Review

COVID-19 transmission and control in land public transport: A literature review

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ABSTRACT

Land public transport is an important link within and between cities, and how to control the transmission of COVID-19 in land public transport is a critical issue in our daily lives. However, there are still many inconsistent opinions and views about the spread of SARS-CoV-2 in land public transport, which limits our ability to implement effective interventions. The purpose of this review is to overview the literature on transmission characteristics and routes of the epidemic in land public transport, as well as to investigate factors affecting its spread and provide feasible measures to mitigate the infection risk of passengers. We obtained 898 papers by searching the Web of Science, Pubmed, and WHO global COVID database by keywords, and finally selected 45 papers that can address the purpose of this review. Land public transport is a high outbreak area for COVID-19 due to characteristics like crowding, inadequate ventilation, long exposure time, and environmental closure. Different from surface touch transmission and drop spray transmission, aerosol inhalation transmission can occur not only in short distances but also in long distances. Insufficient ventilation is the most important factor influencing long-distance aerosol transmission. Other transmission factors (e.g., interpersonal distance, relative orientation, and ambient conditions) should be noticed as well, which have been summarized in this paper. To address various influencing factors, it is essential to suggest practical and efficient preventive measures. Among these, increased ventilation, particularly the fresh air (i.e., natural ventilation), has proven to effectively reduce indoor infection risk. Many preventive measures are also effective, such as enlarging social distance, avoiding face-to-face orientation, setting up physical partitions, disinfection, avoiding talking, and so on. As research on the epidemic has intensified, people have broken down many perceived barriers, but more comprehensive studies on monitoring systems and prevention measures in land public transport are still needed.

1. Introduction

SARS-CoV-2 and its variants have spread all around the world due to their high transmissible infectivity and caused great distress to global public health for more than two years [1–3]. As of 28 September 2022, more than 600 million people had been infected with SARS-CoV-2 and more than 6.5 million people had died from COVID-19 [4]. The epidemic poses a serious threat to all aspects of social and economic life [5], and greater efforts are needed to contain and fight the virus. However, there are still many inconsistent opinions and views on the spread of COVID-19, which limits our ability to implement effective interventions [6–8].

A correct and thorough understanding of how the virus transmits needs to be identified, which is critical to underpin effective non-pharmaceutical interventions to minimize spread. Efforts are currently underway to identify the main transmission routes of SARS-CoV-2. In the early stages of the pandemic, WHO [9] claimed that SARS-CoV-2 was unlikely to spread through aerosol inhalation transmission and could only be through direct contact or virus-laden droplet spray. In July 2020, WHO recognized that SARS-CoV-2 may be possibly transmitted through aerosol [10]. In December 2021, WHO emphasized the roles of short-range aerosol transmission and stated that long-range aerosol transmission could occur in "poorly ventilated and/or crowded indoor settings,
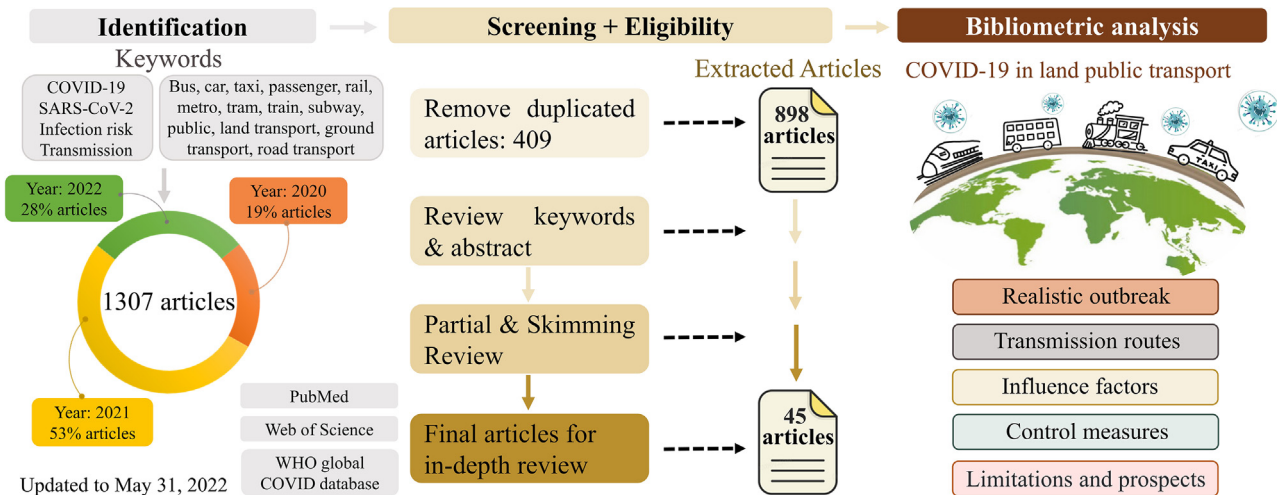
Fig. 1. Systematic literature review flow chart.

where people tend to spend longer periods" [11]. As the importance of ventilation and exposure duration on infection risk is recognized, the indoor environment is beginning to gain attention.

People spend most of their time indoors [12,13], while the indoor ventilation rate is significantly worse than outdoors. Hence, some indoor environments with poor ventilation such as hospital wards [14–16], restaurants [17–19], and public transport [20–22] have become spaces with a high probability of cross-infection. Several studies also found that over 99% of infection cases occurred indoors [23,24]. Qian et al. [23] collected all data related to COVID-19 in China except for Hubei province as of February 11, 2020, and found that the traffic environment was the second most common of these occasions after the household environment. Nonetheless, this outcome was derived from a specific time frame in China, coinciding with the Chinese New Year travel rush. During this exceptional period, the substantial increase in long-distance travel inherently poses a heightened risk of cross-infection within the public transportation environment.

Public transport was identified as a high-risk area for the spread of COVID-19 due to [25–27]: (a) enclosed spaces with limited ventilation; (b) the inability to identify potentially infected people; (c) existing multiple potentially contaminated surfaces and objects; (d) relative long exposure time and short social distance. Moreover, a large number of people all over the world use public transport in their daily lives and the transport network connects the whole world, which means public transport is one of the sectors that have a high possibility of COVID-19 transmission between different countries and cities in the world [25–27]. There are many types of transport (e.g., airplane, cruise, train, bus, and car) and land transport is the most frequently used one among them [28]. According to the U.S. National Transit Database, 9.6 billion passengers are boarding public transit bus and rail systems in a normal year [29]. Overall, COVID-19 transmission on land public transport is a very meaningful study, which is the subject of our review.

Nowadays, there are already numerous studies about COVID-19 transmission on land public transport [21,30-32]. However, outbreaks of infection cases are often accompanied by multiple transmission ways, and the transmission route of an exact case on the vehicle is difficult to determine. While the public transport industry responded quickly early in the pandemic with operational guidelines to reduce the risk of disease transmission, the mitigation measures implemented varied widely [33–35]. It is essential to clearly define strategies for preventing the spread of the epidemic in transport and identify the most effective measures for epidemic prevention. These questions need to be explored further, so a literature review is needed to clarify them. Based on these doubts mentioned above, this review will explore the following scientific questions:

1. What are the characteristics of the spread of COVID-19 in land public transport?
2. What is the main transmission route in land public transport?
3. What are the main factors affecting the spread of COVID-19?
4. Which epidemic prevention policies can effectively reduce the infection risk of passengers in land public transport?

