Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.

Cities 112 (2021) 103139

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Changes in local travel behaviour before and during the COVID-19 pandemic in Hong Kong

Nan Zhang [a], Wei Jia [b], Peihua Wang [b], Chung-Hin Dung [b], Pengcheng Zhao [b], Kathy Leung [c], Boni Su [d], Reynold Cheng [e,*], Yuguo Li [b,c,**]

[a] Beijing Key Laboratory of Green Built Environment and Energy Efficient Technology, Beijing University of Technology, Beijing, China
[b] Department of Mechanical Engineering, The University of Hong Kong, Hong Kong, China
[c] School of Public Health, Li Ka Shing Faculty of Medicine, University of Hong Kong, Hong Kong, China
[d] China Electric Power Planning & Engineering Institute, Beijing, China
[e] Department of Computer Science, The University of Hong Kong, Hong Kong, China

ARTICLE INFO

Keywords:
Human behaviour
Local travel behaviour
COVID-19
Subway
Effective reproduction number
Public transport

ABSTRACT

COVID-19 threatens the world. Social distancing is a significant factor in determining the spread of this disease, and social distancing is strongly affected by the local travel behaviour of people in large cities. In this study, we analysed the changes in the local travel behaviour of various population groups in Hong Kong, between 1 January and 31 March 2020, by using second-by-second smartcard data obtained from the Mass Transit Railway Corporation (MTRC) system. Due to the pandemic, local travel volume decreased by 43%, 49% and 59% during weekdays, Saturdays and Sundays, respectively. The local travel volumes of adults, children, students and senior citizens decreased by 42%, 86%, 73% and 48%, respectively. The local travel behaviour changes for adults and seniors between non-pandemic and pandemic times were greater than those between weekdays and weekends. The opposite was true for children and students. During the pandemic, the daily commute flow decreased by 42%. Local trips to shopping areas, amusement areas and borders decreased by 42%, 81% and 99%, respectively. The effective reproduction number (R_t) of COVID-19 had the strongest association with daily population use of the MTR 7–8 days earlier.

1. Introduction

Coronavirus disease 2019 (COVID-19) has been threatening human life. As one of the most densely populated regions in the world (The World Bank, 2020), Hong Kong is highly susceptible to the widespread transmission of COVID-19 (Sethi and Mittal, 2020). In 2003, 1755 of the 8096 confirmed SARS cases worldwide (21.7%), were recorded in Hong Kong (WHO, 2003). Various influenza viruses, such as H1N1, H5N1 and H7N9, have spread widely through Hong Kong (Tam, 2002; Wu et al., 2010; Wu et al., 2014). In the COVID-19 pandemic, as of 1 June 2020, Hong Kong had reported 1093 confirmed cases (HKCHP, 2020a).

The SARS-CoV-2 virus is mainly transmitted via close contact among people (Rothan & Byrareddy, 2020; Wu & McGoogan, 2020), which is strongly associated with human behaviour. Social distancing can help to reduce the transmission of this virus (Chen et al., 2020; Prem et al., 2020). Local travel behaviour is one of the key factors to assess social distancing in the pandemic (Badr et al., 2020; Koo et al., 2020).

A reduction in mobility was observed, due to the pandemic at all locations such as transit stations, workplaces, and retail and recreation (Pepe et al., 2020). Traffic volume was significantly reduced due to the pandemic (Vingilis et al., 2020). In the United States, an increase in the local infection rate from 0% to 0.003% was associated with a mobility reduction of 10.2% (Engle et al., 2020). In Greece, traffic volume decreased by more than 80% during the most serious period of the pandemic (Katrakazas et al., 2020). In Florida, the overall state-wide traffic volume decreased by 47.5% (Parr et al., 2020). A dramatic drop in mobility was observed in Hong Kong and Singapore between January 24 and 27 (Warren & Skillman, 2020). Public transport (e.g. a subway) has an influential role in the transmission of this virus, especially in highly populated cities (Ghosh et al., 2020; Liu, 2020). New York City was badly affected by COVID-19 infections, and average subway ridership decreased by 88.8% between 23 March and 19 April

* Corresponding author.
** Correspondence to: Y. Li, Department of Mechanical Engineering, The University of Hong Kong, Hong Kong, China.
E-mail addresses: ckcheng@cs.hku.hk (R. Cheng), liyg@hku.hk (Y. Li).

https://doi.org/10.1016/j.cities.2021.103139
Received 30 September 2020; Received in revised form 4 January 2021; Accepted 5 February 2021
Available online 11 February 2021
0264-2751/© 2021 Elsevier Ltd. All rights reserved.

(Harris, 2020; Teixeira & Lopes, 2020; Wang et al., 2020). In the state of Tennessee, USA, the bus ridership dropped by 65%–67% from 2019 baselines, before stabilizing at a decline of 42%–48%. Ridership decline in the higher-income areas was greater than that in low-income areas (Wilbur et al., 2020). In Europe, ridership decreased by 80% in some cities in Germany, Austria, Spain and Italy due to reductions in commuter demand and transport service supply (Bernhardt, 2020). In the Netherlands, the number of trips decreased by 55% (de Haas et al., 2020). In Seoul, subway ridership experienced a 40.6% drop during late February but slowly increased afterward (Lee et al., 2020; Park, 2020). Ridership reduction was caused by reduction in commuter demand during the pandemic period, but people may change their local travel pattern to personal transports in the post-pandemic period (Koehl, 2020; Laverty et al., 2020).

Most of the studies looking at human mobility during the pandemic are based on location data from mobile phones. This introduces some bias since mobile phone usage is not universal. In addition, using the distance as a factor to assess local travel behaviour may introduce some errors. For example, if a person drove their car to a suburb instead of to their workplace during the pandemic, their mobility may not change because the distances of both travel routes may be equivalent. Using smart-card data from public transport systems is a good way to monitor local travel behaviour changes. Hong Kong has an advanced public transport system, and the smart card is divided into five population groups, which enables us to understand the local travel behaviour changes in the different groups.

In Hong Kong, nearly half of all passengers would take the MTR every day. The subway is a popular public transport system, but subways are a vulnerable indoor environment for infection spread, due to crowdedness and poor ventilation. Changes in local travel behaviour reflected not only government strategies, but also citizens' responses to the outbreak (Badr et al., 2020). However, due to a lack of data, earlier studies could not accurately characterize local travel behaviour changes for the various population groups (e.g., adult, child, student, and senior) due to the COVID-19 pandemic. In this study, we focus on changes in local travel behaviour for users of the Mass Transit Railway (MTR) system in Hong Kong. We collected more than 570 million smart-card and ticket data of MTR use by the various population groups, from 1 January to 31 March 2020. We aim to understand the impact of the COVID-19 outbreak on local travel behaviour, and how to predict the spread of COVID-19 by using local travel data.

2. Method

2.1. Data source

Detailed MTR data were provided by the Hong Kong MTR Corporation. The data, from 1 January to 31 March 2020, included masked card/ticket ID (the ID after masked and processed, not the original ID on cards), entry/exit station, entry/exit time, ticket type (smartcard/ticket) and card type of each passenger. The MTR system has five card types: adult, child (ages 3–11 years), student (ages 12–25 years and enrolled in a primary/middle/high school, university or institution of higher education), senior (ages 65 years and above) and others (e.g., disabled, MTR staff). The MTR data excluded airport express lines and the light rail systems.

