

### 2.1 Number of vulnerable people on the bus

When the probability of virus transmission is constant, the number of people with disease on a bus is directly proportional to the number of vulnerable people on the bus: Fewer people will be infected on the bus if the bus has fewer vulnerable passengers. Therefore, pandemic control and prevention on buses need to control the number of vulnerable people on buses. During the operation of a bus, all passengers could be vulnerable people. Due to frequent boardings and alightings, the number of passengers on the bus is constantly changing, which is mainly reflected by the change in the cross-sectional passenger flow. When the cross-sectional passenger flow increases, the number of vulnerable people also rises.

There are two ways to control the cross-sectional passenger flow of a bus: the direct method and the indirect method.

1) Direct method

The direct method is to control the bus load factor which is the ratio of the actual number of passengers on a bus to the rated passenger capacity of the bus [4]. It can reflect the utilization rate of buses. To understand how to control the number of vulnerable people by controlling the bus load factor, which leads to the reduction of virus transmission risks, this paper takes the mode of droplet transmission as an example and develops a model to calculate the reasonable range for the bus load factor during pandemic control and prevention.

Studies have shown that droplets generated when a person speaks, coughs or sneezes can move within 1 m [5], and vulnerable people within this range are very likely to inhale droplets and become infected. Under normal circumstances, a bus's rated passenger density is about 6 people/$m^2$. At this density, there is basically no safe distance between passengers, and the bus load factor is assumed to be 100%. If the rated area on the bus is denoted by $S$/$m^2$, the rated passenger capacity of the bus, denoted by $N$/person, is then equal to $6S$, i.e., $N = 6S$. If the actual number of passengers is denoted by $c$/person and the side length of the square occupied by a passenger is denoted by $y$/m, it can be derived that the bus load factor, denoted by $x$/%, is equal to $1/6y^2$ since $x = c/N = c/6S = c/6cy^2 = 1/6y^2$. Therefore, the following formula can be derived.

$$y = \frac{1}{\sqrt{6x}} . \tag{2}$$

Fig. 1 shows the relationship curve between the bus load factor and the side length of the square occupied by a passenger. It shows that when the side length of the square occupied by a passenger is 1 m, the bus load factor is about 16% and the 1-meter safe distance between passengers can be achieved to reduce the risk of virus transmission through droplets. The specific value for the control indicator of the bus load factor should be determined comprehensively according to relevant factors, such as requirements for pandemic control and prevention, passenger flow demand and bus capacity.

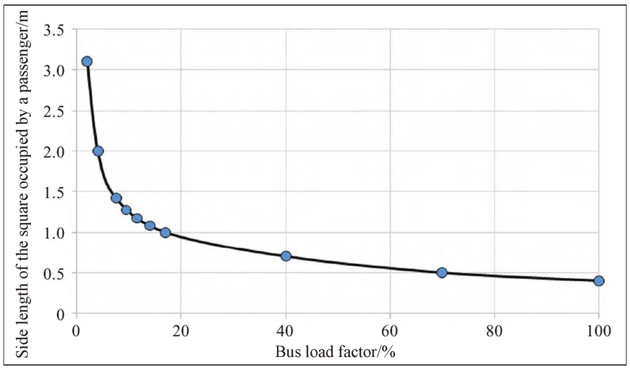


**Fig. 1** Relationship between bus occupation rate and the square area's dimension taken up by passengers

2) Indirect method

The indirect method is mainly to control the bus departure interval. The bus departure interval refers to the time difference of two successive bus departures [4]. It is an important indicator to measure the passenger capacity of a bus line. Generally, the formula to calculate the bus departure interval [6] is

$$t=\frac{n}{C_V}=\frac{\max\left(N(j)\right)}{C_V}, \tag{3}$$

where $t$ is the bus departure interval/min; $n$ is the maximum cross-sectional passenger flow rate of a bus line/(person/min); $C_V$ is the product of the bus load factor and the bus rated passenger capacity/person; $N(j)$ is the cross-sectional passenger flow rate of bus line segment $j$/(person/min).

