WHITE PAPER

Institute of Transportation Studies | UNIVERSITY OF CALIFORNIA

Practitioner Guide: An Inventory of Vehicle Design Strategies Aimed at Reducing COVID-19 Transmission in Public and Private Pooled and Shared Transportation

Angela Sanguinetti, Ph.D., Research Environmental Psychologist, Institute of Transportation Studies, University of California, Davis
Ashley DePew, Ph.D. Student, Energy Graduate Group, University of California, Davis
Kate Hirschfelt, Undergraduate Research Assistant, Department of Design, University of California, Davis
Cindy Ross, Undergraduate Research Assistant, Cognitive Science, University of California, Davis
Ethan Khoe, Undergraduate Research Assistant, Cognitive Science, University of California, Davis
Beth Ferguson, Assistant Professor, Department of Design, University of California, Davis

September 2021

ITS UC DAVIS INSTITUTE OF TRANSPORTATION STUDIES

Report No.: UC-ITS-2020-06b | DOI: 10.7922/G2057D7S

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UC-ITS-2020-06b	N/A	N/A

4. Title and Subtitle
Practitioner Guide: An Inventory of Vehicle Design Strategies Aimed at Reducing COVID-19 Transmission in Public and Private Pooled and Shared Transportation

5. Report Date
September 2021

6. Performing Organization Code
ITS-Davis

7. Author(s)
Angela Sanguinetti, Ph.D., https://orcid.org/0000-0002-9008-7175
Ashley DePew, https://orcid.org/0000-0002-8398-7319
Kate Hirschfelt, https://orcid.org/0000-0002-4577-2245
Cindy Ross, https://orcid.org/0000-0002-4207-6498
Ethan Khoe, https://orcid.org/0000-0001-5227-6023
Beth Ferguson, https://orcid.org/0000-0001-7319-2590

8. Performing Organization Report No.
UCD-ITS-RR-21-59

9. Performing Organization Name and Address
Institute of Transportation Studies, Davis
1605 Tilia Street
Davis, CA 95616

10. Work Unit No.
N/A

11. Contract or Grant No.
UC-ITS-2020-06b

12. Sponsoring Agency Name and Address
The University of California Institute of Transportation Studies
www.ucits.org

13. Type of Report and Period Covered
White Paper (November 2019 – May 2021)

14. Sponsoring Agency Code
UC ITS

15. Supplementary Notes
DOI:10.7922/G2057D7S

16. Abstract
The COVID-19 pandemic has had dramatic impacts on transportation globally, reducing travel and deterring travelers from using shared and pooled modes such as public transit, carpooling, car-sharing, pooled ride-hailing, and micromobility. These modes are critical components of a decarbonized and equitable mobility future, but already comprised a small fraction of pre-pandemic travel in the U.S., and will likely remain further suppressed in the wake of the pandemic if people continue new mode choice habits. Those who do continue to rely on public transportation are disproportionately at risk due the degree that these modes leave them susceptible to disease transmission. For pooled and shared travel to return to and ideally surpass pre-pandemic levels, it is important to implement solutions to reduce the real and perceived risks of infectious disease transmission. This white paper presents an inventory and typology of vehicle design strategies that have been proposed or implemented with the aim of mitigating the risk of COVID-19 transmission in pooled and shared travel modes. Researchers organized these strategies into a COVID-19 Risk-mitigating Vehicle Design Typology and identified the mechanisms by which they may help diminish the risk of COVID-19 transmission. It is intended as a resource for policy-makers, transportation service operators, vehicle manufacturers, and scientists who are tasked with evaluating strategies to mitigate disease transmission risk in shared and pooled transportation services.

17. Key Words
Vehicle design, seats, communicable diseases, COVID-19, shared mobility, public transit, vehicle safety, public health

18. Distribution Statement
No restrictions.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	21. Price
Unclassified	Unclassified	33	N/A

Form Dot F 1700.7 (8-72) Reproduction of completed page authorized

About the UC Institute of Transportation Studies

The University of California Institute of Transportation Studies (UC ITS) is a network of faculty, research and administrative staff, and students dedicated to advancing the state of the art in transportation engineering, planning, and policy for the people of California. Established by the Legislature in 1947, ITS has branches at UC Berkeley, UC Davis, UC Irvine, and UCLA.

Acknowledgments

This study was made possible through funding received by the University of California Institute of Transportation Studies from the State of California through the Public Transportation Account and the Road Repair and Accountability Act of 2017 (Senate Bill 1). The authors would like to thank the State of California for its support of university-based research, and especially for the funding received for this project.

Disclaimer

Table of Contents

Table of Contents

List of Figures

Contents

Background

The COVID-19 pandemic has had dramatic impacts on transportation globally (117th Congress, 2021). Widespread shelter-in-place mandates and public health recommendations including social distancing have resulted in reduced travel and travel mode shifts—away from shared and pooled travel modes. Transportation network companies like Uber and Lyft have halted their pooled ride-hailing options (Lee, 2020). US public transportation ridership decreased by 79% at the beginning of the pandemic and was down 65% from June 2020 through December 2020 (EBP US, Inc., 2021). California Bay Area Rapid Transit (BART) daily ridership remains low (73-85% below baseline the first week of May, 2021) (BART, 2021).

Shared and pooled travel modes are critical components of a decarbonized and equitable mobility future (Sperling, 2018). Public transit, carpooling, electric car-sharing, pooled ride-hailing, and micromobility are less energy- and emissions-intensive alternatives to the more dominant mode of single-occupancy vehicles (Hodges, 2010). These modes already made-up a relatively small fraction of travel in the US before the pandemic and now will likely remain further suppressed in the wake of the pandemic if people continue new mode choice habits (Barbieri et al., 2021; Bratić et al., 2021). On the other hand, those who continue to rely on public transportation are disproportionately at risk to the degree that these modes leave them susceptible to disease transmission (Liu & Zhang, 2020). These people include those with low incomes (National Association for State Community Services Programs, 2008), essential workers (TransitCenter, 2020), and certain sociodemographic groups, such as African Americans, Hispanics, women, and people over the age of 45 years (Liu et al., 2020).

Depending on a variety of factors, shared and pooled modes differ in terms of risks of infectious disease transmission—and specifically COVID-19 transmission. For example, research suggests that ventilation is typically insufficient in buses (Fresno State Transportation Institute, 2020), whereas planes and trains have excellent air change rates (18-30 times per hour) (Bushwick et al., 2020; Boeing, n.d.). Actual risks and public perceptions may differ. For example, a study of perceived risk associated with various travel modes in ten countries found similarly high levels of perceived risk for planes and buses (Barbieri et al., 2021). Strategies like ventilation and air filtration can be complex and unobservable, potentially leading to inaccurate assumptions about risks of shared and pooled modes.

For pooled and shared travel to return to and ideally surpass pre-pandemic levels, it is important to implement solutions to reduce the real and perceived risks of infectious disease transmission (TransitCenter, 2020). Solutions may involve new policies and business models, public awareness programs, and innovative station and vehicle design. This research focuses on vehicle design strategies to facilitate safe and confident use of shared and pooled travel modes in the wake of the pandemic.

This white paper presents an inventory and typology of vehicle design strategies that have been proposed or implemented with the aim of mitigating the risk of COVID-19 transmission in pooled and shared travel modes.

It is intended as a resource for policy-makers, transportation service operators, vehicle manufacturers, and scientists who are tasked with evaluating strategies to mitigate disease transmission risk in shared and pooled transportation services. This paper does not make recommendations and does not directly report on relevant research regarding potential effectiveness of the wide variety of strategies discussed. For official recommendations and some literature reviews, see the sources cited in the next section. A forthcoming report describes subsequent interview research aimed at examining layperson and expert opinions about perceived and actual effectiveness of the identified vehicle design strategies.

Industry Guidance

Pooled and shared travel service operators have been given guidance regarding vehicle design strategies to reduce the risk of COVID-19 spread, but there is a need for a more systematic approach. Most official guidance is industry-specific. For example, the Centers for Disease Control (CDC) has provided separate guidance for different types of transit, including bus (2021-b), rail (2021-c), and rideshare/taxis (2021-a). The American Public Transportation Association has adapted CDC guidance for public transportation (bus and rail) (APTA, 2020-b). Other examples of guidance include: the "Runway to Recovery" for mitigating risk in air travel, from the US Department of Transportation, US Department of Homeland Security, and US Department of Health and Human Services (2020); guidance for mass transit and marine operators regarding heating, ventilation, and air conditioning, from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (n.d.); recommendations for protecting farm workers in employee vehicles from the Occupational Safety and Health Administration (OSHA) (n.d.). The California Department of Public Health (CDPH), State Transportation Agency (CalSTA), and the California Division of Occupational Safety and Health (Cal/OSHA) issued industry guidance that was unique in covering both public and private passenger carrier services (2020). Many similar design strategies (e.g., barriers seating reconfiguration) are recommended across shared and pooled vehicle and service types. Resources tailored to each industry are important, but also analyzing applications across public transit, shared mobility, and air travel could yield a more comprehensive and nuanced shared understanding of vehicle design solutions.

Industry guidance sources do not focus on vehicle design specifically; they are more inclusive, with strong emphasis on policies and procedures. This holistic approach is essential but does not allow for a high level of detail regarding vehicle design strategies. For example, recommendations from the CDPH, CalSTA, and Cal/OSHA include: "Where possible, install Plexiglas or other appropriate barriers in transit and rail vehicles to minimize exposure between operators and passengers" (2020, p.10). This leaves a lot to be determined by the operator, e.g., barrier size, material, location, and whether to install barriers between passengers, all of which vary considerably in practice.