In addition to the MTR data, we collected other relevant data from Hong Kong and other locations, such as demographic data, COVID-19 infection data, intervention policies during the pandemic and travel congestion data from other cities.

- Demographic data including total population, gender and age distribution, were obtained from the Census and Statistics Department of Hong Kong (HKCSD, 2020), and were used for calculating the percentage of passengers, and assessing the relative infection risk by gender and age.
- Reported COVID-19 data from 1 January to 30 April 2020, were obtained from the Centre for Health Protection (HKCHP, 2020b), and were used to analyse the relationship between local travel behaviour and the infection spread.
- The place of residence and visited locations for all confirmed cases, which were obtained from news summaries (WARS, 2020), were used to analyse the spatial relationship between the distribution of the infected and the MTR turnstile data at different stations.
- Data on people arriving in, and departing from Hong Kong, were obtained from the Immigration Department of Hong Kong (HKID, 2020), and were used to assess the policies on lockdown and travel restrictions in Hong Kong. These policies influence local travel behaviour.
- The local pandemic intervention policies adopted by the Hong Kong SAR government, were obtained from a previous study, government websites and online news sources (HKID, 2020; Cowling et al., 2020; HKEN, 2020; HKN, 2020; SCMP, 2020; FORTUNE, 2020; REUTERS, 2020). This information was used to assess the intervention policies in Hong Kong, since these policies influence local travel behaviour.
- Monthly local public transport data, including the average daily population flow by subway (MTR), railway excluding MTR, franchised bus, public light bus, taxi and other public transport, between January 2016 and March 2020 were obtained from Transport Department of Hong Kong (HKTD, 2020). We used these data to analyse the local travel behaviour changes due to the pandemic in Hong Kong.
- Travel congestion data, which were obtained from the TomTom Website (www.tomtom.com), were used to analyse the relative travel behaviour changes in different countries/cities/territories (Tanveer et al., 2020).

2.2. Data processing

For the sake of accuracy and completeness, we screened the MTR data using the following inclusion criteria to remove erroneous data:

(1) Information about a passenger's entry and exit via the turnstiles must be available.
(2) The entry and exit stations should not be the same.
(3) The entry and exit times should be in the range of the operating hours of the MTR.

This data screening eliminated 1.4% of the overall data. More than 272 million records of passenger movement through the MTR were considered valid. Passenger flow from time point A to time point B is defined as the number of passengers leaving the MTR station between A and B. To filter regular daily commutes from these movements, we defined consecutive round trips between the same two stations as regular commutes. We defined the pandemic and non-pandemic weeks to analyse the local travel behaviour during and before the COVID-19 pandemic. Between January 1 and March 31, pandemic week (March 25 to 31) is defined the week when the most weekly confirmed COVID-19 cases were reported. The non-pandemic week (January 6 to 12) is a week without either holidays or any reported COVID-19 cases, and is regarded as a control group. We used the effective reproduction number R_t (Appendix A), to indicate the severity of virus transmission.

In this study, we defined that the mobility change by MTR use to be the percentage difference in average daily subway-use at time t, compared to the average of that in a non-pandemic week (January 6 to 12). Some studies that used mobile phone data to evaluate human movement, defined the mobility change to be the percentage difference in average daily distance travelled in an area at time t, compared to the average of that on the same weekday before the COVID-19 pandemic (Engle et al., 2020).

2.3. Study area

As of the end of 2019, the population of Hong Kong was 7.5 million (HKCSD, 2020). The total average daily passenger load on the MTR, railways excluding MTR, franchised buses, public light buses, taxis and other public transport modes between 2016 and 2019 was 12.6 million (Fig. S1a). The subway (MTR) plays a critical role in local transportation in the city and includes 95 MTR stations and 11 lines (Fig. S1b). In normal times, nearly 5 million people take the MTR each day. We used MTR data to analyse human movement for this study.

3. Results

Since the first confirmed COVID-19 case in Hong Kong on 23 January 2020, the city had recorded 1038 confirmed cases by the end of April 2020. Distribution by age and gender is shown in Fig. S2. All imported and unidentified cases originated from 48 countries and territories (Fig. S3a). Almost all temporary stay locations of the local and unidentified cases were distributed near the MTR stations and lines (Fig. S3b). Eight of these temporary stay locations were visited by more than 10 cases. Hong Kong International Airport ranked first (visited by 105 cases); four bars were ranked second to fifth (visited by a total of 94 cases); and a hotel, party room and religious building were visited by 12, 11 and 10 cases, respectively.

Hong Kong implemented strict travel restrictions starting 30 January 2020 (Fig. 1). The total arriving and departure travellers gradually decreased after the Chinese New Year (CNY) holiday. Following the 14-day mandatory quarantine for individuals from mainland China, the number of imported cases decreased by 94% from the number during 1–20 January. After the travel restrictions were extended to all countries and territories on 26 March, the daily number of arrivals had not exceeded 5000 (including local residents and foreign visitors). Before the CNY holiday, 45.6% of arriving and departure travellers took the MTR to enter and leave Hong Kong (Fig. S4).

3.1. Temporal characteristics of local movement behaviours in Hong Kong

In Hong Kong, around 95% of passengers use a smartcard to take the MTR (Fig. 2a). After the CNY holiday, total MTR ridership decreased by 52.3%. In the non-pandemic week, 76.1%, 3.1%, 5.8% and 11.7% of MTR passengers used adult, child, student and senior cards, respectively. In the pandemic week, the corresponding numbers decreased by 41.9%, 85.5%, 73.3% and 47.8%, respectively. Table S1 lists the detailed data for the non-pandemic and pandemic weeks.

Fig. 2b shows that most people took two MTR trips per day, and we believed that most of these trips were daily commutes (e.g., going to the workplace/school and returning home). All ridership exhibited a more regular pattern of movement (probability distribution of number of MTR trips per day) on weekdays than on Sunday, and in the period before the pandemic compared to during the pandemic. Changes in the patterns of movement of adults and seniors between the non-pandemic and pandemic week were more remarkable than those between workdays and the Sunday of the same week. There was no significant change in the patterns of movement for children before and during the pandemic, but a significant decrease was seen in the number of children using the MTR during the pandemic. Children and students exhibited obvious differences in the patterns of movement between workdays and Sundays.

During the non-pandemic week, the population flows through the MTR on Saturday and Sunday decreased from weekday levels by 9.7% and 23.4%, respectively (Fig. 2c). Compared to the non-pandemic week, the population flow through the MTR during the pandemic week decreased by 43.1%, 49.1% and 58.6% on the weekdays, Saturday and Sunday, respectively. Very few people need to commute to work on Sunday, which means that during the pandemic period, around 60% of Hong Kong residents avoided using public transports if there was no need to go to school or work. During the COVID-19 pandemic, the passenger numbers during in the morning and evening peak hours, decreased by 43.0% and 40.8%, respectively. The peaks of the morning and evening rush hours during the pandemic week were slightly wider than that during the non-pandemic week because the local government advocated that people commute to work at different times.