Formula (3) shows that the bus departure interval is proportional to the maximum cross-sectional passenger flow rate. The passenger flow can be distributed to more buses running on the same bus line by reducing the departure interval, which can lower the cross-sectional passenger flow of a bus and reduce the risk of virus transmission caused by the increase in the number of vulnerable people on the bus.

Accordingly, the bus load factor and departure interval can be selected as the indicators to control the number of vulnerable people on the bus.

### 2.2 Number of infected people on the bus

The probability of virus transmission is positively related to the number of infected people on the bus: The probability of virus transmission is low when the number of infected people on the bus is small. Therefore, pandemic control and prevention on buses need to reduce the number of infected people, usually by controlling the source of infection and the mode of transmission.

1) From the perspective of controlling the source of infection, both drivers and passengers may become the source of infection. For fewer infected people on the bus, it is very important to take hygiene interventions, such as body temperature screening implemented by bus attendants and personal protection measures.

2) From the perspective of controlling the mode of transmission, buses are usually densely packed with passengers and it is easy for viruses to live in equipment, dirt and air on the bus, which creates a good virus transmission route and leads to an increase in the number of infected people on the bus. It is necessary to take hygiene interventions such as cleaning and disinfecting buses.

Accordingly, the hygiene interventions for drivers and attendants and the hygiene interventions for buses can be selected as the indicators to control the number of infected people on the bus.

### 2.3 Exposure time on the bus

The probability of virus transmission is positively correlated with the exposure time on the bus: The probability of virus transmission is low when the exposure time on the bus is short. Therefore, pandemic control and prevention on buses need to decrease the exposure time of a passenger on the bus.

The exposure time of a passenger on the bus depends on the passenger's in-vehicle travel time, which is the passenger's total travel time in a bus trip, excluding the travel time before getting on the bus and after getting off the bus [4]. It reflects the effectiveness of bus operation. A passenger's in-vehicle travel time is determined by the passenger's travel distance and the bus's running speed. When the passenger's travel distance is short and the bus's running speed is high, the passenger's in-vehicle travel time is short and the probability of virus transmission on the bus is low.

Accordingly, the passenger's travel distance and the bus's running speed can be selected as the indicators to control the exposure time on the bus.

### 2.4 Outside air supply rate

The probability of virus transmission is inversely related to the outside air supply rate: The probability of virus transmission is low when the outside air supply rate is high. Therefore, pandemic control and prevention on buses need to strengthen the supply of outside air. The outside air supply rate is related to the bus ventilation conditions, and optimizing the bus ventilation conditions will help reduce the probability of virus transmission.

Accordingly, bus ventilation conditions can be selected as an indicator to control the outside air supply rate.

## 3 Strategies for pandemic control and prevention on buses

During the recovery from the pandemic, urban bus service resumes gradually. Under the premise of not increasing the risk of virus transmission, how to scientifically and reasonably ensure bus transport capacity and meet the mandatory travel needs of urban residents is an urgent problem to solve. Based on the control indicators for pandemic control and prevention on buses, it is recommended to propose adaptive strategies in a targeted manner, which will help improve the reliability of bus service and ensure operational efficiency during the recovery from the pandemic. Meanwhile, in the era of the rapid development of science and technology, it is recommended to adopt intelligent and information-based measures to achieve accurate information communication, efficient directing and dispatching, and real-time supervision and monitoring. These measures will be effective and efficient for pandemic control and prevention on buses.

### 3.1 Reduce vulnerable people on buses

1) Enhance the monitoring of bus operation and master the changes of the bus cross-sectional passenger flow in a timely manner

Intelligent and information-based measures, such as the automated fare collection system based on bus IC cards, the on-board GPS positioning system, and the on-board video monitoring system, can be used to collect the passenger flow data comprehensively and accurately while the bus is in operation. These data should be fully explored and analyzed to evaluate bus operation, master the changing pattern of the bus cross-sectional passenger flow in a timely manner, and provide data to the development of plans for pandemic control and prevention on buses.

