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COVID-19 and Public Transport

A Review of the International Academic Literature

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Foreword

The coronavirus pandemic has had a huge impact on public transport all over the world. Navigating in a turbulent and fast changing landscape is challenging for public transport actors, especially considering the lack of experiences from previous disruptions on a similar scale. Yet, it is more important than ever that actions are based on knowledge. This report provides a structure and an overview of scientific knowledge about COVID-19 and public transport. It provides a snapshot of scientific knowledge presented in international publications right now, in January 2021. I am convinced that we, in the coming year, will see many more publications about the pandemic's consequences for public transport, both from Swedish and international researchers.

John Hultén

Director K2

Summary

The ongoing COVID-19 pandemic has brought a series of unprecedented challenges to the public transport sector. Public transport authorities, operators and users are faced with new constraints and responsibilities and can rely on a still limited and evolving body of scientific knowledge to take informed decisions.

This working paper presents a review of the international academic literature on the way in which public transport operations and use have been affected by the COVID-19 pandemic. Collecting academic articles belonging to multiple disciplines, the review presents a series of findings and recommendations pertaining to the new coronavirus' routes of transmission (Chapter 2), the challenges emerging as a consequence of the pandemic (Chapter 3) and the related recommendations (Chapter 4).

The routes of transmission for SARS-Cov-2, the virus causing COVID-19, are contact transmission (when there is a direct contact with an infected person or a contact with a contaminated surface), droplet transmission (when, in proximity with an infected person, the virus is transmitted by both large and small respiratory droplets containing the virus), and airborne transmission (when the virus is transmitted by smaller droplets and particles suspended in the air). The relative contribution of the different transmission pathways is still uncertain, but the most recent evidence suggests that droplet and airborne transmission are the major ones. Further, there is still no clear knowledge about how SARS-CoV-2 is transmitted in public transport and whether its use increases the risk of being infected. However, higher risks of infection are related to the close proximity among passengers, the many high-touch surfaces, the use of potentially crowded spaces (such as transport hubs and stations), and the lack of access controls. Distance and duration of the trip also play a role. The use of face masks, frequent cleaning, and proper ventilation appear to be important countermeasures.

A series of interrelated challenges and policy responses emerged from the pandemic's impact on public transport. The challenges identified by the literature pertain to public health, changing travel behaviours and attitudes, financial sustainability, social equity and sustainable mobility. The need to safeguard the health of passengers and of on-board workers while, at the same time, guaranteeing the operation of the public transport service led to a series of heterogeneous responses. They include service suspension, reduced frequency, discouraged use, reduced capacity of vehicles, fare suspension and rear-door boarding, hygiene measures, design interventions and use of personal protective equipment (PPE). The relative impact of these responses is still unclear. For what concerns emerging travel behaviours, public transport ridership has seen a steep decrease in many countries as an effect of non-pharmaceutical interventions, public authorities' recommendations, and the concern over contracting or spreading the virus. Not only travel behaviours have changed, but also attitudes towards public transport appear to have worsened. A further challenge pertains to the financial sustainability of public transport. The decline in demand, measures impacting the payment of fares (e.g. compulsory rear-boarding or the decrease in ticket inspections), the increase of certain items of expenditure

(such as those related to hygiene procedures, purchase of PPE and increased supply to comply with physical distancing rules) and the unavailability of public funds to subsidize public transport emerge as the main causes of financial instability and risk of bankruptcy for public transportation. These emerging constraints further jeopardize the ability of public transport to guarantee accessibility and, thereby, contrast the risks of transport-related social exclusion. Public transport may be the only option for many users who are unable or unwilling to walk, cycle or drive a car and who still have to carry out necessary out-of-home activities. Further, research shows that working from home during the pandemic is mostly a privilege of people with higher incomes. Lastly, the pandemic poses a threat to sustainable mobility both because of the shift to private motorized vehicles and since the decreased ridership jeopardizes the role of buses in emissions reductions.

For what concerns scenarios and recommendations, the literature on COVID-19 and public transport stresses the need for further research to support evidence-based decision making. This will be pivotal to address the delicate trade-off between the aforementioned challenges. Public transport needs multi-pronged strategies to enhance safety and find a viable balance between the different demands related to its governance, provision and use. Recommendations emerging from the reviewed literature pertain to general health-related measures, strategies for supply-, crowd- and demand management aimed at physical distancing, and advices for safeguarding the equity and sustainability goals of public transport.

1. Introduction

The coronavirus disease 2019 (COVID-19) pandemic has hitherto had a major impact on people's mobility at the local, national, and global scale. During 2020, more or less stringent non-pharmaceutical interventions, such as travel restrictions, lockdowns, remote work and education, have all affected passenger transport. Research shows that physical distancing policies are effective in reducing the spread of the virus (Islam et al., 2020; McGrail, Dai, McAndrews, & Kalluri, 2020). Nevertheless, distancing has proven to be particularly challenging in some situations and for some groups of people. This is undoubtedly the case of public transport. Public transport's purpose to provide an affordable, accessible and sustainable transport mode for most people might be jeopardized by the need to ensure physical distancing. In this context, public transport authorities and operators face the unprecedented challenge of maintaining adequate levels of service while safeguarding the health of users and workers and, at the same time, dealing with a severe financial instability.

The purpose of this working paper is to review the international academic literature on the several ways in which COVID-19 affects public transport's operation and use. The aim is to provide a state-of-the-art useful to identify crucial challenges and scenarios. By means of a semi-systematic review (Snyder, 2019), the paper presents results and recommendations from a selection of academic articles (both peer-reviewed and pre-prints or working papers) pertaining to multiple disciplines and fields of research (from epidemiology to transport geography, from engineering to urban studies). The articles were collected by means of keyword-searches on major academic search engines (Google Scholar, Scopus, PubMed, Web of Science) and filtered in order to include only relevant results made available online during 2020[1]. The review was further expanded to include relevant articles quoted in the first selection of papers.