Reports of best practices (Schwatrz, 2020; FEMA, 2020) are useful supplements to general industry guidance. For example, in April 2021 the Federal Transit Administration (FTA) released a resource to share practices that have been implemented by bus and rail operators worldwide during the pandemic, providing links to transit agency websites and news articles where operators can see specific examples of a range of strategies (2021).

Though immensely useful, best practices do not include emerging innovative design concepts that have not yet been implemented. The American Public Transportation Association notes, "Due to the magnitude of the COVID-19 pandemic, it is likely that transit agencies will want viral outbreak considerations to be included in future vehicle and facility designs and modifications" (2020-a). Broadening the scope to future vehicles creates room for more radical design innovations that should be considered alongside retrofit strategies. These more radical design strategies may help cope with this pandemic and other existing and future infectious diseases.

Present Research

This research aimed to understand all the ways in which vehicle design can be modified to mitigate the risk of COVID-19 transmission in pooled and shared travel modes. Researchers conducted systematic internet searches, gathering information from news articles, public transit websites, industry reports, and academic literature. Searches targeted planes, trains, subways, buses, shuttles, ferries, taxis, ride-hailing, carpooling, carsharing, and shared micromobility. The focus was on physical aspects of vehicles (e.g., space configuration, onboard features, equipment, and equipment settings/operations), including original equipment and retrofit strategies, new and pre-existing technologies/settings, and temporary and permanent features, either affixed to the vehicle or located on board the vehicle during operation.

Vehicle design strategies were recorded with descriptions, images, and references to the media and/or academic articles that discuss them. Each strategy was also coded with the applicable vehicle/service type(s) mentioned in the sources (only those mentioned in sources and not theoretical considerations about potential applicability), and whether it had been implemented yet according to our sources (as opposed to a conceptual design or under development). Data collected on each strategy are available in the online supplementary material, which also provides links to sources for each identified strategy is available here: https://airtable.com/shr5z4uh9zMZ1aqoZ.

COVID-19 Risk-mitigating Vehicle Design Typology

Identified strategies were organized into a COVID-19 Risk-mitigating Vehicle Design (CRVD) Typology consisting of 12 main categories listed and defined in Table 1. CRVD Typology: Main Categories and Definitions. Strategies were further analyzed to articulate 12 possible mechanisms by which they may help diminish the risk of COVID-19 transmission in shared and pooled vehicles (e.g., increasing distance between passengers or physically separating them from each other). These mechanisms are listed and defined in Figure 1. The following sections provide an overview and illustrate each strategy, including specific examples and hypotheses regarding the mechanisms by which they may reduce the risk of COVID-19 transmission, noting again that this is an inventory of design concepts and not a set of recommendations.

Table 1. CRVD Typology: Main Categories and Definitions

Vehicle Design Strategy Type	Definition
Seating Configuration	Seating layout and other features that specify where riders sit or stand during transit, including location and orientation
Pathways	Features that specify how riders move about the cabin, e.g., boarding and deboarding
Barriers	Partitions of various sizes, configurations, and materials between passengers or passengers and workers
Ventilation and Air Circulation	Equipment or setting that improves ventilation (brings outside air into the vehicle, moves inside air out) or air circulation (movement of air within the cabin)
Air Filtration and Cleaning	Equipment that cleans the indoor air that is being recycled or introduced from outdoors, by trapping and/or killing airborne particles
Onboard Surface Sanitization	Equipment and settings that implement surface cleaning processes
Hygienic Materials	Materials that contribute to vehicle hygiene
Hygienic Construction	Construction techniques that contribute to vehicle hygiene
Touchless Technology	Adaptations or new mechanisms, including automated technologies, that limit driver/rider physical contact and interaction with the vehicle

Vehicle Design Strategy Type	Definition
PPE Provisioning	Onboard PPE dispensers
Communication & Monitoring	Features that collect and/or display information to passengers and/or service providers
Multimodal Support	Features that facilitate multimodal trips to limit time in more shared/pooled modes

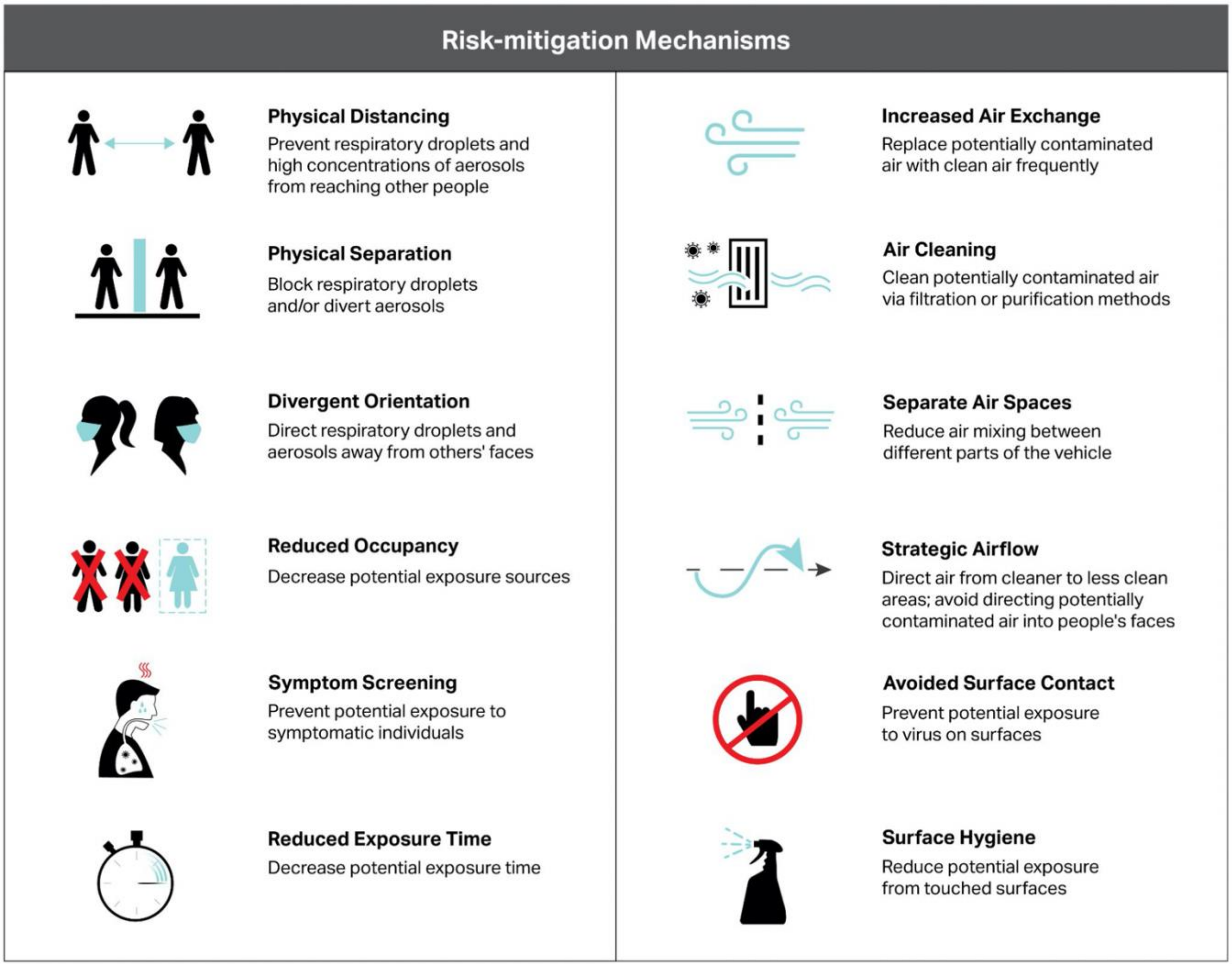

Figure 1. Mechanisms of design strategies that may mitigate the risk of COVID-19 transmission

Seating Configuration

Seating configuration includes three general strategies: eliminating seats, spreading them out, or changing their orientation. Eliminating seats can increase distance between passengers and reduces overall vehicle occupancy. Seats and standing passenger spots may be designated as approved or off-limits using signs or stickers, without any real structural changes. Seats may be temporarily removed or repurposed through flexible structural changes (e.g., removable seats). There are also proposals for permanent new layouts that include a reduced number of seats.

Unlike eliminating seats, spreading out or changing orientation does not necessarily require reducing occupancy. Three methods of spreading out seats (or passengers) were identified: designating a seating area (e.g., train car) for vulnerable populations to keep them away from others; spreading seats out into spaces not typically used for seating; and staggering/off-setting seats within rows. These all involve increased physical distancing. Re-orienting seats—including flipping middle seats and removing tables in train cars to flip alternating rows so all face the same direction—might increase distance slightly, create some degree of physical separation (more so if used in conjunction with a Barriers strategy), or to redirect passengers' respiratory particle trajectories away from each other's faces (mechanism: Divergent Orientation). A seating reorientation strategy with a different aim is to use longitudinal bench seating instead of transverse arrangements, for easier cleaning (mechanism: Surface Hygiene).

