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Making Transit Safe to Ride During a Pandemic: What Are The Risks and What Can Be Done in Response?

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Making Transit Safe to Ride During a Pandemic: What Are The Risks and What Can Be Done in Response?

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16. Abstract

The Covid-19 pandemic dramatically curtailed travel in the spring of 2020 and more moderately in the months that followed. Travel on public transport declined more and remains lower than on other travel modes, such as driving, biking, and walking. Although public transit operators have implemented various measures to reduce the risk of infection for both riders and employees, fear that public transport poses a high risk for transmission of the infectious disease is widespread. Since the onset of the Covid-19 pandemic, debates have raged in the popular and academic literatures regarding the safety of public transit systems and the role they may play in spreading the disease. To inform this debate, we review the public health literature on the spread of communicable diseases on public transport and conclude that current debates over public transit safety with regard to infection risk have tended to simplify a complex question that depends on numerous factors, many of which are well beyond the control of public transit operators. We draw on published studies of previous epidemics and the current pandemic to show that 1) there is a risk of infection on public transport, but the relative magnitude of the risk is often lower than in many other settings including households, workplace, schools, restaurants, and hospitals; 2) both the broader public health response and public transit agency actions can meaningfully reduce the risks of transmission; and 3) public transport (and indeed all travel modes), by moving people from one place to another, can facilitate the geographical propagation of infections, which can be effectively limited by travel restrictions. We highlight the multitude of risk factors that can affect infection risk on public transport, and argue that public transit systems can be made safe by actions taken by individual riders, public transit operators and, most important, by community-wide public health responses.

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Introduction

The Covid-19 pandemic has changed how people travel and how transportation systems function. Travel is down across all modes in 2020, though the declines on public transport were greater and the recovery has been slower than on other travel modes. Whether these changes are mostly temporary or enduring remains to be seen. Several recent studies in Europe and Australia have found that while people are generally making fewer and shorter trips during the pandemic, they are also travelling less on public transport and more in private automobiles and via “active” transportation modes like biking and walking (Beck & Hensher, 2020; de Haas et al., 2020; Molloy et al., 2020). This travel mode shift away from public transit may be largely due to fear of infection during this communicable disease outbreak because public transport hosts large volumes of people in dense and enclosed environments (Beck & Hensher, 2020; Hotle et al., 2020; Meyer & Elrahman, 2019). A recent global survey by McKinsey & Company (2020) found that private vehicle and active transportation (walking and biking) are considered safe by most people, whereas shared modes of mobility including public transportation and ride hailing are generally considered unsafe. The survey also revealed the role of fear of infection in affecting people’s travel choices, as 46 percent of respondents now consider reduced risks of infections as one of the key criteria for choosing a travel mode, in contrast to only 17 percent prior to the Covid-19 crisis. In order to lower the risk of infection on public transit systems and help reduce the spread of Covid-19, public transit agencies worldwide have implemented various measures including improved ventilation and air filtration, increased cleaning and disinfecting, modifications of seating and boarding protocols to ensure physical distancing, route and service modifications, mask-wearing requirements, and temperature screening (WSP, 2020).

People’s reluctance to ride and public transit agencies’ various pandemic response measures are both influenced by the perception that public transportation poses a high risk for the transmission and spread of infectious diseases. Since the beginning of the Covid-19 pandemic, the question of whether it is safe to ride public transit has been widely debated. For example, a recent working paper by Harris (2020) claimed that New York City’s subway system was the major disseminator of coronavirus infection throughout the metropolitan area. Rebuttals to this paper noted that the study failed to support the claim with relevant empirical evidence and that the evidence presented might at best be deemed as correlation rather than causation (Furth, 2020; Levy, 2020). A recent report funded by the American Public Transportation Association analyzed public transport ridership data and local Covid-19 case trends in several U.S. cities including New York City, Hartford, Connecticut, San Francisco, California, Salt Lake City, Utah, Columbus, Ohio, and Austin, Texas, and found no correlation between the two (Schwartz, 2020). While the study’s comparison of ridership and Covid-19 case trends does not appear to have accounted for the range in Covid-19 incubation periods, the lack of observed correlation between patronage and Covid-19 cases in this analysis does suggest that public transport did not play a significant role in the propagation of Covid-19 in the early months of the pandemic. Notably, the study suggests that the various public health interventions implemented by the public transport agencies studied may have played important roles in reducing the risk of Covid-19 infection on public transit. This assertion leaves open the question of whether public transport in the cities studied poses an inherently low risk of Covid-19 infection, or whether the public health interventions implemented were critical to reducing risk of infection among public transit riders.

