NATIONAL ENGINEERING POLICY CENTRE

Engineering response to COVID-19
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A rapid review of the engineering approaches to mitigate the risk of COVID-19 transmission on public transport

This paper summarises input from Fellows of the Royal Academy of Engineering and members of the Institution of Mechanical Engineers on behalf of transport providers and manufacturers. The Academy posed a series of questions about actions being taken to adjust ventilation and decontamination processes based on the understanding of COVID-19 transmission on 16 June 2020.

This paper sets out the context and some evidence about the different ventilation, decontamination and wider strategies being deployed on different modes of transport in the UK and internationally. The ideas and suggestions included in this document have been gathered from discussion with expert stakeholders. This note is a rapid summary of findings with oversight from a member of the Academy's Engineering Policy Centre Committee and is not formal Policy Centre guidance. Connections can be made for further information upon request.

Summary

- Delivering interventions to limit the transmission of COVID-19 in public transport is challenging due to cost, a lack of evidence of efficacy of available solutions and the time required and complexity of retrofitting. However, these steps to adjust practice and retrofit are vital in the context of this pandemic and will have benefits for future pandemics.
- The approach taken to ventilation and surface decontamination depends on the transportation mode and the specific design constraints of vehicles and carriages. This has resulted in different commercial products being used by different providers, which is also reflected in the global variation across approaches.
- The transport carriages should not be viewed in isolation: the layout and ventilation of transport interchanges, mobile ticketing and monitoring will play critical roles in ensuring safety and confidence for both public and staff.
- With the business models for owners, manufacturers and service providers having different priorities, collaboration is vital to ensure that the solutions will give the greatest passenger, staff and equipment safety. For example, as a service train provider, First need to work with the train manufacturer to ensure that the surface decontamination approach doesn't impact the mechanics or electronics.
- Procuring technological solutions has been challenging with lots of people offering innovative solutions with limited evidence, as has gaining timely access to COVID-19 specific test facilities required to understanding solution efficacy.
- Design for infection control could have wider economic benefits beyond a future pandemic by limiting the spread of influenza and the common cold. This should be at the forefront of future public transport design especially where it also provides environmental benefits.

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Context

Public transport is a vital public service, but in the context of the COVID-19 pandemic public transport poses several transmission risks that include;

- shared space and common touch points
- high passenger density and close proximity make it difficult to maintain an appropriate distance
- lack of adequate ventilation
- high turnover of people throughout the day.

Role of ventilation

COVID-19 can be transmitted through aerosols, where lighter droplets form an aerosol and move through the air and therefore could be transmitted from person to person, while larger droplets fall out of the air onto surfaces. Transport vehicles may be ventilated by mechanical ventilation or air conditioning systems, natural ventilation (for example, opening windows), or a combination of both.

In principle, there are several broad strategies that would reduce the risk of transmission including:

- increasing the amount of fresh air introduced into a space, which in turn reduces the concentration of aerosols
- in the case of air that is recirculated via an HVAC[1] system, using mechanisms to filter or destroy virus particles as they pass through the HVAC system
- limiting transmission of air between different zones within a transport vehicle; for example between carriages or between areas where passengers are present and the driver's cab. In some cases, this may involve locally pressurising the air to prevent air passing from one zone to another.

However, the extent to which these strategies are feasible and practical depends on many factors, including the type of ventilation strategy in place – natural ventilation, mechanical ventilation or air conditioning – and the extent to which it can be modified or reconfigured to deal with the virus. Other operating strategies are being considered, such as automatic door opening at all stations, or limiting passenger control of ventilation.

All interventions need to be considered within the context of other constraints such as safety - in the case of opening doors - or other requirements of the ventilation system - delivering air at the right temperature and speed for passenger comfort, dealing with other sources of contamination[2], and minimising energy use[3]. The latter is a constraint on transport modes where there is a limited power supply.

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[1] HVAC: Heating, ventilation and air conditioning.

[2] In the case of rail, these might include general atmospheric dust, diesel fumes, dust and smells from braking friction materials.

[3] For example, there is an international standard for the heating and ventilation in intercity rail coaches (EN 13129); It is based on the assumption that, in winter, the interior of the coach is a 22°C "shirt sleeves" temperature and, in summer, it is allowed to rise to 27°C. The minimum air speed in the coach is not defined but must maintain minimum quantities of fresh air per person. ASHRAE Applications Handbook 2019 has design intent data for transport systems.

