



Research paper

How the COVID-19 pandemic changed travel behaviour? A case study on public bikes in Seoul

Hyewon Goh^a, Gahyun Choi^b, Yena Song^{a,*}

^a Department of Geography, Chonnam National University, Gwangju, 61186, South Korea

^b Department of Industrial Engineering, Yonsei University, Seoul, 03722, South Korea

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ABSTRACT

This study aims to examine how travel behaviour has changed after the COVID-19 outbreak, specifically focusing on the use of public bikes in Seoul. In January 2020, the Korean government reported its first COVID-19 case and implemented several levels of social distancing measures excluding movement restrictions. These measures, coupled with the fear of infection, resulted in reduced social interactions and, further, changed travel behaviour. Transit usage in Seoul has experienced a significant decline of approximately 25% in 2020 and 2021 compared to the previous two years. However, the use of public bikes continued to rise even during the pandemic, unaffected by the prevalence of the disease. Moreover, there was a doubling of public bike usage during commute hours, implying the potential of public bikes as an alternative travel mode for commute purposes. Our findings suggest that COVID-19 acted as a disruptive shock that prompted changes in travel behaviour. Policymakers should seize this opportunity to promote the wider adoption of cycling, potentially through the development of more efficient and safer infrastructure as well as the implementation of various incentives.

1. Introduction

The severity of environmental issues like global warming, climate change, and resource depletion has generated a global sense of crisis. In response, the U.N. Environment Program (UNEP) proposed the “Green New Deal” policy in 2008, calling for investment in the environmental sector to stimulate economic growth. Governments and private sectors have been actively seeking sustainable development approaches that mitigate environmental harm. Bikes have long gained significant attention within the transportation sector as a means for sustainable and active travel that can transform the current transportation system, which has turned car-dependent in many parts of the world (Kenworthy & Laube, 1999; Marshall & Banister, 2000). Bikes are recognised as an environmentally friendly and healthy travel mode as they do not produce carbon emissions, consume no fossil fuel, and encourage an active lifestyle (Bullock et al., 2017; Zhang & Mi, 2018). The Korean government has also been actively promoting bike usage among the general public, with one of the key initiatives being the implementation of a public bike system. Countries that employed public bike policies early on, such as the Netherlands and Denmark, have achieved high rates of bike utilisation, with the Netherlands showing the world’s highest

modal share of bikes at 27%, followed by Denmark at 23%. However, in Korea, the modal share of bikes remains very low, currently standing at only 1.6%, despite extensive efforts to construct bike routes, introduce public bikes, and launch promotional campaigns over the past few decades (KOTI, 2022).

COVID-19, the novel infectious disease, emerged at the end of 2019. It quickly spread worldwide, causing significant public health concerns before its identity and severe impacts were fully understood (Wang et al., 2020). As this disease is contagious before symptoms appear or, in some cases, without any symptoms at all, it spread rapidly when effective pharmaceutical interventions were not yet available at the beginning of the pandemic (Lai et al., 2020). Consequently, many governments adopted the so-called ‘social distancing’ measures, and the general public became increasingly aware and fearful of contracting COVID-19 (Anderson et al., 2020; Bourassa et al., 2020). As a result, people began to prefer personal modes of transportation over public transit, where strangers gathered in a small confined spaces. Numerous studies have reported a decrease in public transit ridership, while personal passenger modes have experienced an increase in users (Gkiotsalitis & Cats, 2021; Kim et al., 2021). This notable change in the mobility paradigm indicates that shared mobility services utilising personal

* Corresponding author.

E-mail addresses: hyewon_127@jnu.ac.kr (H. Goh), cgh000@yonsei.ac.kr (G. Choi), Y.Song@chonnam.ac.kr (Y. Song).

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Fig. 1. Public bikes and a docking station in Seoul. (Photograph by Hye-won Goh).

Table 1
Number of Tareungi and docking stations and length of bike lanes by year.

Year	2015	2016	2017	2018	2019	2020	2021
Bikes	2,000	5,600	20,000	25,000	29,500	37,500	40,500
Docking stations	150	450	1,290	1,540	2,085	2,228	2,600

mobility systems are expected to experience rapid growth in the future (Shin & Cho, 2022).

Given the impact of the pandemic on travel behaviours, it is worth examining the potential of active and personal travel modes as alternatives to inactive ones. This study aims to empirically examine changes in travel patterns by analysing the use of public bikes and public transit in Seoul following the COVID-19 outbreak. The Korean government had implemented no travel ban after the pandemic. However, people reduced personal journeys because of fear, school closures, and the wide adoption of work-from-home. Thus, the changes in travel behaviours during the pandemic were largely voluntary rather than compulsive. This presents an intriguing opportunity to see how the usage patterns of various public transportation modes were affected by the pandemic, particularly in the absence of publicly announced travel restrictions. To this end, we compared and analysed ridership data for Seoul's public bike system, subway, and bus over the past four years, encompassing the period before and after the outbreak of COVID-19.