Thus, the question of whether and under what conditions public transport is safe to ride is a complex one. This is in no small part because the risk of infection on public transit depends on many factors (such as ambient infection rates) beyond public transit operators' control. In a nutshell, the scientific evidence on communicable disease transmission on public transport, drawn mostly from the public health literature, is mixed. A careful review of this literature paints a nuanced picture of the role of public transportation can play in the transmission and spread of infectious diseases. This is because the relative infection risk on public transport depends not only on what public transit operators do, but also on the particulars of the communicable disease, customer and employee adherence to public health guidance, the trip durations and densities of riders on vehicles, as well as the effectiveness of the broader public health response. Thus, arguing in the abstract about whether riding public transit is inherently safe or dangerous during a pandemic is a bit like arguing about the area of a rectangle knowing only the length of one side.

Methodology

To paint this more nuanced picture, this article reviews transportation and public health studies that investigate 1) the association between travelling on public transport and risk of communicable disease infection, 2) the role of travel via public transportation in spatially spreading infectious diseases within a metropolitan region, and 3) what public transit can and should do in response to an outbreak of infectious disease. We conducted searches on Transport Research International Documentation database and Science Direct in order to include studies from both transportation and public health literatures[1]. We used search terms that were combinations of "transit" or "public transport" and "pandemic," "epidemic," or specific respiratory infectious diseases that are similar to COVID-19 in terms of its transmission, such as "H1N1," "SARS," and "MERS." We then excluded studies that do not focus on or directly address the relationship between public transportation and infectious diseases. We also relied on snowballing to find additional sources cited in the pieces reviewed. Eventually, we include 43 articles, reports, and books in this review.

Travelling on public transport and risk of infections

The risk of infection while riding public transportation usually becomes a concern when there is a communicable disease outbreak that can be transmitted by direct and indirect contact with fluids on surfaces or airborne droplets and/or aerosols. These are often respiratory diseases such as influenza, SARS, MERS, and Covid-19. The risk of infection in the public transport system is thought by some to be high because contagion concentrations may be high on surfaces that are frequently touched by passengers and in the air during peak hours when the volume and density

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[1] The literature searches were conducted between June 29th and July 7th in 2020. More research about public transit in the Covid-19 pandemic has since been published, but is not reviewed in this article.

of passengers are high (Meyer & Elrahman, 2019). Thus, during an epidemic, public health guidance regarding public transport often emphasizes the need to increase cleaning and disinfecting, promote physical distancing, and discourage non-essential travel. The perception that public transportation poses high infection risk can result in fear and avoidance of public transport among the traveling public, which may continue after the epidemic wanes and any possible infection risk is minimal, resulting in a lagging recovery of public transit ridership (Wang, 2014). But, perceptions aside, how high is the risk of respiratory disease infection on public transportation? To answer that question, we review public health studies that investigate the relationship between travelling on public transport and the risk of respiratory disease infection via airborne transmission.

The empirical evidence from the public health literature suggests that there is a risk of respiratory infection for public transit riders, but the causality and the comparative magnitude of this risk is unclear. What is clear from the public health research, however, is that the risk of infection in public transit environments depends on a variety of factors such as 1) the characteristics of the contagion in terms of its means and ease of transmission, 2) likelihood of exposure to the contagion, which depends on the proportion of infected cases among those riding public transport, 3) duration of exposure, 4) level of proximate contact which depends on the passenger densities in public transit vehicles and stations, and 5) the types of general and public transit-specific public health interventions implemented. Table 1 summarizes these factors and their relevance to public transport. The rest of this section discusses what specific studies found about the risk of infection on public transport. Although most of the studies reviewed here were published prior to the 2020-2021 pandemic, they all studied respiratory infections that have similar means of transmission to Covid-19, and thus should offer useful insights for how risk of Covid-19 infections may be understood and minimized on public transport.

Table 1. Factors affecting the transmission of communicable diseases on public transport

Factors Affecting Risk of Infection	Considerations For Public Transport
Characteristics of the communicable disease	
Means of transmission	Depending on whether the virus is transmitted through physical contact, droplets from mouth, nose, or eyes, aerosols, or water vapors, different interventions can lower infection risks. Ventilation will play a bigger role for reducing transmission via aerosols and water vapor, whereas cleaning and disinfecting will more effectively reduce transmission through surface contacts.
Ease of transmission	This is the R, which is a measure of how many people are typically infected by an infected person. For example, the R for measles is extremely high, while that for Ebola is much lower. Covid-19 is on the higher side because it can be transmitted via aerosols and due to the high number of asymptomatic carriers. Ease of transmission affects infection risks in all settings, including public transport.
Characteristics of the epidemic	
Likelihood of exposure	This depends on the number/proportion of infected people riding on public transport. This may be lower if the disease has a smaller R or if the public health response has been effective in isolating the infected cases, which means a lower infection risk for public transit riders.
Travel behavior characteristics	
Duration of exposure	This is the duration of time spent in a particular setting, which can vary greatly on public transport, but generally tends to be considerably less than time spent at work, school, or home.
Level of proximate contact	This depends on the proximity and density of potential carriers of the virus. This can be low in socially distanced public transit settings, or high on crowded vehicles and in crowded stations.
Characteristics of public health interventions	
Community-wide public health interventions	This includes community-wide compliance with mask-wearing, social distancing, hand-washing, travel limitations, quarantine requirements, and, when available, vaccination recommendations.
Public transit-specific public health interventions	This includes passenger and employee adherence to mask-wearing and social distancing while on the system, as well as cleaning and disinfecting practices and vehicle and station ventilation and filtering systems employed by the system.