2. Methods

A rapid narrative review of the literature was conducted by researching in Web of Science, PubMed, and WHO global COVID database (Fig. 1). The title, abstract, and keyword search strings for indexed studies were determined based on various combinations of keywords and alternatives. The search keywords included: COVID-19, SARS-CoV-2, infection risk, transmission, bus, car, taxi, passenger, rail, metro, tram, train, subway, public, land transport, ground transport, and road transport. After removing 409 duplicate articles, 898 papers were identified from the time of the COVID-19 outbreak to May 31, 2022.

To identify articles more suitable for our research subject, some screening criteria were developed: (1) studies that reported realistic outbreaks in vehicles; (2) studies that estimated the possible transmission routes in land public transport; (3) studies that explored factors affecting the transmission of the epidemic in land public transport; (4) studies that investigated control measures or assessed its effectiveness. Moreover, the exclusion criteria were: (1) studies focused on the influence of COVID-19 on travel, transport behavior, economy, or industry; (2) studies that reported how the lockdowns affect public transport; (3) studies about consumption behavior in land public transport during the epidemic; (4) studies on the biological characteristics of viruses in land public transport; (5) non-English papers. As shown in Table. 1, 45 papers were selected and included after following the application of these criteria. Among the 45 papers, 23 papers utilized computational fluid dynamics (CFD) simulation to conduct the research, 12 papers carried out experiments in vehicles, 10 papers assessed the infection risk, 7 papers were epidemiological surveys that reported realistic outbreaks, and 4 papers conducted studies by mathematical models.

3. Results

3.1. Realistic outbreaks in land public transport

As shown in Table 2, 7 studies reported and investigated the outbreak in land public transport. The 'mask-wearing condition' in Table 2 refers to the paper mentioning that some passengers wore masks

Table 1
Characteristics of papers included in the review.

Transport	Research Methodology	Reference
Control measures		
Bus	CFD simulation	Yang et al. [36]
	CFD simulation and experiments	Nathan et al. [35]
	Mathematical model	Moore et al. [37]
Passenger car	CFD simulation	Shu et al. [38]
	Experiments and risk assessment model	Kumar et al. [39]
Railway	CFD simulation	Ahmadzadeh and Shams [40]
	CFD simulation	Yun and Kim [41]
	CFD simulation	Mao et al. [42]
	Experiments	Baselga et al. [43]
	Experiments	Woodward et al. [44]
Influence factors		
Bus	CFD simulation	Duan et al. [45]
	CFD simulation	Duchaine et al. [46]
	CFD simulation	Mesgarpour et al. [31]
	CFD simulation	Pavansai et al. [47]
	CFD simulation	Pichardo et al. [48]
	CFD simulation	Yang et al. [49]
	CFD simulation	Yao and Liu [50]
	Mathematical and risk assessment model	Dai and Zhao [51]
Passenger car	CFD simulation	Arpino et al. [52]
	CFD simulation	Mathai et al. [53]
	CFD simulation	Mathai et al. [54]
Railway	CFD simulation	Ahmadzadeh and Shams [55]
	Mathematical model	Seong et al. [56]
	Mathematical and risk assessment model	de Kreij et al. [57]
	Mathematical and risk assessment model	Li et al. [58]
	Mathematical and risk assessment model	Miller et al. [59]
Influence factors and Control measures		
Bus	CFD simulation	Zhang et al. [60]
	Experiments	Shinohara et al. [61]
Railway	CFD simulation and risk assessment model	Wang et al. [62]
	CFD simulation and risk assessment model	Xu et al. [63]
	Epidemiological survey and risk assessment model	Hu et al. [64]
	Experiments	Moreno et al. [65]
	Experiments	Shinohara et al. [66]
Realistic outbreak		
Bus	Epidemiological survey	Ramirez et al. [67]
	Epidemiological survey	Shen et al. [68]
	Epidemiological survey	Tsuchihashi et al. [69]
	Epidemiological survey	Vlacha et al. [70]
Passenger car	Epidemiological survey	Pongpirul et al. [22]
Transmission routes & Realistic outbreak/Control measures/Influence factors		
Bus	Mathematical and risk assessment model	Cheng et al. [30]
	Epidemiological survey, experiments, and CFD simulation	Ou et al. [20]
	Experiments	Di Carlo et al. [71]
	CFD simulation and risk assessment model	Luo et al. [72]
Passenger car	Experiments	Lednicky et al. [32]
Railway	Experiments	Liu et al. [73]
	Experiments	Zhang et al. [74]

during the epidemic outbreak, but not all passengers wore masks. Shen et al. [68] examined a COVID-19 outbreak that happened on a bus trip in Zhejiang province, China. During the 100-minute round bus trip, an index patient infected 24 passengers on the same bus. The authors found that passengers close to the index patient did not have a significantly higher risk than those in a relatively long distance, and the phenomenon was explained by long-range aerosol transmission among passengers. Ou et al. [20] also confirmed the possible long-range aerosol transmission on the insufficient ventilation coach bus and minibus. Both buses were poorly ventilated with a time-averaged ventilation rate of 1.7 L/s per person on the coach bus and 3.22 L/s per person on the minibus. Ou et al. concluded that aerosol transmission in the indoor environment was possible when the ventilation rate was less than 3 L/s per person under sufficient exposure duration.

Likewise, a high attack rate (45%) caused by insufficient ventilation happened on a Japanese tour bus that only opened the air conditioning system [69]. Similar to Shen et al. [68] and Ou et al. [20], the infected passengers were not concentrated in the two rows around the index patient. Authors attributed the high attack rate and the unfocused infected distribution to the high density of passengers, narrow space, long exposure time, and poor ventilation. Another high COVID-19 attack rate (92%) appeared on a Greek tour bus [70]. In this case, three index patients took an 8-day tour and spent 10 h every day on the bus, which caused 48 of 52 passengers infected. Vlacha et al. [70] also mentioned that 58 healthcare workers contacted 3 patients, 43% of them were exposed for more than 15 min, 74% of them were within a distance of < 1 m and about half of the contacts were not wearing a surgical mask. However, none of them had been diagnosed with COVID-19. Differences from the tour bus, the healthcare workers were exposed in a large room (15 m^2) with the window or the door opening during their exposure. The findings pointed out the high transmissibility of the virus in insufficient ventilation indoor environment, and natural ventilation could significantly reduce the infection risk. The effectiveness of ventilation in preventing the spread of COVID-19 was verified by Ramirez et al. [67] as

Table 2
Summary of COVID-19 realistic outbreaks in land public transport.