It may not be possible to reconfigure HVAC systems to increase the amount of fresh air brought in if they were designed to operate by recirculating large amounts of air. There may be a risk that the HVAC system is damaged in this situation.

There may be more scope to retrofit filters or other devices into HVAC systems. Some suppliers are suggesting software modifications and enhanced filtration packs. Typical solutions put forward include adding HEPA filters, ultraviolet (UV) treatment of filter surfaces and electrostatic treatment of airflow. The feasibility of some of these air cleaning technologies on moving transport is still being explored. One operator has also developed the use of ozone on buses to decontaminate empty vehicles, which is passed through the HVAC system and potentially kills virus particles that may be present on the surfaces of the HVAC system.

Natural ventilation tends to be less controlled than mechanical ventilation, relying on vents, open windows and doors, or in the case of certain lines on the tube, the piston effect of trains moving through stations, which forces foul air out through ventilation tunnels in the station and brings in fresh air through other tunnels. It is unclear what this mechanism of ventilation may mean for the viral load at platforms.

In practice, there are a very large number of ventilation systems present across the different transport modes. Even within rail, there are a huge variety of ventilation strategies, which depend on the age and type of rolling stock. For example, more modern rolling stock (post 1990) is more likely to have air conditioning, whereas older trains may be ventilated naturally by opening windows. Interventions need to be considered on a case-by-case basis and the efficacy measured where possible. Airflow modelling may help identify areas at risk.

There are groups within the various transport industry sectors collating and sharing best practice on ways to modify or reconfigure HVAC systems and change operating practices and identifying areas for further research.

Role of surface decontamination

The likely prevalence of fomite transmission[4] due to droplets and surface contact makes cleaning of surfaces, especially frequent touch points, a vital component of limiting transmission. Chemical cleaning is the primary decontamination mechanism, but the role of other longer lasting antimicrobial or UV-activated decontamination technologies and safe and effective mechanisms to deploy these remotely are being explored. The effectiveness of these technologies depends on design factors such as the layout of the vehicle and seating materials and whether the product is being applied in the form of liquid, vapour or as a coating layer. There may be learnings from infection control in hospital environments that should inform practice.

Wider system interventions

While there are some opportunities to adjust the surface decontamination protocols, ventilation strategies and air filtering practices, how people interact with the wider system, including how tickets are booked and the flow of people through a station, should also be considered. Reducing the transmission risk requires a systems approach to the engineering interventions and to the human factor considerations for implementation.

[4] Fomites are inanimate objects that can become contaminated with infectious agents and serve as a mechanism for transfer between hosts.

This will include influencing an individual's behaviour as they plan to take an action, execute the task and making them aware of what they have done. There will be a role for cues and affordances that explain how an item, such as a contactless ticket, should be used. Some possible adjustments have been detailed below.

- **Modifications at interchanges:** Many of the same ventilation and surface decontamination adjustments apply to stations and interchanges. Stations with high ceilings encourage upward airflows taking the virus with it. Bringing fresh air into the space at low levels and UV air cleaners can help reduce the risk in stations without the ventilation features of high ceilings or outdoor stations. Hygiene points to encourage hand washing and use of hand sanitiser can be important additional measures.
- **Reducing contact:** Frequent touch transmission points could be reduced by having no-touch waste bins, taps and toilet flushes and automatic opening of doors at stops and stations. Voice activated information stations and mobile ticketing can reduce interaction with touch screens. Contactless ticketing that enables movement between different modes of transport also reduces risk of additional pinch points. Antimicrobial coatings are likely to play a role in future vehicle designs, however their effective integration into plastics and fabrics requires further research and development.
- **Maintaining distancing**: Mobile and e-tickets can help limit queuing at pinch points in stations. Reducing train capacity, seat reservation systems that allocate distanced seating and temporary seat blockers are being used to uphold social distancing measures within the confines of the carriage. Communication for staff and passengers both inside the station and before travel, alongside directed passenger movement can help avoid congestion.
- **Protecting staff:** Protecting staff with physical barriers and provision of appropriate PPE is important. Considering how ventilation and decontamination affect drivers and staff specifically is an important consideration before deploying any engineering solution.
- **Monitoring**: Temperature scanning has been used internationally to identify passengers who may pose a risk, however surface temperature measurements can be an unreliable measure of infection. Remote monitoring of traveller numbers and early identification of signs of crowding can enable mitigation responses. Longer term data trends can also allow planning for anticipated demand peaks so transport capacity can be increased where possible.

Adjustments in UK transport modes

The role that each of these industries plays in their response depends on the constraints of that mode and model, the role of the organisation and the business model they operate on as this defines the financial drivers, priorities and need for public approval.

