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A CFD research study on the validity of dividers in vehicles

Xilai Xiao

City University of Hong Kong. Tat Chee Avenue Kowloon, Hong Kong, China

xilaixiao2-c@my.cityu.edu.hk

Abstract. People who misjudge the infectious ability of Covid-19 pathogen may abandon non-pharmaceutical interventions (NPIs), such as masks, gloves, especially in today's situations where isolation rules and mask limitations have been eliminated in most nations. Consequently, in public spaces with poor ventilation and high population density, individuals who do not wear masks are more likely to become infected. This article focuses on the scenario of Covid-19 pathogen spreading in a cab with only the driver and a passenger present. We also examine whether the use of a divider - a plastic board that separates the front and back of the cab, can lower the likelihood of infection compared to the situation that a divider is installed. To access the likelihood of infection, we simulate the fluid field inside a closed cab using the computational fluid dynamics (CFD) approach. We set the mutual situations – one is with infected driver and another is with infected passenger, in order to make our simulation more general.

keywords: Ultra-Wide Band (UWB), RTT ranging motion recognition, keyframe.

1. Introduction

1.1. Background information

In 2019, the novel coronavirus, known as COVID-19, made its first appearance and was discovered to be highly contagious. The question of how the virus is transmitted from person to person was investigated and debated.

It was discovered that the coughing and wheezing are the main causes of the spread of respiratory droplets and aerosols, which in turn leads to the spread of the coronavirus [1]. These contaminated airborne particles and particulates accumulate with the respiratory activities of the infected individuals, indicating a risk of exposure in the locations where COVID-19 patients have recently stayed [2]. Therefore, the risk is generally high in areas with high population density and inadequate ventilation conditions, such as supermarkets, movie theaters, and various modes of public transportation (taxis, buses, etc.).

It has been highlighted that maintaining a reasonable social distance and ensuring proper ventilation are effective methods to refresh the contaminated air [3]. This, in turn, helps to reduce the concentration of airborne viruses. Besides, non-pharmaceutical interventions (NPI) such as wearing masks can also prove to be effective in blocking pathogens to some degree. This is especially important in potentially hazardous environments where there is a certain amount of accumulated coronavirus. Such measures can prevent human-to-human transmission as well as transmission from the environment to humans. Therefore, it is imperative to implement these measures to mitigate the risk of coronavirus transmission in public spaces [4].

Despite the establishment of herd immunity against various Covid strains over the past three years, the infection rate has been decreasing gradually. As a result of this trend, mask restrictions and isolation regulations have been lifted in most parts of the world. Even in China, where the situation was once dire, these regulations have been lifted. Based on this premise, we decided to exclude the consideration of non-pharmaceutical intervention (NPI) protections, including shields, during our research. However, it is important to note that the decision to disregard NPIs should be taken with caution, as there is always a possibility of new Covid strains emerging and causing another outbreak. Therefore, it is crucial to stay vigilant and follow the recommended preventive measures to curb the spread of Covid-19.

1.2. Research done in this field

The researchers took into consideration the interior conditions of COVID-19 investigations. This involved examining the production, transmission, and control techniques of aerosols and droplets that contained the coronavirus [5]. Several environments, including regular workplaces, classrooms, grocery stores, dining establishments, and various types of automobiles, have already been covered by scientific research. The findings of these studies have shed light on the potential risks associated with being in such environments and have enabled policymakers to formulate appropriate guidelines to mitigate the spread of the virus. It is essential to continue conducting research in this area to ensure that public health guidelines remain up-to-date and effective in controlling the spread of the virus.

It is worth noting that computational fluid dynamics (CFD) simulation can provide a comprehensive understanding of the distribution of airborne particles. This technique is particularly useful in determining the spatial distribution of contaminated droplets and aerosols containing pathogens. By using CFD simulation, researchers can obtain a detailed picture of the movement of these particles in a given environment. This information can be used to identify high-risk areas and develop effective mitigation strategies to reduce the spread of airborne viruses. Therefore, CFD simulation is a valuable tool in the fight against infectious diseases and should be employed in conjunction with other measures to create a safer environment for all.