Transport mode	Location	Exposure condition	Attack rate[a]	Provided information	Reference
Bus	Zhejiang, China	1 index patient took a 100-minute round bus trip.	34% (23/67)	Physiological information[b] of patient and infectors, exposure time, seat arrangement[c], mask-wearing condition, ventilation pattern, spatial distance[d]	Shen et al. [68]
Coach bus, minibus	Hunan, China	1 index patient took a 200-minute coach bus and a 60-minute minibus.	Coach bus - 15.2% (7/46), minibus - 11.8% (2/17)	Physiological information of patients, exposure time, seat arrangement, mask-wearing condition, ventilation pattern and rate, spatial distance	Ou et al. [20]
Tour bus	Hokkaido, Japan	1 index patient had a 4-day tour and spent 18.5 h in a tour bus.	45% (18/40)	Physiological information of patients, exposure time, mask-wearing condition, ventilation pattern, spatial distance	Tsuchihashi et al. [69]
Tour bus	Greece	3 index patients had an 8-day tour and spent 10 h every day in a tour bus.	92% (48/52)	Physiological information of patients, exposure time, mask-wearing condition, ventilation pattern, spatial distance	Vlacha et al. [70]
School bus	Virginia, USA	39 index patients took school buses from Aug.31, 2020, to Mar.19, 2021.	0% (0/52)	Mask-wearing condition, ventilation pattern, occupancy rate	Ramirez et al. [67]
High-speed train	Mainland China	2334 index patients took high-speed trains from Dec.19 2019 to Mar.6, 2020.	0.32% (234/72, 093)	Exposure time, spatial distance	Hu et al. [64]
Taxi	Thailand	Index patients took a taxi.	100% (1/1)	Physiological information of patients and infectors, mask-wearing condition	Pongpirul et al. [22]

[a] Calculated by infected people/total people excluded infectors.
[b] Including gender, age, sojourn history, and asymptomatic/symptomatic of index patient or infected people.
[c] The seat locations of the index patients and infected people.
[d] The distances between the index patient and infected people.

well. School buses of an independent school in Virginia employed mitigation including opening windows to increase natural ventilation and wearing masks from Aug. 24, 2020, to Mar. 19, 2021. Even at the height of the epidemic, 39 index patients did not cause the spread of COVID-19 on the almost fully occupied school buses.

Besides the ventilation, spatial distance, and exposure duration are also important factors during COVID-19. A study analyzed the spatiotemporal distribution of COVID-19 transmission among train passengers to elucidate the relationship between infection, spatial distance, and co-travel time [64]. The data from 2334 index patients and 72,093 co-travelers who had co-travel times of 0–8 h were quantified from Dec. 19, 2019, to Mar. 6, 2020, in China. The average attack rate of passengers in seats on the same row as the index patient was 1.5% and the rate of passengers on seats within a distance of 3 rows and 5 columns of the index patient was 0.32%. Both were higher than that in other rows (0.14%). Among all passengers, the highest attack rate appeared at the person adjacent to the index patient (3.5%). In addition, the hourly attack rate increased by an average of 0.15% when traveling together while next-seat passengers increased by 1.3%.

There was an epidemic reported in the taxi [22], in which the driver contacted passengers who had frequent coughing and did not wear masks, and then received a diagnosis of COVID-19. Unfortunately, the authors did not provide information on the exposure time and ventilation. According to Tsuchihashi et al. [69], there were also passengers wearing masks being infected on a Japanese tour bus. But in the other 4 papers that provided mask-wearing conditions [20,67,68,70], all passengers who wore masks were not infected. However, Tsuchihashi et al. [69] did not point out whether infected passengers wear masks correctly, so it is hard to prove that wearing masks incorrectly leads to the spread of COVID-19.

From the 7 empirical studies, aerosol transmission has been confirmed to exist under insufficient ventilation and long exposure duration in transport. Natural ventilation can reduce infection risk effectively by supplying large amounts of fresh air. The risk reduces with a longer distance but increases with a longer exposure period. Wearing masks is also

an effective way to block the virus spread among passengers, especially in a crowded public transport environment. However, the influencing mechanism of these factors on the transmission of COVID-19 and resulting infection risk needs more case studies to investigate which is discussed in the following sections.

3.2. Factors influencing transmission of COVID-19

3.2.1. Ventilation

Ventilation has been proven as a strategy to mitigate the infection risk of COVID-19 by diluting the concentration of pathogens in the air or expelling the exhalation droplets from the exhaust air outlet. As depicted in Fig. 2a, there are mainly two vehicle ventilation modes: natural ventilation and mechanical ventilation [8,9]. Natural ventilation is a passive ventilation way of supplying fresh air to an indoor environment normally due to the external and internal differences in wind velocity, pressure, or temperature [75–77]. Mechanical ventilation is the intentional movement of supplying or exhausting air by using heating, ventilation, air-conditioning, and cooling (HVAC) [78–80].

3.2.1.1. Natural ventilation

Natural ventilation is a low-cost, economical, and energy-saving alternative in land public transportation. It can effectively reduce the infection risk, which has been verified in real cases [67,68,70], experiments [35,39,66], and modeling [38,48,50,53-55,72,81,82]. When the vehicle is driving, the external airflow generates a pressure distribution over the vehicle - the areas near the front are lower-than-atmospheric pressures, while the areas toward the middle and rear of the vehicle are neutral or higher-than-atmospheric pressures (Fig. 2b-c). Therefore, various ways of natural ventilation have different efficiencies in supplying fresh air and removing pathogen-laden droplets. Natural ventilation is mainly associated with the locations of ventilation openings (e.g., windows, doors, and skylights), the sizes of ventilation openings, and the driving speed.
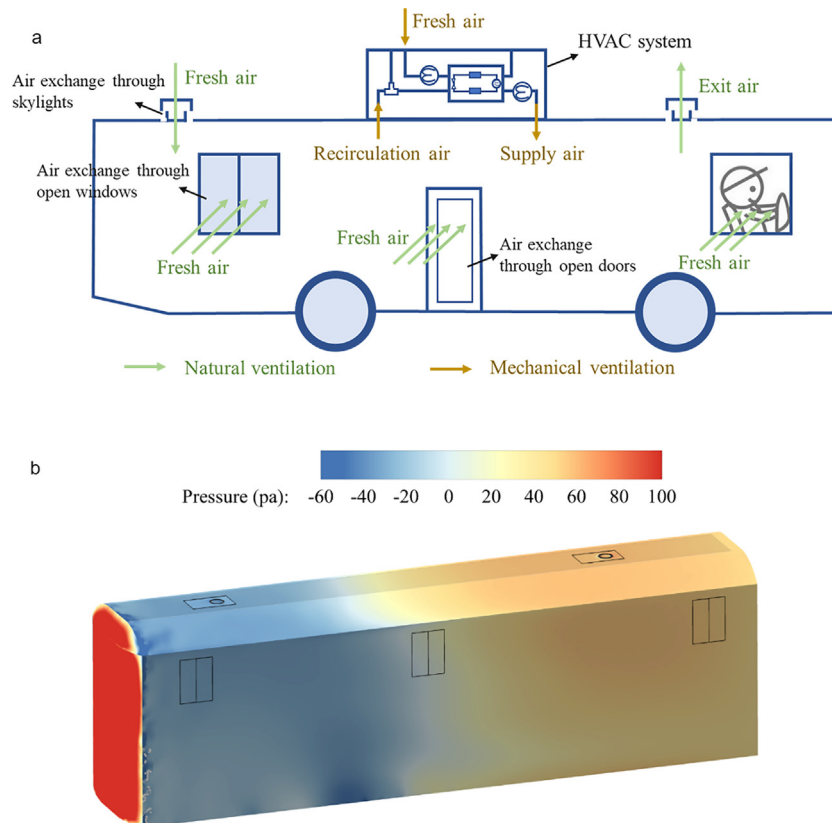
Fig. 2. (a) Schematic diagram of natural and mechanical ventilation in vehicle; (b) pressure distribution on coach bus exterior [53].

According to Li et al. [83], when opening the front windows of a school bus, the ventilation was better than opening the middle windows. The same applied to the minibus and taxis, only opening the front windows provided the most ventilation compared to only opening the middle windows or the rear windows [84]. Moreover, inlet ports at the frontal and sunroof could also effectively carry fresh air into the vehicle [48,54,81,85]. Two studies revealed that when the infector was near ventilation openings, especially the windows in the row in front of the infector, could effectively remove his exhaled droplets and thereby reduce the infection risk of other passengers [50,55] Meanwhile, droplets generated by the front-seated person were easier to be discharged by opening windows than that generated by rear-seated passengers [38,53]. In a nutshell, the potential infector should sit in the front seat and open the windows near him, especially the front-row windows, to reduce the pathogen-laden droplets in the cabin.