3.2. Spatial characteristics of local movement behaviours in Hong Kong

To examine changes in patterns of movement in Hong Kong, we selected six stations in different types of areas: residential, workplace, school, shopping area, amusement area and border (Fig. 3). At the workplace area station, the number of regular adult commuters decreased by 47.3% during the weekdays in the pandemic week. At the University station, the numbers of adults and students decreased by

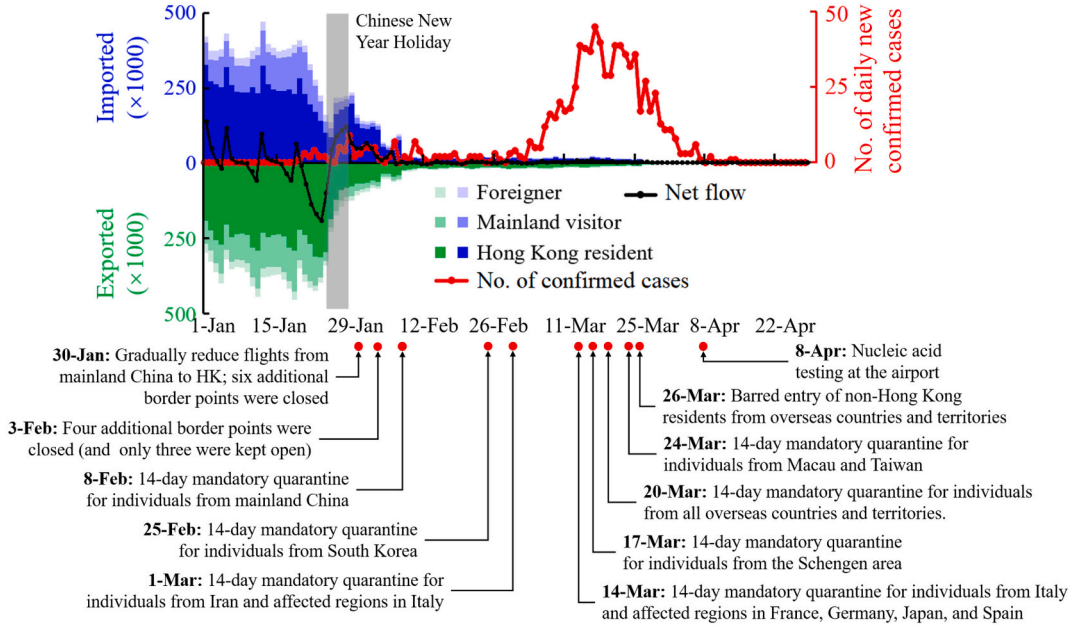

Fig. 1. Daily arrivals and departures, COVID-19 case report, and related local policies between 1 January and 30 April 2020.

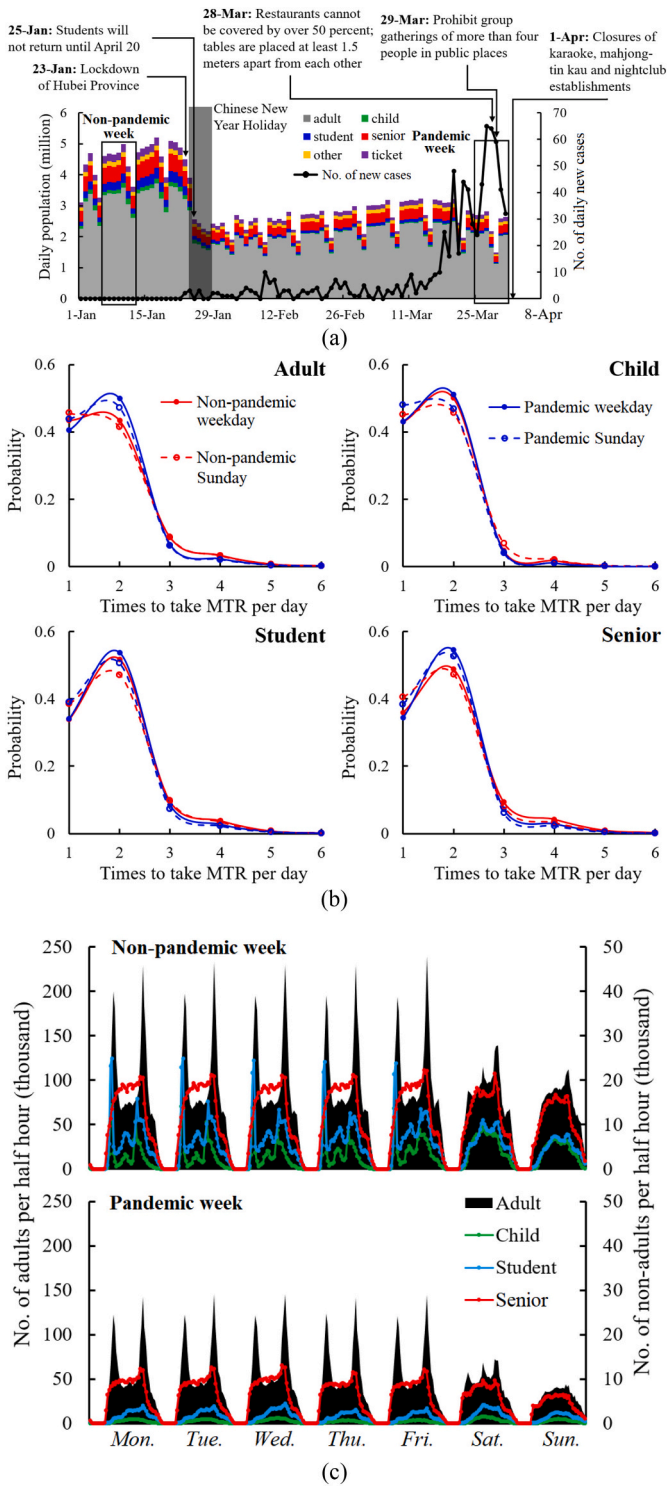

Fig. 2. Local travel behaviour via MTR during the non-pandemic and pandemic weeks. (a) daily changes in population flow through the MTR against the number of new cases between 1 January to 31 March 2020; (b) probability distribution of number of MTR trips per day on workdays and Sunday during the non-pandemic and pandemic weeks; (c) half-hourly MTR population flow by card type.

56.3% and 93.1%, respectively, because of the pandemic. The peak in the shopping area occurs between 18:00 and 19:00 on weekdays. The populations of adults, children, students and seniors visiting the shopping area decreased by 39.4%, 80.9%, 65.0% and 42.2%, respectively. Many children visit the amusement areas (e.g. Disneyland), especially on Fridays and over the weekends. The pandemic had a massive effect on the population inflow to amusement areas. The numbers of children, students and seniors decreased by 98.9%, 95.8% and 79.2%, respectively. During the pandemic week, there was no rush hour in the morning and evening. Lo Wu represents the largest border between Hong Kong and Shenzhen, China. During the pandemic week, almost no passengers entered or left via Lo Wu station. Overall, the populations in the residential area, workplace, school, shopping area, amusement area and border decreased by 35.3%, 41.6%, 67.9%, 42.1%, 80.5% and 99.5%, respectively, during the pandemic week.