The remainder of this paper is organized as follows. Section 2 provides a general explanation of the public bike system in Seoul, Korea. Section 3 outlines the study scope and introduces the data used in our analysis. Section 4 presents the results and discussion. Finally, Section 5 concludes the study.

2. Public bike system in seoul

Since the first bike-sharing system introduced in 1965, it has gained widespread adoption, with over 800 cities recently implementing such systems (DeMaio, 2009; Fishman, 2016). A bike share, also known as a public bike system, is a passenger transportation system that enables the general public to make a journey conveniently by cycling at anytime and anywhere. Bikes are provided for rent by the state, local governments, or private companies, enabling the public to use and return them after their journeys. Bikes are suited for short-distance travel, making them a viable alternative to many short-vehicle journeys in urban areas (Yoon & Cho,

2014).

The modal shift from motorised to non-motorised ones can have several positive effects, including alleviating traffic congestion, reducing emissions, saving energy, and enhancing public health (Bullock et al., 2017; Cools et al., 2009; Zhang & Mi, 2018). Additionally, public bike users are not burdened with the costs and responsibilities associated with owning a bike (Faghih-Imani et al., 2017). Privately owned bikes incur costs associated with storage facilities and the risk of theft (Ji et al., 2017; Márquez & Soto, 2021). With advancements in technology, various management methods have been introduced to prevent theft and enhance user convenience. Users can easily access bikes through docking stations or by locating idle bikes distributed throughout the city or along designated tracks using their mobile phones (Chen et al., 2020; Li et al., 2019). Furthermore, the public bikes are typically available for rental and return 24-hour a day, allowing users the flexibility to use them whenever needed. As such, the public bike system offers excellent convenience, as users can access bikes near their desired starting point and destination without the burden of ownership and time restrictions. This flexibility enables public bikes to complement public transit systems, providing convenient last-mile mobility solutions (González et al., 2016).

Seoul's public bike system¹ was initially introduced as a pilot project in 2014, drawing inspiration from the French public bike system called

"Believe". Subsequently, in October 2015, the city officially launched a shared public bike system with 2,000 bikes and 150 docking stations (Fig. 1). Seoul City has progressively expanded its shared bike services by increasing the number of bikes available and installing more docking stations (Table 1). This expansion has resulted in a significant increase in bike availability throughout Seoul. More specifically, between 2015 and 2021, the number of bikes increased over 20 times, while the number of docking stations increased 17 times. Notably, during COVID-19 period in 2020, bike usage became even more prevalent, leading to a substantial surge in the number of bikes available. The progress is quite remarkable in a short period of time compared to other cities, such as Paris Valley with 23,600 units, London BCH with 13,600 units (2017), and New York City Bike with 12,000 units (2018) (Seo & Cho, 2021). Currently, over 3.3 million people have registered to ride the public bike scheme in Seoul, implying that one in three citizens of Seoul has demonstrated their willingness to use this service. In order to ensure the safety of users during the pandemic, shared bikes and docking stations underwent daily sterilisation, and hand sanitizers were installed at every docking station.

3. Methodology

3.1. Study scope and data

The spatial scope of this study is Seoul, the capital city of South Korea, with a population of 10 million approximately. This large population generates over 32 million trips a day and more than a half of these trips are carried out by public transit (Jung et al., 2022). As of 2019, the subway and buses accounted for 41.6% and 24.0% of

¹ The public bike was named "Tareungi", mimicking the sound of a bike bell in Korean. For readability and consistency, we used the term public bike to refer to Seoul's public bike rather than Tareungi.