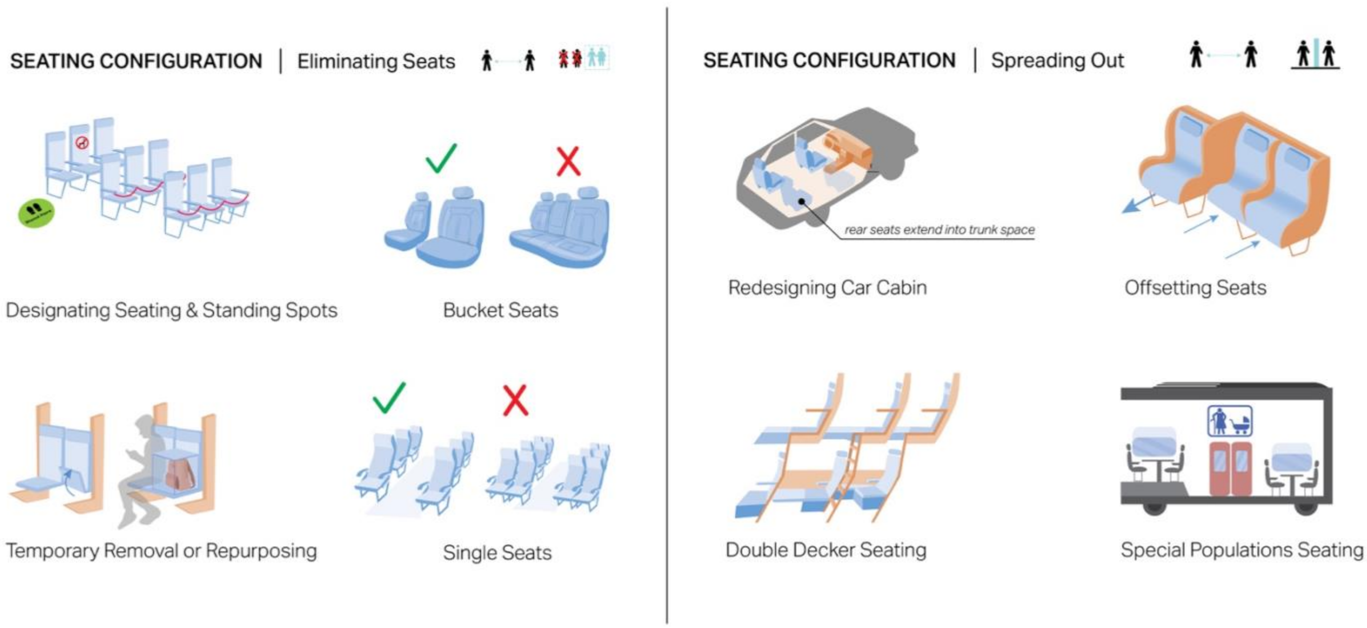

Figure 2. Examples of strategies for altering seating configurations by eliminating or spreading out seats.

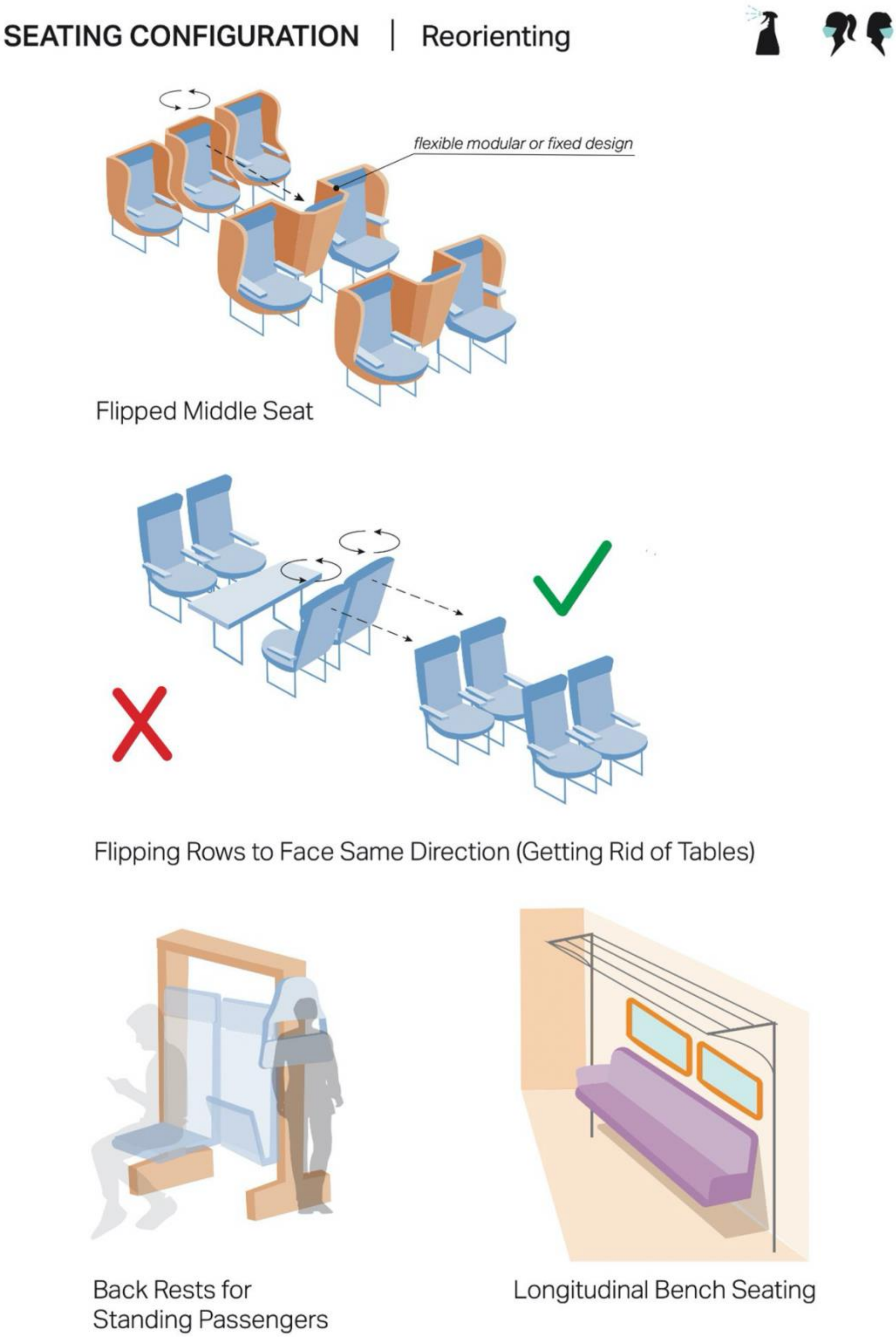

Figure 3. Examples of strategies for reorienting seating.

Pathways

In addition to specifying or changing where passengers sit (or stand) during the ride, vehicle design strategies can specify or change how passengers move about the cabin, e.g., while (de)boarding. These strategies also leverage distancing and/or orientation. Some bus services are roping off the front of the bus and requiring passengers to use the rear door only, limiting their proximity to the driver. On the other hand, some vehicles are designating separate doors for entry versus exit. Other Pathways strategies include an open gangway layout so passengers can more easily move from one train car to another (perhaps less crowded), and relocating ticketing machines in buses, where passengers linger before finding a seat, further away from the driver.

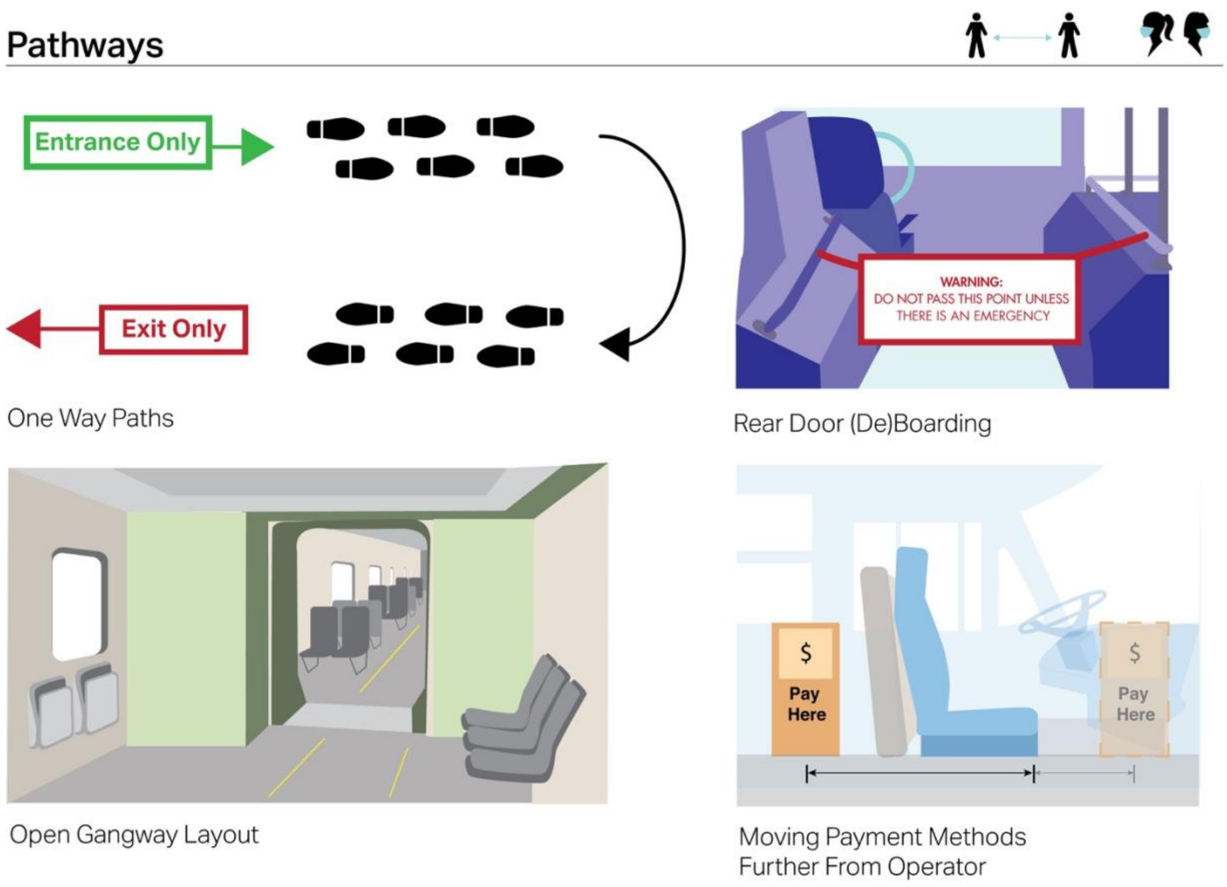

Figure 4. Examples of strategies for changing how passengers move about the cabin.