The risk of infection on public transportation has been reasonably well studied, though most are simulation studies; we identified only three observational studies. One case-control study surveyed 72 patients with acute respiratory infection (ARI) and 66 patients with acute non-respiratory infection in Nottingham, U.K. during the 2008-09 influenza season, about their use of buses or trams, along with socio-economic characteristics and health status factors such as pre-existing medical conditions, smoking status, and vaccination history (Troko et al., 2011). The authors found a statistically significant positive association between ARI contraction and bus or tram use five days preceding the onset of symptoms. They did not find a statistically significant difference in ARI risks between occasional and regular riders. The authors conclude by recommending good hand hygiene and cough etiquette as well as refraining from unnecessary travel on public transport, but note as well that household exposure tends to pose higher infections risks than riding public transit.

Another U.K. study used Oyster card (the electronic public transport ticket in London) data on underground trips and data on influenza-like illnesses (ILI) infections in London to examine the association between underground use and ILI infection rates at the borough level (Goscé & Johansson, 2018). The authors found that boroughs with higher incidence rates were more likely peripheral, which could mean that public transit passengers from these boroughs tend to spend more time in the underground system and were more likely to transfer between lines, both of which increase the number and duration of exposure to other passengers. The authors then estimated the number of passenger contacts during the underground trips, which were found to have a statistically significant correlation with ILI infection rates of the passengers' departing boroughs. However, they found no statistically significant difference in ILI infection rates between boroughs with and those without underground stations.

Apart from these two relatively recent studies focused on influenza, there are several earlier studies focused on tuberculosis (TB), which can also spread via airborne transmission. A 2011 literature review by Edelson and Phypers examined a dozen studies, mainly contact investigations, of TB transmission among train, bus tour, school bus, and commuter van passengers (Edelson & Phypers, 2011). Among the 12 studies, eight found between 8.7 and 55 percent infection rates among tested passengers, while six reported identifying between 1 to 24 active TB cases through contact tracing. Seven studies found skin test positivity rates among students riding the same school bus as the index case to be higher than reactivity rates among other students at the same school who did not ride the same school bus. However, a contact investigation involving train exposure found that only four of the fifteen positive cases were exposed on the train and only two were likely infected on the train. Moreover, a cohort study of 142 commuters found that, while commuting behavior was significantly associated with TB infection, the infection risks for commuting by minibus and commuting by any means were not statistically significantly different. Thus, these papers collectively suggest a non-zero risk of TB transmission on buses or trains, but none were able to isolate and quantify the public transit-specific risk of transmission. The review also noted that these cases involved either long exposure durations, such as longer train rides and bus tours, or shorter daily exposures but repeated over weeks and months. Notably, many of the studies found poor ventilation in the studied transportation settings.

Overall, these observational studies find positive correlations between respiratory infections and public transport use, but in general fail to establish either causality or measure the comparative magnitude of the estimated risks. In contrast, studies that simulate an infectious disease outbreak in urban settings can compare estimated infection rates on public transportation with estimated infection rates in other settings such as school, workplace, or household, based on a set of assumptions about the disease in question, the populations involved, and the characteristics of these environments. One such study simulated interactions of subway riders with their workplaces, schools, households, and community activities in New York City during an influenza outbreak, using disease transmissibility data about the 1957-1958 influenza pandemic and travel survey data from the 2000s (Cooley et al., 2011). The simulation shows that subway use was estimated to contribute just 4.4 percent of total cumulative infections, of which commuters account for 3.6 percent while non-commuters account for less than 1 percent. However, the relatively low public transit contribution to overall infection risk in this simulation was due more to the relatively small amounts of time people spend on public transit compared with many of the other activities analyzed, and not to inherently low population-adjusted risk factors. The simulated risk factor for subway commuting was 78.7 per 1,000 individuals, which is comparable to workplace interactions (79.1 per 1,000) but smaller than household transmission (99.0 per 1,000), community activities (106.8 per 1,000), and school attendance (438.2 per 1,000). Simulations of various public health interventions also found that contact-reducing interventions on the subway system, such as hand washing, microbial disinfectant applications, and mask wearing, are far less effective than the same contact-reducing interventions implemented across the entire community. Similarly, a relatively low-compliance vaccination program is estimated to be more effective than subway-specific interventions on community-wide risk. Such findings do not mean that public health interventions on subways are not effective, but rather point to the importance of community-wide public health interventions in reducing the spread of infections on public transport.