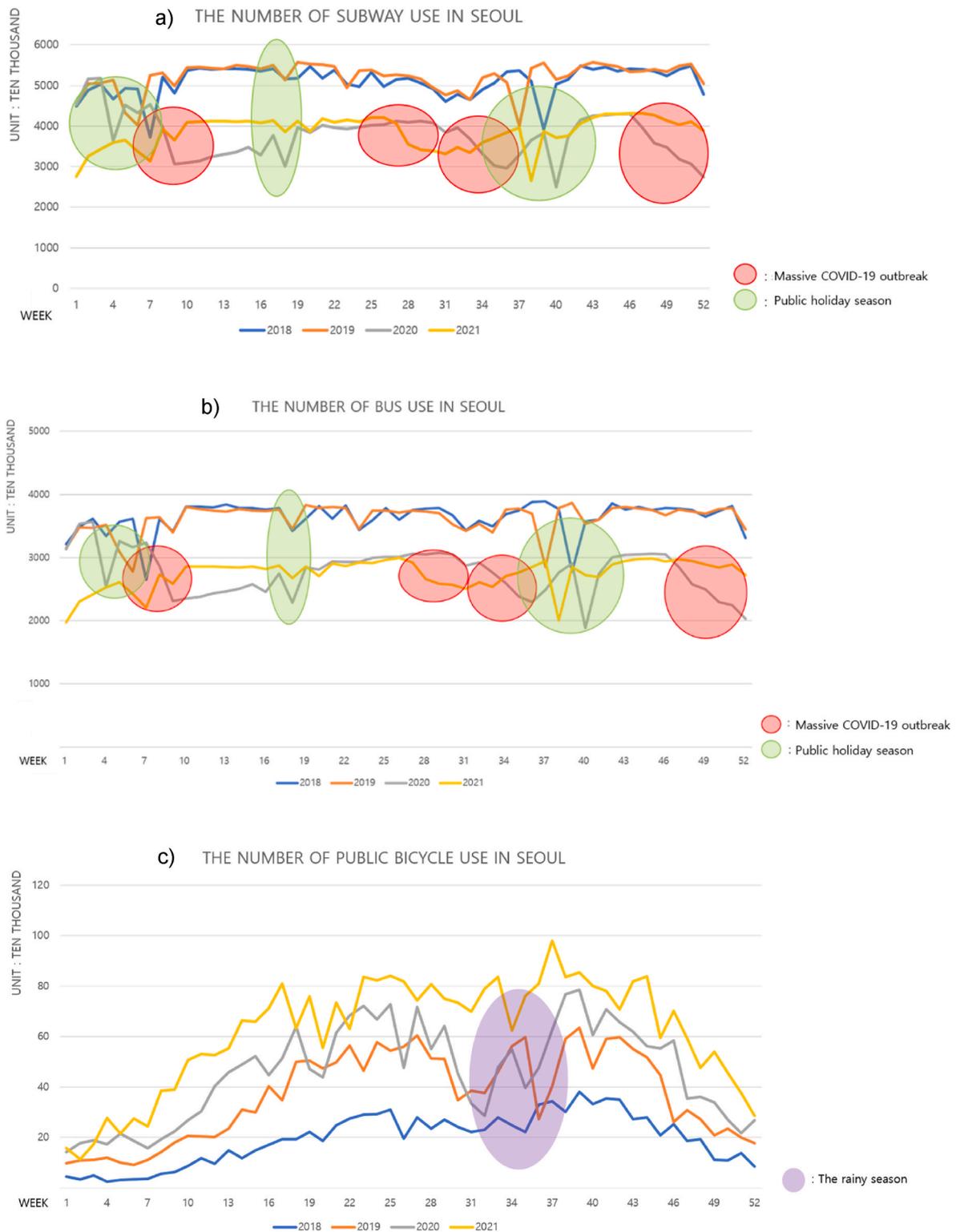


Fig. 2. Weekly ridership by transport mode in Seoul, 2018–2021: a) subway, b) bus, and c) public bike.

passenger trips, respectively, whilst private vehicles accounted for 24.5% of the modal share. Following the outbreak of COVID-19, the Korean government implemented non-pharmaceutical interventions such as mandatory facial masks and business hour restrictions, along with social-distancing campaigns. However, there were no travel restrictions in place unless a person was confirmed to be infected with the COVID-19 virus. Since the public transit system is the dominant mode of

travel in the metropolitan area and no travel bans were enforced, Seoul serves as an ideal case study site for studying the impact of the COVID-19 pandemic on travel behaviour, particularly in relation to the use of public transit and public bikes. The study period encompassed two years before the COVID-19 outbreak and two years after, i.e., from 2018 to 2021.

For this study, we collected data on public transit and bike usage, as

well as COVID-19 prevalence, from [Seoul Open Data Square](https://data.seoul.go.kr) (data.seoul.go.kr). Specifically, we obtained daily data on confirmed COVID-19 cases, public bike rental history, public bike rentals categorised by time, subway ridership, and bus ridership from the publicly available data portal.

3.2. Data analysis

This study employs descriptive statistics and multivariate statistical analysis to examine changes in travel behaviour before and after the COVID-19 outbreak. Daily ridership data for three public transport modes (subway, bus, and bike) were cleaned and analysed using descriptive statistics over a four-year period. Recognising the weekly rhythms of urban travel behaviours and traffic conditions (Jung et al., 2022), we aggregated the daily ridership data into weekly data. This enabled us to compare the usage of each mode without being influenced by daily activity differences throughout the week.

