

14th Conference on Transport Engineering: 6th – 8th July 2021

Tools for the monitoring, user characterization, and their applications to the Public Integrated Transport System due to the COVID-19 disease effects: A case study in Bogotá, TRANSMILENIO company

Felipe Andrés Ramírez-Buitrago^a, Nicolás Adolfo Correal-Huertas^a, Laura Daniela Ramírez-Leuro^a, Daniel Andrés Sandoval-Pedrerros^{a,*}, Luis Alberto Rubio-Caballero^a

^a*Empresa de Transporte del Tercer Milenio – TRANSMILENIO S.A.*

Abstract

The pandemic made the transport system administration switch the way decisions were made in topics such as the response speed, resilience to shifts in the demand, and the new policy needs. Therefore, public transport requires monitoring tools, such as dashboards, and an emphasis in user characterization, in addition to traditional modeling and supply-demand indicators historically used by TRANSMILENIO to command the operation of the public transport system of Bogotá D.C. This study employed descriptive spatial and statistical analysis to comprehend the relations among the registers of contagion waves, user survey and the boarding information on Public Transport Integrated System (SITP for their Spanish initials). Complementarily, the article shows the shifts in the demand towards the regulatory milestones for the pandemic, and how short-term changes in bus supply were made due to these set of regulations. The paper also provides a recap of the international discussion about the occupation, efficiency, and biosecurity of massive public transport systems. The main results for TRANSMILENIO were some supply changes, among others.

© 2021 The Authors. Published by ELSEVIER B.V.

This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

Peer-review under responsibility of the scientific committee of the 14th Conference on Transport Engineering

Keywords: COVID-19 pandemic; public transport; TRANSMILENIO S.A.; technological tools; policies

* Corresponding author. Tel.: +57-1-482-4304.

E-mail address: daniel.sandoval@transmilenio.gov.co

1. Introduction

The entity in charge of planning and coordinating the public transport system of Bogotá D.C, Empresa de Transporte del Tercer Milenio – TRANSMILENIO S.A., has three different services. The first one is the worldwide known as BRT, with a fully dedicated lane, central stations, high floor buses, and payment outside the bus. The second one is a conventional bus service with validation on board that covers the demand of the zones where there are not BRT lanes, carrying people from their neighborhoods to the BRT stations, making last mile solutions or trips to remote places in Bogotá's rural zone. The third one is TransMiCable, which is a cable system included statistically in the demand of the BRT and serves the locality of Ciudad Bolívar. The TRANSMILENIO system comprises 761 articulated buses, 1,323 bi-articulated buses and 273 dual standard buses for the BRT, as well as 7,105 bus services with validation on board and 160 cabins for the cable.

2. Literature review

2.1. Literature about the pandemic and public transport

The reviews and recommendations about COVID-19 and the challenges of public transportation indicate a general context about the service and the risk for users (Gutiérrez, Miravet, & Domènech, 2020). Likewise, changes in the demand for transport modes were evident, as well as the decrease in public transport systems (Le , Sheng, & Sharp, 2021) (Komla Junior Dzis, Obeng-Atuah, Ackaah, Yaw Tuffour, & Eric Aidoo, 2021) and research needs (Gkiotsalitis & Cats, 2020). The case studies during COVID-19 about the effects on public transport show a global problem that includes analysis of supply, demand and biosecurity, in countries like Turkey (Deveci, Aydin, & Kusakci, 2021), Finland (Tiikkaja & Viri, 2021), Poland (Przybylowski, Stelmak, & Suchanek, 2021) and United Kingdom, regarding the future of public transport (Vickerman, 2021). Trying to predict the dynamism of a contagious disease is not an easy task, however, getting as close to reality as possible through models and analyses, such as those shown in this study, is an effort that can save human lives (Gomez, Prieto, Leon, & Rodríguez, 2021) .