The MTR lines from Central to Quarry Bay and from Central to Tsim Sha Tsui are the busiest lines in the entire network (Fig. 4a). In the non-pandemic week, the daily number of people using Tsim Sha Tsui, Central and Mong Kok stations exceeded 250,000 on weekdays, whilst the number of people using Mong Kok, Sheung Shui and Lo Wu (border) stations exceeded 210,000 on Sunday. In the pandemic week, the total number of passengers decreased by 43.1% on the weekdays. Mong Kok, Kwun Tong and Tsim Sha Tsui ranked in the top three in terms of number of users of MTR stations. Because of the travel ban regulation, stations near the border had very few passengers. Sham Shui Po, Mong Kok and Causeway Bay had more than 80,000 passengers each on Sunday of the pandemic week. Hong Kong International Airport, a church, four bars, a hotel and a party room were eight places visited by at least 10 confirmed local cases. Except for the airport, six of the seven high-risk places were located in areas with high MTR populations. The pandemic strongly impacted the border MTR populations (e.g., Lo Wu, Lok Ma Chau) and amusement areas (Disneyland and Ocean Park), and the traffic flows in those areas decreased by more than 99% and 80%, respectively.

There was no significant correlation between passenger volume changes before and during the pandemic and the daily passenger volumes of the MTR station on weekdays, whilst a significant correlation ($p = 0.027$) was observed on the weekend before and during the pandemic. This implies that Hong Kong citizens intentionally avoided going to densely crowded public places during the COVID-19 pandemic (Fig. 4a). In the pandemic week, there was a greater reduction in MTR use at the weekend than for weekdays, however, the correlation was not very significant ($p = 0.082$). No such trend was seen before the pandemic (Fig. 4b). The number of passengers at Quarry Bay station during the pandemic week, a business district, decreased by approximately 68% compared to that of the non-pandemic week (Fig. 4b). In the non-pandemic week, the borders and amusement areas have 10%–70% more visitors on Sunday than during the rest of week. The detailed spatial distribution of daily MTR ridership is shown in Fig. S6.

Fig. 5 shows that the modularity of the MTR network and the proportion of the population flow within communities on weekends are both higher than those on weekdays, with the exception of the CNY holiday. These data suggest that people travelled more locally (within communities) on weekends. After CNY, both figures tended to decrease overall, possibly suggesting that increasing awareness of the pandemic led people to reduce unnecessary travel, whilst daily commutes for work, which normally occur across communities, were not heavily influenced. The detailed network information is found in Fig. S5.

3.3. Relationship between COVID-19 transmission and MTR populations

A significant correlation ($R = 0.73$) was found between total MTR population and effective reproduction number (R_t) (Fig. 6a). R_t was better correlated with the child and student population (delayed by 7 days), followed by that of seniors (Fig. 6b). Therefore, daily MTR card data for adults can be used as a plausible indicator for predicting R_t.

4. Discussion

In 2020 thus far, travel behaviours have been affected by disease prevalence and restrictive orders to stay at home. Many countries and

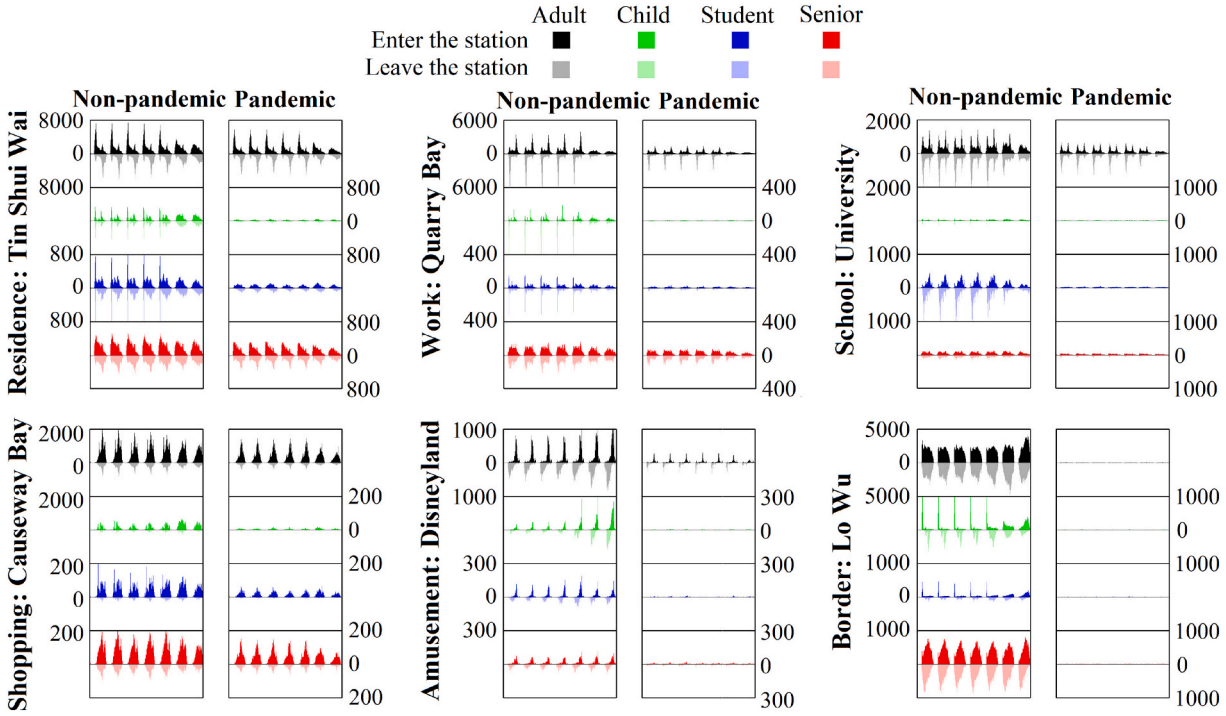

Fig. 3. Half-hour subway ridership in the six MTR stations from different types of area, during the non-pandemic and pandemic weeks. (The y-axis shows the half-hourly population flow through the station. The workplace and school areas only show the data of regular daily commuters, whilst the shopping and amusement area only show the data of non-regular daily commuters.)