Provider	Mode	Ventilation and air cleaning approach
Siemens	Trains	**Ventilation**: Siemens trains are ventilated by HVAC systems, 1 per carriage operating at between 3000m^3 and 4320m^3 per hour. There are separate HVAC systems for the driver cabs operating at between 680m^3 and 750m^3 per hour. Under normal operating conditions there is no exchange of air between the passenger saloon and driver cab.

		Design intention: The HVAC design intention is to provide a comfortable temperature environment. Some of the later model trains can regulate air quality based on CO_2 levels and are designed to support the fire detection/suppression system. **Opportunity to increase fresh air supply**: With the current HVAC systems and carriage layouts, there is a limitation to increasing the fresh air supply in the vehicles. Drivers have a 'drop window' to provide additional fresh air into the cab. There are strict regulations and safety requirements related to the air flow rates on passenger trains. Some later model trains can be adapted to increase the maximum fresh air flow rates, however this will impact the cooling / heating performance of the HVAC systems. **Alternative mitigation measures**: Siemens Mobility is looking to trial high-efficiency particulate air filtration systems, that could filter out bacteria and viruses on public transport.
First	Trains	**Ventilation:** Eight air changes/hour. **Design intention**: The HVAC uses up to 90% air recirculation to be energy efficient. **Alternative mitigation measures**: First have been exploring air cleaning options with CO_2 sensing capabilities. HEPA filters cannot be fitted to current rail HVACs due to the pressure drop so First have been exploring the potential for UV-C or plasma and ionising radiation filters.
First	Buses	**Ventilation:** The majority of regional buses don't have air conditioning so recirculation is less of an issue. **Alternative mitigation measures**: Currently recommending that windows are open although passenger comfort will be a limitation. Where possible the driver has their own air supply that isn't recirculated through the bus with a barrier from ceiling to floor that creates its own pressurised zone as additional protection.
First	Greyhound and transit	**Alternative mitigation measures**: Misting Ozone O3 through the HVAC to kill any contaminants in the system. The process is carried out with a remote machine at a distance from all people to prevent risk of respiratory irritation.
Knorr-Bremse	Train	**Ventilation:** Combination of recirculated air and fresh air, which is modulated depending on various parameters, such as occupation and outdoor air temperature. It can be adjusted for air purification depending on thermal loads. This typically is four to six air changes per hour. **Design intention**: To provide ventilation, heating, cooling and acceptable levels of CO_2 in accordance to EN 14750, EN 13129. **Opportunity to increase fresh air supply**: Difficult to increase fresh air and maintain comfort but it is possible to optimise the ratio of fresh air to returned air and prioritise maximising the fresh air used. The suggested working mode maintains the internal set point for the car temperature by adjusting the fresh air rate in a closed loop to the maximum. This rate is adjusted depending on the capacity of the HVAC system to manage the thermal loads that appear in the carriage in each moment.

		Alternative mitigation measures: Improving filtration using higher grade filtration materials and exploring the combination electrostatic filter paired with a UV-C light source to be retrofitted in existing Knorr-Bremse HVAC systems, which includes 40% of the UK fleet.
TfL	Tube	**Ventilation:** Tube train acts as a piston to push air through the carriages [more information anticipated].
Boeing	Planes	**Ventilation**: Fresh air continuously enters both jet engines then air is passed through a control valve sent through the air conditioning system and mixes with the cabin and recirculated air within a segment. Typically planes have three segments. **Design intention**: The HVAC systems on planes are required to provide 0.25kg/minute of fresh air to each occupant while maintaining a comfortable environment. **Alternative mitigation measures:** HEPA filters to remove contaminants where the air to be recirculated and the air from the outside are mixed.
RIA/RDG	Trains	**Ventilation**: There are a range of ventilation systems on trains, depending on the age and type of rolling stock. All modern trains (built since around 1990) have air-conditioning with no opening windows but there remain substantial numbers of vehicles relying on open windows and/or mechanical ventilation. On routes with many stops regular door opening greatly influences the rate of air changes. As a generalisation eight to 10 changes per hour can be assumed in vehicles fitted with air-conditioning but without frequent door opening, which would be increased without recirculation. **Design intention**: The HVAC systems on trains provide passenger air and temperature control as well as significantly reducing the noise inside vehicles and air contamination issues. Energy consumption is also a key consideration, for economic, environmental and power supply limitations. **Opportunity to increase fresh air supply**: Investigating changing door control systems to ensure all doors open when at stations. **Alternative mitigation measures:** Typical solutions include adding HEPA filters, UV treatment of filter surfaces and electrostatic treatment of airflow. Software modifications and enhanced filtration packs are also being explored.