We also examined the timing of public bike rentals. Although the available public data did not provide information on trip purposes or users, we were able to indirectly infer trip purposes based on the time of use. For instance, if a bike was hired during the morning peak hour on a weekday, it was likely used for commuting rather than leisure. On the other hand, if a bike was used in the afternoon on a Sunday, it was more likely rented for leisure rather than work-related activities. Jones (2012) has shown that people often start using bikes for leisure and gradually incorporate them into their practical journeys. Commuting trips are typically obligatory, so integrating public bikes into commuting trips suggests a more habitual or intensive use of bikes compared to recreational usage. We considered trips between 7 a.m. and 9 a.m. and between 6 p.m. and 9 p.m. as indicative of commuting purposes (Kim et al., 2021). The evening commute hours were set to be 1 hour longer than the morning peak because ‘going home’ trips tend to require less punctuality than the morning commutes.

In order to statistically confirm the differences in travel behaviour, we conducted a MANOVA (Multivariate Analysis of Variance) using daily ridership data for the three public transportation modes before and after the COVID outbreak. MANOVA was chosen over Analysis of Variance (ANOVA) or the *t*-test as it utilises the covariance between variables in the calculation.

Furthermore, a regression analysis was conducted to determine whether the number of confirmed COVID-19 cases was associated with changes in bike usage compared to other public transport modes. This analysis used a seven-day sum for the number of newly confirmed cases and urban travel behaviour, as they exhibit weekly variation patterns. Moreover, since the ridership data used in this study were constructed as a form of daily time series, they are likely to have possible time trends and seasonality issues. In order to de-trend or eliminate time series properties, we used the ratio of ridership data, as defined in equation (1):

$$\text{ridership ratio} = \frac{\text{weekly public bike riderships}}{\text{weekly transit and public bike riderships}} \quad \text{equation (1)}$$

Then, a simple Ordinary Least Square (OLS) linear regression model was applied to explore the impact of the infectious disease on the modal share of passenger trips in Seoul, as shown in equation (2):

$$Y = \beta_0 + \beta_1 X + \varepsilon, \quad \text{equation (2)}$$

where *Y* was the ridership ratio, *X* was confirmed COVID-19 cases, β_0 was an intercept, β_1 was a regression coefficient, and ε was an error term of the model.

4. Results and discussion

Fig. 2 illustrates the weekly ridership fluctuations for different modes of transportation over the last four years. It is evident that the subway

Table 2
Average vehicle speed and number of daily trips in Seoul.

Year	2018	2019	2020	2021
Average Speed in km/hour (CBD)	23.9 (18.3)	23.8 (18.5)	24.1 (20.5)	23.0 (19.7)
Average number of daily trips (thousands)	32,248	32,162	26,497	–

Source: Seoul Metropolitan Government, 2023

and bus exhibit similar patterns, while the public bike has its own distinct pattern along with a strong seasonality. One notable observation is that the subway and bus graphs display a significant decrease in ridership in 2020 and 2021, following the outbreak of COVID-19, compared to the years 2018 and 2019, prior to the pandemic. The combined subway ridership in 2020 and 2021 was approximately 25% lower than that of 2018 and 2019. Similarly, bus usage experienced a decline of around 26% after the pandemic. This decrease in transit ridership aligns with trends observed in other cities (Gkiotsalitis & Cats, 2021). However, in contrast to the decline in public transit ridership, the usage of public bikes in Seoul has continued to increase both before and after the pandemic. After the outbreak, public bike usage witnessed a significant surge, with a 90% increase compared to the two preceding years. This upward trend in public bike usage in Seoul sets it apart from the experiences reported in other countries where travel bans or lockdown measures were imposed. Literatures reported that various travel restrictions implemented during the pandemic led to an immediate decrease in shared bike usage in cities such as London, Bangkok, Chicago, and New York (Hu et al., 2021; Lei & Ozbay, 2021; Li et al., 2021; Sangveraphunsiri et al., 2022). However, once travel bans were lifted, these cities observed a rapid increase in bike rentals, surpassing the recovery rate of public transit modes (Gkiotsalitis & Cats, 2021; Lei & Ozbay, 2021; Li et al., 2021). These findings provide empirical evidence supporting Seoul’s experience and highlight the resilience of private, shared modes of transportation during the time of the pandemic.