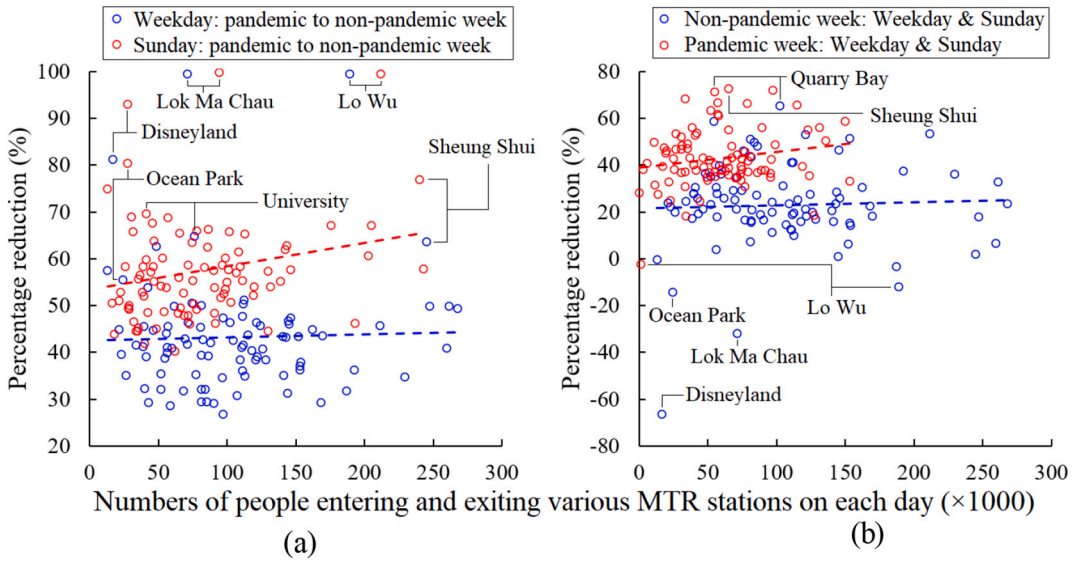

Fig. 4. Relationship between population and percentage reduction by MTR station in (a) the non-pandemic and the pandemic weeks and (b) weekdays and Sundays.

cities have imposed travel restrictions during the COVID-19 pandemic (Chinazzi et al., 2020; Kraemer et al., 2020), which have strongly affected international and intercity travel behaviours. However, local travel, which is one of the most important factors reflecting personal responses to disease transmission, has not been restricted to a large extent. Public transportation contributes to the spread of diseases due to the many users (Megahed & Ghoneim, 2020). In this study, we analysed changes in local travel behaviours in Hong Kong during the pandemic, based on more than 500 million smartcard and ticket data obtained from MTR for the period between 1 January and 31 March 2020.

Most major cities worldwide have been affected by COVID-19, and traffic patterns have changed considerably. During the pandemic week (the week with the highest number of newly reported cases each day), traffic congestion decreased by 96.5%, 95.0%, 91.6%, 91.3%, 91.3%, 90.3%, 86.9%, 80.4%, 79.3%, 75.5%, 63.1%, 55.4%, 40.7% and 34.7%, in Shanghai, Singapore, Moscow, New York, Beijing, Paris, Wuhan, Madrid, Rome, London, Los Angeles, New Delhi, Tokyo and Hong Kong, respectively (Fig. 7). This shows that the interventions implemented in Hong Kong had the least impact on local travel behaviours out of all these other cities. However, the local behavioural changes between weekdays and weekends in Hong Kong were not regular, like those in Beijing and Shanghai.

In Hong Kong, children (reduced by 86%) and students (reduced by 73%) experienced the greatest change in their local travel behaviours,

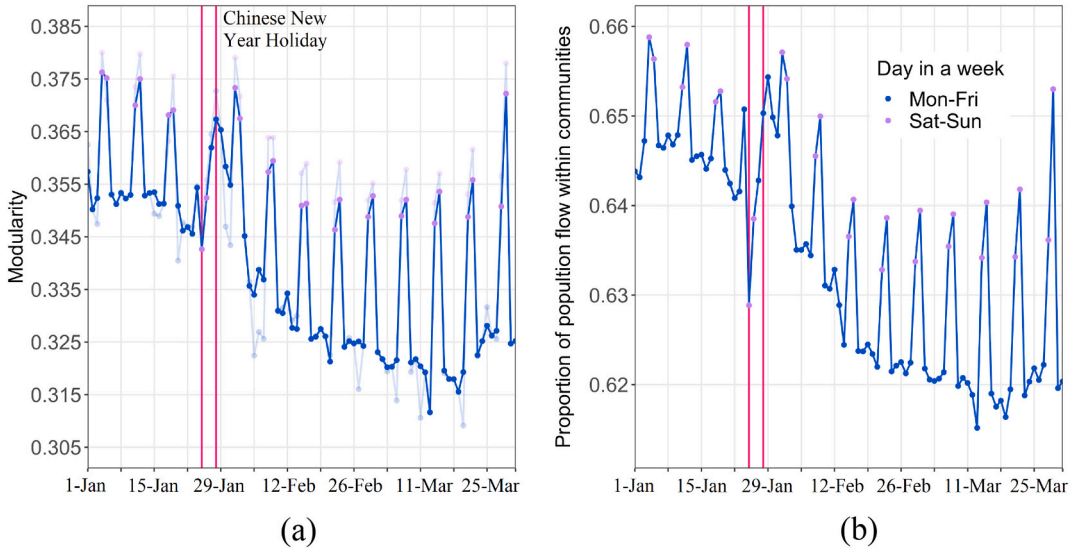

Fig. 5. (a) Modularity of the MTR network. The faint lines highlight the modularity based on the best community partition, obtained using the Louvain algorithm. The blue lines show the modularity determined based on the most common community structure (fixed). (b) Proportion of population flow within communities (fixed). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

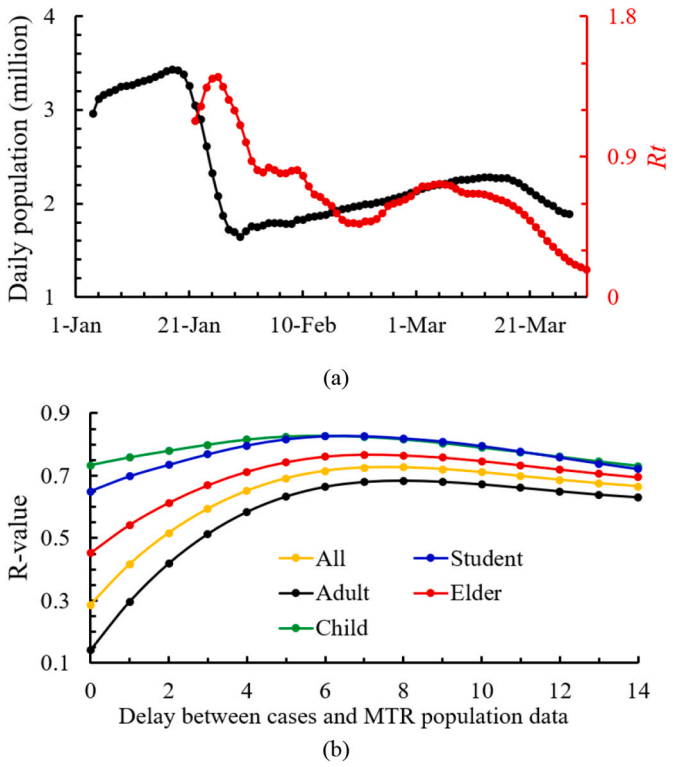

Fig. 6. Prediction of Covid-19 transmission. (a) Changes in R_t with daily MTR population data (both population and R_t are average values per week, which means the value on date i is the average value from three days before and three days after). (b) Changes in R-value with delay between confirmed cases and MTR daily population data.

possibly due to school closures. Seniors (8%) and adults (42%) saw smaller reductions. In the Netherlands, by contrast, approximately 80% of people reduced their outdoor activities, with the most significant decrease being among seniors (de Haas et al., 2020). Brough et al. (2020) found that travel intensity declined considerably less among less-educated and lower-income individuals, even after accounting for mode substitution and variation across neighbourhoods in terms of the effects of reduced public transit services. Fraiberger et al. (2020) also found that mobility reduction of people in the top 10% of wealth was twice that of those in the bottom 10% of wealth. The poorer population is more vulnerable and they generally have to keep going to work during the pandemic, which may lead to a higher infection risk.