The ventilation condition, which is typically characterized by the air flow rate, people density, and surface type and area that may cause the attachment of virus-laden particles, were the primary focus of earlier studies conducted on the topic of viral distribution in typical locations. Researchers conducted a case study on the spread of the virus in supermarkets, and their findings indicated that equipping some shelves with plastic boards in appropriate positions is an effective method to prevent the virus from spreading from one person to another. Similarly, these types of plastic boards were installed in areas designated for communal dining. These measures were found to be effective in reducing the risk of virus transmission in public places. Hence, it is crucial to consider such measures while designing public spaces to prevent the spread of the virus [6].

In this paper, we will use the scenario of taking a taxi as a reference point. This situation can occur anywhere and at any time and is considered to pose an extremely high risk of infection, especially if an infectious person is traveling with you or was the passenger in the taxi just before you. To test the effects of various variables, including the heating, ventilation, and air-conditioning (HVAC) system, the location of the passengers, and whether or not the windows were open, simulations of a similar situation have been carried out under various circumstances. These simulations aim to understand the factors that influence the concentration of airborne viruses in a taxi and how they can be mitigated to reduce the risk of transmission. Therefore, the findings from these simulations can inform the development of effective strategies to reduce the risk of transmission of infectious diseases in taxis and other public transportation vehicles [7-12].

Table 1. Researches done about this field.

Subject	Variables chosen by early researchers		
Human	In/Exhale mode: Breath, Sneeze, Cough …	In/Exhale speed	Infected risk definition: Inhaled amount, flux around the face, …
Vehicle	Car, train, airplane…	Windows opened or not	HVAC mode: Windshield defrosting, air cycling, front vent supply mode, …
Droplets	Diameter: typical diameter, modeling diameter distribution, …		Physics model: Interaction with phases, evaporation, …

According to Professor Arpino et al, in windshield defrosting mode, if the driver is infected with a virus, the most secure position for a passenger in a vehicle with closed windows would be diagonally opposite to the driver. Conversely, the most dangerous position would be behind the driver [11]. To provide a more general overview, when two people are riding in a vehicle together, the safest seating arrangement would be for them to sit diagonally opposite of one another. This arrangement ensures that there is maximum distance between the individuals, thereby minimizing the risk of virus transmission. Therefore, it is recommended to follow this seating arrangement in vehicles to reduce the risk of infection transmission.

1.3. Research aims and postulates

In the majority of countries worldwide, legislation mandating the wearing of masks has been repealed. Consequently, taxis have begun implementing a new type of equipment called a divider. This device is installed inside the vehicle and serves to create a physical barrier between the front and back of the vehicle. The divider is similar to the plastic boards commonly found in communal eating areas. Specifically, the partition has a rectangular shape, and underneath it, there is a rectangular opening that allows for the exchange of money between the driver and passenger. This new piece of machinery has proven to be an effective measure in preventing the transmission of the coronavirus in confined spaces like taxis. It is an innovative solution that provides both drivers and passengers with an added layer of protection while traveling.

The presence of a partition in a car can alter the conventional shape of the flow field within the vehicle. This aspect has not been investigated to this point, and therefore, the viral dissemination findings obtained from earlier research may not be suitable to accurately forecast the current state of affairs. Under such circumstances, it is crucial to determine whether or not such a barrier could make viral dissemination safer in different situations. For instance, when an affected individual is placed in different chairs while the windscreen defroster HVAC mode is active. Furthermore, it is important to establish the circumstances in which the divider could decrease the risk of viral transmission. Based on our hypothesis, the barrier will slow down the spread of virus-infected particles as they travel across the partition. Therefore, it is necessary to conduct further research to validate these assumptions and investigate the effectiveness of partitions in reducing the risk of viral transmission in cars.

2. Method

Computational fluid dynamics (CFD) simulation is the branch of fluid mechanics that employs numerical analysis and data structures to analyze and solve problems related to fluid flows. In our task, we use CFD simulation to process our task. Computers are utilized to perform the necessary calculations required to simulate the free-stream flow of fluids and their interaction with surfaces defined by boundary conditions. Our task involves adopting SpaceClaim, ICEM, and Ansys fluent separately to perform three main steps of CFD simulation, namely model construction, mesh establishment, and CFD calculation. These steps are essential for accurately processing a CFD simulation. Through the use of CFD simulations, we can effectively analyze and solve various problems related to fluid dynamics, making it a valuable tool in many industries.

2.1. Geometry model

Here is our geometry model constructed by SpaceClaim – a typical taxi model with a divider installed. The feature parts are indicated in Figure 1.