The remainder of the paper is organized as follows: Chapter 2 presents the current knowledge on how SARS-CoV-2, the virus causing COVID-19, is transmitted, especially in public transport; Chapter 3 summarizes the key challenges and relative policy responses identified in the literature, focusing on four areas of concern: public health, travel behaviours and attitudes, financial sustainability, social equity and sustainable mobility; Chapter 4 presents a series of policy suggestions and recommendations stated in the reviewed articles pertaining to health-related measures, physical distancing management, equity and sustainability.

[1] The review includes articles published until the end of November 2020.

2. Transmission of SARS-CoV-2 in public transport

SARS-COV-2 belongs to the family of coronaviruses, a set of viruses that affect the respiratory system. Respiratory viruses can be transmitted mainly in 3 ways:

- contact transmission (when there is a direct contact with an infected person or a contact with a contaminated surface),
- droplet transmission (when, in proximity with an infected person, the virus is transmitted by both large and small respiratory droplets containing the virus),
- airborne transmission (when the virus is transmitted by smaller droplets and particles suspended in the air) (The Lancet Respiratory, 2020).

The relative contribution of the different transmission pathways is still uncertain (Morawska et al., 2020; Tirachini & Cats, 2020). Specifically, there is still no clear knowledge about how SARS-CoV-2 is transmitted in public transport. We can rely on recent but still limited studies and, partly, on knowledge based on previous respiratory infectious diseases.

The greatest risk for infectious diseases in public transportation is related to the fact that people sit or stand in proximity in a confined, closed environment (Musselwhite, Avineri, & Susilo, 2020), that there are many high-touch surfaces that can host microorganisms, and that the control on potentially infected passengers' access is difficult to perform—especially considering the fact that asymptomatic persons can spread the virus too (Tirachini & Cats, 2020). Furthermore, the use of public transport also implies the use of public spaces (such as transport hubs and stations), which are exposed to a higher risk of crowding. The remainder of the chapter presents the most recent knowledge on the routes of transmission (contact-, droplet- and airborne transmission) and the infection risks in relation to public transport.

2.1. Contact transmission

Contact transmission occurs both in the case of direct contact with an infectious person (e.g., touching during a handshake) or of contact of unanimated surfaces hosting the virus. Transmission via unanimated surfaces (also called "fomites") has been a major concern in the initial stages of the pandemic, but as of now appears not to be a so relevant route of transmission (Mondelli, Colaneri, Seminari, Baldanti, & Bruno, 2020). Despite there being no solid evidence of surface transmission (Goldman, 2020; The Lancet Respiratory, 2020), this route of transmission is still considered relevant in guidelines and countermeasures. The new coronavirus can survive on surfaces even from hours to days on different types of surfaces (Tirachini & Cats, 2020), but its ability to infect is still

uncertain. Furthermore, SARS-CoV-2, likewise other human coronaviruses, can be efficiently inactivated by specific surface chemical or physical disinfection procedures (Musselwhite et al., 2020). Surfaces on public transport that can host infectious microorganisms include handrails, ticket machines, smart-card machines, doors, handles, windows, panels, floors, elevators and seats (Musselwhite et al., 2020). Cleaning and sanitation of public transport vehicles is a common measure, together with installing hand sanitizing units. However, it is not clear if these measures are effective to reduce the risk of transmission (Tirachini & Cats, 2020). Also "it is questionable whether frequent cleaning and sanitation by staff is sustainable over time, as it demands much human resources and its logistics might be complicated" (Musselwhite et al., 2020, p. 2). However, as suggested by Tirachini and Cats (2020), the use of PPE and hygiene measures—even if the risk of infection may be low—might have the effect of reassuring personnel and passengers and maintain confidence in public transport.

2.2. Droplet transmission

Transmission through infected droplets (5 to 10 μm) produced by coughing, sneezing and breathing in close proximity to another person is indicated as a major transmission route for most respiratory virus and is at the basis of physical distancing (also called "social distancing") advices. Physical distancing is a non-pharmaceutical measure widely applied all over the world to prevent the new coronavirus transmission. Nevertheless, there is still confusion about the safe distance required to avoid transmission (The Lancet Respiratory, 2020). At the moment of writing, most authorities recommend a minimum distance of 1-2 meters and don't mention exposure time (see, e.g., the recommendations by WHO[2] and CDC[3]). According to the review of physical distancing literature by Jones et al. (2020), the currently recommended 1-2 m minimum distance is based on dated studies, and rules on distancing should consider multiple factors that affect risk, such as ventilation, occupancy, and exposure time. According to the review by Hörcher, Singh, and Graham (2020), the maximum observed distance for infection varies between 3 meters up to the entire vehicle space and the minimum exposure time for infection ranges from zero to 15 minutes. Distancing has significant consequences for public transportation (Tirachini & Cats, 2020), especially since, in order to accommodate passengers while guaranteeing physical distancing, vehicles and stations have to reduce their capacity (that is, the amount of people allowed in a given space). As argued by Musselwhite et al. (2020), physical distancing is "obviously in conflict with the concept of public transportation" (p. 2). A further measure to prevent droplets transmission is the use of personal protective equipment, such as face masks (see section 2.4).

[2] https://www.who.int/westernpacific/emergencies/covid-19/information/physical-distancing (Accessed 16/12/2020).

[3] https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/social-distancing.html (Accessed 16/12/2020).