Although the total number of MTR trips decreased significantly during the pandemic, the percentage of regular travel (taking the subway twice per day) increased, especially for adults and seniors. Students and children were not required to attend school since the schools closed on 22 January 2020, and no obvious changes in regular travel were seen during the pandemic. Because parents may have taken children and students outside during the weekends, changes in the local travel behaviours of this demographic between the non-pandemic and pandemic weeks were smaller than changes between weekdays and weekends. More than 75% of MTR passengers sampled in this study were adults. The extent of decrease on the weekend was much greater than the decrease on weekdays. A 60% decrease in local travel was seen on Sunday, which indicates that the perception of personal risk was high, and only a small number of residents had to travel to work on Sunday, especially during the pandemic. During the pandemic, residents deliberately avoided areas with a high density of people, as indicated by greater declines in passenger flow at the stations with higher passenger volumes. A previous study also found that areas with higher population densities were more responsive to the pandemic (Engle et al., 2020).

Local travel behaviour was also influenced by intervention strategies, such as regional lockdowns, stay-at-home orders, and travel restrictions (Zhang et al., 2020; Pappalardo et al., 2020). For instance, an official stay-at-home restriction order decreased mobility by 7.87% in the United States (Engle et al., 2020). In the UK, movement was seen to gradually decrease by 80%, after a lockdown order was imposed (Hadjidemetriou et al., 2020). In Germany, mobility was reduced by roughly 40% due to the lockdown policies, but mobility returned to normal levels with the lifting of the restrictions (Schlosser et al., 2020). It is difficult to calculate mobility reduction due to personal response to the pandemic without considering the intervention strategies.

Compared to the week from March 25 to 31, 2019, the mobility at work and retail/recreation areas decreased by 19%, and 30%, respectively during the most-serious pandemic week (March 25 to 31, 2020) (Apple Maps, 2020; Google LLC, 2020). We found that passenger flows to work, shopping malls, and amusement areas reduced by 42%, 80%, and 99%, respectively. The data showed that local travel behaviour

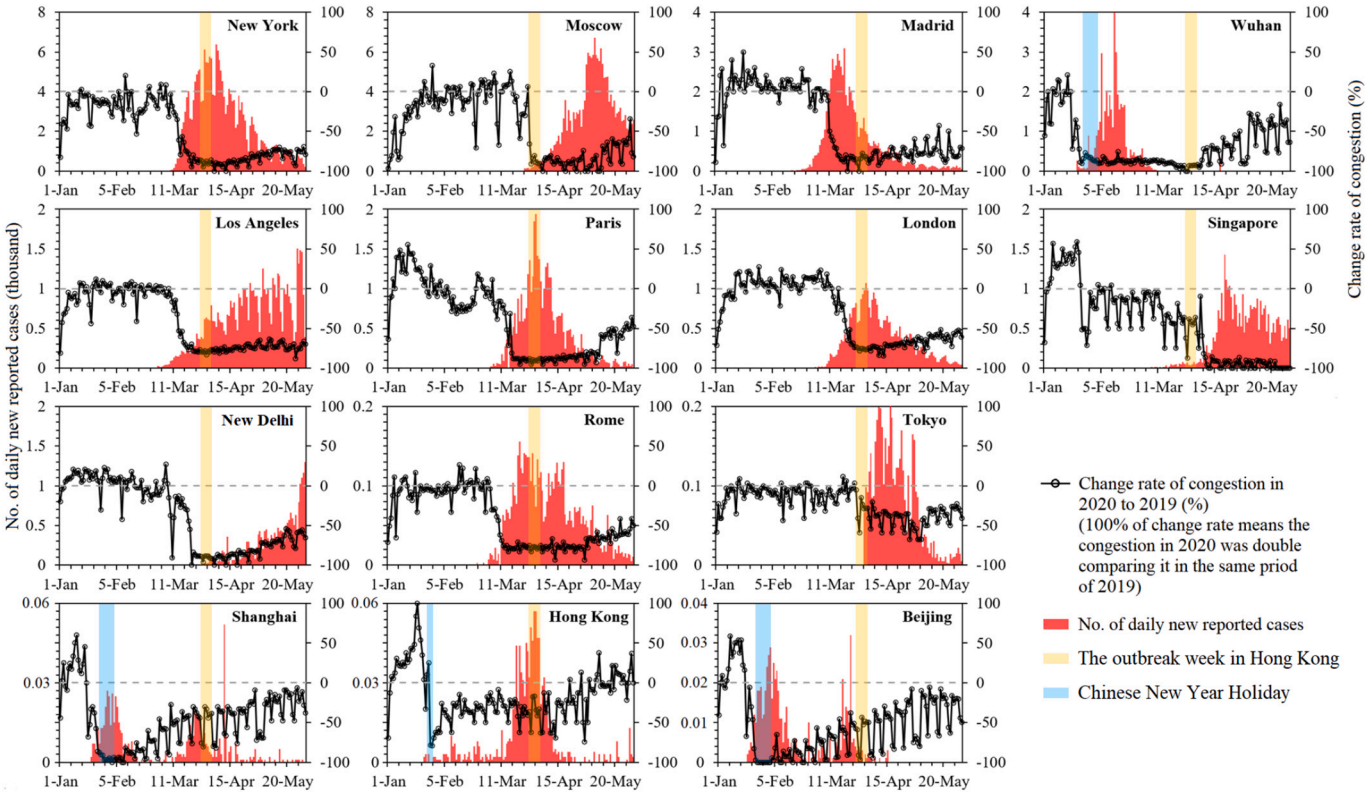

Fig. 7. Traffic congestion and daily reported cases of COVID-19 in different cities.

related to going to the workplace changed the least. Many densely-populated areas, such as shopping centres and zones with high densities of bars and karaoke rooms are near MTR stations. In Hong Kong, cluster infections were reported associated with bars, karaoke rooms and party halls. Therefore, the changes in local travel behaviours to these stations can serve as an indicator of the reduction in infection risk at high-risk locations. Central urban areas (e.g., amusement areas, business districts, workplaces and schools) are located in different parts of Hong Kong, so changes in local travel behaviour observed at different stations can be used to deduce the changes in activities in different urban central areas, and based on these observations, the infection risks in these areas can be further analysed. In Wuhan and Shanghai, daily contact decreased 7–8-fold during the COVID-19 pandemic (Zhang, et al., 2020), and the daily traffic congestion also decreased by more than 86%. In Tokyo, human movement decreased by around 50%, resulting in a 70% reduction in social contacts (Yabe et al., 2020). In New York City, there was a strong correlation between turnstile usage data from the subway system, and reported COVID-19 deaths and cases (Fathi-Kazerooni et al., 2020). Therefore, local travel behaviour can be considered as an important factor in increasing the probability of close contact, which directly affects the infection risk. Our data show that infection spread had the strongest relationship with the daily population using the MTR, albeit with a 7–8-day delay.