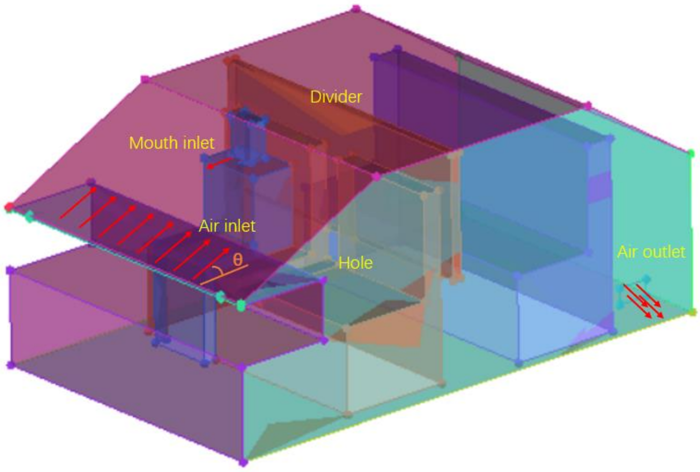


Figure 1. Geometry model for the situation where a taxi has a divider installed and passengers sit beside the driver.

The parameters of essential parts are shown below.

Table 2. Geometry model parameters setting.

Parts	Geometry parameters
Inlet	One Rectangular Slit. Area: 1400mm×15.9mm
Outlets	Two Rectangular Holes. Area: 169.9mm×86.5mm
Mouth	One Rectangular Slit. Area: 40mm×12mm
Divider	One Rectangular Solid. Area: 1640mm×652.5mm×50mm
Hole under the divider	One Rectangular Hole. Area: 200mm×157.5mm

2.2. The mesh calculated

ICEM is adopted here to implement meshing progress. A mesh picture of the taxi model with divider is shown below.

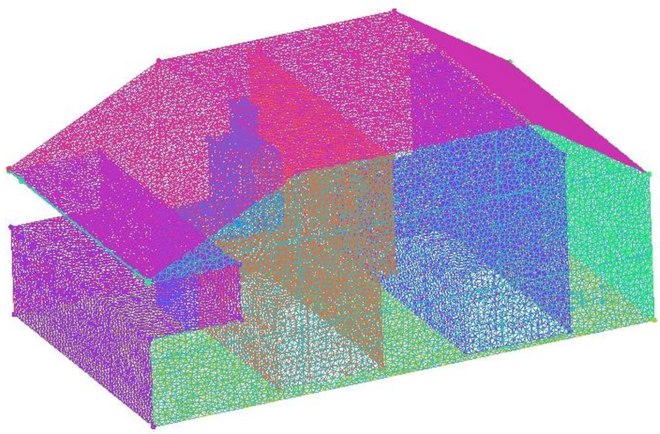


Figure 2. The mesh picture of the taxi model with divider.

For our simulation, we utilized tetrahedral meshing as our primary meshing type. This was appropriate as the geometry model was formed by only planes. The fluid field consisted of approximately 1340000 grids in all scenarios, and we conducted a mesh independent analysis, which yielded reasonably good results. To further enhance the mesh quality in Fluent, we improved the 2 percent least orthogonal grids and repeated this procedure three times. As a result, the orthogonal quality was lowered to less than 0.4. This approach played a crucial role in ensuring accurate and reliable simulation results.

2.3. Solution setting

In our study, we utilized the inhomogeneous Eulerian model with implicit volume fraction formulation. The two Eulerian phases were set as air and liquid water, respectively. The interaction between these two phases was described solely by the Schiller-Naumann drag coefficient. To simulate the droplets derived from speaking, we considered a typical diameter of 1.5 μm, which is a simplified representation of the real airborne aerosol distribution. The solution settings for this model are presented in Table 3, which mainly includes boundary condition settings. By adopting these settings, we were able to accurately simulate the behavior of the aerosol particles in the given environment.

Table 3. Solution settings.

Position	Settings
Inlet	Velocity inlet. Velocity fixed as 1.1m/s. The direction angle relative to the horizontal surface is θ, tanθ = 0.5.
Outlets	Pressure outlets. The gauge pressure there is set to be 1 atm.
Mouth	Velocity inlet. Velocity fixed as 1.1 m/s. The direction is perpendicular to the mouth.