2.2. Literature on geographic information systems and their use with infectious diseases

In 1854, an English doctor named John Snow, through the spatial location of cholera cases in London, managed to realize a pattern that until then no one had noticed, thus discovering the source of the outbreak of the disease in a water pump of the place (Fradelos, Tsaras, Papathanasiou, & Kleisiaris, 2014). Although geographic information systems did not exist in 1854, this example makes it clear that having information on a map allows us to ask ourselves questions and solve problems, as we do with current tools. Another investigation on the spread of hepatitis C was carried out in Connecticut (Navarro, Trooskin, & Hadler, 2005) through cluster analysis. This study was able to identify clusters in the most densely populated urban areas, which had previously been identified as areas of substantial injection drug use. Although local demographic characteristics alone do not follow a particular phenomenon, crossing them with other geographic variables helps to prevent disease transmission. Currently, with the COVID-19 pandemic that can affect a population very quickly, it is necessary to have a solid support of spatial information for decision-making, formulation of measures and evaluation of the effectiveness of prevention and control of COVID-19 (Zhou, y otros, 2020). Hence, the cities with updated information day after day on dashboards, and maps on the location of infections and availability of care in medical centers for decision-making are those that have the least consequences to regret.

2.3. Changes in the individual preferences and behavior

A preference is a comparative evaluation of a set of objects and works as a cognitive marker that reminds people how to interact with the environment. The objects of preferences are not given for being organized but are those that can be perceived by a human being, whose experience allows to differentiate, and those which a human being's cognitive capacity can remember (Druckman & Lupia, 2000). In the case of the preferences for a contagious disease, as COVID-19, the preference for staying home or going out to work depends on factors such as the education received

by the person related to viruses, their risk tolerance, among others. Thus, two people who receive the same information about a first case detected can react in two different ways.

Elster (1996) says that the social behavior responds mainly to the decisions made individually, which are the consequence of a rational thought, when analyzing from the rational choice theory. This is an instrumental rationality, which means that people use reason to obtain something they want. Once the person identifies the rule of decision, the decisions of public health are linked with people's personality (Blagov, 2020) or a consequence of the current political discourse with which people identify (Hatcher, 2020). A rational choice explains each one's behavior as the decisions made to accomplish that rule. Therefore, the rationality, in this case, is guided by the results an individual plans to obtain. This mechanism of decision is similar to the one described by Przybylowski, Stelmak, & Suchanek (2021). In that way, each individual's decision plays a key role that has to be taken into account when modeling demand.

3. Summary of the international benchmarking

3.1. Benchmarking of the policies adopted in the early stages of the pandemic

The benchmarking is presented in Table 1:

Table 1. Policies adopted at the beginning of the pandemic by COVID-19.

City	Country	Population	Urban area	Type of system	Strategies used
Sidney	Australia	5,3 millions of inhabitants (2018)	12367,7 km ²	9 subway lines and one train line	There is no capacity to clean en-route buses during shifts. They requested to avoid travelling during rush hours if possible and to limit travels to those who are strictly necessary.
Lima	Peru	8,8 millions of inhabitants (2017)	2672,3 km ²	2 subway lines and 5 BRT lines	Since Monday, March 16 th , 2020, only BRT operates, the other systems are closed. BRT is working with the Saturday schedule with difficulties for the transport of operators. Cleaners and all employees of the system have gloves and masks.
Shenzhen	China	12.53 millions of inhabitants (2017)	1748 km ²	8 subway lines and bus system	Buses are disinfected after each trip. At night, some routes are suspended. Floor markings (also adopted in Europe) are used as a guide to minimum distances between passengers for social distancing.
Vancouver	Canada	2,2 millions of inhabitants (2016)	114,97 km ²	3 skytrain lines, SeaBus (ferry) and bus system	The free service was implemented. There was a change in frequencies. In addition, the entry and exit of passengers was required only through the back door or the one furthest from the driver. They increased the disinfection of buses per day.

Source: Own elaboration with information from BRT Data and official public transport websites

3.2. Benchmarking of the occupancy

After adopting some of the decisions mentioned above, TRANSMILENIO S.A. faced a new situation, in which the economy was progressively being reactivated. At the international level, there were restrictions to the occupancy of public transport, in cities such as: Shenzhen, where the limit in place was of the 50% (Ma, 2020); Jakarta, where public transport was shut down and then, on June 8th, 2020 opened at 50% of its capacity (Widadio, 2020), or Mumbai, where the occupancy limit was also 50% (Mumbai Mirror, 2020). At the national level, the order was to have a 35% capacity limit. The main reason to do this was that the local health authorities considered that public transport could be a place where massive contagion clusters of the virus SARS-CoV-2 could appear. However, more international

evidence about the behavior of the contagion clusters started to appear and it suggested that public transport was not as risky as thought. First, discussing the recent epidemics caused by other Coronaviruses (SARS and MERS), Avineri, Musselwhite, and Susilo (2020) argued that there was no significant evidence of reduction of the contagion in the cities that closed their transport system.