Governments can adopt different levels of intervention policies to reduce pandemic spread according to the local infection risk. Flexible working hours can shave the peak of daily ridership, to reduce the infection risk during the commute. A low-risk occupancy rate in the subway spaces should be further evaluated, and the frequency of public transport can then be changed to accommodate the real-time ridership to reduce traffic congestion on public transport. Various levels of intervention schemes can be implemented in MTR stations according to the corresponding congestion levels, since MTR stations have a high infection risk due to the high activity level and crowdedness (Peng & Jimenez, 2020). The entry policy should be evaluated according to the recent newly reported cases in the corresponding region. Finally, the daily MTR population can be used as an indicator to track the pandemic progress, and for the government to adjust intervention policies.

When considering long-term epidemic infection control policies, shopping malls, supermarkets and the business district can be allowed to conduct normal business, but with a guaranteed occupancy limit. This is based on both our results and other studies that have shown that people take the initiative to reduce travel to these crowded areas. However, bars, karaoke establishments and other highly crowded spaces should be closed due to the high risk of close contact. For people of different ages, different supporting polices should be applied. For example, adults could be allowed to work more flexibly to reduce rush hour peaks and office occupancy. For seniors who lack livelihood support, temporary government assistance should be provided during the pandemic. Common school closure policies for children and students were imposed by governments around the world, as our study of the data showed to have been the correct policy.

This study has a few limitations. We grouped all Hong Kong residents and visitors into five categories: adults, senior, children, students and others. However, it is likely that not all seniors, children and students used their own discounted card, and some may have used a regular or normal card (adult), which would introduce some errors in our analyses. In addition, we assumed that all passengers used only their own card when taking the MTR, which may also have introduced some errors. Moreover, choosing the specific pandemic week and the non-pandemic week to represent the status of the pandemic and of normal times may also introduce some errors.

In the future, other local travel data for other types of public transport (e.g., bus, taxi), which were not available to us, should be collected for similar analysis. In addition, long-term MTR turnstile data should be collected to analyse how local travel behaviour changes after the pandemic. Local travel habits may have been changed because of the pandemic. Moreover, when another outbreak comes, the difference in local travel behaviour between the different waves of the COVID-19

pandemic will be of great value, and new policies focusing on local travel behaviour could be developed.

5. Conclusion

The study analysed changes in the local travel behaviour of adults, students, children, and seniors on the Metro Transit Railway in Hong Kong before and during the pandemic (between January 1 and March 31) by using second-by-second smartcard data. Due to the pandemic, local travel volume decreased the most on Sundays. Students and children reduced their MTR-travel the most because of school closures, whilst adults and seniors reduced their MTR-travel by 42% and 48%, respectively. The changes in local travel behaviour of adults and seniors between the non-pandemic week and the pandemic week were greater than the changes between weekday and weekend, but the reverse was true for children and students. Local travel behaviour became more regular during the pandemic. Using the daily MTR-use data could well predict the severity of infection spread 7–8 days later.

CRediT authorship contribution statement

Zhang Nan: Conceptualization, methodology, data analysis, software, writing, validation. **Jia Wei:** data analysis, software, writing, validation. **Wang Peihua**: data analysis, software, writing. **Dung Chung-Hin**: data collection. **Zhao Pengcheng**: methodology, data analysis. **Leung Cathy**: methodology. **Su Boni**: software. **Cheng Reynold**: Conceptualization, methodology, data collection, supervision. **Li Yuguo**: Conceptualization, methodology, validation, supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to the MTR for providing data for analysis. This work was supported by a General Research Fund Grant (grant number 17202719) and a Collaborative Research Fund (grant number C7025-16G) provided by the Research Grants Council of Hong Kong.

Appendix

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2021.103139.

References

Apple Maps. (2020). Mobility trend reports. Retrieved April 1, 2020, from https://covid19.apple.com/mobility.

Badr, H., et al. (2020). Association between mobility patterns and COVID-19 transmission in the USA: A mathematical modelling study. *The Lancet Infectious Diseases.*. https://doi.org/10.1016/S1473-3099(20)30553-3.

Bernhardt, J. (2020). Decline in ridership, adapted timetables and disinfection-robots–The impact of corona/COVID-10 on public transport. Retrieved August 20, 2020, from https://www.urban-transport-magazine.com/en/decline-in-ridership-adapted-timetables-and-disinfection-robots-the-impact-of-corona-Covid-10-on-public-transport/.

Brough, R., Freedman, M., & Phillips, D. (2020). Understanding socioeconomic disparities in travel behavior during the COVID-19 pandemic. *University of California, Irvine Department of Economics Working Paper Series.*. https://doi.org/10.2139/ssrn.3624920.

Chen, S., et al. (2020). COVID-19 control in China during mass population movements at new year. *The Lancet, 395*(10226), 764–766.

Chinazzi, M., et al. (2020). The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science, 368*(6489), 395–400.

Cowling, B., et al. (2020). Impact assessment of non-pharmaceutical interventions against coronavirus disease 2019 and influenza in Hong Kong: An observational study. *The Lancet Public Health, 5*(5), e279–e288.

Engle, S., Stromme, J., & Zhou, A. (). *Staying at home: Mobility effects of covid-19*. Retrieved from. https://doi.org/10.2139/ssrn.3565703.

Fathi-Kazerooni, S., et al. (2020). Time series analysis and correlation of subway turnstile usage and COVID-19 prevalence in New York City. *arXiv*, Article arXiv:2008.08156. preprint arXiv:2008.08156.

FORTUNE. (2020). *Hong Kong gets thousands of mainland Chinese visitors each day. How it's kept coronavirus at bay*. Retrived from https://fortune.com/2020/03/15/coronavirus-hong-kong-cases-response/.

Fraiberger, S.P., et al. (2020). Uncovering socioeconomic gaps in mobility reduction during the COVID-19 pandemic using location data. arXiv preprint arXiv: 2006.15195.

Ghosh, A., Nundy, S., Ghosh, S., & Mallick, T. K. (2020). Study of COVID-19 pandemic in London (UK) from urban context. *Cities, 106*, 102928.

Google LLC. (2020). Google COVID-19 community mobility reports. See how your community is moving around differently due to COVID-19. Retrived April 1, 2020, from https://www.google.com/covid19/mobility/.

de Haas, M., Faber, R., & Hamersma, M. (2020). How COVID-19 and the Dutch "intelligent lockdown" change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands. *Transportation Research Interdisciplinary Perspective, 6*, 100150.

Hadjidemetriou, G. M., Sasidharan, M., Kouyialis, G., & Parlikad, A. K. (2020). The impact of government measures and human mobility trend on COVID-19 related deaths in the UK. *Transportation Research Interdisciplinary Perspectives, 6*, 100167.

Harris, J. (2020). *The subways seeded the massive coronavirus epidemic in New York City*. NBER Working Paper. w27021. Retrieved from https://ssrn.com/abstract=3580579.

HKCHP. (2020a). Latest situation of cases of COVID-19. Retrieved June 4, 2020 from https://www.chp.gov.hk/files/pdf/local_situation_covid19_en.pdf.

HKCHP. (2020b). COVID-19 case report. Retrieved June 2, 2020 from https://chp-dashboard.geodata.gov.hk/covid-19/zh.html.