The size of ventilation openings is also a factor that affects natural ventilation. Several studies found a notable improvement in the ventilation rate when opening windows increased to two pairs from one pair [48,83,84]. Two pairs of opening windows could supply ventilation rates close to even exceeding WHO recommended per-person requirements for high-risk clinical areas [84]. Therefore, it is very important for proper circulation and renewal of air to leave at least two open windows. Experiments conducted by Shinohara et al. [66] indicated that air exchange rates in a train increased from 0.60/h with all windows closed to 4.4/h with all windows fully open, leading to the infection risk of other passengers reduced by 91%–94%. Mathai et al. [53] found that all windows half open had almost the same ventilation effectively as all windows fully open when the door was open. It means that the open area of windows becomes less important once sufficient ventilation is supplied (enough windows, doors, skylights, etc. open), which is also mentioned in Shinohara et al. [66]. When driving at a relatively high speed or under inclement weather, partially open windows in multiple

locations present a practical compromise. Maintaining at least two open windows on each side wall, two at the front and rear, is very important for proper air circulation and renewal. Moreover, when it is safe and possible to do so, it was recommended to open the door when parking for better air exchange [35].

Under the same window opening conditions, the amount of ventilation brought by various vehicle speeds will be different. Generally, increased bus speed can enhance natural ventilation [38,54,66,72]. The air exchange rates in the train with all 12 windows opened to 10 cm increased from 10/h to 42/h as the train speed increased from 20 km/h to 57 km/h [66]. Matose et al. [84] found that with the decrease in the ventilation rate caused by the decreased vehicle speed, more windows needed to be opened to meet WHO ventilation requirements. Hence, we should pay more attention to the ventilation of vehicles driving at low speeds or stuck in traffic. The study by Mathai et al. [54] recommended opening the left front window near the driver and running the air conditioner to the maximum to eliminate the aerosol contaminants released by the driver/rear passenger at low speeds. Nikam and Borse [86] suggested opening all windows on the bus at low operating speed to ensure adequate ventilation. Therefore, no matter what the situation is, it is the most effective way to ensure that the windows are opened as large and as many positions as possible.

3.2.1.2. Mechanical ventilation

Mechanical ventilation is a mode that mainly relies on the wind pressure generated by the fan to achieve the purpose of ventilation. As this mode can provide constant fresh air with suitable temperature independently of external weather conditions, it plays an important role in the passenger cabin to optimize energy efficiency and ensure passenger comfort, especially in enclosed vehicle cabins or under extreme external weather conditions. Since the outbreak of COVID-19, much current literature on the indoor environment paid attention to ventilation strategies applied in mitigating cross-infection risk
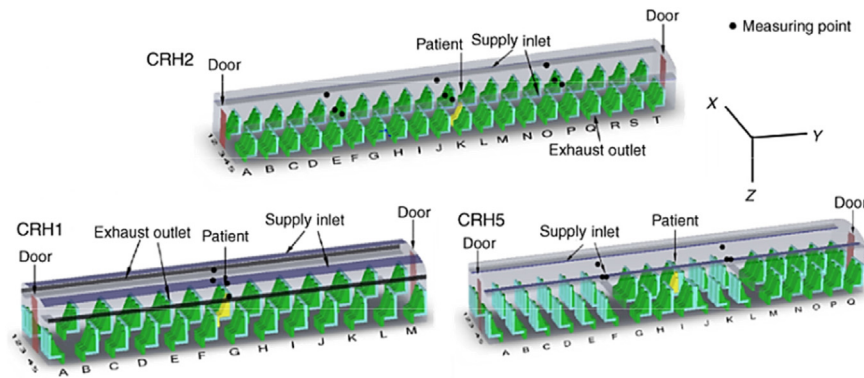
Fig 3. The geometry and air distribution system of CRH1, CRH2, and CRH5 models [92].

among occupants indoors [87,88]. The air-conditioning system (HVAC) can significantly change the concentration distribution of SARS-CoV-2 and a reasonable airflow pattern can help reduce the accumulation of the virus [89]. Most railway public transport (trains, high-speed rails, subways, etc.) are relatively enclosed environments, and poor ventilation in these transport cabins has been proved as one vital reason for cross-infection [40,62]. Increasing the overall ventilation rate under a well-mixed situation and improving the ventilation efficiency in the target area can reduce the infection probability in the indoor environment [90,91].

Mixing ventilation system is the most common full ventilation mode of public transport cabin, increasing the air change rates (ACH) of mixing ventilation (MV) can effectively dilute the concentration by accreting the aerosols mixing with ambient air and decreasing the droplet residence time [40]. However, the high ACH also may promote the spread of the virus among the passengers and increase energy consumption. The time scale of transit from an infector to other passengers is less than a minute with the HVAC system under its maximum settings [60]. When the ventilation system is under a typical setting (75% force cooling), the air cannot be well mixed along the length of an intercity train carriage [44]. This is caused by the interaction of multiple airflows (e.g., body plume, supply jet, exhaust airflow, and respiratory airflow) which significantly increases the complexity of airflow organization. Apart from that, the arrangement of air supply inlets and exhaust outlets can also affect the airflow distribution a lot [40]. Wang et al. [92] evaluated three different air distribution systems in typical China railway high-speed cabins (CRH1, CRH2, and CRH5) (Fig. 3). With different air distribution systems, the ventilation efficiency in CRH1, CRH2, and CRH5 train cabins was 0.1278, 0.1618 and 0.5356, respectively. The most effective ventilation system in removing the cough droplets was when the supply air inlets were located above the luggage on each side wall and the door was considered as an exhaust air outlet.

Some non-uniform ventilation systems (e.g., displacement ventilation (DV) and personalized ventilation (PV)) can also reduce the risk by providing high-efficiency ventilation in target areas. Compared to MV, the DV system plays a more positive role in controlling pathogen-laden droplets spread in the breathing zone of occupants, while the DV can also lead to poor thermal comfort due to the thermal stratification in the vertical direction [93,94]. PV can supply fresh air directly into the human microenvironment thus increasing the ventilation efficiency in the breathing zone, which means the PV also has the potential to mitigate the infection risk of passengers in transport [93,95]. Mboreha et al. [96] investigated six innovative PV system characters in the passenger cabin by CFD simulation and found that setting a personal outlet on both sides of the passenger's head was the most effective set to remove pathogen-laden droplets. The strengths and weaknesses of three typical ventilation modes are listed in Table 3. Yun and Kim [41] proposed a novel vertical drop air (VDA) flow system in a high-speed train cabin

and found that the droplet number decreased by 72.1% from the conventional system to the VDA system.