Barriers

Most Barriers strategies identified are after-market partitions added to vehicles on or near seats. They vary in terms of location (e.g., between individual passenger seats, above passenger or driver seat rows, around a driver), size and coverage (e.g., at the head area only, floor-to-ceiling), and material (e.g., soft plastic, plexiglass). These characteristics were used to come up with a naming convention for the distinct types of Barriers identified: e.g., Passenger Row Curtain (located above a rows of passenger seats and made of soft plastic), Driver Face Shield (located at the face area of the driver seat and made of hard plastic). Another set of strategies involves the use of seats as barriers, which includes a design concept where seatbacks are tall and there are no gaps between headrests, and podlike seats with wrap-around sides that separate adjacent passengers. Barriers are intended to block people from others' expelled respiratory particles.

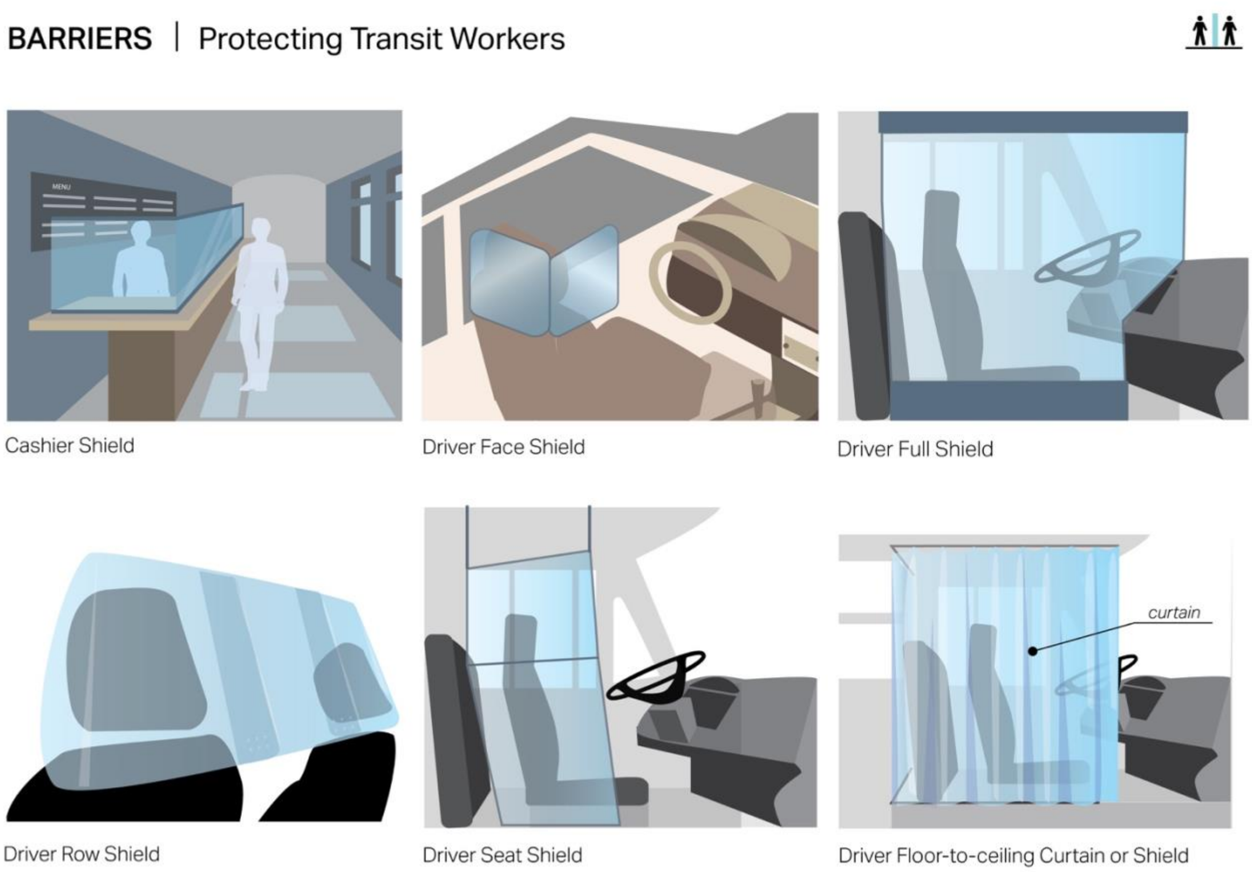

Figure 5. Types of barriers to protect transit workers.

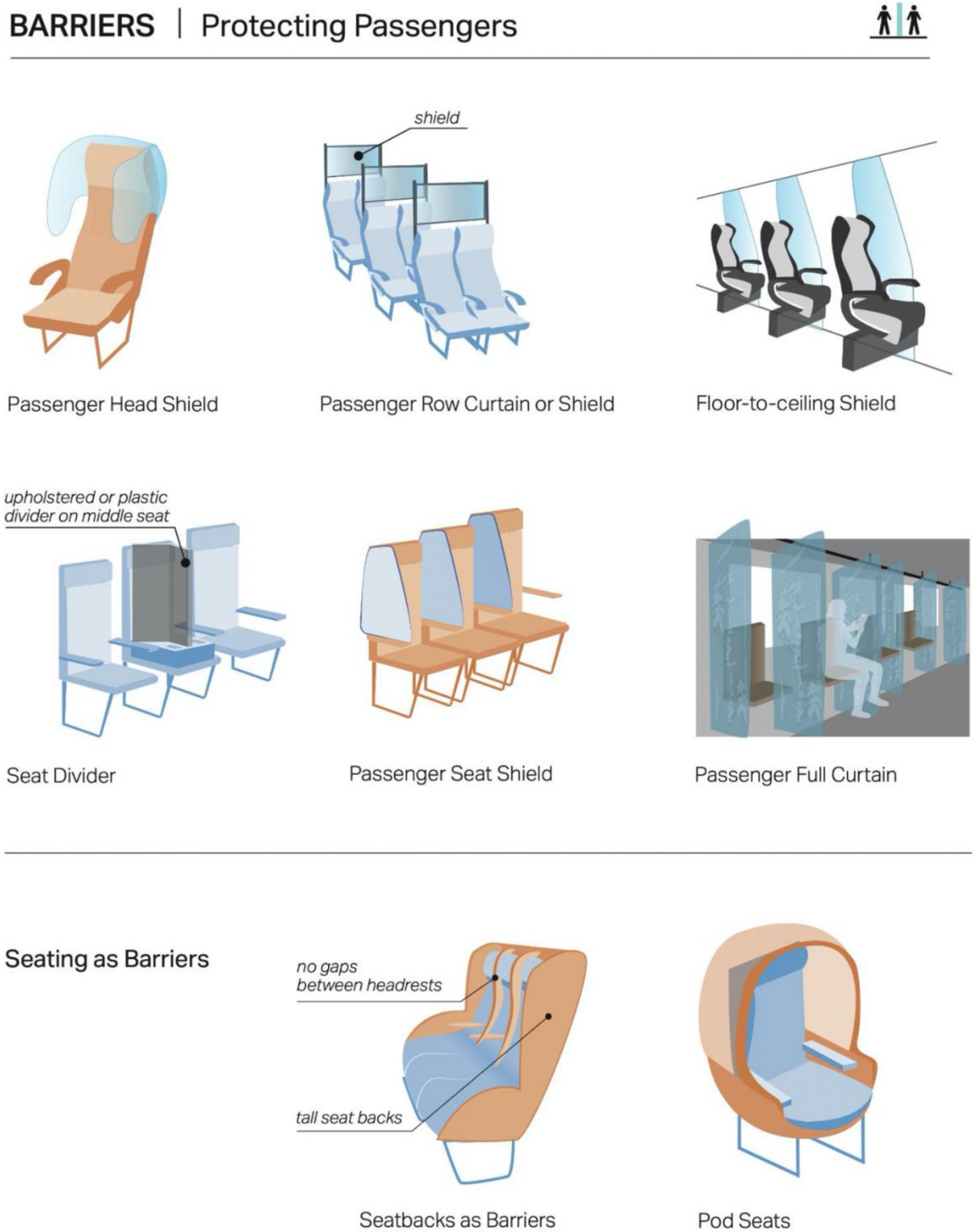

Figure 6. Types of barriers to protect passengers.

Ventilation and Air Circulation

This category consists of equipment or system settings that improve ventilation (exchange with outdoor air) and circulation (movement of air within a space). Strategies to improve ventilation include opening windows, doors, and roof hatches, even when heating or air conditioning; running the fan continuously and at maximum speed; using fresh (outdoor) rather than recycled air for heating, ventilation, and air conditioning (HVAC); and adding/using vents and fans, including exhaust fans. There are also recommendations to control airflow within the vehicle strategically, including directional airflow from clean to less clean areas, configuring open windows to create cross-ventilation flow, and indirect airflow from floor vents upward instead of horizontal flows directly into riders' faces.