2.3. Airborne transmission

Airborne transmission occurs when microorganisms are contained in aerosols (<5 μm), which can remain suspended in the air and travel relatively far, even tens of meters from where they originated (Luo et al., 2020; Morawska & Cao, 2020). Airborne transmission, initially thought to be an unlikely form of transmission for SARS-CoV-2, is now supported by growing evidence (Luo et al., 2020; Morawska et al., 2020; The Lancet Respiratory, 2020; Wilson, Corbett, & Tovey, 2020). Infective aerosols can remain suspended in the air over longer distances and time than droplets and expose persons at distances beyond 2 meters from an infected person to the risk of contagion, especially in cases of poor ventilation and extended exposure (>30 min) (The Lancet Respiratory, 2020). Despite being proved for SARS-CoV-1 (the coronavirus causing SARS), this form of transmission has been underestimated in the case of SARS-CoV-2 (Chen, 2021). Luo et al. (2020) conducted a retrospective investigation of a SARS-CoV-2 outbreak event during a bus trip in Hunan Province, China, suggesting potential airborne transmission of SARS-CoV-2. In this case, closed windows and running ventilation could have facilitated the aerosol transmission. Measures and precautions to avoid airborne transmission indoor include decreasing occupancy, improving ventilation — with natural ventilation and avoiding air recirculation (Luo et al., 2020; Morawska & Cao, 2020) or using advanced ventilation systems (Chen, 2021) — and wearing PPE (personal protective equipment), such as face masks or eye protection, especially when density of people is high and ventilation potentially inadequate (Chen, 2021; Luo et al., 2020; Morawska & Cao, 2020). Both in case of droplet or airborne transmission, the risk of infection is lower with better ventilation. Considering the current winter season, risks associated with indoor activities, crowding and ventilation have to be addressed (The Lancet Respiratory, 2020). Similar to other respiratory infections, “the risk of transmission is associated with: seating proximity to an index case, duration of time spent aboard, inadequate ventilation and the consequential recirculation of contaminated air” (Zhen et al., 2020, p. 5).

2.4. The use of face masks

When worn correctly, the face mask is considered to be an important health measure in limiting the spread of the virus (Babu, 2020; Rab, Javaid, Haleem, & Vaishya, 2020; Tirachini & Cats, 2020). The filtration efficiency varies among different kinds of masks (e.g. N95 — the ones with the highest filtration efficiency —, surgical, and cloth masks). In the case of cloth masks, filtration is improved when there are no gaps, when high thread fabrics are used and when the mask has multiple layers (Konda et al., 2020). Both in the case of droplet and aerosol transmission, the use of face masks appears to increase protection significantly (Konda et al., 2020; Babu, 2020; Leung et al.,2020). According to some studies, the effectiveness of face masks and shields is still uncertain in case of airborne aerosol transmission (The Lancet Respiratory, 2020). Notwithstanding their proved effectiveness in filtering at least part of the infected particles, some have argued against the use of masks mentioning the risk that people might not use them correctly and that masks might provide a false sense of safety. These arguments are rebutted, among others, by Greenhalgh et al. (2020), who claim that, given the gravity of the current public

health crisis, people are most likely highly motivated to learn techniques for an effective use of face masks. A second reported argument against masks is that universal mask use would create shortages for the healthcare and frontline workers. Reusable masks might be a solution to this (Greenhalgh et al., 2020), especially considering the last research on the filtration efficacy of multi-layered fabric masks (Konda et al., 2020). In conclusion, the precautionary principle suggests the adoption of universal mask wearing, since its potential benefits to public health largely outweigh its risks (Greenhalgh et al., 2020; Tirachini & Cats, 2020). For what concerns public transport, where keeping a safe distance might not be possible and, considering the recent results on airborne transmission, not sufficient to prevent the spread of the virus, face masks play a crucial role in protecting passengers and workers.

2.5. Does using public transport increase the risk of being infected?

According to the comprehensive review by Tirachini and Cats (2020), "All in all, without face protection, frequent cleaning, and ventilation, public transportation ticks all the boxes as a prime virus spreader" (p. 5). Previous studies on the transmission of respiratory viruses have shown a statistically significant association between acute respiratory infection in winter and bus or tram use in the five days before symptom onset (Troko et al., 2011). A study by Hayward, Beale, Johnson, and Fragaszy (2020) on the activities carried out by infected people in the week before infection shows how visiting potentially crowded places, using public transport and being exposed to individuals with a cold increases the risk of being infected with circulating respiratory viruses. Empirical epidemiological studies reviewed in a working paper by Hörcher et al. (2020) show a statistically significant association between case incidence and train travel using previous years' travel data (S. Zhao et al., 2020), significant positive correlations between trip frequency by plane, bus and train originating in Wuhan and daily and cumulative case incidence (Zheng, Xu, Wang, Ning, & Bi, 2020), and an association between higher risk of infections, proximity to infected cases and longer co-travel times (Hu et al., 2020). Other studies have reported that transmission to 22 passengers (out of 67) by an asymptomatic infected passenger occurred during a bus travel where no one was wearing a mask (Shen et al., 2020). A study by Zhao, Zhang, and Li (2020) identifies clusters connected to public transport, but is cautious in affirming that the infection event happened during the travel. However, some vehicles (namely regular trains) seem to expose their passengers to a higher risk of infection in comparison to others (e.g. high-speed trains and aeroplanes), due to longer exposure times and facing seats/beds (P. C. Zhao et al., 2020). Conversely, results from a study on the city of Chicago using census level data from the American Community Survey and COVID-19 fatalities data show that public transport use was not robustly associated with COVID-19 mortality (Bryan et al., 2020). Similarly, results from a study conducted in Sweden did not suggest a strong correlation between ridership and transmission rates at an aggregate level (Jenelius & Cebecauer, 2020). Nevertheless, evidence from Sweden shows also that bus and tram drivers are among the workers at highest risk of infection (Folkhälsomyndigheten, 2020 in Jenelius & Cebecauer, 2020). As reported by Tirachini and Cats (2020), in some

countries (such as Japan and Singapore) where the public transport system was running without reduced capacity and without physical distancing measures, there were no COVID-19 outbreaks attributed to public transportation when everyone was wearing masks. This evidence will need to be monitored to understand the medium- and long-term impacts of such measures to guide decision-making in supply and demand management of public transport.