Novel surface decontamination technologies are being trialled and deployed alongside ventilation and air cleaning.

Provider	**Mode**	**Surface decontamination**
Siemens	Trains	Siemens is exploring the use of a novel technology for surface sterilisation.
First	Trains	First is now applying a decontamination product with 30-day residual protection following more than 30 days trial of Zoono-Z71. This product is applied to surfaces and creates spikes with negative charge that mechanically rupture the positively charged virus.

		It has been using spare drivers and catering staff for support to clean the touch points.

International insights

These international examples draw on information gathering exercises from National Manufacturing Institute Scotland and University of Strathclyde, Metro Rolling Stock Platform and examples shared in conversation with experts.

	Place	System	Approach
Ventilation	China	Bus	Bus operator Cling produced guidelines for appropriate use of bus ventilation systems including how to use air conditioning and windows/skylights in tandem to ensure rapid air exchange, cleaning procedures, and air flow for drivers.
	Spain	Coaches	Irizar suggests constantly running air-conditioning or climate-control systems with inlets fully open to renew the air every three to six minutes. Air flow nozzles in the convenience panel above the passengers provides for individual climate comfort control, while air renewal gates above the luggage rack ensures a constant top-down flow of clean air. If passengers open the individual ventilation nozzles above them, the vertical air flow will also reduce the risk of cross-contagion between them.
	Spain	Metro de	Operate the HVAC normally.
	Austria	Wiener Linien	Operate the HVAC normally to ensure a high level of fresh air supply from outside the vehicle.
	Germany	VGF FFM	Operate the HVAC normally.
	Germany	KVB	Operate the HVAC normally to ensure a high level of fresh air supply from outside the vehicle.
	Hong Kong	MTR - HK	Continue to maintain air conditioning system working with enhanced filter change and cleaning. The vehicle design is equipped with hopper windows in case the air conditioning fails, which can be opened to improve ventilation.
	Turkey	Kayseri Ulasim	Continue to maintain HVAC operation with increased frequency filter change, every 15 days rather than 30 for first model trams and every 25 days rather than every 75 days on second model trams.
	Czechia	DPP	Operate the HVAC normally and open all doors at stops so fresh air can enter the vehicle.
S	Hong Kong	Train	Robot sprays bleach solution in train saloons.

	USA	Greyhound and FirstTransit	Ozone fogging systems.
	China	Bus	Buses disinfected after each trip.
	Spain	Coaches	Eco3 ionizer, which can be fitted to any coach equipped with air-conditioning. This releases negative ions and ozone into the interior airflow of the coach, causing virus-bearing particles to fall out of suspension, and attacking the viruses themselves.
	Shanghai / Moscow	buses /trains	Using UV to disinfect buses and trains.
	USA	buses /trains	Using bleach to wipe down contact points.
	St Petersburg	Tram	Trams are cleaned daily in the depot with a special disinfectant solution to wipe handrails and handles. At the end stations, during a planned stop, the tram cabin is also treated with a cold fog generator using a disinfectant.
	Hong Kong		Hydrogen Peroxide Vapour with silver nanoparticles.
		Aeroplane	UV self-cleaning plane bathrooms.
Wider system	Tehran	Contactless	Dismantled all handles, made push buttons automatic.
	UK	Contactless	Contactless toilet flush on trains.
	Singapore	Staff	Distribution of vitamin C tablets to staff.
	Seoul	Staff	Use of isolation rooms to monitor staff.
	Manila	Communications	Installation of new intercom systems.
	Taipei	Monitoring	Using infrared temperature monitoring in stations.
	Japan	Communications	Using posters and public screen to display hygiene information.
	Beijing	Communications	TikTok and Wechat to communicate with commuters and employees.
	Austria	Communications	Taking measures to reduce panic.
	France	Monitoring	Trialling AI from DatakaLab to identify mask use on public transport. Creates anonymous data to help authorities understand spread.
	Spain	Monitoring	Passenger screening.
	St Petersburg	Tram	Remote sensing of body temperature at the entrance to the depot.
	Italy	Aeroplanes	New seating arrangements and seating adjustments for air travel.
	Hong Kong	Airports	Contactless disinfection kiosks in airports.

	China	Scheduling	Data-driven tracking and scheduling systems to analyse crowd distribution in buses in near real-time.