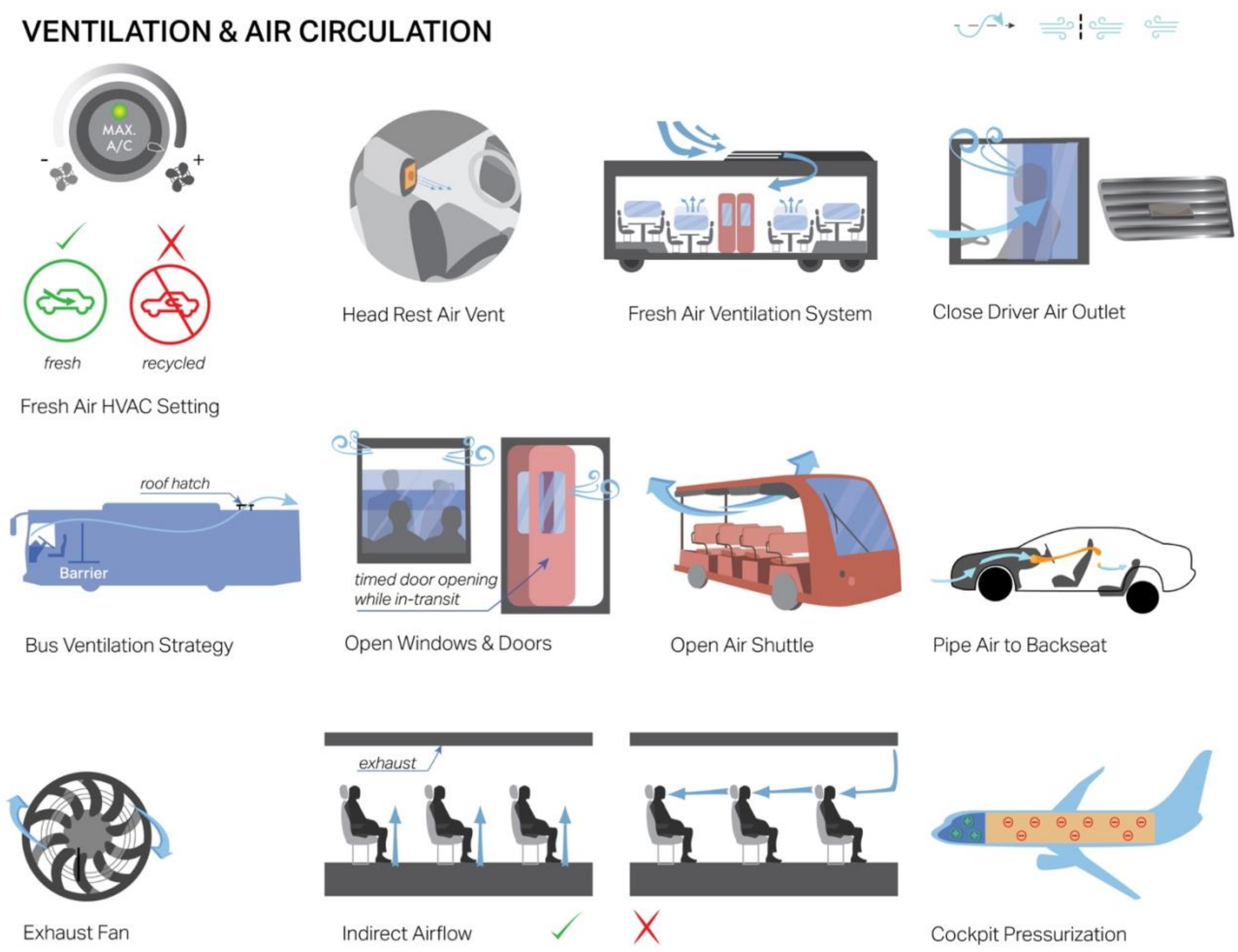

Figure 7. Strategies for improving ventilation and air circulation.

Air Filtration and Cleaning

In terms of air filtration, advanced mechanical filters are widely recommended, including High Efficiency Particulate Air (HEPA) filters and filters with a high Minimum Efficiency Reporting Value (MERV) rating (e.g., MERV 13). These can be installed in the HVAC system or used in an after-market device added to the vehicle (e.g., a cupholder-sized air purifier with a HEPA filter). Other air cleaning technologies include ultraviolet (UV) light (specifically UVC) and ionization, which can be integrated into the HVAC system or provided by an after-market device. UVC is extremely damaging to human eyes and skin, so when used outside of the HVAC ducting it needs to be enclosed in a system located on the ceiling that treats the air at the top of the vehicle without exposing riders.

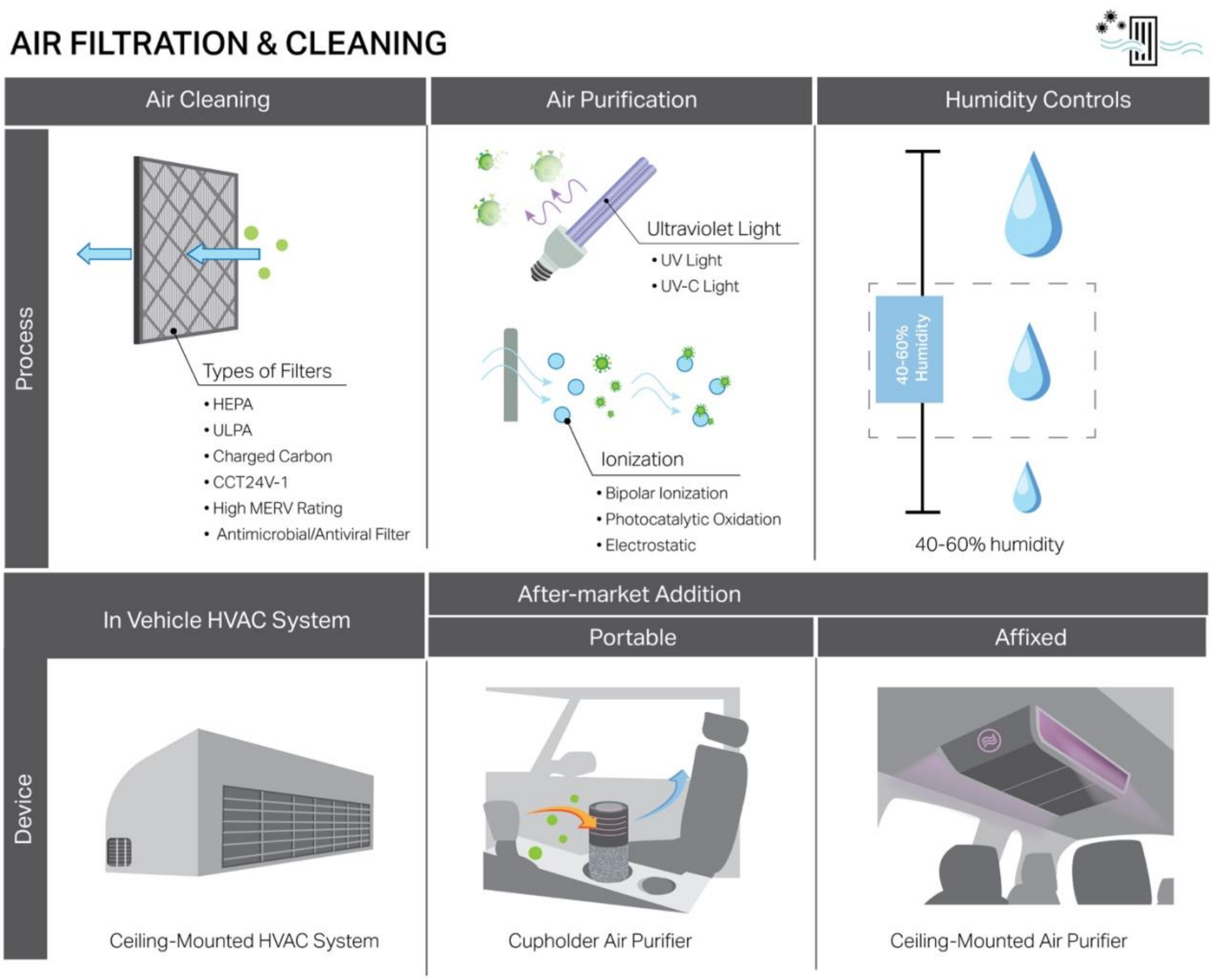

Figure 8. Types of air filtration and cleaning technologies.

Onboard Surface Sanitization

Onboard Surface Sanitization involves equipment installed in the vehicle that controls cleaning processes, as opposed to cleaning services conducted manually or with equipment brought onto the vehicle during servicing. Four onboard cleaning methods were identified: light, heat, chemical, and air. UVC and LED (light emitting diode) lamps have been installed in vehicles, intended to kill the virus on surfaces between transit services. Foggers have been installed to spray chemical disinfectants between uses. Adapting an HVAC system to heat the vehicle cabin to a very high temperature is another strategy intended to kill the virus on vehicle surfaces between uses. Positive air pressurization of a bus cabin has been tested as a strategy to prevent the virus from settling on surfaces during vehicle operation.