3. Challenges and policy response

The current chapter examines what challenges have been identified by the academic literature and what responses have been analysed. Responses to the pandemic adopted by various decision makers related to public transport pertain to different and interdependent challenges and, in some cases, generate further challenges that need to be addressed. The main challenges identified pertain to:

1. Public health;
2. Changing attitudes and behaviours towards public transport;
3. The financial sustainability of public transport;
4. Social equity and accessibility issues;
5. Sustainable mobility.

3.1. Public health: The need to contain the spread and protect passengers and workers

A first challenge pertains to the need to safeguard the health of passengers and of on-board workers while, at the same time, guaranteeing the operation of the public transport service. As noted above, there is an essential conflict between the principles at the basis of public transport and physical distancing, making it particularly hard to run a COVID-safe service. This has led to a heterogeneous series of responses, the impact of which is still unclear. These responses include:

- Suspension of the public transport service. In some cases (e.g. in Wuhan), public transport has been suspended. The effectiveness of suspending public transport to reduce the spread is not supported by the scientific literature (Musselwhite et al., 2020). According to some studies, the closure of public transport didn't have substantial effects on the incidence rate ratio (IRR)[4] and on the time-varying reproduction number (R)[5] when other physical distancing interventions where in place (such as school and workplace closure, restrictions on mass gatherings and lockdown) (Islam et al., 2020; Li et al., 2020).
- Reduced frequency. As reported by Gkiotsalitis and Cats (2020b, p. 4), "in the face of a dramatic reduction in ridership, governmental regulations and public health

[4] IRR is a metric showing the incidence of COVID-19 cases before and after the implementation of distancing measures (Islam et al., 2020).

[5] R is a metric describing the viral transmission and is "defined by the expected number of secondary cases arising from a primary case infected at time *t*" (Li et al. 2020, p. 2).

fears", several train and bus operators around the world have significantly reduced the service frequency and limited their service span.

- Discouraged use of public transport. In many countries, public transport has been associated with health risks, leading public authorities to advise against its use (Gutiérrez, Miravet, & Domènech, 2020; Lindström, Ahlstrand, & Kärrholm, 2020; Tirachini & Cats, 2020).
- Reduced capacity of vehicles. In some cases, in order to allow for physical distancing on the vehicles, the capacity (i.e. the allowed number of passengers) of busses and train carriages has been reduced, sometimes with the aid of cameras to check the capacity compliance (Wong, 2020 in Tirachini and Cats, 2020).
- Fare suspension and/or rear-door boarding. These measures have been introduced in some cases in order to protect on-board workers (drivers and controllers) and avoid crowding while boarding (Finbom et al., Forthcoming).
- Hygiene measures. Measures such as mandatory wearing of masks, temperature screening, sanitation of exposed surfaces, and improvements in ventilation have been introduced by some authorities (Morawska et al., 2020; Tirachini & Cats, 2020).
- Design interventions. In some cases, the interiors of vehicles have been reconfigured by installing screens between seats (Budd & Ison, 2020) or marking them to allow for distancing, or introducing contactless door sensors and hand sanitizers. As stated by Budd and Ison (2020, p. 2), "Although such interventions provide a visible manifestation of a response to a manifest public health threat, their efficacy and levels of public acceptance are unknown".
- Use of personal protective equipment (PPE). Some countries — especially in Asia (Tirachini & Cats, 2020) — have not imposed strong restrictions or warnings concerning public transport. Instead of discouraging the use of public transport, these countries have only made the use of masks compulsory, recommended good hygiene and advised passengers not to talk to each other (How and Thiagarajan, 2020 in Tirachini and Cats, 2020).

Research assessing the impact of different measures in different contexts, still extremely limited at the time of writing, will be crucial to inform decision-making in the future.

3.2. Changing attitudes and behaviours: The steep decrease in ridership

If general mobility has seen a decline in many places around the world, it is public transport that has been hit the most among all the land-based modes (Jenelius & Cebecauer, 2020; Tirachini & Cats, 2020). The decrease in public transport ridership levels represents both an expected outcome of public health measures (such as advices against the use of public transport, lockdowns, remote working/teaching and social distancing recommendations) and a challenge, especially for public transport authorities and operators.