Our goals center on making a comparison of risks rather than making an accurate projection as to whether or not someone riding in a taxi would become infectious. We not only take into account as a potential risk the virus-carrying particles that people inhale, but we also take into account as a potential risk the virus-carrying particles that strike people on the face. As a result, the procedure that is used to evaluate the level of danger involves, first, positioning some surveillance spheres over the locations where heads would be, and then determining the volume percentage of droplets that are crossing through these spheres. When compared to the previous calculation of inhaled virus-carrying particles, it has the potential to save simulation resources because in our simulation, the mouth is not considered an outlet, and as a result, the mesh complexity is released. To gain a better understanding of the findings, the outcomes have been multiplied by the same constant. The parameter - concentration of exhaled virus-laden droplets has a very limited impact on our risk within an acceptable range, which has already been tested by our simulation, so the concentration is not highlighted here. A consistent breathing velocity of 1.1 meters per second helps to simplify the speaking simulation as well; the mouth in this case only functions as an entrance and not as both an inlet and an outflow simultaneously.

We have decided to run a simulation to study the transmission of infectious diseases in taxis. The simulation will last for 20 minutes, slightly longer than the typical taxi ride in Shanghai, which is 15 minutes. We have chosen to use the windshield defrosting option, which is the most common ventilation setting found in taxis. The simulation is divided into two distinct halves. One half will simulate a taxi with a divider inserted, while the other half will simulate a taxi without a divider. In each type of taxi, we will simulate four scenarios where an infected person is in the driver's seat, beside the driver, behind the driver, or diagonally opposite the driver, with a total of two people riding the taxi. We will keep all other parameters the same in both types of taxis.

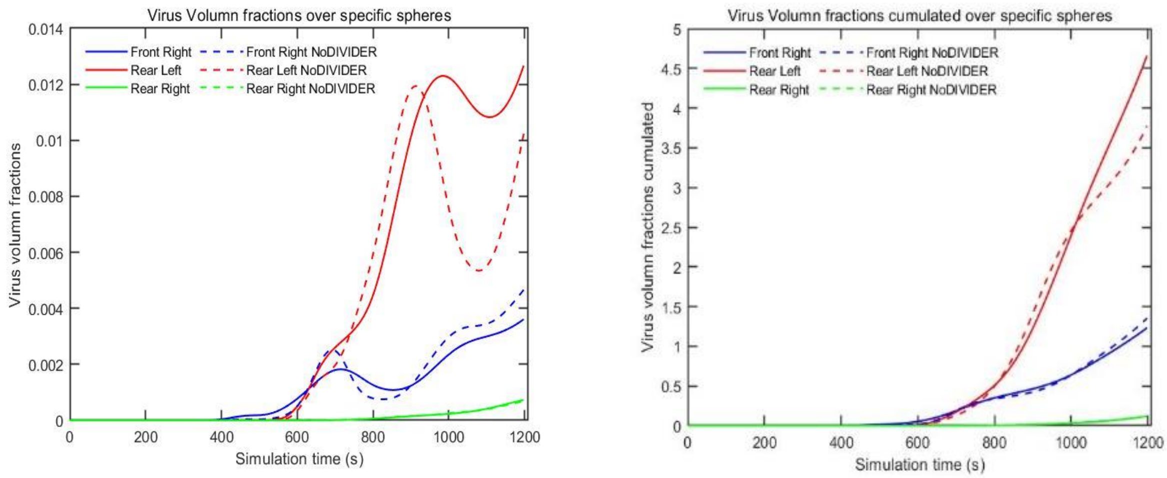
3. Results

3.1. Infected driver

In our study, we placed the infected driver in the front left seat and set up three monitoring spheres in other specific locations. We then conducted two models, one with a divider and one without, to compare the effects on the spread of Covid-19.

(a) (b)

Figure 3. Geometry model of an infected driver scenario with three monitoring spheres (a) Divider installed in the taxi (b) No-divider situation.



(a) (b)

Figure 4. Virus volume fraction through the sphere results in a with or without a divider scenario (driver-infected situation) (a) The transient virus volume fraction through the monitoring sphere (b) Cumulated virus volume fraction within the monitoring sphere.

From the figures above, the virus dispersion doesn't achieve equilibrium, i.e., the transient virus volume fraction going through the sphere doesn't become zero, thus the cumulated virus fraction inside the monitoring sphere doesn't approach a constant.