Second, referring to the COVID-19 pandemic, the evidence collected from the tracking and contact tracing strategies did not suggest a statistically relevant effect of public transport on contagion. For example, Japan, at the beginning of its outbreak, followed a strategy that consisted in detecting contagion clusters. Despite its robust contact tracing strategy, no single cluster was detected in passenger trains (Normile, 2020). Likewise, in New York, from 1300 patients admitted with positive COVID-19 results, only the 4% of them affirmed to have used public transport in recent days (Shwartz, 2020). The evidence found suggested that the transmission of the virus is low, if users wear their masks in the appropriate way and if they do not talk at all during their trip, although the evidence was not yet conclusive (Tirachini & Cats, 2020). Even though inside the vehicles, that are enclosed places, there are concentrations of people who do not keep the prudent distance, but the implementation of other non-pharmaceutical measures, such as the use of mask or the prohibition of speaking (as in the case of Singapore), helps to reduce the probability of contagion (Tirachini & Cats, 2020).

4. Institutional policies adopted

An additional policy implemented by TRANSMILENIO S.A. and Bogotá D.C. was to organize public employee's schedules in different turns, as well as pilot schedules for some universities. Due to the occupancy limit of 35%, if activities were to be made in person once again, the transport system would not have been able to maintain a low occupancy, especially in some points of the city and during rush hours. The most important schedule was developed with the Departamento Administrativo del Servicio Civil, the entity that regulates the exercise of public employees in Bogotá D.C. They designed a survey which asked, first, basic data, such as the institution they worked for, their municipality and department of residence, and, if the place of residence was Bogotá, the planning unit they lived in, the days of the week they worked and the mean of transport they used.

Afterward, the team assigned the expanded observations of the survey to the nearest bus stop, for the Bus Rapid Transit (BRT), or bus stops for on board validation bus service, of the surrounding area. However, the analysis of the on board validation bus service was not considered, because it was close to surpass the current threshold set by the local government, that is, the 35% of the occupancy. For the BRT, the team made a projection of the maximum additional demand that the public employees could represent, given that 38% of the public servers, in average, would rather choose to use it. The value obtained was added to the demand profile observed recently. Fig. 2 represents the results obtained for the CAD station:

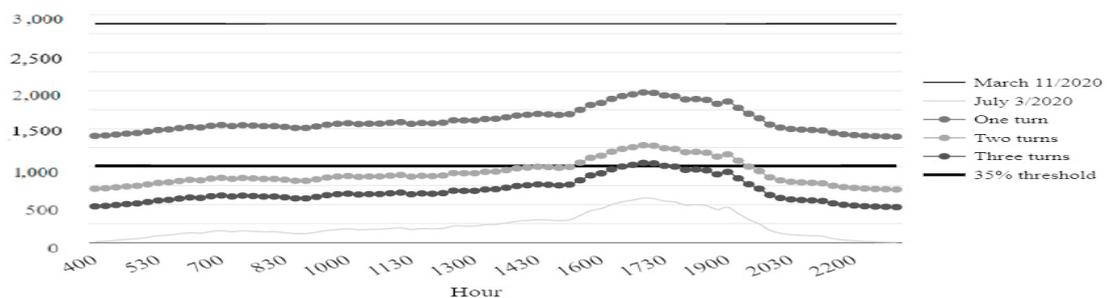


Fig. 1: Scenarios for the CAD station. Own elaboration using DataStudio.

The uppermost or first horizontal line represents the maximum number of ticket validations observed during an hour on March 11th /2020, day in which the system reached its highest demand on the year. The second line represents its 35%, which was the threshold in July. The light gray line shows the volume of ticket validations observed on July 3rd, which was the day when the maximum demand was observed, after the first confinement. The first dotted line

represents the biggest extra demand that the station could receive during an hour if all public employees in Bogotá D.C went out at the same time. The second and third dotted lines expose how much variation on the hourly demand could be observed if these people went out of their jobs in two or three different, but equal in the number of employees, turns, etc. Consequently, TRANSMILENIO S.A. recommended that the institutions located near CAD returned to in person activities in two or three turns but avoiding the station rush hours (15:30 to 19:30 for two turns, or 16:30 to 17:30 for three turns).