Non-pharmaceutical interventions related to social distancing, public authorities' recommendations and the concern over contracting or spreading the virus have discouraged the use of public transport in many countries. The modal share of public transport shrunk dramatically according to several studies. Bucsky (2020) conducted a study on the city of Budapest, one of the EU cities with the highest public transport ridership levels, based on data from the local Public Transport Authority on passenger counting and from the Google mobility report, showing that demand declined by 90%. De Haas, Faber, and Hamersma (2020) conducted a study on a representative sample of members of the annual Netherlands Mobility Panel; the results show that trips by public transport declined by 90% after the pandemic. Aloi et al. (2020) carried out a study on Santander (Spain), using various data from traffic counters, vehicles' GPS, and ticketing data and showed a decrease in public transport ridership of 93% in comparison to pre-pandemic periods. Jenelius and Cebecauer (2020) used ticket validations, sales and boarding data from the three most populated Swedish regions (Stockholm, Västra Götaland, Skåne) and showed how public transport ridership in the first months of the pandemic decreased by 40%-60% across the regions in comparison to the previous year. According to the authors, supply remained generally unchanged in the observed period and reduction in ridership is primarily related to a decrease in the number of active public transport travellers; the daily average number of trips per active traveller stayed relatively stable. For what concerns ticketing, those who continued to travel by public transport switched to more flexible ticket types (Jenelius & Cebecauer, 2020). Teixeira and Lopes (2020) analysed data on the operation of subway and bike share systems during the COVID-19 outbreak in New York City. The bike share system saw a smaller drop in ridership in comparison to the subway system (71% vs 90%) and an increase on its trips' average duration (from 13 to 19 minutes). The study also shows evidence of a modal transfer from some subway users to the bike sharing system. Wilbur et al. (2020) studied the impact of COVID-19 on ridership in Nashville and Chattanooga, Tennessee. At its peak, ridership dropped between 65% and 70% and then stabilized between a 43% and 48% reduction compared to 2019. Further, their data showed that the most significant temporal factor in ridership decline occurred during morning and evening commute times.

Other studies have shown how not only travel behaviours changed, but also attitudes towards public transport. De Haas et al. (2020) show how attitudes towards public transport in the Netherlands worsened further (people were already the least positive about public transport before the pandemic) with less than 10% of people expressing a positive attitude towards public transport. Further, 88% of respondents indicated that they currently prefer individual modes (e.g. car or bicycle) over public or shared modes of transport. A study by Borkowski, Jażdżewska-Gutta, and Szmelter-Jarosz (2020) showed that the fear of getting infected also proved to affect travel time reductions, regardless of gender and age (and, hence, of exposure to higher risks in connection to COVID-19).

Public transport ridership did not decrease in the same way for all users. Tan and Ma (2020) constructed a logistic regression analysis model to analyse survey data from China and showed how type of occupation, commuting modes used before the pandemic, walking time to the nearest subway station, the possibility of being infected in cars and in public transport all influence the commuters' travel choices. Park (2020) studied ridership levels in different metro stations in Seoul, classified on the basis of the age of

the passengers (based on senior pass use data) and of the purpose of visit (work or leisure, on the basis of weekly patterns and proximity to business districts or leisure districts respectively). The results showed how a marked decrease of passengers during late February in Seoul was followed by a slow increase afterwards, suggesting decreasing levels of risk perception. Other studies showed the negative and statistically significant relationship between mobility and the stringency of anti-COVID-19 measures—e.g. Vannoni, McKee, Semenza, Bonell, and Stuckler (2020) and, with a focus on public transport ridership, Wielechowski, Czech, and Grzęda (2020).

Shamshiripour, Rahimi, Shabanpour, and Mohammadian (2020) designed and distributed a survey to investigate changes in people's travel attitudes and behaviours during the pandemic in the Chicago metropolitan area and to explore whether they will persist. The results suggest to pay particular attention, among other issues, to the evolution of telecommuting (being "home workability" affecting the willingness to be mobile), to a potential shift from shared mobility options to modes that avoid contact (both active and not), to equity issues related to the fact that not all users can stay at home or have access to alternative modes of transport/proper infrastructures for active mobility. Borkowski et al. (2020) conducted a study on everyday mobility in Poland and concluded that different socio-demographic groups have been impacted differently by the pandemic. Travel time reductions affected very differently those who did not change their job-related behaviours, especially blue-collar workers. Literature investigating the relation between public transport use during the pandemic and socio-economic inequalities will be treated in higher detail in section 3.4.

3.3. Financial sustainability of public transport

Public transport, as per its definition, relies on people travelling together in a shared space. If, as it is likely, the risk of infection increases with the occupancy rate of vehicles, public transport faces a "delicate trade-off": "too high demand leads to the violation of social distancing rules and increased infection risk (combined with the degradation of the public image of the service), while too low demand endangers the financial sustainability of operations" (Hörcher et al., 2020, p. 3). In order to tackle this trade off, sophisticated supply-, crowd- and demand management tools are needed (see section 4.2).

Public transport faces an unprecedented financial instability and, in some cases, a risk of bankruptcy. According to the reviewed articles, the main causes of this adversity pertain to:

- the decline in demand (caused by isolation measures, remote work, decrease in out-of-home activities, public advice to avoid public transport, capacity/frequency reduction and, hence, higher risk of annoyance and negative attitudes towards public transport, users' perceived risk of infection on vehicles, which persists even after the loosening of distancing and isolation measures);
- measures impacting the payment of fares (such as compulsory rear-boarding or the decrease in ticket inspections);

- the increase of certain items of expenditure (such as those related to the intensification of hygiene procedures, purchase of PPE and increased supply to comply with physical distancing rules);
- the unavailability of public funds to subsidize public transport (funds are directed towards other urgent measures such as health and income support) (Hörcher et al., 2020; Lima, de Carvalho, & Figueiredo, 2020; Tirachini & Cats, 2020).

Even if it's possible for public transport operators to reduce some expenses by operation adjustments (e.g. lowering the frequency), most of the operating costs of public transport are not demand dependent and can't be quickly adjusted, e.g. labour fixed costs (Hörcher et al., 2020; Lima et al., 2020). These costs may not be covered by revenues anymore, making it particularly hard for operators relying on self-financing to bear them (Lima et al., 2020). Operators that are more reliant on public subsidies might be less affected in the short run, but might suffer the consequences of the increasing financial pressure on public actors in the medium and long run (Hörcher et al., 2020).