As depicted in Fig. 2, the ridership patterns of different transit modes exhibited similar trends. There are a couple of notable points to highlight. First, there was a significant decrease in ridership immediately after the outbreak of COVID-19. The first COVID-19 case was reported on January 20, 2020, corresponding to the fourth week of that year. Before the pandemic, transit usage remained relatively stable. However, following the official confirmation of COVID-19 cases in the country, ridership experienced a sharp decline, which persisted even after extensive vaccination efforts in late 2021. Specifically, subway ridership witnessed a 27.6% decrease in 2020, following a modest 2% increase in 2019. In 2021, subway ridership showed a slight recovery, with a 2% increase. Similarly, bus ridership saw a 0.3% decrease in 2019, followed by a substantial drop of 23.5% in 2020 and a further decrease of 1.2% in 2021. It is worth noting that no travel bans were imposed in Seoul following the outbreak of the COVID-19 pandemic. However, people voluntarily reduced their travel and avoided confined travel modes with strangers due to fear of infection (Cho & Park, 2021; Parker et al., 2021). This is supported by Table 2 and Fig. 2. Vehicle speeds increased immediately after the COVID crisis was announced but gradually slowed down in subsequent years, except in CBD areas. Meanwhile, public transit still struggled heavy loss of passengers. Also the total number of passenger trips dropped by 17.6% between 2019 and 2020. These observations collectively indicate that people reduced all types of travel at the beginning of the pandemic but started to travel again, preferring private modes over public transits.

Second, it is worth noting that transit usage experienced fluctuations in all four years, but additional significant drops were observed during the pandemic years. In Fig. 2, the green circles represent Korean holiday seasons, such as New Year’s Day, family days in May, and Thanksgiving Day. These holidays corresponded to sharp drops in transit usage, regardless of the pandemic. However, a few more substantial

Table 3

Number of new members registered for the shared bikes.

Year	2018	2019	2020	2021
Newly registered members	583,090	804,957	1,185,372	673,245

Table 4

MANOVA and post MANOVA regression results (n = 1460).

	Statistic	f-value	p-value
COVID-19	W ^a 0.4823	521.06	0.0000
	p ^b 0.5177	521.06	0.0000
	L ^c 1.0736	521.06	0.0000
	R ^d 1.0736	521.06	0.0000
Residual	1458		
Post MANOVA regression			
	Coefficient	t-value	p-value
Bus (f-value: 547.28 ^e)			
COVID	-1269325	-23.39	0.00
Constant	5176645	136.62	0.00
Subway (f-value: 641.12 ^e)			
COVID	-1964584	-25.32	0.00
Constant	7363120	135.89	0.00
Public bike (f-value: 537.98 ^e)			
COVID	38028.9	23.19	0.00
Constant	39634.05	34.60	0.00

^a W=Wilks' lambda.

^b L = Lawley-Hotelling trace.

^c P= Pillai's trace.

^d R=Roy's largest root.

^e Indicates significance at the level of 1%.

fluctuations (indicated by red circles in Fig. 2-a and 2-b) were observed during the pandemic years. These sharp declines in transit usage coincided with four waves of massive COVID-19 outbreaks during the pandemic period. The first massive infection wave occurred in February 2020, when the first infection cluster was discovered in a church, resulting in widespread fear of infection across the country. Following this outbreak, subway ridership dropped by 18.5% below the annual average. After a period of time, ridership recovered to some extent, only to decline again during the second mass outbreak in August 2020, triggered by a mass protest in the centre of Seoul. The third outbreak occurred in late 2020, with mass infections reported in various nursing facilities and churches. The fourth wave, caused by the delta variant, occurred in July 2021. Although ridership showed a slow recovery, it still remained below the levels observed in 2018 and 2019.

The weekly ridership graph of public bikes (Fig. 2-c) exhibits distinct differences compared to public transit. Since 2018, there has been a consistent upward trend in the number of public bike users in Seoul City, partly attributed to the expansion of bike-sharing infrastructure and increased visibility. Notably, even in the midst of the COVID-19 pandemic, public bike ridership has continued to rise at an impressive level. Moreover, there was an unprecedented surge in newly registered users in 2020 (Table 3). This suggests that shared bikes have rapidly emerged as an alternative mode of transportation embraced by a larger population in Seoul in response to the pandemic. Furthermore, it is worth mentioning that public bike ridership was not significantly affected by holidays or mass outbreaks of the infectious disease. This reflects different characteristics of bike usage from that of transit. Bikes can serve both practical and recreational purposes. For instance, during holidays, bikes may be used for recreational purposes, while during morning peak hours on weekdays, they can be utilised for commuting. Additionally, biking typically involves riders in an open-air environment, in contrast to public transit, where people have to stay with strangers in confined spaces. Consequently, bikes are considered relatively unaffected by infectious diseases, and thus, the fluctuations in public bike ridership appear unrelated to the massive outbreaks. However, the fluctuation pattern does indicate that weather conditions can