In addition to the ventilation system, the amount of fresh air would also have an important impact on virus removal efficiency. The more outdoor clean air supplied by the ventilation system, the lower the infection risk can be achieved. When fresh outdoor air accounts for the supplied air increase from 25% to 100%, the risk will be reduced by 27% [21]. While, the outdoor air usually requires to be heated or cooled before being supplied into the cabin to meet the thermal comfort needs of passengers in transport, which typically means a large energy requirement. To minimize the energy consumption of the ventilation system, most of the supplied air is set as a mixture of outdoor air and recirculated air (typically 60%–70% recirculated air) rather than full outdoor air [97]. However, the recirculation of air can contribute to the dispersion of SARS-CoV-2 throughout the whole cabin space [68]. Moreno et al. [65] collected samples inside the buses and subway trains, 4 of 9 samples collected in filter dust showed SARS-CoV-2 RNA, which confirmed the possibility of the virus being transmitted through the air in circulation. Besides, Kumar et al. [39] compared three ventilation settings in a taxi car, the infection risk increased fastest when the windows were closed with air-conditioning on recirculation mode compared with the other two settings with air-conditioning on ambient air mode. Therefore, the recirculated air should be avoided as much as possible when air-conditioning is used.

Edwards et al. [35] proved that adding an air filter to the HVAC return air vent on a transit bus could significantly improve the removal of aerosol. Besides that, the filter efficiency of the filtration system is also a vital element that affects droplet transmission in the transportation environment. The efficiency varies significantly from country to country in the design of vehicle carriages. ASHRAE developed MERV (minimum efficiency reporting value) and HEPA (high-efficiency particulate air) are the criteria for measuring the efficiency of air filters. The typical filter efficiency of aerosols ranges between 1%–15% for MERV4 filters, 17%–50% for MERV7 filters, and 99.9% for HEPA filters [98]. Unlike airplanes and hospitals, most land transportation usually uses rough filters to clean recirculated air instead of HEPA. These rough filters are too coarse to remove small aerosols, so aerosols will back to the cabin with recirculated air and cause a high infection risk among passengers. Anozie [99] found the removal efficiency of particles greater than 3 μm on a typical UK long-distance train filtration system was 35%–85%, which is much lower than HEPA. Baselga et al. [43] tested the performance of a typical filter installed on a tram (coarse 75% filter media) to evaluate the removal effectiveness of submicron particles. The test results presented that the filter efficiency for 0.3 μm particles was about 27.9% and the filtration system was not efficient against the submicron matter. de Kreij et al. [57] presented that increasing filtration efficiency, especially for small-size particles could significantly reduce the average infection risk, and the maximal efficiency of 100% could reduce the risk

Table 3
Advantages and disadvantages of three typical ventilation modes.

Ventilation mode	Advantages	Disadvantages
Mixing ventilation (MV)	Better thermal comfort; accelerated dilution; simple control system [40]	Promote aerosol diffusion in the whole cabin; high energy consumption [44,60]
Displacement ventilation (DV)	Inhibit virus dispersion; low air supply velocity [93,94]	Poor thermal comfort; contaminated gas accumulation [93,94]
Personalized ventilation (PV)	High ventilation efficiency; Individual needs; low energy demand [93,95,96]	Complex ventilation setting systems; immature design application specifications [91,95]

Table 4
Information of droplets generated from human respiratory activities.

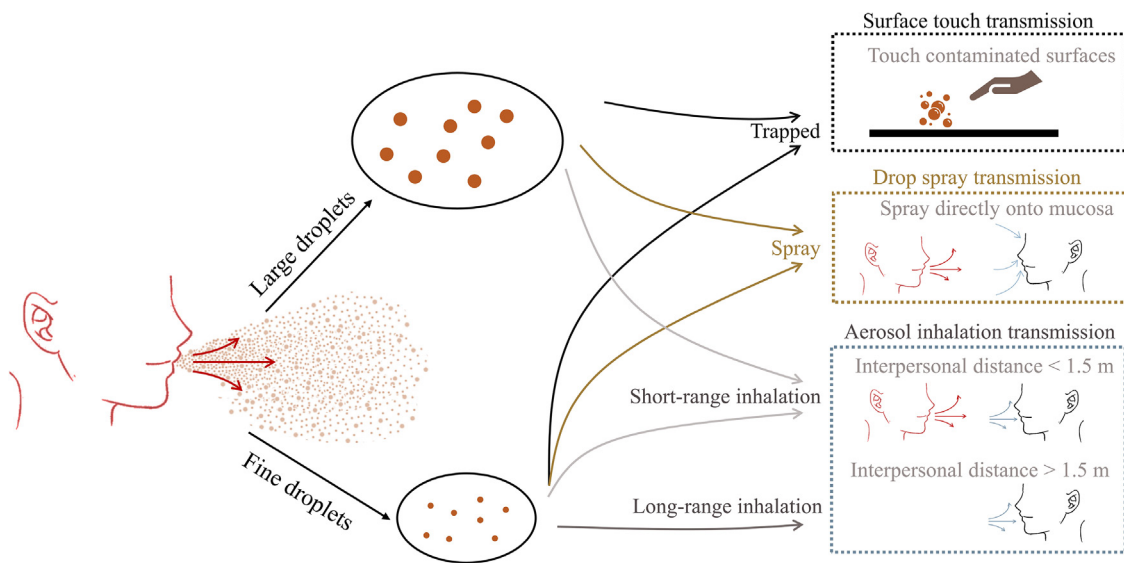| Activity	Droplet number	Diameter distribution	Initial velocity	Ref.
Breathing	50–92 L^{-1}	0.3–20 μm	0.58–1.03 m/s	[105,106]
Coughing	947–2085 event^{-1}	3–750 μm	11.7 m/s on average	[110]
Sneezing	1×10^6 event^{-1}	10–420 μm	Up to 46 m/s	[108]
Speaking	112–6720 event^{-1} (counting 1–100)	3–750 μm	3.9 m/s on average	[110]

Fig 4. Droplets of various diameters caused different COVID-19 transmission routes (Modified from ref. [73]).

by 60% compared with no filter. Wang et al. [62] found that if increasing the filtration efficiency of a long-distance train from 20% to 100%, the reduction in the average number of secondary infections would be up to 40%.

3.2.2. Human respiratory activities

Surface touch transmission, drop spray transmission, and aerosol inhalation transmission have been proven as three major transmission routes of COVID-19 [100,101] (Fig. 4). The characteristics of human respiratory activities (e.g., breathing, coughing, sneezing, and speaking) are generally thought to be important vectors of disease transmission [102,103]. This is because droplets generated by various respiratory activities have different initial velocities and diameters, these features of droplets can significantly affect their transmission routes. The diameter distributions and initial velocities of four common respiratory activities are listed in Table 4. Breathing is a persistent respiratory pattern, more than 95% of droplets released by breathing were smaller than 5 μm with a speed of 0.58–1.03 m/s [104–106]. Coughing and sneezing are transient respiratory patterns [107]. The diameter of droplets expelled by sneezing can reach 420 μm and the speed can reach 46 m/s [108]. Speaking is one of the most common activities, the duration of speaking is random in different situations. Xie et al. [109] found that the number of droplets produced in a 5-minute speaking was the same as single coughing.

Droplets with a diameter smaller than 5 μm are regarded as fine droplets, while droplets with a diameter larger than 5 μm are regarded as large droplets [73,111,112]. Large droplets are always generated through coughing, sneezing, and speaking. Due to gravity, the large droplets are too heavy to remain in the air and quickly land on nearby surfaces in the cabin [50]. Passengers can be infected by touching contaminated surfaces thus leading to surface touch transmission (Fig. 4). Of all surfaces in the vehicle cabin, the droplets deposit most on human body surfaces, especially those of the person adjacent to the infector [36,40,72]. For the short social distance, high-velocity droplets sprayed by infectors can also directly settle on nearby passengers' mucous membranes (such as eyes, nose, and mouth) or be inhaled, causing drop spray transmission and aerosol inhalation transmission (Fig. 4). As for fine droplets, they can quickly evaporate into relatively small-diameter droplet nuclei before deposited, the small size droplets has good airflow following and can travel long distances in the cabin [49,72]. Studies found that droplets smaller than 20 μm could remain in the air and disperse far in the cabin, which increased the risk of aerosol inhalation transmission [38,60,72,82]. Such pathogen-laden droplet nuclei are capable of infecting people in the whole cabin, thereby transmitting COVID-19 over long social distances (Fig. 4).