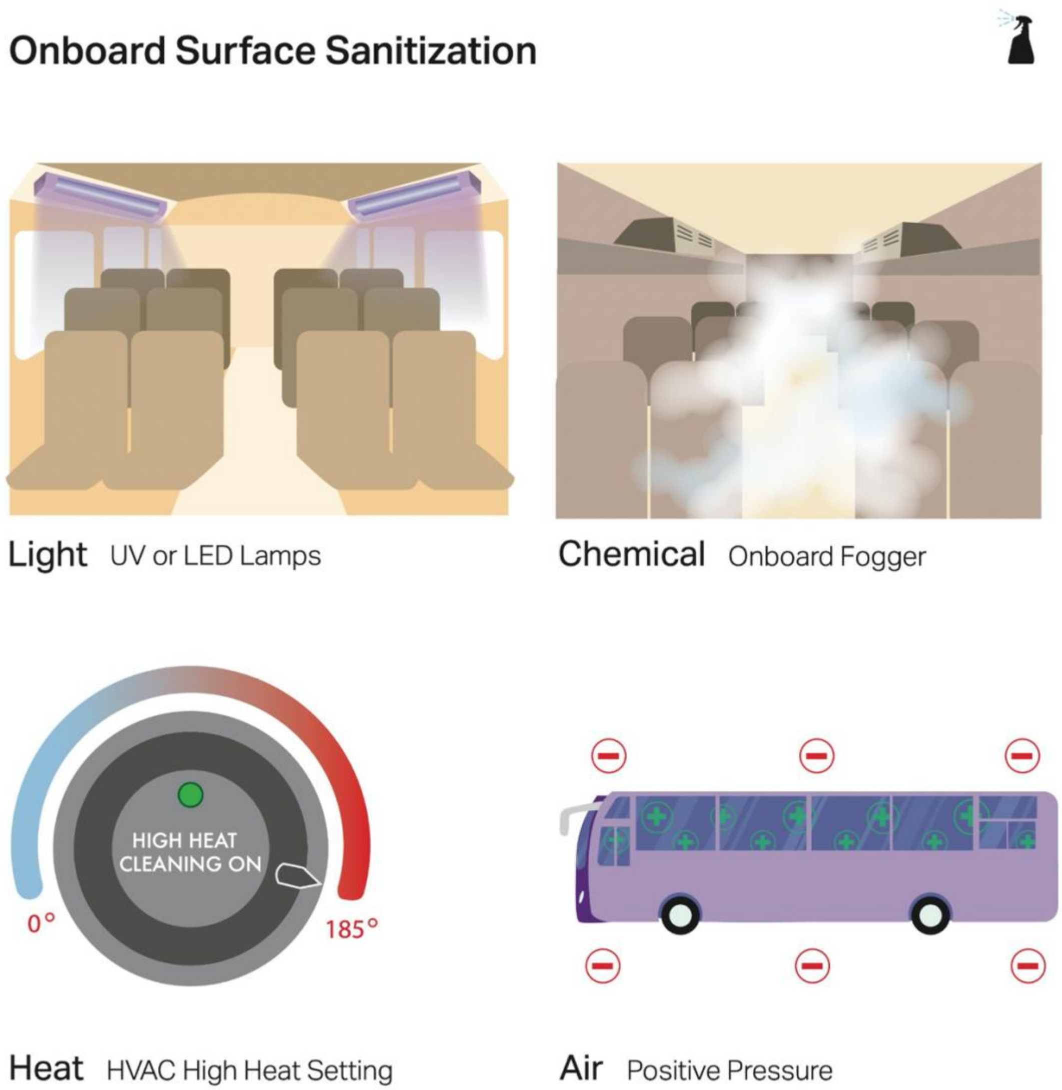

Figure 9. Types of onboard surface sanitization equipment.

Hygienic Materials

Recommendations can be found for easy-to-clean surface materials, including to avoid or remove cloth (e.g., rugs and fabrics on seats) and other porous materials, and/or use protective coatings, including clear-coat floor finishes, to facilitate cleaning. Relatedly, durable materials to hold up to harsh and frequent cleaning have been recommended, as well as disposable seat and floor coverings. Biocidal materials (e.g., copper) and coverings (films and spray-on shields), i.e., those with internal properties that might irradicate the virus, have also been suggested. One source suggested replacing plastic surfaces with cardboard.

Figure 10. Examples of hygienic materials that facilitate cleaning or have germicidal properties.

Hygienic Construction

Two general categories of construction techniques have been considered. The first is minimizing seams and joints, including non-ribbed flooring, sealing floor seams, and upholstering seats so that the bottom and back connection is seamless to avoid a gap where dirt and germs can accumulate. The second is accommodating cleaning, including detachable food trays, cantilever seating (easier to clean under), planning space for cleaning equipment to come on board, floor-mounted piping to hook up a hose to clean, and holes in the bottom of seats (for wet cleaning).

Figure 11. Examples of hygienic construction techniques that facilitate cleaning and minimize germ accumulation.

Touchless Technology

Touchless Technology strategies are divided into three sub-categories: automation strategies that eliminate the need for physical contact with the vehicle and/or reduce vehicle occupancy; low-touch mechanical strategies that minimize physical contact; and personal props that involve replacing shared surfaces with accommodations for personal items. Examples of automation include fully automated (i.e., driverless) vehicles, touchless card and ticket scanners, automated doors, and automatic hand sanitizer dispensers (rather than pumped). Examples of low-touch mechanisms include a pedal door opener and pedal tray table control. Personal props include personal handholds distributed to passengers to attach to vehicle grab rails to avoid the shared surface, and mounts in planes for personal mobile electronic devices and bags, replacing shared touchscreen tablets and seat-back literature pockets, respectively.

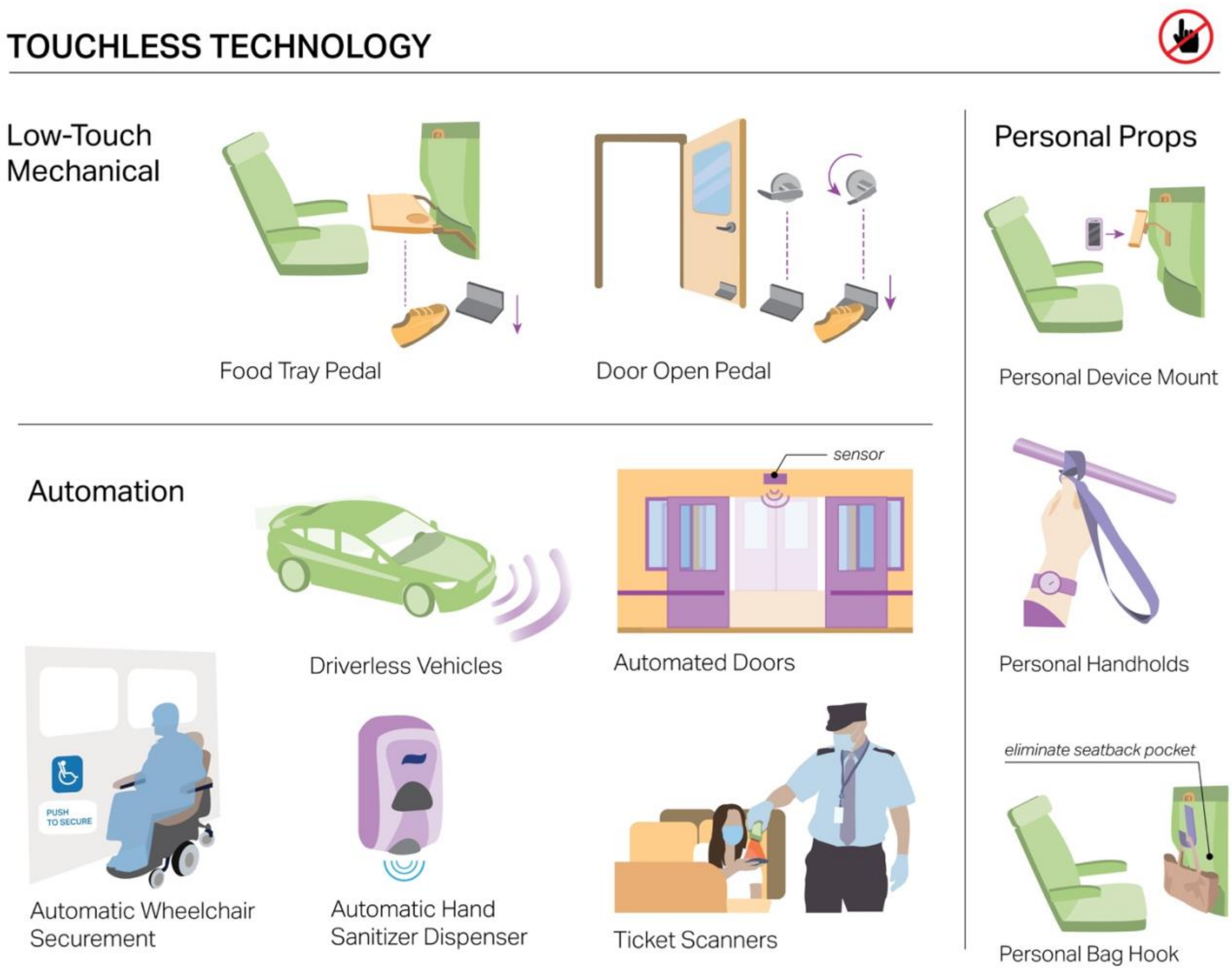

Figure 12. Examples of touchless technologies that minimize physical contact.

Personal Protective Equipment (PPE) Provisioning

Service operators have added dispensers to their vehicles to supply users with hand sanitizer, disinfecting wipes, and masks. In addition to onboard dispensers, many operators are supplying PPE to their workers. Other related strategies include locating trash receptacles in vehicles (e.g., to dispense of wipes), and making sure onboard restrooms are adequately stocked with soap and dryers or paper towels. These strategies are indirectly related to the risk-mitigation mechanisms listed in Figure 1. Mechanisms of design strategies that may mitigate the risk of COVID-19 transmission, since the mediating role of occupant behavior is more significant, but they have implications for Surface Hygiene, and Physical Separation in the case of masks.