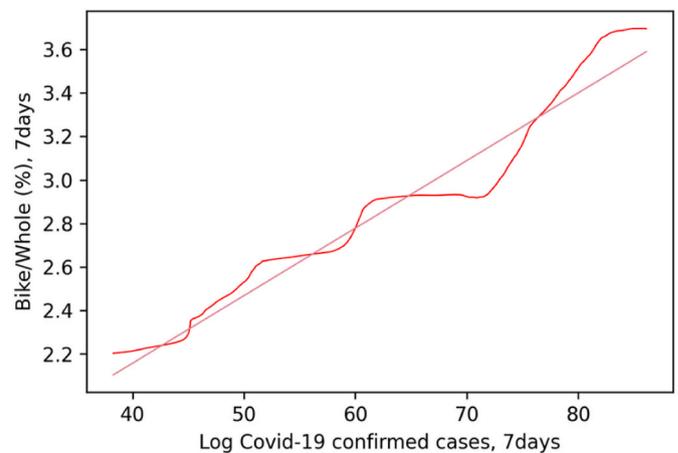


Fig. 3. Ridership ratio along with confirmed COVID-19 cases in Seoul.

Table 5

Regression analysis results.

	Coefficients	Standard Error	t-value	p-value	R ²
COVID-19	0.031	0.000	89.795***	0.000	0.925
Intercept	0.915	0.023	39.026***	0.000	

*p < 0.1, **p < 0.05, ***p < 0.01.

significantly influence bike usage. During cold winters and rainy seasons, ridership tends to decrease, whereas more bikes are hired when the weather is warm and mild.

To statistically confirm the changes in ridership before and during the pandemic, a balanced one-way MANOVA was carried out. This analysis utilised the daily ridership of each mode as the dependent variable and COVID-19 status as a grouping variable. Additionally, a post-test analysis was performed as a form of simple regression, using the number of ridership and a COVID-19 dummy variable to ascertain the direction of changes along with statistical significance. The results of MANOVA and post-test analysis are presented in Table 4, clearly demonstrating some difference in ridership in three modes before and after the pandemic, and these changes are statistically significant. Further, the coefficients and t-values of the COVID-19 variable in the regression results confirm that the directions of ridership changes appear to be, as previously noted, more public bikes and less public transit. So it can be concluded that the ridership pattern of public transport modes experienced significant changes during the course of the pandemic.

Fig. 3 illustrates the ridership ratio of public bikes compared to all public transportation modes, alongside the daily new cases of COVID-19 in the years 2020 and 2021. This figure shows a potential positive association between these variables, and this relationship was statistically confirmed by the regression analysis results presented in Table 5. The regression analysis revealed a statistically significant coefficient of the ridership ratio (0.031), indicating a positive relationship. The R² and the p-value indicated that the model was fitted properly. This finding implies that the severity of COVID-19 has contributed to an increased preference for public bikes among public transportation modes. However, it is important to note that the regression results do not imply a modal shift from buses and subways to shared bikes. Rather, they provide valuable insights into the clear relationship between the pandemic's severity and the growing prominence of bike usage. This observation aligns with empirical evidence from other cities during the pandemic. For instance, Santander et al. (2022) documented a significant 33% increase in global revenue for bike-sharing in 2020, showcasing its resilience despite pandemic-related disruptions and highlighting further potential for growth. Similarly, Jiao et al. (2022)

Table 6

Peak time ridership before the pandemic.

2018 + 2019	Mon	Tue	Wed	Thu	Fri	All
Peak hour (7:00–9:00)	335,816	359,290	290,388	281,159	346,622	1,613,275
Peak hour (18:00–21:00)	679,508	682,946	612,706	610,005	713,139	3,298,304
All	1,015,324	1,042,236	903,094	891,164	1,059,761	4,911,579

Table 7

Peak time ridership after the pandemic.

2020 + 2021	Mon	Tue	Wed	Thu	Fri	All
Peak hour (7:00–9:00)	694,957	732,007	725,291	779,218	718,961	3,650,434
Peak hour (18:00–21:00)	1,395,647	1,443,129	1,505,157	1,566,534	1,528,745	7,439,212
All	2,090,604	2,175,136	2,230,448	2,345,752	2,247,706	11,089,646

demonstrated the positive impact of the COVID-19 pandemic on bike-sharing ridership in Seoul, while Heydari et al. (2021) observed a positive relationship between the pandemic and bike-sharing in London, exemplified by a noticeable rebound in cycle hires and extended hire times. Moreover, previous studies examining both shared bikes and public transit have consistently found that the pandemic led to a significant decrease in transit ridership, while shared bike usage increased even more than before the pandemic, particularly in the absence of travel bans (Sangveraphunsiri et al., 2022; Teixeira & Lopes, 2020). Therefore, our regression results provide further confirmation of these previous findings.

To explore the viability of public bikes as a means of commuting, we analysed the ridership data during peak hours on weekdays. Tables 6 and 7 respectively, depict the aggregate ridership data across days of the week before and after the pandemic.