Similar results were also obtained in a study that simulated an outbreak of smallpox, which can be transmitted through respiratory droplets, in Hong Kong (Zhang et al., 2018). This simulation shows that, among all settings, households account for the biggest share of infections (59.6%), followed by office (18.1%), school (13.4%), restaurants (7%), hospitals (1%), with public transport below all of these at 0.9 percent. The authors suggested that the high percentage of household infections is likely explained by (1) the relatively long durations of exposure, while the relative risk across the other venues is due to (2) the level of proximate contact in these various settings and (3) the proportion of people who are infected. So, for example, durations of exposure tend to be high at home, close contact is common at schools and in offices, and infection rates are typically highest in hospitals. Another key simulation result, and certainly relevant to the current Covid-19 pandemic, is that improving ventilation helps reduce infection probability in all of the settings studied.

Another recent study simulated an outbreak of H1N1 influenza in Changsha, China, using geospatial data on traffic as well as data on infection dynamics and spreading characteristics (Mei et al., 2015). This study simulated scenarios in which a combination of public health interventions including vaccination of 10 percent of the total population, seven-day isolations of those with close contacts with confirmed cases, and seven-day suspension of office work, were activated on the

4th and the 5th day of the outbreak. While the main finding was that activating these interventions one day earlier can reduce the maximum total infected cases by more than half from approximately 6,800 to about 3,100, the authors noted that about 19 percent of patients were projected to become infected on public transport and transfer points. This percentage is substantially higher than the public transport transmission rates estimated in the simulations from the other studies reviewed here because the modelled interventions – a vaccine, quarantines, and office closures – are projected to dramatically reduce infections in the other settings studied.

Across all of these studies, the observed or modelled percentage of infections in a particular setting without public health interventions is affected by the seven factors summarized in Table 1: (1) the means by which infection occurs (surfaces, air, etc.) (2) the relative ease by which infections are transmitted, (3) the proportion of the population infected, (4) exposure duration, (5) level of proximate contact, (6) the level and effectiveness of community-wide public health interventions, and (7) public transit-specific public health interventions. Notably, many of the risk factors, beyond the particulars of the disease and its transmission, are beyond the control of public transit managers. For example, the proportion of infected people riding public transport varies depending on many different factors, such as the proportion of asymptomatic carriers of the virus, mask wearing, extent of testing and contact tracing, the degree of self-quarantine compliance, and whether transit agencies enforce preventive measures like temperature checks.

The interplay of these factors helps to explain the relatively low estimated infection risks on public transport suggested by most simulations, and higher estimated risks in a few of the simulations. For example, while the level of proximate contact can be high on public transport, especially during peak hours, this can be substantially reduced by lower passenger loads during an outbreak. Likewise, riders making long duration public transit trips in poorly ventilated vehicles face higher risks, although the time spent on public transport tends to be substantially shorter than time spent in close proximity to housemates, classmates, or work colleagues, and risks on public transit are typically reduced further by good air ventilation and filtering (Centers for Disease Control and Prevention, 2020).

Making public transport safer

A number of studies also investigate measures to make public transport a safe environment during an infectious disease outbreak. One study simulated the spread of an infectious disease in and through the public transport systems and found that increasing transportation efficacy (how quickly passengers reach destinations), improving sanitation and ventilation, discouraging non-essential travel, and limiting travel by infected individuals in particular can substantially lower the risk of infection on public transportation (Xu et al., 2013). Similarly, a recent study that specifically simulated transmission of the SARS-Cov-2 virus via aerosols in indoor environments showed that public transport and other crowded public indoor spaces should focus on controlling passenger densities and improving ventilation to lower infection risks, while passengers should practice physical distancing and seek to minimize time spent in such spaces (Vuorinen et al., 2020). The authors also note that masks can lower the release of virus-containing droplets and aerosols into the air, protecting other passengers.

One earlier study also focused particularly on the role of ventilation by specifically simulating airborne transmission of influenza in bus microenvironments equipped with different ventilation and filtering systems (Zhu et al., 2012). Simulations show that air-recirculation ventilation using high efficiency filtration has similar performance in lowering infection risk to non-air-recirculation systems that use 100 percent outdoor air supply, showing the benefits of filtration. Moreover, the study also found that displacement ventilation systems that replace contaminated air with fresh air perform better at reducing infection risk than mixing ventilation systems that dilute contaminated indoor air with fresh air.