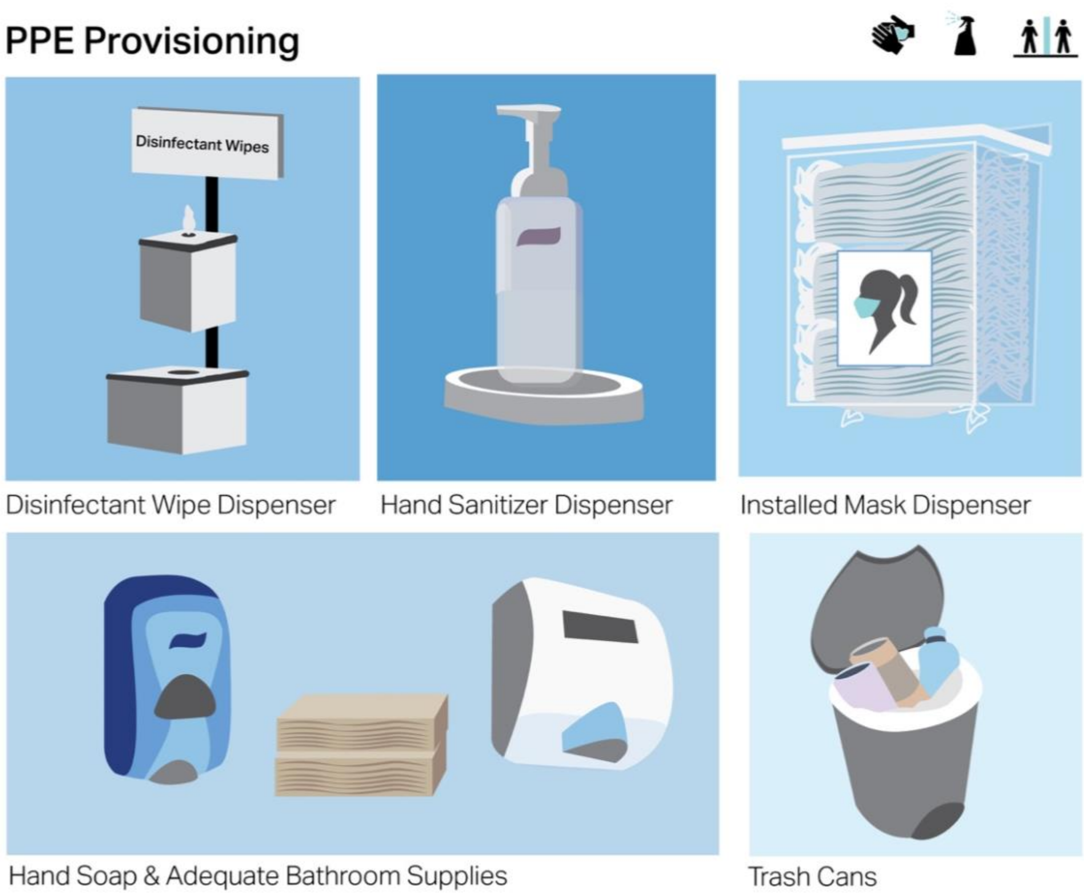

Figure 13. Types of PPE and supply provisioning.

Communication and Monitoring

Communication & Monitoring strategies are divided into three sub-categories: Education and Prompts, Environmental Feedback, and Symptom Detection and Contact-tracing. Education and prompts remind passengers to comply with the federal mask mandate and other operator policies and recommendations (e.g., to practice good hygiene), as well as communicate CDC guidance and general COVID-19 information. Environmental feedback involves devices that monitor and/or display dynamic information about environmental conditions in the vehicle related to the risk of virus transmission, such as occupant density, surface cleanliness, and CO_2 levels. Symptom detection and contact-tracing strategies collect data to monitor passengers. Examples include a QR code in pooled vehicles that passengers scan to enable contact-tracing in the case of exposure to another passenger with COVID-19, and cameras with facial recognition to detect mask-wearing or thermal imaging to detect whether a passenger has a fever.

Figure 14. Examples of prompts reminding travelers to comply with health guidelines and policies.

COMMUNICATION & MONITORING

Occupant Screening and Monitoring

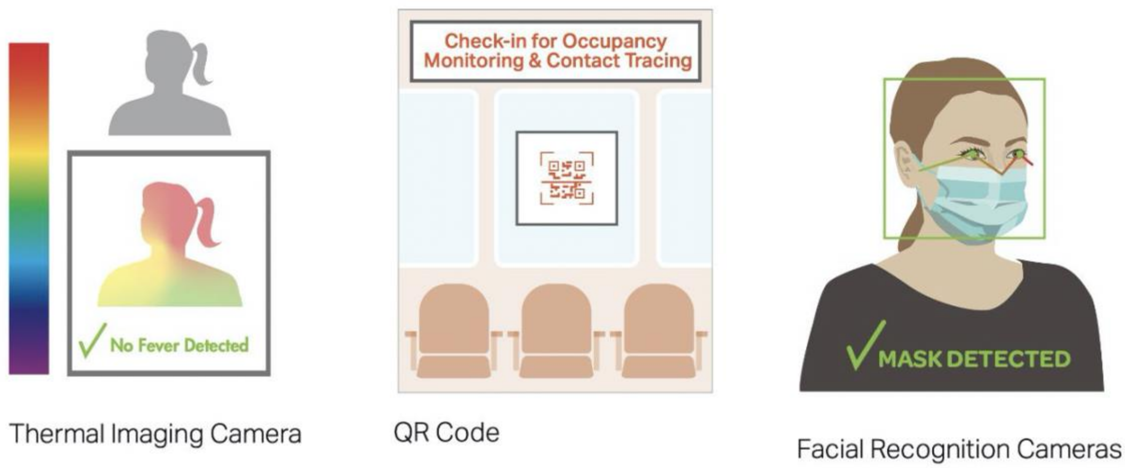

Figure 15. Examples of occupant screening and monitoring strategies.

Environmental Monitoring and Feedback

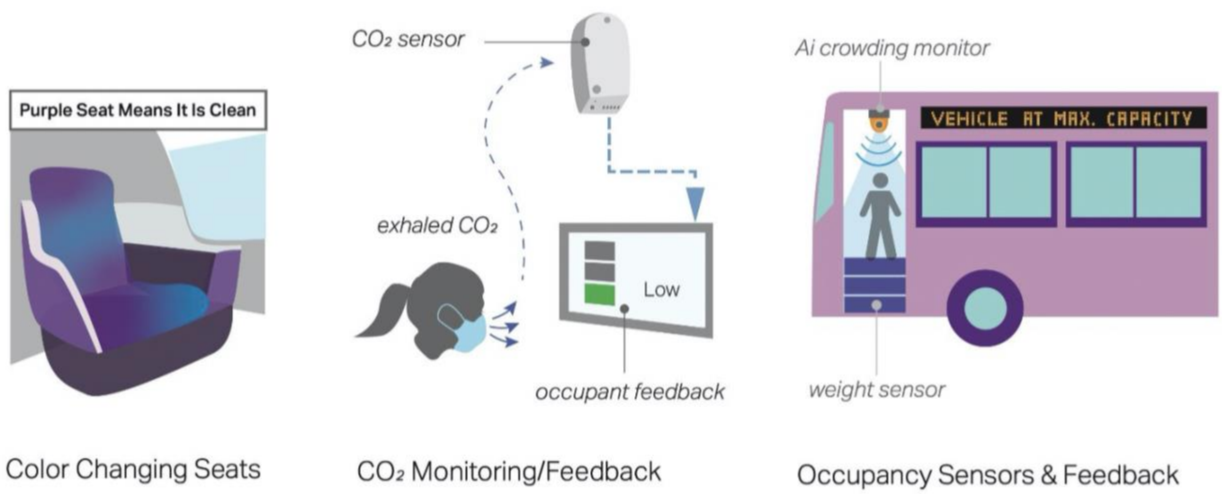

Figure 16. Examples of environmental monitoring and feedback strategies that can collect and display dynamic information about the risk of virus transmission.

Multimodal Support

A unique feature of a train car design concept was the flexible repurposing of some seating as convenient bike storage for passengers. This Multimodal Support strategy could facilitate or encourage the use of bikes in conjunction with pooled and shared travel modes, to shorten the duration of trip legs made in pooled vehicles where exposure risk is higher. Although no mentions of added bike racks for this purpose were found for other types of shared and pooled vehicles, this strategy is also relevant for cars (taxi, ride-hailing, and vanpooling) and buses.

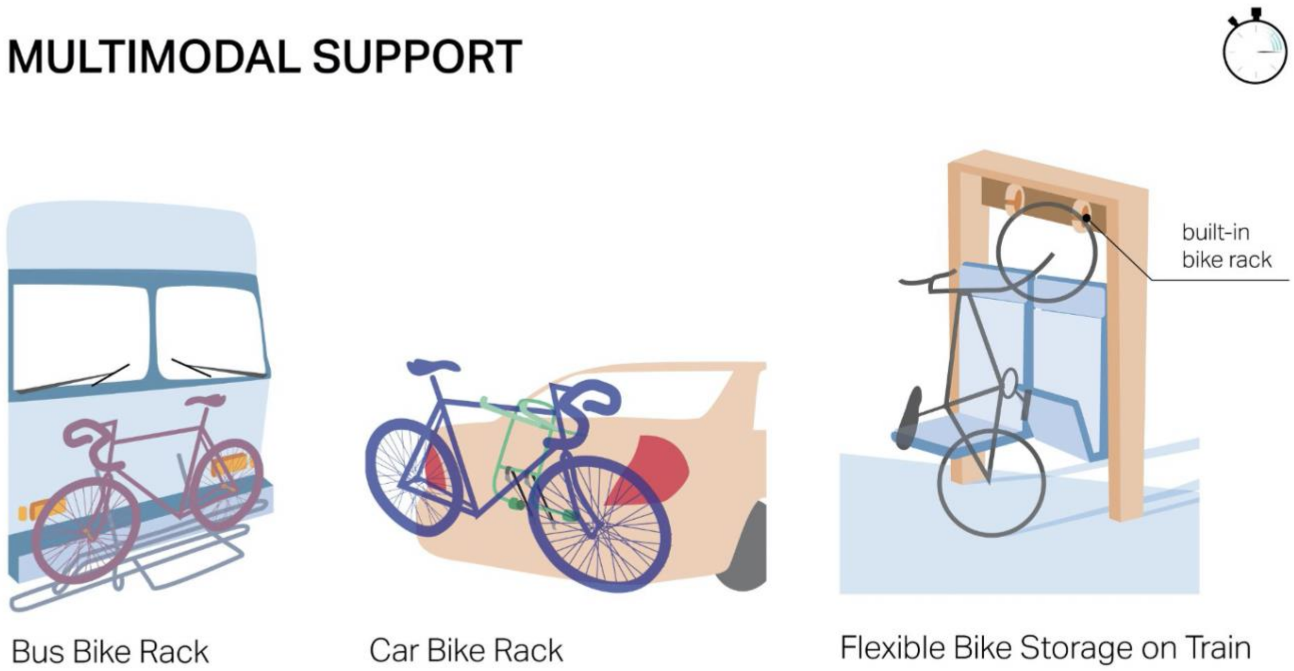

Figure 17. Examples of multimodal support strategies to shorten the duration of trip legs made in shared vehicles.