In general, the evening peak hours exhibited about twice the ridership of public bikes compared to the morning peak hours. After the pandemic, there was a significant increase in the number of public bike users during peak hours, amounting to a 126% rise. The ridership during morning peak hours in 2020 and 2021 increased by about 126.28% compared to the figures recorded in 2018 and 2019. Similarly, the ridership during evening peak hours experienced an increase of about 125.54% after the pandemic. These increases were notably higher than the overall ridership growth, which was about 90%. Looking at it from a different perspective, in 2018 and 2019, around 16.8% of public bike trips occurred during peak hours. However, this figure surged to 20% after the outbreak of COVID-19, suggesting immense potential for using public bikes as a commuting mode.

5. Conclusion

This study showed how COVID-19, a global pandemic, changed travel patterns in Seoul. Despite the absence of travel restrictions, our findings reveal a significant decrease in transit ridership after the pandemic. On the other hand, the usage of public bikes exhibited a consistent increase throughout the study period, regardless of the spread of COVID-19. Remarkably, the ridership of public bikes remained unaffected by the massive outbreak of COVID-19 infections, whereas such outbreaks clearly discouraged the use of public transit. This trend is further confirmed by the statistically significant and positive association between the daily ridership ratio of public bikes to transit and the number of confirmed COVID-19 cases. Moreover, an analysis of ridership during peak hours indicates a notable rise in practical trips undertaken using public bikes, surpassing the average increase. This suggests the potential for public bikes to serve as an alternative mode of transportation, replacing motorised modes in certain situations.

The way of travel is often decided habitually. Thus, travel behaviour change takes time and efforts (Gärling & Axhausen, 2003; Song et al., 2017). Moreover, transitioning to a less convenient or comfortable mode of transportation often necessitates a disruptive event that interrupts

established travel routines. The COVID-19 pandemic was a devastating global crisis that profoundly impacted public health and the global economy. Paradoxically, the fears of infection associated with the pandemic had a positive effect by prompting a greater preference for personal modes of transport (Kim et al., 2021; Teixeira & Lopes, 2020) and offered a momentum to promote more active and sustainable travel modes for inner city journeys (Nikitas et al., 2021).

However, the increased usage of shared bikes in Seoul cannot be solely attributed to the pandemic. The city has actively expanded its bike-sharing infrastructure, resulting in improved convenience and accessibility, which likely contributed to the rise in bike rentals. Additionally, the length of bike lanes has increased, from 869 km in 2016 to 1,290.38 km in 2021 (KOSIS, 2022). Particularly between 2019 and 2020, there was a significant 33.8% growth in bike lane length compared to the previous year. However, it should be noted that approximately 60% of this increase was in multi-use trails that are shared with pedestrians. This clearly shows the multi-dimensional factors contributing to the rise in bike usage during the pandemic. Together with all the efforts from provider side, the modal share of bicycles in Seoul rose from 1.4% in 2016 to 3.4% in 2021 (Gyeonggi Transportation Information Centre), which aligns with other countries' experiences (Buehler & Pucher, 2021). While this may appear relatively low compared to other cities, it is important to consider Seoul's context. Biking has not been a popular mode of travel in Seoul due to its hilly terrain and narrow road networks. However, the pandemic provided a unique opportunity for bike journeys, as well as the use of personal mobility devices, to be perceived as viable options for short-distance transportation.

In conclusion, the increase in bike rentals during the COVID-19 pandemic in Seoul City can be attributed to a combination of factors, including the expansion of bike-sharing infrastructure, convenience, and the unique circumstances created by the public health crisis. The findings of this study support previous literature showing the paradoxical potential of the pandemic for sustainable travel behaviour and emphasise the need for continued efforts from policymakers to further promote the use of bicycles as a sustainable and efficient mode of transportation in the post-pandemic era. If people who began using bikes during the pandemic recognise their benefits in terms of avoiding disease transmission, realise the positive effects of cycling, and acknowledge the convenience of bike travel, they may continue to use bikes even after the public health crisis subsides. In contrast, the significant loss of ridership and low resilience of public transit during the pandemic should serve as an opportunity for policymakers to prepare for future public health crises and seek compromising solutions that enable necessary travel while minimising the risk of contagion (Gkiotsalitis & Cats, 2021). Policymakers should be mindful that this unfortunate public health crisis could be a catalyst for facilitating travel behaviour changes and should consider providing more efficient infrastructure and incentives, such as safe cycling facilities, traffic education, and integration with public transport, to encourage more people to embrace biking as a mode

of transportation (Pucher & Buehler, 2008).