2) Under the premise of ensuring the bus transport capacity, shorten the departure intervals reasonably and control the bus load factor

According to the requirements of pandemic control and prevention, passenger flow demand and bus transport capacity, it is recommended to control the bus cross-sectional passenger flow by shortening the departure interval and controlling the bus load factor, which will reduce the risk of virus transmission. The bus load factor should be controlled to be in the range of 15% to 20% in order to maintain the safe distance between passengers.

3) Adjust the operation mode of connection buses flexibly to reduce the gathering of passengers at transportation hubs

It is recommended to strengthen the bus connection at airports, railway stations, and intercity bus terminals, and master passenger travel information accurately. It is also suggested to adjust the departure time and frequency in a timely manner to respond to the changes in passenger flow, transport large-scale passenger flow promptly, minimize the risk of rapid increase in the bus cross-sectional passenger flow, and provide support services actively to ensure safe bus travel for residents.

### 3.2 Prevent infections on buses

1) Check the temperature of passengers before they board the bus, and strengthen the hygiene interventions of drivers and passengers

Passenger temperature screening should be enhanced and implemented before passengers board the bus. Passengers whose body temperature is above the cut off temperature should be transferred to the health department as soon as possible in accordance with relevant procedures. Meanwhile, passengers and front-line practitioners should wear masks throughout the course to enhance hygiene protection.

2) Implement bus cleaning and disinfection procedures strictly and strengthen the training of employees

Public transportation enterprises should implement vehicle disinfection procedures strictly, and implement sanitation and cleaning procedures on buses. At the same time, they should strengthen the training of employees on operating procedures, such as disinfection of vehicles and measures for pandemic control and prevention. The focus of the training is to improve the employee's ability in pandemic control and prevention and emergency response.

### 3.3 Shorten the exposure time on buses

1) Develop customized or temporary bus lines flexibly and rationally based on the passenger demand to shorten the travel distance for passengers

In response to employees' commuting demand and residents' centralized travel need, it is recommended to give full play to the flexibility of bus line planning and to develop customized bus routes or point-to-point transportation services. This measure can avoid unnecessary bypasses and reduce the number of passengers who board or alight the bus on the way. It can not only shorten the travel distance for passengers but lower people's contact frequency and the risk of cross-infection during the bus ride.

2) Operate express buses that stop only at major stops to transport passengers quickly and to meet residents' demand for rapid travel

It is recommended to add express buses that stop only at major stops on bus lines with large passenger flow to transport passengers quickly. These express buses mainly stop at stops with large passenger flow, which can greatly improve the speed and operating efficiency for buses and shorten the travel time for passengers.

### 3.4 Optimize bus ventilation

When a bus is in operation, it is necessary to strengthen ventilation and promote air circulation on the bus. It is recommended that under normal weather conditions, windows on the bus should be open to ensure ventilation. For air-conditioned vehicles with poor ventilation, bus companies are recommended to remodel buses running on bus lines with large passenger flow when conditions permit. For example, the side windows of a fully-enclosed air-conditioned bus can be modified [7] to ensure enough windows on each air-conditioned bus.

## 4 Conclusion

In the context of the outbreak of COVID-19, this paper applied the theory of indoor virus transmission in the air through droplets to the bus interior space. This paper found that the virus transmission on buses is mainly related to the number of vulnerable and infected people on the bus, the exposure time on the bus and the outside air supply rate. This paper then identified relevant control indicators based on the characteristics of bus operation and management, and put forward the strategies for pandemic control and prevention on buses in a targeted manner. In future research, it is necessary to study the relationship between the pandemic control and prevention on buses and the control indicators. Due to the integrity of the public transportation system, it is also necessary to extend the study of pandemic control and prevention strategies to the level considering bus network, such as transfer bus lines and connection rail transit lines, to facilitate a pandemic control and prevention system for urban buses.

## Annotation

① Quanta: quoted from Reference [3], which is used to describe the randomness factor of an airborne disease.

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