3.4. Social equity and accessibility: The privilege of immobility

A crucial challenge for public transport is to guarantee accessibility to relevant destinations contrasting transport poverty and the risks of transport-related social exclusion. Public transport may be the only option for many users who are unable or unwilling to walk, cycle or drive a car and who still have to carry out necessary out-of-home activities (Budd & Ison, 2020; Pawar, Yadav, Akolekar, & Velaga, 2020; Smith & Judd, 2020).

Research shows that working from home during the COVID-19 pandemic is mostly a privilege of people with higher incomes, who have also left public transport in larger numbers (Tirachini & Cats, 2020). Hence, not only lower income workers still need to leave their home to reach their workplace, but, additionally, they often rely on public transport as the only suitable transport option. Further, even when not able to work from home, higher income users might have access to a different mode or reduce their out-of-home activities by, for instance, shopping online. Preliminary research mentioned in Gutiérrez et al. (2020) has shown that the impact of COVID-19 is higher in working class neighbourhoods where residents can't rely on remote work and are more exposed to the virus in their daily commute. Further, a working paper by Brough, Freedman, and Phillips (2020) focused on King County, Washington, concludes that the intensity of travel declined significantly less among less-educated and lower-income individuals. Wilbur et al. (2020) combined the spatial distribution of public transport ridership decline with census economic data in Nashville and found that high-income areas saw a decreased ridership 19 percentage points higher compared to low-income areas (77% vs 58%). A working paper by Almlöf, Rubensson, Cebecauer, and Jenelius (2020) focused on Sweden concludes that those with a higher socio-economic status stopped using public transport to a higher degree than those with a lower status. They found that education level, income and age are strong predictors of the propensity to stop travelling by public transport, but that workplace type and sector also substantially affect the propensity of public transport travel.

Finbom et al. (Forthcoming) discuss "qualities and inequalities" of public transport during COVID-19 going beyond ridership figures to include perceptions, atmospheres, everyday experiences and power structures. By means of a survey, semi-structured interviews in Belgium, Estonia, Germany and Sweden, media and policy documents analysis, their study highlights, among other themes, the emerging inequalities in ridership and the role played by solidarity with public transport-dependent users in affecting travel behaviour of more privileged ones. Further, social equity issues are related to working conditions for public transport workers, who are among the professional group exposed to the highest risk of infection (Folkhälsomyndigheten, 2020 in Jenelius & Cebecauer, 2020; Finbom et al., Forthcoming).

Measures aimed at suppressing public transport or at reducing its frequency, insufficient measures for the enforcement of distancing rules or of protective equipment use, and lack of cleaning procedures can exacerbate the perception of unsafety for public transport users and, hence, represent a threat to public transport's accessibility and social equity goals.

3.5. Sustainable mobility: Back to the car?

The decline in public transport ridership poses serious threats to sustainable mobility, both in relation to current and future travel behaviours and to the environmental efficiency of public transport. Discouraging public transport use or individual preferences have produced a noticeable shift towards the use of private motorized vehicles (Gutiérrez et al., 2020). According to a study conducted in the Netherlands, people have a more positive attitude towards the car and a much more negative one towards public transport in comparison to pre-pandemic times (de Haas et al., 2020). Further, Sutherland, McKenney, and Elkbuli (2020) highlight that the decline of public transport ridership jeopardizes the role of buses in emissions reductions. Their study on China estimates that, if ridership drops by more than 40%, buses can be as polluting as cars. The use of active modes (e.g. walking and cycling) has also increased according to several studies (Abdullah, Dias, Muley, & Shahin, 2020; Bucsky, 2020; de Haas et al., 2020). In some cases, the public health advice against the use of public transport was accompanied by measures aimed to contrast a too steep increase in the use of private cars and safeguard accessibility, such as temporary pedestrianizations and extension or introduction of cycling paths — obtained, for instance, closing down roads to motorized vehicles (De Vos, 2020; Gutiérrez et al., 2020; Kraus & Koch, 2020).

Barbarossa (2020) points out a widespread awareness among policy makers regarding the need to rethink urban spaces, urban services and urban mobility and accelerate the transition to low-carbon, more sustainable post-pandemic cities. Policies implemented or announced until now are designed to allow walkability, safety and physical distancing to those who travel across urban spaces, enhancing non-motorized mobility (Barbarossa, 2020). According to Barbarossa (2020) emergency street design and better transportation practices will be essential to cope with the current pandemic and in case of future ones. Although the medium-long term impacts on ridership of COVID-19 are still unpredictable, the risks related to a steady public transport ridership decline have to be taken into account by policy-makers to plan for a possible upcoming urban mobility crisis.

4. Scenarios and recommendations

The scenarios envisioned and the recommendations presented in the academic literature can highlight major research needs and support the preparedness of decision-makers in the field of public transport. In their comprehensive review, Tirachini and Cats (2020) warn from the risks related to the perception of public transport as unhealthy and as "poorly transitioning to post-pandemic conditions" (p. 15). Honey-Rosés et al. (2020) reviewed emerging questions related to the impact of COVID-19 on public space and, in particular, to its use, the behaviours and perceptions of its users, its design, and its impact on inequities and exclusion. For what concerns public transport specifically, the authors stress some crucial issues that will impact its future:

- the users' perception of safety from infection while riding public transport,
- the needed adjustments to operations and vehicles' design,
- crowd management measures in stations and terminals and, in general, physical distancing measures,
- public transport's even more relevant role in guaranteeing access to those dependent on it while dealing with the increasing budget pressure (Honey-Rosés et al., 2020).

One envisioned worst-case scenario is that

> public transit systems go bankrupt as a result of the massive fall in ridership. Without public support these systems may be privatized or dismantled. The impacts on city public space will be deleterious – increase in road congestion, pollution, and more social division (Honey-Rosés et al., 2020, p. 5).