Conclusion

This research distilled the wide variety of vehicle design solutions aimed at mitigating the risk of COVID-19 transmission in public transportation and shared mobility into a COVID-19 Risk-mitigating Vehicle Design (CRVD) Typology. The CRVD Typology can be a resource for transit and shared mobility operators. Paired with public health and industry guidance, it can help them assess the range of possible vehicle design solutions and determine which are suitable for their vehicles and services. Public transit and shared mobility operators and their regulatory bodies face the challenge of deciding which of these strategies to adopt. These decisions are further complicated by the need to balance them with other types of strategies (e.g., station design strategies, policies, new business models, website and app features, and new cleaning protocols) to make up a portfolio of complementary solutions to recover ridership and keep workers and riders safe. All this must be accomplished within financial limitations resulting from drastic revenue losses.[1]

The CRVD Typology can also be used by service operators and designers as a guide to generate more solutions, within and beyond vehicle design. For example, they can challenge themselves to identify more strategies of a given type such as Communication & Monitoring strategies (e.g., onboard signs or audio messages explaining ventilation systems), or more strategies that accomplish a particular mitigation mechanism such as Reduced Exposure Time (e.g., faster travel times, fewer stops, more doors). They can also explore categories with few strategies (e.g., Multimodal Support) to see whether more can be developed.

Finally, the CRVD Typology outlines a research agenda. Environmental exposure scientists and other experts can advise on the value of vehicle design strategies, both across and within the CRVD and mitigation mechanism categories, and they can identify the important research gaps. Social scientists and travel behavior researchers can assess the influence of CRVD strategies on worker and rider attitudes, intentions, and behaviors. The most effective CRVD strategies are top priority, but it is also important to address user perceptions and prioritize strategies that help workers and riders feel safe.

[1] https://www.wmata.com/about/news/GM-federal-Covid-funding-statement.cfm

References[2]

American Public Transportation Association (APTA). (2020-a, June 22). Cleaning and Disinfecting Transit Vehicles and Facilities During a Contagious Virus Pandemic. Retrieved 2021, from https://www.apta.com/wp-content/uploads/APTA_WP_Cleaning_and_Disinfecting_Transit_Vehicles_and_Facilities_During_a_Contagious_Virus_Pandemic_FINAL_6-22-2020.pdf

American Public Transportation Association (APTA). (2020-b, August 11). The COVID-19 Pandemic Public Transportation Responds: Safeguarding Riders and Employees. Retrieved 2021, from https://www.apta.com/wp-content/uploads/COVID-19_Transit_Guide_REVISON-2020_08_11.pdf

American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). (n.d.). Transportation. Retrieved 2021, from https://www.ashrae.org/technical-resources/transportation

Barbieri, D. M., Lou, B., Passavanti, M., Hui, C., Hoff, I., Lessa, D. A., ... & Rashidi, T. H. (2021). Impact of COVID-19 pandemic on mobility in ten countries and associated perceived risk for all transport modes. *PloS One*, *16*(2), e0245886.

Bay Area Rapid Transit (BART). (2021, June 25). Ridership watch: Daily updates related to riders returning to BART. Retrieved 2021, from https://www.bart.gov/news/articles/2020/news20200225

Bratić, M., Radivojević, A., Stojiljković, N., Simović, O., Juvan, E., Lesjak, M., & Podovšovnik, E. (2021). Should I stay or should I go? Tourists' COVID-19 risk perception and vacation behavior shift. *Sustainability*, *13*(6), 3573.

Boeing. (n.d.). How airplane cabins reduce COVID-19 transmission risk. Retrieved 2021, from https://www.boeing.com/confident-travel/story.html?id=reduce-transmission-risk

Bushwick, S., Lewis, T., & Montañez, A. (2020, November 19). Evaluating COVID Risk on Planes, Trains and Automobiles. Retrieved 2021, from https://www.scientificamerican.com/article/evaluating-covid-risk-on-planes-trains-and-automobiles2/

California Department of Public Health (CDPH), California State Transportation Agency (CalSTA), & State of California Department of Industrial Relations (Cal/OSHA). (2020, July 29). COVID-19 INDUSTRY GUIDANCE: Public and Private Passenger Carriers, Transit, and Intercity Passenger Rail. Retrieved 2021, from https://files.covid19.ca.gov/pdf/guidance-transit-rail.pdf

[2] Scholarly, grey literature, and media references that form the basis of our data analysis are provided in the supplementary material: https://airtable.com/shr5z4uh9zMZ1aqoZ

Centers for Disease Control and Prevention (CDC). (2021-a, January 30). What Rideshare, Taxi, Limo, and Other Passenger Drivers-for-Hire Need to Know About COVID-19. Retrieved 2021, from https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/rideshare-drivers-for-hire.html#

Centers for Disease Control and Prevention (CDC). (2021-b, May 7). COVID-19 Employer Information for Bus Transit Operators. Retrieved 2021, from https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/bus-transit-operator.html

Centers for Disease Control and Prevention (CDC). (2021-c, May 9). COVID-19 Employer Information for Rail Transit Operators. Retrieved 2021, from https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/rail-transit-operator.html

EBP US, Inc. (2021, January 27). Retrieved 2021, from https://www.apta.com/wp-content/uploads/APTA-COVID-19-Funding-Impact-2021-01-27.pdf

Fresno State Transportation Institute. (2020, November 17). COVID-19 Public Transportation Air Circulation and Virus Mitigation Study. Retrieved 2021, from http://fresnostate.edu/engineering/institutes/fsti/news/covidfsti.html

Hesse-Biber, S. N., & Leavy, P. (2010). *The practice of qualitative research.* Sage.

Hodges, T. (2010, January). Retrieved 2021, from https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/PublicTransportationsRoleInRespondingToClimateChange2010.pdf

Lee, A. (2020, March 17). Uber and Lyft suspend pool rides in US and Canada to reduce the spread of coronavirus. Retrieved 2021, from https://www.cnn.com/2020/03/17/business/coronavirus-uber-pool-trnd/index.html

Liu, L., Miller, H. J., & Scheff, J. (2020). The impacts of COVID-19 pandemic on public transit demand in the United States. *Plos One*, *15*(11), e0242476.

Liu, X., & Zhang, S. (2020). COVID-19: Face masks and human-to-human transmission. *Influenza and Other Respiratory Viruses*, *14*(4), 472-473.

National Association for State Community Services Programs. (2008). The Stranded Poor: Recognizing the Importance of Public Transportation for Low-Income Households. Retrieved 2021, from https://nascsp.org/wp-content/uploads/2018/02/issuebrief-benefitsofruralpublictransportation.pdf

Occupational Safety and Health Administration (OSHA). (n.d.). *Preventing Farmworker Exposure to COVID-19 in Employer-Provided Vehicles.* Retrieved 2021, from https://www.osha.gov/sites/default/files/publications/OSHA4107.pdf

Protecting Transportation Workers and Passengers from COVID-19: Hearings before the House Transportation and Infrastructure Committee. 117th Cong. (2021). https://fas.org/congressional-science-policy-initiative/hearings/2021-01-27/

Schwartz, S. (2020, September). Public Transit and COVID-19 Pandemic: Global Research and Best Practices. Retrieved 2021, from https://www.apta.com/wp-content/uploads/APTA_Covid_Best_Practices_09.29.2020.pdf

Sperling, D. (2018). *Three revolutions: Steering automated, shared, and electric vehicles to a better future.* Island Press.

TransitCenter. (2020, March 24). Transit Is Essential: 2.8 Million U.S. Essential Workers Ride Transit to Their Jobs. Retrieved 2021, from https://transitcenter.org/2-8-million-u-s-essential-workers-ride-transit-to-their-jobs/#:~:text=According%20to%202018%20Census%20data,and%2036%20percent%20in%20Miami

U.S. Department of Homeland Security Federal Emergency Management Agency (FEMA). (2020, May 7). COVID-19 Best Practice Information: Public Transportation Distancing. Retrieved 2021, from https://www.fema.gov/sites/default/files/2020-07/fema_covid_bp_public-transportation-social-distancing.pdf

U.S. Department of Transportation Federal Transit Administration (FTA). (2021, April). COVID-19 Recovery Practices in Transit. Retrieved 2021, from https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-04/TSO-COVID-19-Recovery-Practices-in-Transit-3-26-21-v4-2-2.pdf