Duchaine et al. [46] researched droplet dispersion due to continuous breathing and talking of infected occupants on a bus by CFD simulation. Since this was a continuous process, Duchaine did not compare the difference in droplets spread between these two respiratory activities. Kumar et al. [39] estimated the probability of transmission from an infected occupant in a car by using the Wells-Riley equation and revealed that the probability of COVID-19 transmission increased by 28.5%, 5.1% and 1.1% per hour when loudly speaking, speaking, and oral breathing in the car with recirculation air-conditioning. Experiments conducted in rush-hour subway found that the infection risk for short-range inhalation, long-range inhalation, and deposition was 31.6, 10.2 and 159.8 times higher when the talk rate raised from 0% to 50%, respectively [73]. All these results lead to the conclusion that avoiding speaking in public vehicles can effectively reduce the infection risk.

3.2.3. Environment inside land public transport

Environmental factors such as ambient relative humidity (RH), temperature, and sunlight can significantly affect disease transmission. Apart from that, van Doremalen et al. [113] discovered that SARS-CoV-2 could survive outside a host for variable durations with different environmental conditions.

The diameter of the exhaled droplets would decrease under evaporation, which was mainly driven by the vapor concentration gradient between the droplet surface and the surrounding air [114]. Several studies found that at high RH, the evaporation rate of droplets was slow and resulted in a low mass decline speed of droplets [40,49,72]. As the time required for evaporating increased, the droplets would deposit more quickly due to gravity. Thus, Yang et al. [49] and Ahmadzadeh and Shams [40] both claimed that increasing the RH of the supply airflow could accelerate the deposition of droplets and reduce the infection risk of passengers. For droplets smaller than 10 μm, they evaporated too fast that could not show an obvious difference in the evaporation time under RH = 30% and 95% [49,72], thus RH rarely influenced their dispersion for small-size droplets.

Increased temperature of supply air will supply more latent heat to accelerate the evaporation process of droplets [40]. Hence, droplets at higher ambient temperatures will be deposited slower and less on surfaces than at lower ambient temperatures [40]. Duan et al. [45] stated that the droplet concentration on the bus was significantly higher 1 to 2 times when the ambient temperature was 25 °C than that of others (5 °C, 15 °C, 35 °C). Thus, Duan claimed that there might be an optimal temperature (25 °C) for droplet spread. Moreover, the temperature difference between indoors and outdoors affects the natural ventilation as well. Experiments by Shinohara et al. [66] revealed that natural ventilation rates through opened windows were positively correlated with the absolute value of the indoor and outdoor temperature difference, but the correlation was weak. Besides, the effect of the temperature difference on natural ventilation rates became smaller when outdoor wind speed was greater.

3.2.4. Spatial distribution of passengers

Keeping suitable social distance is an effective strategy to control the spread of the epidemic because this measure avoids direct contact among people and reduces the infection risk of drop spray transmission [115,116]. CDC recommended that 2 m should be kept from others [117], Sun et al. [118] proposed that 1.6–3.0 m was the safe social distance when considering the proximity of large drop spray transmission during mutual conversation activities, and the aerosol with the virus could spread 8.2 m under calm air environment. Li et al. [58] recommended the average distance between passengers in a subway should be at least 1 m. However, most of the social distance between adjacent passengers in public vehicle cabins is usually less than 1 m. For example, the average interpersonal distance in the subway during rush hour is only 0.8 m [73], which is smaller than most other social distances in the indoor environment. The proximity exposure typically means a higher

infection probability. Especially during rush hours, the rapidly increasing passenger loading leads to even smaller social distances between passengers. The risk of infection increased with the reduction of social distance significantly, if the loading rose from 70% to 100%, the exposure dose would increase by 60% [59]. When raising the capacity of a train from 14 to 85 passengers, the average infection probability would increase by 46% [62]. Thus, it is necessary to control the density of passengers in the carriage during the epidemic. Sun et al. [118] indicated that halving the occupancy density could achieve a decrease in infection risk by 20%−40% under the same ventilation system. Moreover, Hu et al. [64] quantified the infection risk of COVID-19 in a high-speed train and found that the passenger sitting in the same row as the infected passenger had the highest attraction rate. When the distance between the passenger and the infector was 0, 1, and 2 rows, the average infection risk would decrease by 6%, 14% and 22%, respectively [57]. Therefore, when the epidemic situation is serious, sitting in the same row should be avoided, and it is better to sit a few rows apart when conditions permit.

The infection risk in vehicle cabins was non-uniformly distributed, and the infector position could impact the infection risk distribution significantly. de Kreij et al. [57] investigated the relationship between the infector position and average infection risk by 1-D model. The result illustrated that if the infector sat in the middle zone of the cabin, the infection risk of other passengers would be the highest under the same ventilation setting. The relative position of the infected source and air exhaust outlets also plays an important role in the spatial distribution of infection risk. Ahmadzadeh et al. [55] found that when the source sat near the airflow exit and the outlet was located at the bottom of the train wall with windows open, the infection risk of other passengers would decrease by 87%. Duan et al. [45] estimated the concentration of the droplets on a bus with various infector positions. The results indicated that regardless of the infected passenger's location, seats located in the last row of the bus, away from the doors, were associated with lower risk, while the middle seats near the door presented higher-risk conditions in all scenarios. Edwards et al. [35] observed that the rear seating area of the bus tended to accumulate more particles with windows closed when the two cough sources were located in the middle and front of the cabin. This result indicated a higher exposure risk in the back seats.

The relative face orientations of the infector and other people affect the virus exposure significantly. Liu et al. [73] considered the infection risk of four face orientations in a subway, namely random (RD), same direction (SD), face-to-face (FF), and face-to-side (FS). The short-range inhalation and deposition exposure were the highest for FF, followed by RD, SD, and the lowest for FS. Nielsen et al. [119] found that the highest exposure was obtained in the face-to-face orientations, followed by face-to-side and face-to-back. Liu et al. [95] investigated the effects of relative orientations on the infection risk of passengers under personal ventilation, and the results revealed that the target passenger back to the infector was a recommended orientation for infection risk mitigation.

3.2.5. Masks and partitions

Wearing masks is a primary strategy for blocking the spread of virus-containing aerosols among passengers in public transport. Edwards et al. [35] and Yun et al. [41] both proposed that wearing masks could effectively reduce the total number of droplets released into the cabin and decrease the spread distance. When both the infector and susceptible person wear masks, the required safe ventilation rate will be reduced, which means lower energy consumption [51]. The proportion of passengers wearing masks can impact the mean dose of the received pathogen significantly while having a modest effect on the median dose [59]. Moreover, different types of masks have different protective effects, and the reduction in the average emission rate ranges from 30% to 95% [120]. Zhang et al. [82] showed that both the surgical mask and handmade mask could reduce the transmission of diseases and the protective effect of surgical masks was higher than handmade ones. When both

infected and susceptible passengers wore a surgical mask, the transmission of this disease could be nearly eliminated. Liu et al. [73] compared different situations of mask-wearing to the no-masking case in a subway. They found that personal exposure was reduced by 99.5%, 82.0% and 41.5% when all passengers wore N95 respirators, surgical masks, and cloth masks (without filtration layer), respectively. This study also proposed that the infector wearing a surgical mask alone was more effective than only the susceptible wearing a mask. Wang et al. [62] coupled Wells-Riley (WR) model and CFD to analyze the COVID-19 infection probability (IP) in two typical Chinese long-distance trains: the train CRH1 (top inlet and side wall outlet) and train CRH2 (side wall inlet and seat bottom outlet). For both scenarios, when 90% of passengers wore high-efficiency masks (e.g., N95), the average IP was reduced by 95% compared with the basic case (40% of passengers wearing low-efficiency masks) after 8-hour exposure time.