Whether the decline in ridership will become a structural behaviour change is still an unanswered question. A survey conducted by de Haas et al. (2020) shows that most people think they will go back to using all travel modes after the pandemic. However, for what concerns public transport, the group considering a decrease in its use is larger, and so is the group considering the increase in car use. According to de Haas et al. (2020), a structural behaviour change will depend on the duration of the crisis, its economic consequences and the physical distancing measures adopted.

As pointed out by Tirachini and Cats (2020), public transport systems will need to deal with a delicate trade-off "between effectiveness (defined in terms of the accessibility and level-of-service offered), robustness (the health risks associated with traveling by public transport), and efficiency (the amount of resources needed to offer a given service supply)" (p. 10). In order to do this, there is a need for "methods to support evidence-based decision making and for professionals to convey to decision makers and the public the dilemmas and decisions made" (Tirachini & Cats, 2020, p. 9). Public transport needs multi-pronged strategies to enhance safety (Shen et al., 2020) and find a viable balance between the different demands related to its governance, provision and use. The

remainder of the chapter summarizes some possible measures and recommendations emerging from the reviewed literature with a focus on general health-related measures, physical distancing management, equity and sustainability of public transport.

4.1. General health-related measures

The reviewed papers provide some general recommendations to minimise health risks for both passengers and workers. They include:

- Guaranteeing adequate supplies of disinfectants, masks, and other safety devices (Shen et al., 2020);
- Monitoring the health of staff and passengers (e.g. temperature detection) (Shen et al., 2020);
- Contact tracing in combination with smart card data (Tirachini & Cats, 2020);
- Improving ventilation (i.e. guaranteeing the flow of outdoor air) and avoid air-recirculation (which might transport the virus) (Morawska et al., 2020; Shen et al., 2020; Sutherland et al., 2020). Particle filtration and air disinfection devices might be useful too (Morawska et al., 2020);
- Improving environmental cleaning and disinfection (Shen et al., 2020; Suman, Agarwal, & Bolia, 2020; Sutherland et al., 2020);
- Guarantee that those travelling are respecting respiratory etiquette and performing good hand hygiene (before and after public transport use) (Shen et al., 2020; Zhen et al., 2020);
- Enforcing the use of personal protective equipment, such as face masks (Shen et al., 2020; Sutherland et al., 2020; Zhen et al., 2020). Eye protection devices are considered effective too and could be taken into consideration to protect bus drivers (Tirachini and Cats, 2020).
- Guarantee a safe physical distance (Shen et al., 2020).

According to Sutherland et al. (2020), health-related measures can also contribute to increase the confidence of passengers in a safe public transport.

4.2. Supply, crowd and demand management for physical distancing

We still lack knowledge on the role played by physical distancing in minimizing the risk of transmission in public transport, especially considering the quite recent scientific recognition of airborne transmission for SARS-CoV-2. However, the evidence available supports the adoption of physical distancing measures (Hörcher et al., 2020). Guaranteeing physical distancing in vehicles and at stations/stops in order to not exceed a certain threshold of occupancy emerges as a new task for public transport (Hörcher et al., 2020) and requires new knowledge on supply-, crowd- and demand management.

4.2.1. Supply management

A possible approach to guaranteeing physical distancing on public transport consists in reducing vehicle capacity while increasing the service frequency. This measure, which should allow for distancing both in vehicles and at stops, has high costs, especially in non-automized systems (Aloi et al., 2020). In some cases, the shortage of resources (vehicles, drivers, operators) might make its adoption impossible (Tirachini & Cats, 2020). Further, the present and upcoming financial instability, the reduced availability of drivers due to illness or to absenteeism, and the need to protect drivers exposed to higher risks (which might also mean a reduction of their working times) appear to be obstacles to the adoption of such measures (Tirachini & Cats, 2020). When possible, increased subsidies by public administrations and financial support from governments would be needed (De Vos, 2020).

According to the reviewed literature, more efficient approaches to the re-design of the service supply can be achieved through:

- System optimization models (Suman et al., 2020) or optimal frequency models (Gkiotsalitis & Cats, 2020a) to efficiently allocate the bus fleets to different levels of physical distancing and travel demand, reaching a trade-off between passenger-related and operational-related costs;
- Network adjustments, e.g. using adapted stop-skipping models, such as the ones reviewed by Gkiotsalitis and Cats (2020b);
- Development of on-demand door-to-door services for, e.g., risk groups (Tirachini & Cats, 2020).

4.2.2. Crowd management

The literature presents several measures aimed at avoiding crowding on vehicles and at stations/stops:

- Reorganize the interiors of buses and trains (De Vos, 2020) or mark seats (Morawska et al., 2020; Suman et al., 2020);
- Minimize crowding in each phase of the journey, adopting measures such as one-way entrances or designated vehicle doors for boarding and alighting to reduce interaction between passengers — considering the possible increase in dwell time at stops (Tirachini & Cats, 2020);
- Protect the drivers avoiding crowding at the entrance by means of rear-door boarding and ticket purchase via app (Suman et al., 2020);
- Adopt models and algorithms for real-time assessment of crowding and risk situations on vehicles (Gkiotsalitis & Cats, 2020b) and in stations or transport hubs (Alawad, An, & Kaewunruen, 2020; Pouw, Toschi, van Schadewijk, & Corbetta, 2020)
- Provide real-time information on crowding so that passengers can plan and adjust their journey accordingly (Suman et al., 2020). It will be also important to guarantee that the reliability of real-time crowding information is not hindered by an over-response by passengers, which would defeat its purpose (Tirachini & Cats, 2020). According to Tirachini and Cats (2020, p. 14), this could be achieved through

"demand-anticipatory travel information schemes inspired by developments in the car traffic context".