Another study focused particularly on virus transmission via frequently touched surfaces (von Braun et al., 2015). This study collected a sample of 49 swabs from frequently touched surfaces in public transport vehicles, ticket and coffee vending machines, as well as from high-touch surfaces in a hospital and a medical school in Geneva, Switzerland during the peak of the 2009 H1N1 pandemic to test whether the H1N1 virus could be detected. Only one specimen collected from the bedrail of an infected patient tested positive for the virus. The authors suggested that such surfaces in public transportation had low virus quantity because acutely infected patients are less likely to ride public transport, while increased public alerts regarding hand hygiene may also result in less virus transmission by virus carriers through surface contacts. The authors also suggested that high frequency of touches might have reduced the virus concentration on these surfaces, which would not necessarily lower risk of infection. The authors did not report or consider effects of cleaning and disinfecting practices by the public transport operator.

Overall, the literature suggests that the risk of infections on public transport can be reduced with targeted policies and procedures. To reduce virus transmission via surfaces, public transit agencies can increase their cleaning and disinfecting efforts; to reduce airborne virus transmission, public transit agencies can improve ventilation and filtration systems in their vehicles and stations, and they can vigorously enforce policies mandating physical distancing and mask-wearing. As noted earlier, during the Covid-19 pandemic, many public transit agencies are taking such measures to reduce infection risks while continuing their operations to provide service for those with few travel options (WSP, 2020). In fact, these measures were also included in national guidance on pandemic planning and response for public transport agencies published in 2014 (National Academies of Sciences, Engineering, and Medicine, 2014). However, the extent to which these measures are implemented likely varies across public transit agencies because there exist considerable variations among them with regard to system sizes and available resources. Moreover, the effectiveness of these measures taken by public transit agencies will also vary because it depends greatly on factors, such as population infection levels and community-wide public health guidance compliance, beyond the control of public transit managers.

The role of public transportation in the (geographical) spread of infectious diseases

Apart from the risk of disease transmission among people on public transport, another concern about public transport in a pandemic is that it may, like any means of transportation, advance the geographic spread the disease by moving people from one place to another where they can infect others at destination venues. The role of transportation in spreading infectious diseases geographically has been studied by many, although past studies have primarily focused on the role of air travel. A recent review of studies about respiratory virus spread in and via transportation systems concluded that the weight of the empirical evidence suggests that air travel accelerates the spread of contagions to new areas and that inflight transmission as well as transmission in airports can occur (Browne et al., 2016). This review also found that viruses can spread on cruise ships, and have historically spread to new areas via sea travel, but there is no evidence of such transmission in modern day pandemics. Regarding ground transportation, long distance or inter-regional buses and trains can spread contagions to new areas, but they found very little evidence for intra-region spread through public transportation and disease transmission aboard buses and trains[2].

Published studies on the geographical spread of disease via public transport are mostly simulations rather than observational studies. These analyses simulate how an outbreak of infectious disease might be expected to spread within a metropolitan area via the public transport system, as well as the effect of travel restrictions on containing the spread of the outbreak.

One study used travel survey data on travel modes and residential locations to simulate an influenza outbreak in metropolitan Tokyo (Ohkusa & Sugawara, 2007). The simulation assumed that an individual contracted the virus from abroad and returned to Tokyo on day 1, and consulted the doctor on day 5 when symptoms started to show; the public health interventions started on day 6. This simulation showed that the disease had already spread to much of the metropolitan region by day 7, which, the authors argued, indicated that localized quarantine or lockdown of particular areas within the metropolitan region where active cases are found were likely too late to be effective. The simulation projected that commuter trains played an important role in spreading the virus to places throughout the metropolitan area by moving infected people around, which may be less relevant in regions, like in the U.S. where residents do not rely as heavily on rail public transit for transportation as those in Tokyo.

Another study also simulated the spread of an influenza outbreak in Tokyo, but with a focus on its suburban commuter towns along rail lines (Yasuda et al., 2008). The study compared scenarios of where the first patient is located, and found that commuting via rail transit plays a bigger role in the local spread of infection if the first patient is in Tokyo, whereas infection among school children plays a bigger role if the first patient is in a satellite town. Thus, the role of

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[2] Browne et al. (2016) only included one study on public transportation by Troko et al. (2011), which is also included in this review.

commuting via rail in these scenarios is moving infected individuals from one place to another, thereby facilitating the geographical propagation of the outbreak. The study also tested the effects of interventions like traffic suspension, school closures, and vaccination of school children, and found that traffic suspension has no effect on the number of infected individuals after the influenza reaches the suburban town (where commuting via rail is common), but can delay the spread if implemented early enough, while both school closures and vaccinations were projected to be more effective than travel bans.