Setting physical partitions between passengers in the public transport system is also a low-cost way to block disease transmission. Installing physical partitions around the head and above the seat could reduce the infection risk of passengers, and the partition could decrease the fraction of suspended particles by more than 50% [40]. The partitions combined with different ventilation strategies could effectively reduce cross-infection among passengers indoors, and setting desk partitions above 60 cm could reduce the infection risk by 72% with a proper ventilation mode (with 1.73 m^3/s supply air rate) [121].

4. Discussion

4.1. Characteristics of COVID-19 outbreaks in land public transport

The traffic network has been considered as a critical way for COVID-19 transmission, especially the railway network (e.g., road and train traffic) [122]. Public transport, which has poor ventilation, high passenger density, and prolonged exposure, poses a high risk of COVID-19 transmission. Compared to airplanes and cruise ships, land public transport is a more common way of traveling and commuting (e.g., bus, subway, car, taxi, train). While land public transport usually has lower criteria for the environment and rougher ventilation systems compared with aircraft. For instance, aircraft install HEPA filters to purify the recirculated air with an efficiency of up to 99.9%, while the filtration efficiency of most land public transport is less than 85% [43,99]. Moreover, the mobility and sources of passengers are larger and more random with an undemanding nucleic acid testing system before and after travel. Therefore, the lack of rigorous screening of passengers' identity and travel history on land transportation, unlike on airplanes, leads to a higher risk of infection.

Ventilation methods in land public transportation vary. Some modes, such as trains and subways, are relatively enclosed environments where mechanical ventilation is employed to maintain passenger comfort and air quality. In contrast, others like buses and taxis have the flexibility to utilize a combination of natural ventilation through open windows and mechanical ventilation. For mechanical ventilation, the ventilation-related parameters (e.g., temperature, relative humidity, and velocity) can be controlled precisely by related settings, while this ventilation mode needs a large amount of energy consumption to supply enough clean air and ensure the safety and comfort of passengers. In addition, the recirculated air in the HVAC system may lead to secondary infections [65,68]. Nature ventilation is an energy-saving ventilation mode but is influenced by the outdoor environment and other elements (e.g., vehicle speed, location of window, window opening size) that cannot be accurately controlled [54,66,84]. Therefore, how to coordinate nature and mechanical ventilation according to the specific transportation environment need to be further investigated.

Moreover, the limitation of passengers' activity varies in land transport. Passengers can walk around freely in the carriage of some vehicles (e.g., bus, subway, train) and even stand in the aisle when no seat is available, while the passengers on the coach bus are not allowed to stand

or leave their seats during the journey for safety. The complex human activities and doors opening at stations will affect the spatial distribution of droplets inside the cabins and bring difficulties to disease transmission control. Besides, the relative orientations of passengers in land transportation also have a significant impact on cross-infection. Among the common orientations (e.g., face-to-face, face-to-side, and side-by-side) in land transportation, face-to-face is considered as the highest infection risk orientation for adjacent passengers. Avoiding face-to-face conversation during the journey can be helpful to mitigate the infection risk [73]. The social distance between passengers and the capacity of land transport is random and varies with time, and the infection risk is generally highest during rush hours due to the great passenger capacity [73]. Therefore, staggered travel is recommended during daily commuting or long-distance traveling.

4.2. Transmission routes in land public transport

The relative importance of various transmission routes needs to be determined which is critical for making effective interventions to minimize transmission. Based on the ability of SARS-CoV-2 to survive on common surfaces, it was suspected in the early days of the outbreak that COVID-19 was mainly through surface touch transmission [113,123]. However, Goldman [53] pointed to a low risk of surface touch transmission, a view shared by Mondelli et al. [124] and Pitol and Julian [125]. Shen et al. [68] and Ou et al. [20] conducted epidemiological surveys on buses with COVID-19 outbreaks and revealed that aerosol inhalation transmission should be the main transmission route rather than surface touch transmission. Subsequently, Cheng et al. [30] refined previous research and calculated the infection risk of each passenger in a two-bus COVID-19 outbreak reported by Ou et al. [20]. Results suggested that the overall infection risk via airborne transmission was much higher (approximately 1×10^6–1×10^8 fold higher) than that via fomite (surface touch) transmission. One reason is that no one left seats during the whole trip, except when getting off, and no one used the toilet on the bus. This means that there is no opportunity for passengers to touch each other during the trip. In addition, buses used digital tickets, so the only chance for passengers to touch shared surfaces was when they got on or off. These greatly reduced the chance of surface touch transmission. Moreover, the index case did not have any symptoms or talk to anyone, so the only direct way he could have spread virus-laden droplets was by normal breathing. Only a low amount of exhaled tiny droplets were left on touchable surfaces on the buses. This means it was likely that very few live viruses would have been on only a few shared surfaces. Moreover, Zhang et al. [74] monitored SARS-CoV-2 in air and surfaces in buildings and buses on a university campus, and found that the risk of aerosol inhalation transmission is much higher than surface touch transmission - about 1,000 times higher. Similarly, Liu et al. [73] confirmed inhalation exposure was much higher than deposition exposure in the subway as well. At the same time, due to the particularity of the traffic environment, the average distance between people is 0.8 m [73], which is far less than the recommended safe social distance of 2 m. Thus, drop spray transmission can occur commonly in the traffic environment, while it has been proven to be relatively insignificant in comparison with aerosol inhalation transmission [126–128]. Thus, compared to surface touch transmission and drop spray transmission, aerosol inhalation transmission is more noteworthy.

Aerosol inhalation transmission can occur both in the short range and long range. The short-range aerosol transmission which mainly happened within 2 m is considered to be the main route for COVID-19 transmission [128,129]. Liu et al. [73] found that the infection risk was the highest through short-range aerosol inhalation, and was 7.5 times higher than long-range aerosol inhalation in the rush-hour subway. However, long-range aerosol transmission can also occur in public transport due to the high density of passengers, insufficient ventilation, and long exposure time. Aerosol concentrations are a function of source intensity, ventilation rate, and exposure duration. When ventilation is low enough

and exposure time is long enough, indoor average concentrations can be large enough to cause transmission [51,64,128]. Many outbreaks such as the Japanese tour bus outbreak [69], the two-bus outbreak in Hunan [20], and the bus outbreak in Zhejiang [68] all attested that long-range aerosol transmission was also an important transmission route, especially in the crowded and poorly ventilated indoor environment. Moreover, air-conditioning with air recirculation is a mechanical ventilation method commonly used in public transport, which also provides favorable conditions for long-range aerosol transmission [35,130]. In a nutshell, aerosol inhalation transmission plays a primary role in COVID-19 transmission on land public transport, no matter long-range or short-range.