The analysis for the universities was made in a similar way. First, the team took data from the Encuesta de Movilidad 2019, which is a survey made by the mobility authority (Secretaría Distrital del Movilidad-SDM) and contains information about the purpose of the trips and the zones that attract them, among other aspects. The database provided by the SDM had also information disaggregated by Zona de Análisis de Transporte (ZAT), which are geographic demarcations of the territory that contain trips of people with similar conditions. The ZAT located downtown, in the historic center, were eligible for the analysis, because that zone concentrates most of the private universities. For each one of them, the team calculated the percentage of trips per purpose, and chose those ZAT where the trips that had “education” as their purpose were predominant. Then, we took the sum of the expansion factor of the observations that had education as their purpose and assigned them to three stations located in the area. (Museo del Oro, Las Aguas and Universidades), with the same three occupancy restrictions, which is shown by Fig. 3.

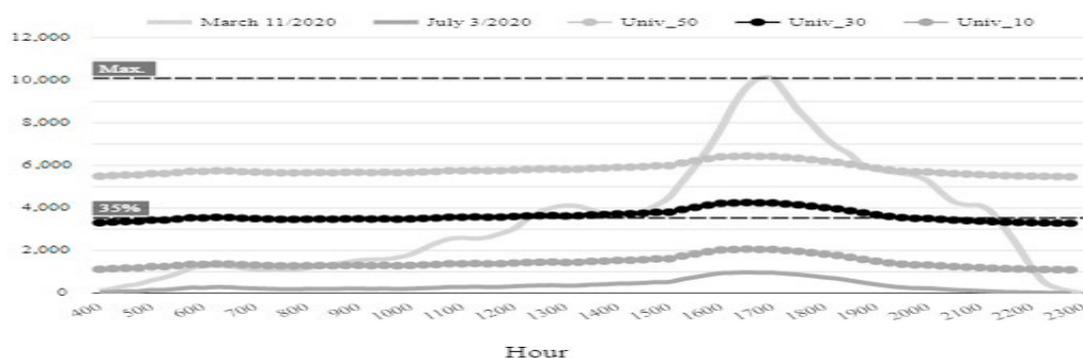


Fig. 2: shows the result, with the same 35% threshold.

It can be observed that, although the scenario with the 30% of the normal occupancy of the campus do not exceed the threshold imposed to the system, the limit is surpassed in the stations that attend the ZATs analyzed. So, in both cases, the recommendations had to seek to change people’s behavior in a sectorized way.

5. Response of the demand

5.1. Vulnerability to COVID-19 and the transport system

The entity responsible for the planning, collection, processing, analysis and dissemination of official statistics of Colombia, Departamento Administrativo Nacional de Estadística” ((DANE), 2020), carried out an analysis in which an index of vulnerability to COVID-19 considering demographic characteristics such as age and population density, as well as their previous health conditions.

Based on the previous study, it was possible to know the risk that the main users of the BRT have. The analysis using ArcGIS included the population that is 1km away or the so-called last mile and consisted of identifying the level of vulnerability our users are in the highest proportion. As shown in the following table, the highest proportion of vulnerability is found in the range of low and medium-low vulnerability with 41% and 36% respectively. Vulnerability could be a factor that explains people’s behavior related to the interaction with public transport. People would probably use more public transport if their risk perception due to the vulnerability of their home was low, and if they did not coexist with relatives with previous health conditions.

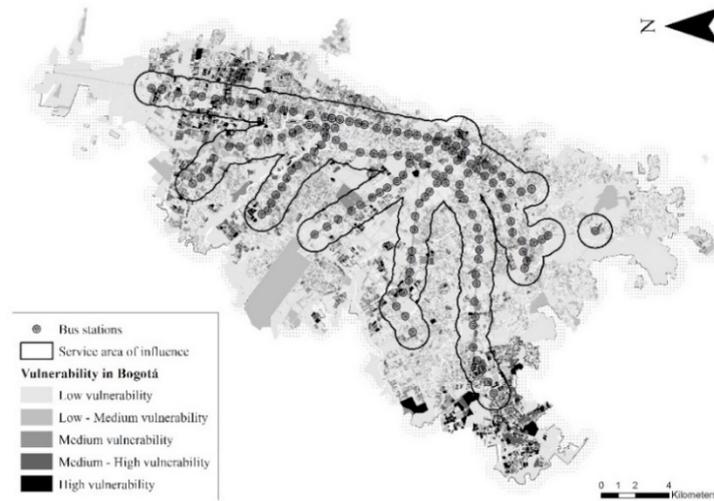


Fig. 3: Vulnerability to COVID 19. Source: Own elaboration based on data from ((DANE), 2020).