Similarly, one study models the transmission of TB in an urban setting where individuals of a town either commute daily via public transportation to other parts of the urban area or interact with one another in the local community (Pienaar et al., 2010). This simulation also helps to investigate the role of intra-city travel on public transportation in spreading infectious diseases. Simulating over a 20-year period shows that commuter suburbs with very high numbers (90%) of public transit out-commuters are expected to have nearly twice the rate infections than a suburb where only 30 percent of workers commute to the central city via public transport, suggesting that high numbers of public transit commuters can significantly increase rates of TB infection in local communities. Simulations also show that behavioral interventions, such as mask wearing, can reduce airborne disease transmission, but that the effectiveness of such measures depends considerably on the degree of compliance.

A more recent study simulated the spread of an outbreak of airborne infectious disease in Beijing and compared the relative effectiveness of suspending subway, bus, and taxi services in containing the spread of the disease (Zhang et al., 2016). Simulation results showed that suspending subway service can significantly slow the rate of spread and reduce peak levels of infected cases; suspending bus service can also reduce peak infection levels but, because buses carry fewer passengers than rail in Beijing, is projected to be less effective in delaying the spread; suspending taxi service was projected to have minimal effect. The reason that the subway system is projected to have the biggest effect among all three modes analyzed is due to the very high passenger volumes (Beijing is the world's most heavily patronized metro system, although Tokyo's multiple systems carry slightly more riders) and densities in the stations and on the trains. In addition, the simulations also showed that suspending office work can significantly reduce peak infections, but is less effective than suspending subway service in delaying peak infection levels.

Some studies also investigate the effect of travel restrictions broadly, rather than just suspending public transport, on controlling an infectious disease outbreak. One study simulated an outbreak of an infectious disease in Sweden with the origin of the outbreak in Stockholm and tested the effect of banning travel over 50 and 20 kilometers on containing the outbreak (Camitz & Liljeros, 2006). Simulations of the no-restriction, 50km travel restriction, and 20km travel restriction scenarios showed that both travel restrictions can drastically reduce the rate and geographical spread of the outbreak, even at compliance levels well below 100 percent. Moreover, while 50km travel ban can effectively limit the spread of the disease between Stockholm and other large Swedish cities, the 20km travel ban was shown to limit the spread *within* Stockholm and its surrounding small cities.

Recent studies of the current Covid-19 pandemic also reveal the effect of travel restrictions on controlling an infectious disease outbreak. One study modelled the spread of the disease in London and compared scenarios with different levels of interventions (Goscé et al., 2020). Simulation results suggest that in the absence of a vaccine, a combination of non-pharmaceutical interventions including universal testing and case isolation, contact tracing and isolation, and mask wearing in a continued lockdown can significantly reduce infections and deaths. Such a comprehensive approach was projected to eliminate the infection in London over four to six months, after which the lockdown could be lifted but with sustained efforts to prevent imported cases and contain mini-outbreaks until a vaccine becomes available. In contrast, if lockdowns were lifted sooner, interventions such as universal testing, social distancing, use of face masks, and isolation of individuals over 60-years were projected to reduce infections and deaths to some extent, but not as effectively as the continued-lockdown approach. London and the U.K., of course, chose the latter, less aggressive path.

Another study modelled the propagation of the outbreak in Wuhan using data on Covid-19 cases to estimate how transmission rates varied (Kucharski et al., 2020). The model estimates showed that transmission of the disease likely declined in Wuhan during late January, which coincides with the implementation of travel restriction measures. However, the authors also noted that the transmission rate had already declined before the enforcement of travel restrictions, which might reflect the effect of other public health interventions and growing public awareness and precautions.

The evidence reviewed thus far suggests that, in the absence of a vaccine, behavioral interventions, albeit sometimes drastic ones, can effectively limit the spread of infectious diseases and reduce infections and deaths. However, some argue that such measures may, from an economic perspective, result in even lower welfare relative to the do-nothing scenario (Fenichel, 2013). In order to maximize social welfare, the optimal scenario is one in which infected individuals are isolated and make minimal contacts with the rest of the population, while recovered individuals, having developed some level of immunity, can increase their activities without exposing those still susceptible to the virus to higher infection risks. In a scenario with no public intervention at all, individuals may not act in the socially optimal manner such that infected individuals may be more active than they should, thereby propagating disease transmission, while recovered individuals may be less active than they could be, given the low risks of infection to themselves and to others – both of which increase welfare losses.