4.3. Epidemic prevention measures in land public transport

Since the outbreak of COVID-19, most countries have taken corresponding control measures for epidemic prevention and control of public vehicles. For instance, Numerous studies have confirmed that increasing ventilation can effectively reduce the infection risk (e.g., [40,72,131]). However, a higher ventilation rate always means larger energy consumption, especially in some relatively enclosed vehicle cabins that can only use a mechanical ventilation system. Three ways may balance the energy saving and risk decrease. The first one is to improve the efficiency of a ventilation system. For example, reduce the distance between the air supply vent and passengers' breathing zones or provide personalized ventilation to passengers directly [131]. The second one is to consider opening windows or skylights to supply natural ventilation if the weather conditions are suitable to ensure the comfort of passengers. This ventilation mode achieves a balance between energy saving and disease control. The last one is to increase the proportion of fresh air in the air conditioning circulation system as much as possible [132]. If using recirculating air, the 'dirty' air should be disinfected before supplying it to the cabin. Apart from this, increasing the filter efficiency of the ventilation system filter, especially for the small size droplets can reduce infection risk significantly. Moreover, Querol et al. [133] revealed the effect of ventilation systems on CO_2 levels and suggested the application of this type of monitoring system for real-time virus transmission risk warning on public transport. This provides a new idea for the monitoring system of future public vehicles. In addition to the filter of the ventilation system, installing ultraviolet germicidal irradiation (UVGI) systems can also be considered as an air cleaning strategy. [132,134]. Upper-room UVGI was always combined with other control strategies. The pathogen removal effectiveness of a well-designed upper-room UVGI system is equal to supplying 12 to 16 ACH to the room [132,135]. The pathogen removal rate relies upon the operation time and the pathogen inactivation rate of UVGI. The UVGI system is equal to providing 9.6 ACH under a displacement ventilation system, which is only 80% of mixing ventilation [134]. The application of UVGI in land transportation needs to be further studied and experimented with.

Increasing the social distance of passengers and reducing the passenger capacity of vehicles have been recommended by various health organizations. For example, during May 2020 in New South Wales, Australia, the capacity of the standard 12-meter-long bus and the train carriage has been reduced to 12 and 32 passengers, respectively [34]. Hu et al. [64] concluded that within 1 hour spent together, the safe social distance was > 1 m, while after 2 h of contact, a 2.5 m distance may not be enough to prevent transmission. Therefore, to effectively lower the infection risk and ensure the capacity of vehicles, different interpersonal distances can be adopted for vehicles with different travel durations. Moreover, the relative position and orientation of exposed passengers and infected passengers also affect the infection risk significantly. Avoiding face-to-face orientation can effectively reduce the infection risk. Apart from this, setting partitions between passengers can block the diffusion of droplets [136], while the partitions can also be a limitation of human activities and ventilation flow. Therefore, professional design of partitions must be done to optimize the air distribution

and reduce infection risk in the transport environment. Moreover, as a recommended precaution, high-touch surfaces on public transport and stations should be cleaned frequently which is an effective way to avoid surface-touch transmission.

In addition to making recommendations for the transportation system, many countries have also taken epidemic prevention measures for passengers themselves. Countries such as Japan, South Korea, and China all require people to wear masks in public [137]. Wearing masks on public transport is an effective way to stop the spread of the COVID-19 virus, provided that the appropriate masks are used and that people know how to wear and handle them properly. Education on the proper use of masks is as important as mandating universal mask use because the incorrect wearing of masks can reduce aerosol filtration efficiency by 60% [138]. Eye protection can also reduce the probability of COVID-19 transmission [139], but it is not mandatory for public transport passengers to use eye protection. Only high-risk workers such as bus drivers may be considered. Measures such as the prohibition of talking, not spitting, and maintaining personal hygiene (such as washing hands frequently) can also greatly reduce transmission possibility, and countries such as Singapore have already adopted these measures [137]. Contact reduction measures such as using electronic tickets, choosing online payment, and avoiding going to the toilet as much as possible should be also advocated during the epidemic.

4.4. Limitation and outlook

Since the first patient infection by SARS-CoV-2 was reported at the end of 2019, the COVID-19 epidemic has coexisted with humans for more than three years. The number of studies about the COVID-19 epidemic on land public transport is also increasing rapidly. However, when we conducted literature research, we found that there were only 7 studies on epidemiological investigations of realistic epidemics, and the information provided was also limited. There was only one epidemiological investigation that provided data on the ventilation rate of buses at the time of the outbreak [20], and three studies mentioned the ventilation pattern (i.e., natural ventilation or mechanical ventilation) in the venue vehicle [67–69]. This poses an inconvenience for later researchers who want to utilize information on real events to explore the relationship between ventilation and infection risk. Moreover, it is necessary to obtain data on passengers' behavior in the transport at the time of the outbreak (e.g., exposure time, behaviors and activities, mask-wearing conditions, and spatial distribution). However, access to these data will be challenging. Although recordings from closed-circuit television (CCTV) cameras may be available, owners may be reluctant to share this information due to privacy concerns.

As for modeling and simulations, more real and detailed situations need to be considered. Vaccination has become widespread worldwide, and this is an important factor that should be considered in prediction models and risk assessment models. New variants of SARS-CoV-2 will appear about every six months and their transmissibility and pathogenicity are very different [140]. Thus, various infection rates should be considered for different virus epidemic periods in modeling. Moreover, more simulations should be conducted based on realistic cases (e.g., [49,72,141]) to explore transmission reasons and influence factors, rather than limited to ideal environments. Although the public transport industry responded quickly in the early stages of the pandemic and developed operational guidelines to reduce the risk of disease transmission [33,34], the mitigation measures implemented varied widely and the effectiveness of epidemic prevention remained to be accessed due to the guideline lacking a clear scientific basis. Thus, it is significant to assess the effectiveness of various control measures. In addition, by combining risk assessment models, simulations, and experiments, researchers can estimate the spread of pathogen-laden droplets and the resulting infection risks. Determining the impact of various factors on reducing infection risks (e.g., [36,72,131]) requires further investigation in future research.

5. Conclusion

Land public transport is an indoor environment where people stay daily. However, due to its crowded passengers, insufficient ventilation, close social distance, and long exposure time, it is a high outbreak area for the COVID-19 epidemic. The main transmission route of COVID-19 in the transportation environment is aerosol inhalation transmission. Unlike outdoor and well-ventilated indoor environments, there is inadequate ventilation within the land public transportation environment, resulting in long-range aerosol transmission. Moreover, due to the large variety of contaminable surfaces and the proximity of passengers, surface touch transmission and drop spray transmission cannot be ignored as well.

Many factors affect the spread of COVID-19 in land public transportation environments, such as ventilation conditions, ambient conditions (e.g., temperature and RH), social distance and relative orientations, and mask-wearing situations. Ventilation is an important influencing factor; increasing the ventilation rate, especially the amount of natural fresh air, can effectively reduce the infection risk of passengers. Meanwhile, properly wearing masks, increasing social distance, avoiding face-to-face orientation, setting partitions, and disinfection frequently are all reasonable and effective preventive measures. Through this review, we can further improve the knowledge of the transmission characteristics, transmission routes, and influencing factors of COVID-19 in land public transport. We also discuss the existing epidemic prevention measures, providing valid suggestions and a scientific basis for establishing epidemic prevention measures in the future.

Declaration of competing interest

The authors declare that they have no conflicts of interest in this work.

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