5.2. A brief graphical analysis

We are going to present some descriptive analysis of statistics, that can be explained by the influence of political decisions (which work as restrictions to people’s behavior). The first one of them is Fig. 5, a graph that relates the percentage of decrease in the demand of both, BRT and on board validation bus service, with the COVID-19 cases identified, by the date in which the results of the tests were given. The focus of the analysis will be the two waves of cases that can be identified, particularly between July 11th/2020 to August 28th/2020 and from December 14th/2020 and January 31st/2021, and the time after they took place.

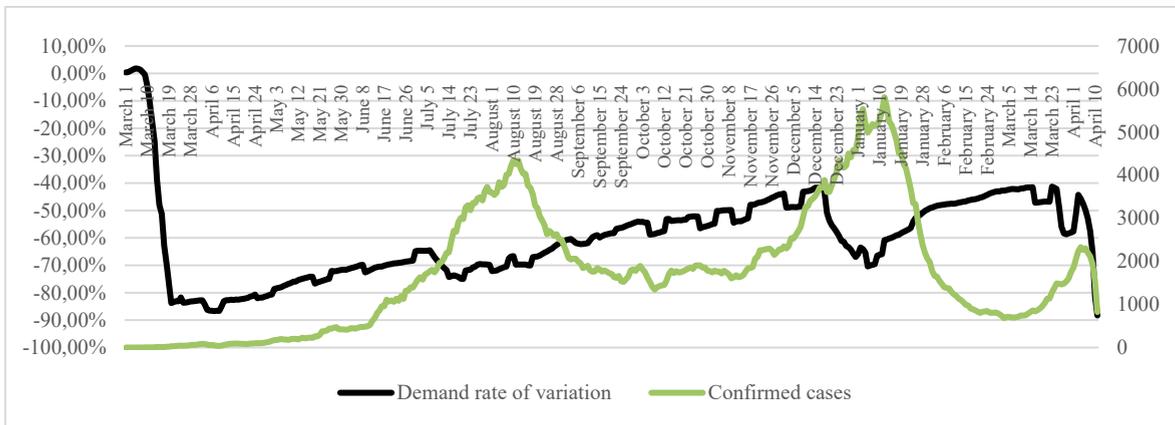


Fig. 4: Change in the demand and cases by diagnose date.

On the first interval, as the cases start to rose, the administration took restrictive measures to prevent the effective contacts between people. This reflects in the transport system as a strong decline on the daily demand. Then, the demand of the system starts growing slowly, while cases continue increasing. After that, the ticket validations kept growing even when the diagnosed cases start dropping. Once the wave passed, the demand of the system grew faster, but the number of confirmed cases kept stable during most of the “valley” observed.

On the second interval, the pattern is similar. The growth of cases can be observed since November 21st, day in which the anniversary of the national strike was commemorated. This was followed by a decrease on the demand of

the system since December 18th, not due to the policies chose by the administration anymore, but because of the Christmas celebrations. As the demand of the system decreased, reaching its lowest point on January 5th (which was the first day of the second cycle of localized confinements), the confirmed cases grew onto the peak of the second wave of the pandemic. When the cases started to decline, the demand was already growing. This can be evidence of the uncorrelatedness of COVID-19 cases with the use of public transport.