The policy debate: how should public transit respond

During the current Covid-19 pandemic, debates about whether governments should implement drastic measures, such as lockdowns and strict travel restrictions, often refer to the contrasting approaches of China and South Korea in responding to the pandemic. While both countries were more successful than many others around the world in containing the spread and reducing infections and deaths in 2020, their public health interventions have been very different, as China adopted lockdowns and other drastic measures whereas South Korea did not. What also makes the comparison of China and South Korea interesting is that they both experienced past pandemics like SARS and MERS and these past experiences informed their response to the Covid-19 outbreak. A comparison of these two countries offers insights on the effectiveness of travel restrictions as a public health intervention during a pandemic.

One recent study compares China's responses to the 2003 SARS outbreak and the 2020 Covid-19 outbreak (Yang et al., 2020). The authors note that one of the key lessons learnt from the 2003 SARS outbreak was aggressively-enforced quarantine and contact tracing, which was also implemented as part of the Covid-19 response. Public transport service is typically suspended as part of the aggressive quarantine efforts. The authors also noted the importance of other measures relevant to public transport, such as mask wearing in all public spaces including on public transit and temperature screening at key transportation hubs including subway stations. Wilder-Smith and Freedman (2020) also point out that while China learned from the past experience with SARS and implemented isolation, contact tracing, and quarantines with medical observation relatively quickly, the exceptionally high number of cases and the greater transmissibility of Covid-19 as compared to SARS led to the implementation of more drastic community containment and lockdown measures, which included suspension of public transport service.

Several studies have evaluated the effectiveness of such quarantine and lockdown measures. Shen et al. (2020) evaluated the effects of metropolitan-wide quarantine on the spread of Covid-19 in public spaces (including public transport) and in households. Their model estimates suggest that the quarantine strategy may have reduced infections by more than 70 percent compared to a no-quarantine scenario, and the effect was estimated to be greater for public space infections than household infections, as public space infections were estimated to account for about 30 percent of all infections under the quarantine scenario, but about 48 percent under the no-quarantine scenario. Peng et al. (2020) assessed the effectiveness of various medical and non-medical measures on the spread of Covid-19 and found that medical treatments in the absence of a vaccine only had moderate success, whereas the enforcement of drastic quarantine measures, including the suspension of public transport service may have played the bigger role. The authors further suggested that the early implementation of quarantine measures is critical as it reduces the likelihood of resource depletion, both human and equipment. Tian et al. (2020) examined the effectiveness of travel restrictions and social distancing measures on controlling the spread of Covid-19 during the first 50 days of the outbreak. Their regression models show that cities that suspended public transport, closed entertainment venues, and/or banned public gatherings had fewer cases in the first week of their outbreaks, and the sooner they did these things, the fewer the cases overall. Islam et al. (2020) evaluated the association between physical distancing interventions and incidence of Covid-19 through a natural experiment that synthesized data from 149 countries and regions using meta-analysis. They find that physical distancing measures, including closures of schools, workplaces, and public transport, restrictions on mass gatherings and public events, and travel restrictions or lockdowns, were indeed associated with lower rates of Covid-19 cases. They also find that earlier implementation of lockdowns was associated with a larger reduction in Covid-19 cases. However, they also find that closure of public transport did not have an independent effect on reducing Covid-19 cases if the other four measures were in place. While these findings all confirm the effectiveness of physical distancing measures including drastic interventions like lockdowns, in reducing infections, the work of Islam et al. highlights that the effect of suspending transit service depends on the extent to which physical distancing is adopted by the wider society.

Contrary to the above findings, South Korea's experience seems to suggest that the outbreak may be controlled without measures as drastic as lockdowns and travel bans. South Korea's early pandemic response measures included avoiding mass gatherings, universal mask wearing, voluntary physical distancing, limiting operations of crowded indoor places and collecting visitor logs at these places, delaying school openings, and the 3T strategy (Test, Trace, and Treat). Notably, South Korea's approach did not include any forced business closures, lockdowns, or suspension of public transportation (S. Kim & Castro, 2020). Kim and Castro suggest that the most important lesson that South Korea learned from the 2015 MERS outbreak was aggressive and extensive contract tracing, which informed the country's response to the Covid-19 outbreak. They also noted that the MERS experience led to amendments to South Korea's Infectious Disease Control and Prevention Act to enact government's authority to collect credit card, mobile phone, and other data from confirmed patients and reconstruct their travel trajectories that are then made public in order to facilitate contact tracing.

Although South Korea did not suspend public transport service, public transit ridership did decline during both MERS and Covid-19 outbreaks due to fears of infection. One study that examined the effect of public fear of MERS on travel behavior found that public transit trips declined by 11.8 percent between May 20th, the start of the outbreak, to June 10th 2015, when public fear was at its height; more broadly, trips to traffic analysis zones with potential MERS hotspots dropped by 13.9 percent, which was more than half again as much as the decline in trips to zones without hotspots (8.8%) (C. Kim et al., 2017). The authors also found that people's ability to alter their behavior differed among population groups, as children and the elderly reduced public transit use much more than adults and teens who had work and school responsibilities. Likewise, off-peak trips dropped much more than peak-hour trips, which makes it more challenging to reduce passenger densities and increase social distancing during peak periods. Park (2020) examined the changes in subway ridership in Seoul during the Covid-19 outbreak using ridership data between January 1st and March 31st 2020 and found a similar "fear effect" on subway ridership. The study showed that ridership declined only slightly after the alert level was raised on January 27th, but then dropped dramatically to about 60 percent of normal ridership level in late February after reports of the first death and mass infections.