- Prioritize public transport not only to reduce travel times, but also to mitigate passenger crowding at stops and on vehicles. Prioritization will keep the fleet constant and, due to the regular frequency and headway, reduce the average occupancy of vehicles (Tirachini & Cats, 2020);
- Control bus headway to avoid bus bunching (e.g. holding, station skipping, speed control) to avoid overcrowding in vehicles too (Tirachini & Cats, 2020).

4.2.3. Demand management

Possible measures to effectively manage the limited vehicles capacity include (a combination of) interventions, each with strengths and weaknesses, that need to be chosen considering the specific cases:

- Peak spreading strategies (Hörcher et al., 2020) obtained, for instance, desynchronizing school and work starting times to minimize the rush hour factor (Aloi et al., 2020). The experience of "territorial time plans" and "urban time policies" in Europe might provide some useful strategies to facilitate the coordination between several stakeholders (see e.g. Mareggi, 2002; van Schaick, 2013).
- Determining/estimating the travel demand in advance via data from trip planning apps (Suman et al., 2020);
- Queuing to control inflow, a strategy that might be easily implemented and accepted by passengers, but that has many risks connected to time losses, service unpredictability and crowding (Hörcher et al., 2020; Tirachini & Cats, 2020);
- Capacity reservation with advance booking, which can support service planning and operations and minimize the risk of queues, but requires high levels of predictability of travel times and reliability — passengers may in fact lose their slots in case of delays (Hörcher et al., 2020);
- Prioritizing or restricting access, for example, for essential workers or for those who can't perform their work from home (Tirachini and Cats, 2020);
- Dynamic pricing to manage capacity: "For example, greater discounts might be offered in the off-peak periods to stimulate passengers who can shift their departure time to do so and thereby reduce crowding levels in periods when capacity is scarce" (Tirachini and Cats, 2020, p. 13). Nevertheless, "their implementation requires costly data inputs to estimate the shape of (dynamic) demand functions a priori. The social acceptance of peak pricing during the pandemic is also uncertain" (Hörcher et al., 2020, p. 27);
- Methods such as *slot auctioning* and *tradeable travel permit schemes*, which are attractive but with a limited feasibility (Hörcher et al., 2020);
- Making use of the potential provided by MaaS systems to facilitate bookings, payments and priorities (Campisi et al., 2020; Tirachini & Cats, 2020), ensuring that no users are excluded by such methods, e.g. because of digital poverty.

4.3. Equitable and sustainable mobility

In order to safeguard accessibility and transport equity and avoid further negative impacts on low-income households, public transport frequency and capacity should not be drastically reduced (De Vos, 2020) and fares should not be increased (Gutiérrez et al., 2020). Many cities have introduced (temporary) fare suspension measures as a consequence of the COVID-19 pandemic (Finbom et al., Forthcoming). Fare suspension was introduced for particular categories of workers or for the general users, with the aim to protect users and public transport drivers and controllers from risky interactions.

For what concerns environmental issues related to sustainable mobility, recommendations in the reviewed literature include:

- Promoting the usage of low-carbon buses to reduce emissions in the medium-long term (Sutherland et al., 2020). In case of limited funding, Sutherland et al. (2020) suggest to prioritize routes with lower ridership and uneven emissions characteristics.
- Prioritize public transport, walking and cycling and stimulate active travel by means of street design interventions (e.g. introducing dedicated public transport lanes, adding cycling lanes and bicycle parking spaces and reducing the crossing waiting times for pedestrians) (Barbarossa, 2020; De Vos, 2020). For an overview of guidelines and best practices concerning street design during and after the pandemic we refer to Barbarossa (2020).

The recovery of public transport will be strictly connected to the way in which cities will re-think and redistribute the use of public space (Gutiérrez et al., 2020). This requires coordinated actions from different actors, such as policy makers, public transport authorities, employers, users (Tirachini & Cats, 2020). According to some, the current crisis might offer a window of opportunity to foster changes in urban design and in travel behaviour (de Haas et al., 2020; De Vos, 2020).

5. Conclusions

The impact of COVID-19 on public transport poses a series of challenges to authorities, operators and users. The review presented in this paper highlights the multidimensional relationship between the current pandemic and public transport operation and use. Chapter 2 summarized the findings related to the different routes of transmission for SARS-CoV-2 (Contact, droplet and airborne transmission), especially in relation to transmission occurring while using public transport. Chapter 3 reviewed the challenges identified in the literature related to the impact of the pandemic on public transport highlighting 5 main areas of policy concern: public health, changing travel behaviours and attitudes, financial sustainability of public transport, social equity and accessibility, and sustainable mobility. Chapter 4 reported the main recommendations to tackle the aforementioned challenges, with a focus on health-related interventions, supply-, crowd- and demand management, equity and sustainability.

The following months will be crucial to get a better understanding of how the virus spreads in public transportation and, consequently, adapt guidelines and recommendations to the evolving knowledge (Tirachini & Cats, 2020). Further, research on changing travel behaviours, effectiveness of policy responses and unequal social, environmental and health impacts of the pandemic will be essential the define evidence-based guidelines (Gutiérrez et al., 2020). In order for the recommendations to be effective, communication will be pivotal. The diffusion of knowledge to the public needs to be promoted through prevention and control guidelines shared via several media formats and platforms, both online and offline (Shen et al., 2020; Zhen et al., 2020). Training and health education for employers and employees in the transport sector will be also very important (Shen et al., 2020). Lastly, inter-institutional coordination, transparency and trust in decision-making processes will be paramount (Lima et al., 2020; Shen et al., 2020).

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