A counterargument can be that the effect of the confinements or the dropping of the demand can be lagged. That can be answered with another indicator generated by the SDS: the effective reproduction number, which is calculated subtracting five days to the date in which the symptoms were initiated, with a time window that may vary through time. We use the latest boundary of the window. Fig. 6 illustrates this indicator:

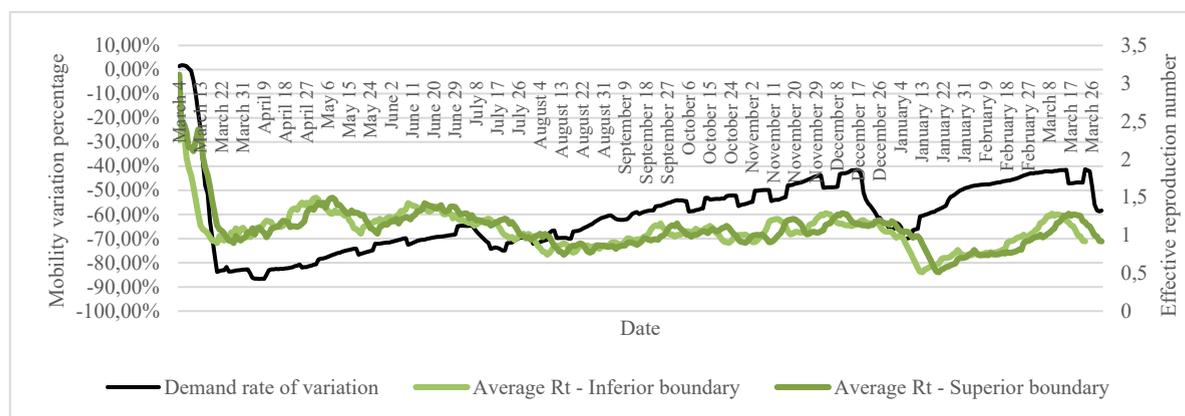


Fig. 5: Daily effective reproduction number and demand rate of variation.

The patterns do not reflect the behavior of each other. For example, after December 15th the demand drops two weeks earlier than the effective reproduction number or even three weeks superior boundary is used. The last figures indicate that the big changes in the relevant variables of the pandemic depend on factors that are different from the decisions taken with respect of the transport system. So, there is not a direct relationship between the demand and the contagion.

6. Conclusions and policy lessons

- The use of geographic information tools helps public transport systems to manage the demand variations, caused by the response to the state of the COVID - 19 pandemic, to make informed and focused decisions to prevent and mitigate the contagion on each of the areas of the city.
- Analyzing the data of one year of the pandemic, during the time lapses when there was a progressive increase in demand for the TRANSMILENIO system, this slow growth does not appear to have a direct relationship with the number of infections or the reproduction rate of COVID - 19.
- The entity used data of public servers of universities to analyze the demand caused by different economic activities, and to identify which of them affect it the most. This paper encourages other transport system to do the same with their cities.
- It was possible to show that the policies of the decrees implemented in Bogotá are reflected in the changes in the demand of public transport which shows that most of the population effectively complies with social isolation and biosafety measures.
- For the next research, this study suggests analyzing the possible causal or non-causal link between the contagion and the public transport system.