HKCSD. (2020). Population estimates. Retrieved from https://www.censtatd.gov.hk/hkstat/sub/sp150.jsp?tableID=002&ID=0&productType=8.

HKEN. (2020). English news of Hong Kong. Retrieved June 1, 2020, from https://news.rthk.hk/rthk/en/.

HKID. (2020). Statistics on passenger traffic. Retrieved June 4, 2020, from https://www.immd.gov.hk/eng/message_from_us/stat_menu.html.

HKN. (2020). News website of Hong Kong government. Retrieved June 1, 2020, from https://www.news.gov.hk/eng/index.html.

HKTD. (2020). Monthly traffic and transport digest. Retrieved from https://www.td.gov.hk/en/transport_in_hong_kong/transport_figures/monthly_traffic_and_transport_digest/index.html.

Katrakazas, C., Michelaraki, E., Sekadakis, M., & Yannis, G. (2020). A descriptive analysis of the effect of the COVID-19 pandemic on driving behavior and road safety. *Transportation Research Interdisciplinary Perspectives, 7*, 100186.

Koehl, A. (2020). Urban transport and COVID-19: Challenges and prospects in low- and middle-income countries. *Cities & Health.*. https://doi.org/10.1080/23748834.2020.1791410.

Koo, J., et al. (2020). Interventions to mitigate early spread of SARS-CoV-2 in Singapore: A modelling study. *The Lancet Infectious Diseases, 20*(6), 678–688.

Kraemer, M., et al. (2020). The effect of human mobility and control measures on the COVID-19 epidemic in China. *Science, 368*(6490), 493–497.

Laverty, A., et al. (2020). COVID-19 presents opportunities and threats to transport and health. *Journal of the Royal Society of Medicine, 113*(7), 251–254.

Lee, H., et al. (2020). The relationship between trends in COVID-19 prevalence and traffic levels in South Korea. *International Journal of Infectious Diseases, 96*, 399–407.

Liu, L. (2020) Emerging study on the transmission of the novel coronavirus (COVID-19) from urban perspective: Evidence from China. Cities, 103: 102759.

Megahed, N., & Ghoneim, E. (2020). Antivirus-built environment: Lessons learned from Covid-19 pandemic. *Sustainable Cities and Society, 61*, 102350.

Pappalardo, L., et al. (2020). A dataset to assess mobility changes in Chile following local quarantines. *arXiv*, Article arXiv:2011.12162. preprint arXiv:2011.12162.

Park, J. (2020). Changes in subway ridership in response to COVID-19 in Seoul, South Korea: Implications for social distancing. *Cureus, 12*(4), Article e7668.

Parr, S., et al. (2020). Traffic impacts of the COVID-19 pandemic: Statewide analysis of social separation and activity restriction. *Natural Hazards Review, 21*(3), Article 04020025.

Peng, Z., & Jimenez, J. L. (2020). Exhaled CO_2 as COVID-19 infection risk proxy for different indoor environments and activities. Retrieved from https://www.medrxiv.org/content/10.1101/2020.09.09.20191676v1.

Pepe, E., et al. (2020). COVID-19 outbreak response, a dataset to assess mobility changes in Italy following national lockdown. *Scientific Data, 7*(1), 1–7.

Prem, K., et al. (2020). The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: A modelling study. *The Lancet Public Health, 5*(5), e261–e270.

REUTERS. (2020). Hong Kong extends school suspension until April 20 to control spread of virus. Retrieved from https://www.reuters.com/article/us-china-health-hongkong/hong-kong-extends-school-suspension-until-april-20-to-control-spread-of-coronavirus-idUSKCN20J0MC.

Rothan, H., & Byrareddy, S. (2020). The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. *Journal of Autoimmunity, 109*, 102433.

Schlosser, F., et al. (2020). COVID-19 lockdown induces disease-mitigating structural changes in mobility networks. *Proceedings of the National Academy of Sciences.*. https://doi.org/10.1073/pnas.2012326117. Retrieved December 21, 2020, from.

Sethi, M., & Mittal, S. (2020). Improvised rental housing to make cities COVID safe in India. *Cities, 106*, 102922.

South China Morning Post (SCMP). (2020). *Hong Kong takes emergency measures as mystery 'pneumonia' infects dozens in China's Wuhan city*. Retrieved from https://www

.scmp.com/news/china/politics/article/3044050/mystery-illness-hits-chinas-wuhan-city-nearly-30-hospitalised.
Tam, J. (2002). Influenza A (H5N1) in Hong Kong: An overview. *Vaccine, 20*(2), S77–S81.
Tanveer, H., et al. (2020). Monitoring 2011–2020 traffic patterns in Wuhan (China) with COSMO-SkyMed SAR, amidst the 7th CISM military world games and COVID-19 outbreak. *Remote Sensing, 12*(10), 1636.
Teixeira, J., & Lopes, M. (2020). The link between bike sharing and subway use during the COVID-19 pandemic: The case-study of New York's Citi Bike. *Transportation Research Interdisciplinary Perspectives, 6*, 100166.
The World Bank. (2020). Population density (people per sq. km of land area). Retrieved from https://data.worldbank.org/indicator/EN.POP.DNST.
Vingilis, E., et al. (2020). Coronavirus disease 2019: What could be the effects on road safety? *Accident Analysis & Prevention, 144*, 105687.
Wang, D., et al.. *Impact of COVID-19 behavioral inertia on reopening strategies for New York City transit.* (2020). Retrieved from https://arxiv.org/abs/2006.13368.
Warren, M., & Skillman, S.. Mobility changes in response to COVID-19. (2020). Retrieved from https://arxiv.org/abs/2003.14228.
WARS. (2020). Wuhan acute respiratory syndrome. Retrieved June 4, 2020, from https://wars.vote4.hk/.
WHO. (2003). Summary of probable SARS cases with onset of illness from 1 November 2002 to 31 July 2003. Retrieved from https://www.who.int/csr/sars/country/table2003_09_23/en/.
Wilbur, M., et al.. *Impact of COVID-19 on public transit accessibility and ridership*. (2020). Retrieved from https://arxiv.org/abs/2008.02413.
Wu, J., et al. (2010). School closure and mitigation of pandemic (H1N1) 2009, Hong Kong. *Emerging Infectious Disease, 16*(3), 538–541.
Wu, P., et al. (2014). Responses to threat of influenza A (H7N9) and support for live poultry markets, Hong Kong, 2013. *Emerging Infectious Diseases, 20*(5), 882–886.
Wu, Z., & McGoogan, J. (2020). Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: Summary of a report of 72,314 cases from the Chinese Center for Disease Control and Prevention. *JAMA, 323*(13), 1239–1242.
Yabe, T., et al. (2020). Non-compulsory measures sufficiently reduced human mobility in Tokyo during the COVID-19 epidemic. *Scientific Reports, 10*(1), 1–9, 2020.
Zhang, J., et al. (2020). Changes in contact patterns shape the dynamics of the COVID-19 outbreak in China. *Science, 368*(6498), 1481–1486.
Zhang, X., Ji, Z., Zheng, Y., & Ye, X. (2020). Evaluating the effect of city lock-down on controlling COVID-19 propagation through deep learning and network science models. *Cities, 107*, 102869.