In addition to government interventions and orders, the degree of compliance among the general public also matters. One study surveyed people in Argentina, Japan, Mexico, the U.K., and the U.S. about whether they adopted various personal protective behaviors, social distancing behaviors, and/or got vaccinations during the H1N1 pandemic (SteelFisher et al., 2012). The survey found that respondents were more likely to adopt personal protective behaviors than social distancing behaviors in all five countries, although the degrees to which people adopted these behaviors varied across the countries. For example, Mexicans were the most likely to avoid travel, followed by Argentinians, Japanese, Americans, and the British, whereas Americans and the British were much less likely to wear masks than were those in other countries.

Thus, the experience of China and South Korea and other countries in responding to the ongoing Covid-19 pandemic as well as past pandemics all suggest that public transport in these countries is part and parcel of the larger public health response to infectious disease outbreaks, but it is not the most important target area for interventions. On the one hand, countries like South Korea did not suspend public transport service or implement other measures specific to public transportation. On the other hand, even in countries like China where public transport was suspended, the suspension was part of a wider lockdown effort in which many, if not most, economic and social activities were suspended. In other words, there certainly are things that the public transport operators can do in a pandemic to protect its employees and customers as well as to help control the spread of infection, but the effect of which will likely be limited. What matters more for risk on public transport is the society-wide public health response, as well as the degree of compliance among the general public.

Conclusion

We have reviewed studies, primarily from the public health literature, on public transport and infectious disease outbreaks, focusing on three main issues: 1) risk of infections on public transportation, 2) the role of public transportation in the spatial spread of infectious diseases, 3) what public transportation can and should do in response to an outbreak of infectious disease. The weight of the empirical evidence suggests that there is an association between travelling on public transport and infection, but risk of infections on public transportation tends to be lower than in many other settings. This is because, while population density on public transit is often high during peak hours, people generally spend less time on public transit and thus spend less time potentially exposed to a contagion than in other settings like school, workplace, and at home. The risks of infection can be further reduced by universal mask-wearing, minimizing crowding on vehicles, increasing cleaning and disinfecting of surfaces (for some types of outbreaks), and improving air ventilation and filtration on vehicles and in stations – all in addition to a broader, comprehensive public health response that implements aggressive testing, contact tracing, quarantine, and vaccination.[3]

Many simulation studies published on epidemics and transportation suggest that intra-urban or intra-regional travel via public transport can spread the disease across metropolitan areas (as can travel via other modes such as driving and, especially, flying), and that travel restrictions, such as suspending public transport service or limiting driving, can delay the spread of infections, provided that they are implemented early on. However, these simulations also suggest that other measures, such as school closures and working from home, that target higher risk settings, are likely more effective than measures that focus exclusively on public transport.

These simulation study findings are supported by studies that examine the public health response to pandemics in China, South Korea, and other countries. The experiences of these countries in responding to past and current pandemics indicate that public transport need not be a primary target of interventions. Instead, the most effective pandemic responses for public transit focus on society-wide interventions that include public transit: mask-wearing and social-distancing; testing, contact tracing, and quarantining; regular cleaning and disinfecting of public spaces; and vaccinations when available. If the larger public health response is scattershot, conflicting, and not very effective, then riding public transit can pose non-trivial risks of infection because the number of asymptomatic and pre-symptomatic riders will be much higher. But if the public health response is effective in tracing and quarantining infected cases and those who have been in close

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[3] In October 2020 the U.S. Centers for Disease Control sought to mandate mask-wearing on public transport as part of the recommend Covid-19 response, but these recommendations were overruled by the Trump Administration (New York Times 2020).
https://www.nytimes.com/2020/10/09/health/coronavirus-covid-masks-cdc.html

contact with active cases, then chances of public transit riders being exposed to the virus will be lowered, making public transit a relatively safe venue.

So is it safe to ride public transport during a pandemic? The research reviewed here collectively suggests that it certainly can be. But it depends on levels of mask-wearing compliance and hand hygiene; it depends on for how long and at what levels of social distancing people ride; it depends on vehicle sanitation and in particular the effectiveness of air ventilation and filtration on vehicles and in stations; and perhaps most importantly, it depends on the effectiveness of the community-wide public health response to the pandemic.

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