Under windshield defrosting mode, it is clear that whether there is a divider, it has a very limited effect on the rear right seat. Actually, if we zoom in on the data of transient virus volume fraction, there is an intersection of two curves in the rear right places with or without a divider around 1070 seconds. Before 1070 seconds, the without-divider curve is always higher than the with-divider curve. After 1070 seconds, this relationship is inverse. However, regardless of which curve has a higher value, the difference between these two curves is always less than 10 percent of a correspondingly higher value.

Then, zooming in on the data of the cumulated virus volume fraction, the with-divider curve on the rear right seat is always higher than that without-divider, although the difference is small.

Based on the data collected on the rear left seat, both with and without a driver, we can observe a clear difference. The transient virus volume fraction on the rear left seat without a divider oscillates considerably, so we focus on the cumulative data instead. Prior to 1000 seconds, the cumulative virus volume fraction on the rear left seat without a divider is slightly higher than that with a divider, but the difference is minimal. After 1000 seconds, the transient virus volume fraction without a driver decreases, resulting in a higher increasing rate of the data with a driver. The cumulative data figure shows that the curve for data with a driver is significantly higher than that without a driver, consistent with our prediction.

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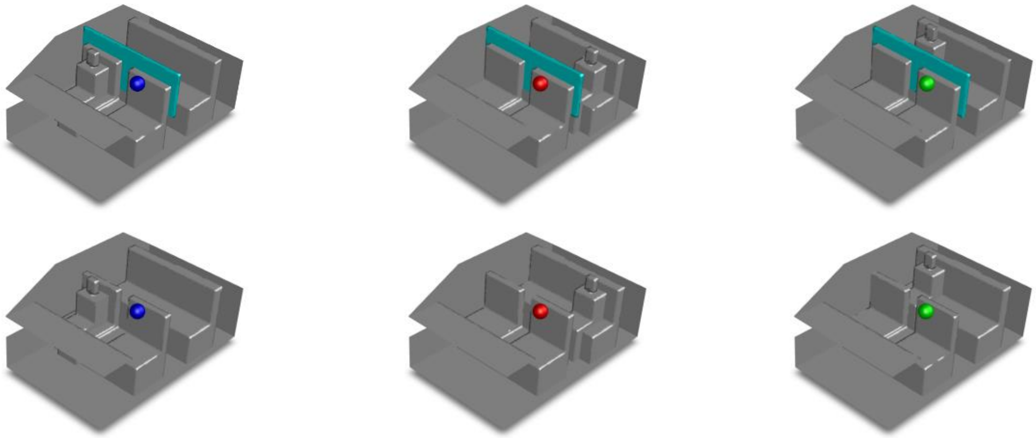
The data on the front right seat is similar in both scenarios; such oscillation progress doesn't illustrate enough useful information.

3.2. Infected passenger

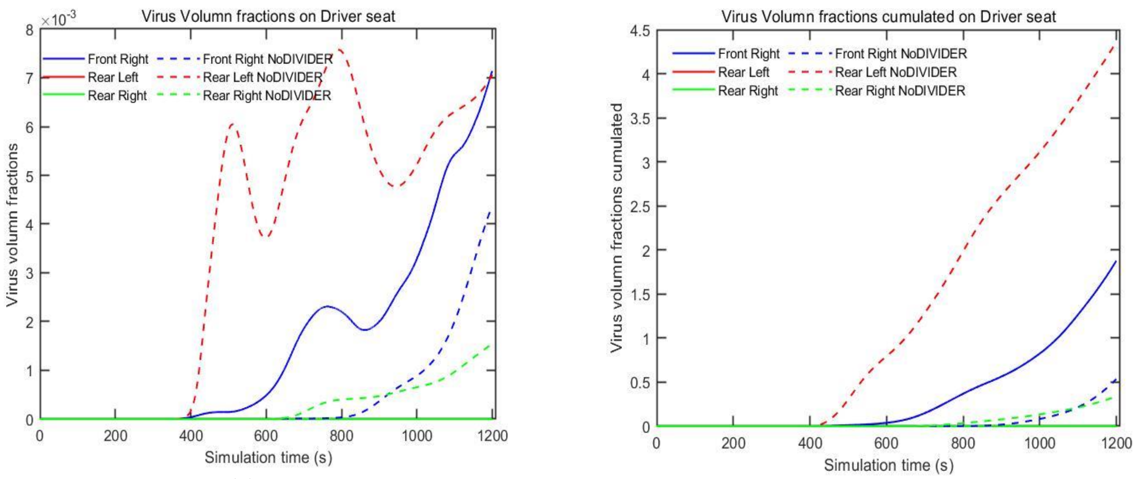
In our study, we placed the infected driver in the front left seat and set up three monitoring spheres in other specific locations. We then conducted two models, one with a divider and one without, to compare the effects on the spread of Covid-19.