References

- Avineri, E., Musselwhite, C., & Susilo, Y. (16 de 03 de 2020). Editorial JTH 16 –The Coronavirus Disease COVID-19 and implications for transport and health. *Journal of Transport & Health*, 16, 1-3.
- Blagov, P. S. (07 de 07 de 2020). Adaptive and Dark Personality in the COVID-19 Pandemic: Predicting Health-Behavior Endorsement and the Appeal of Public-Health Messages. *Social Psychological and Personality Science*, 20(10), 1-11.
- Departamento Administrativo Nacional de Estadística. (2020). Nota metodologica indice de vulnerabilidad.
- Deveci, M., Aydin, N., & Kusakci, A. (2021). Managing public Transport during COVID-19: an analysis of the impact and preventive response in Istanbul. *Journal of Naval Sciences and Engineering*, 77-102.
- Druckman, J. N., & Lupia, A. (2000). Preference Formation. *Annual Review of Political Science*, 3, 1-24.
- Elster, J. (1996). Elección racional. En J. Elster, *Tuercas y tornillos* (págs. 31-38). Barcelona: Gedisa.
- Fradelos, E., Tsaras, K., Papatthasiou, I. V., & Kleisariis, C. F. (2014). Health Based Geographic Information Systems (GIS) and their Applications. *Acta Informatica Medica*. doi:10.5455/aim.2014.22.402-405
- Gkiotsalitis, K., & Cats, O. (2020). Public transport planning adaption under the COVID-19 pandemic crisis: literature review of research needs and directions. *Transport Reviews*, 1-19. doi:https://doi.org/10.1080/01441647.2020.1857886
- Gomez, J., Prieto, J., Leon, E., & Rodríguez, A. (2021). INFEKTA—An agent-based model for transmission of infectious diseases: The COVID-19 case in Bogotá, Colombia. *PLoS ONE*, 1-16. doi:https://doi.org/10.1371/journal.pone.0245787
- Gutiérrez, A., Miravet, D., & Domènech, A. (2020). COVID-19 and urban public transport services: emerging challenges and research agenda. *Cities & Health*. doi:https://doi.org/10.1080/23748834.2020.1804291
- Hatcher, W. (2020). A Failure of Political Communication Not a Failure of Bureaucracy: The Danger of Presidential Misinformation During the COVID-19 Pandemic. *American Review of Public Administration*, 50(6-7), 614-620.
- Komla Junior Dzis, E., Obeng-Atuah, D., Ackaah, W., Yaw Tuffour, A., & Eric Aidoo, N. (2021). Uptake in on-demand ride-hailing for intracity long distance trip making during COVID-19. *Urban, Planning and Transport Research*, 1-10. doi:https://doi.org/10.1080/21650020.2021.1872415
- Le, W., Sheng, M., & Sharp, B. (2021). The impact of COVID-19 on changes in community mobility and variation in transport modes. *New Zealand Economic Papers*, 1-9. doi:https://doi.org/10.1080/00779954.2020.1870536
- Ma, J. (27 de 03 de 2020). Guardians of Mobility: from the front lines in Shenzhen, China. Recuperado el 22 de 07 de 2020, de UITP: <https://www.uitp.org/news/guardians-of-mobility-from-the-front-lines-in-shenzhen-china/>
- Mumbai Mirror. (18 de 01 de 2020). COVID-19: Suburban trains, Maharashtra buses to run with 50%. Recuperado el 23 de 07 de 2020, de Mumbai Mirror: <https://mumbaimirror.indiatimes.com/coronavirus/news/covid-19-suburban-trains-maharashtra-buses-to-run-with-50-seating-capacity/articleshow/74698847.cms>
- Navarro, L. V., Trooskin, S., & Hadler, J. (2005). Geospatial Analysis of Hepatitis C in Connecticut: a Novel Application of a Public Health Tool. *Public Health*.
- Normile, D. (26 de 05 de 2020). Japan ends its COVID-19 state of emergency. *Science*.
- Przybylowski, A., Stelmak, S., & Suchanek, M. (2021). Mobility Behaviour in View of the Impact of the COVID-19 Pandemic—Public Transport Users in Gdansk Case Study. *Sustainability*, 1-12. doi:https://doi.org/10.3390/su13010364
- Shwartz, S. (08 de 06 de 2020). Transit: safe and vital to reopen. Recuperado el 17 de 07 de 2020, de New York Daily News: <https://www.nydailynews.com/opinion/ny-oped-our-covid-response-could-worsen-unrest-20200608-af5nwbg66nawffu77kkvurhq6q-story.html>
- Tiikkaja, H., & Viri, R. (2021). The effects of COVID-19 epidemic on public transport ridership and frequencies. A case study from Tampere, Finland. *Transportation Research Interdisciplinary Perspectives*, 1-7. doi:https://doi.org/10.1016/j.trip.2021.100348
- Tirachini, A., & Cats, O. (2020). COVID-19 and Public Transportation: Current Assessment, Prospects, and Research Needs. *Journal of Public Transportation*, 22(1), 1-21.
- Vickerman, R. (March de 2021). Will Covid-19 put the public back in public transport? A UK perspective. *Transport Policy*, 95-102. doi:https://doi.org/10.1016/j.tranpol.2021.01.005
- Widadio, N. A. (04 de 06 de 2020). 'New normal': Jakarta set to ease virus restrictions. Recuperado el 22 de 07 de 2020, de Anadolu Agency: <https://www.aa.com.tr/en/asia-pacific/new-normal-jakarta-set-to-ease-virus-restrictions/1864990>
- Zhou, C., Su, F., Pei, T., Zhang, A., Du, Y., Luo, B., . . . Xu, J. (2020). COVID-19: Challenges to GIS with Big Data. *Geography and Sustainability*.