(a)

(b)

Figure 5. Geometry model of infected driver scenario with monitoring spheres set in three positions. (a) Divider installed in the taxi. (b) No divider situation.



(a) (b)

Figure 6. Virus volume fraction through the sphere results in with/without a divider scenario (Passenger infected situation). (a) The transient virus volume fraction through the monitoring sphere. (b) Cumulated virus volume fraction within the monitoring sphere.

In these scenarios, we locate an infected person as a passenger and then analyze the virus data on the monitoring sphere on the front left seat (the driver's seat). Overall, the divider has a clear effect on these scenarios.

First, we figure out that in the with-divider situation, if the infected passenger is located on the rear left or right seats, no virus would reach our monitoring sphere, indicating the divider blocks out all virus exhaled in the rear.

Then, consider the without-divider situation. The red line representing the virus exhaled by the passenger right behind the driver is always dominant, as windshield defrosting mode is not strong enough to blow away this direct exhaled airflow. There is an intersection of the transient virus concentration curves of the passenger located on the front right seat and on the rear right seat at around 900 seconds. Before 900 seconds, the position of the rear right seat has a higher virus concentration, mainly because, although we adopt windshield defrosting mode, the entire trend of air flowing into the car points to the rear, and the virus dispersion is in the process of achieving equilibrium, making the rear the first to be affected. And, after 900 seconds, the difference in concentration increasing rates in the two places shows the consequence. Considering the overall cumulated virus concentration data, the intersection of the corresponding curves occurs around 1100 seconds.

Next, another change made by the divider is when the passenger is located beside the driver. The divider makes the airflow between the front and the rear more difficult, causing virus concentrations to rise when the divider is added.

4. Discussion

Our hypothesis is that the divider would reduce the transmission of virus-laden particles crossing the divider, and our findings support this claim. In a taxi without a divider, the safest place for a passenger is to sit diagonally opposite the other person in the car. However, with the use of a divider, the safety of the passenger sitting opposite the driver is further enhanced.

However, our research procedure is not yet entirely rigorous. Firstly, we only consider the scenario where the windows are closed, and the ventilation mode is set to windshield defrosting. We did not simulate the second most common situation, where the windows are open, and the car's built-in ventilation system is closed. Secondly, the efficiency of the divider would vary under different airflow rates of the ventilation system. Therefore, considering only the typical flow rate is insufficient.

5. Conclusion

After conducting our research, we have found that in situations where the windshield defrosting is active, the installation of a divider can result in safer virus dispersion for the driver. However, this is only applicable if the passenger chooses to sit diagonally opposite to the driver. It is important to note that the divider will have a limited impact on the virus dispersion if the driver is already infected. The effectiveness of the divider is at its maximum when the passenger is infected and sits in the rear. Therefore, it is recommended to install dividers in vehicles with active windshield defrosting, and passengers should sit diagonally opposite to the driver to minimize the risk of virus transmission. However, it is important to note that the divider may not be effective if the driver is already infected.

Therefore, we strongly advocate that taxi drivers should install partitions in their cabs to ensure the safety of both passengers and drivers. Additionally, it is essential to encourage passengers to remain in the back of the cab whenever possible. The non-infectious safety of a taxi ride is largely dependent on the health of the taxi driver. This is because, on average, the taxi driver is exposed to more individuals in a potentially infectious environment in close proximity than any other passenger. By installing partitions and encouraging passengers to remain in the back, the risk of transmission between the driver and passengers can be significantly reduced. Therefore, it is crucial to implement these measures to ensure the safety of everyone involved.

When considering things from the perspective of passengers, it is crucial to ensure their safety while traveling. Thus, we strongly advise them to avoid sitting directly behind the driver, as this position poses the greatest risk of exposure to potential hazards. This is true regardless of the presence or absence of a barrier. To minimize the risk of exposure, we encourage passengers to sit diagonally opposite to the driver. This position provides a safer distance and reduces the chances of getting exposed to potential hazards. By following these simple measures, passengers can ensure their safety while traveling and minimize the risk of exposure to potential hazards

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