CRedit authorship contribution statement

Hyewon Goh: Conceptualization, Data curation, Writing – original draft. **Gahyun Choi:** Formal analysis, Writing – original draft. **Yena Song:** Methodology, Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

Authors declare that there are no conflicts of interest.

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References

- Anderson, R. M., Heesterbeek, H., Klinkenberg, D., & Hollingsworth, T. D. (2020). How will country-based mitigation measures influence the course of the COVID-19 epidemic? *The Lancet*, *395*, 931–934.
- Bourassa, K., Sbarra, D. A., Caspi, A., & Moffitt, T. E. (2020). Social distancing as a health behavior: County-level movement in the United States during the COVID-19 pandemic is associated with conventional health behaviors. *Annals of Behavioral Medicine*, *54*(8), 548–556.
- Buehler, R., & Pucher, J. (2021). COVID-19 impacts on cycling, 2019–2020. *Transport Reviews*, *41*(4), 393–400.
- Bullock, C., Brereton, F., & Bailey, S. (2017). The economic contribution of public bike-share to the sustainability and efficient functioning of cities. *Sustainable Cities and Society*, *28*, 76–87.
- Chen, Z., van Lierop, D., & Ettema, D. (2020). Dockless bike-sharing systems: What are the implications? *Transport Reviews*, *40*(3), 333–353.
- Cho, S. H., & Park, H. C. (2021). Exploring the behaviour change of crowding impedance on public transit due to COVID-19 pandemic: Before and after comparison. *Transportation Letters*, *13*(5–6), 367–374.
- Cools, M., Moons, E., Janssens, B., & Wets, G. (2009). Shifting towards environment-friendly modes: Profiling travelers using Q-methodology. *Transportation*, *36*(4), 437–453.
- DeMaio. (2009). Bike-sharing: History, impacts, models of provision, and future. *Journal of Public Transportation*, *12*(4), 41–56.
- Faghih-Imani, A., Hampshire, R., Marla, L., & Eluru, N. (2017). An empirical analysis of bike sharing usage and rebalancing: Evidence from Barcelona and Seville. *Transportation Research*, *97*, 177–191.
- Fishman, E. (2016). Bikeshare: A review of recent literature. *Transport Reviews*, *36*(1), 92–113.
- Gärbling, T., & Axhausen, K. W. (2003). Introduction: Habitual travel choice. *Transportation*, *30*(1), 1–11.
- Gkiotsalitis, K., & Cats, O. (2021). Public transport planning adaption under the COVID-19 pandemic crisis: Literature review of research needs and directions. *Transport Reviews*, *41*(3), 374–392.
- González, F., Melo-Riquelme, C., & de Grange, L. (2016). A combined destination and route choice model for a bicycling sharing system. *Transportation*, *43*, 407–423.
- Gyeonggi transportation information center. <https://gits.gg.go.kr/>. (Accessed 30 May 2023).
- Heydari, S., Konstantinou, G., & Behsoodi, A. W. (2021). Effect of the COVID-19 pandemic on bike-sharing demand and hire time: Evidence from Santander Cycles in London. *PLoS One*, *16*(12), Article e0260969.
- Hu, S., Xiong, C., Liu, Z., & Zhang, L. (2021). Examining spatiotemporal changing patterns of bike-sharing usage during COVID-19 pandemic. *Journal of Transport Geography*, *91*, Article 102997.
- Jiao, J., Lee, H. K., & Choi, S. J. (2022). Impacts of COVID-19 on bike-sharing usages in Seoul, South Korea. *Cities*, *130*, Article 103849.
- Ji, Y., Fan, Y., Ermagun, A., Cao, X., Wang, W., & Das, K. (2017). Public bicycle as a feeder mode to rail transit in China: The role of gender, age, income, trip purpose, and bicycle theft experience. *International Journal of Sustainable Transportation*, *11*(4), 308, 3017.
- Jones, T. (2012). Getting the British back on bikes – the effects of urban traffic-free paths on everyday cycling. *Transport Policy*, *20*(1), 138–149.
- Jung, P. H., Kim, H., Lee, K., & Song, Y. (2022). Examining day-to-day dynamic transit accessibility using functional data analysis. *The Professional Geographer*, *74*(3), 503–515.
- Kenworthy, J., & Laube, F. B. (1999). Patterns of automobile dependence in cities: An international overview of key physical and economic dimensions with some implications for urban policy. *Transportation Research*, *33*, 691–723.
- Kim, J., Ki, D., & Lee, S. (2021). Analysis of travel mode choice change by the spread of COVID-19: The case of Seoul, Korea. *Journal of Korea Planning Association*, *56*(3), 113, 1291.
- KOSIS. (2022). *Bike lane status, Korea statistical information service*.
- KOTI. (2022). *Report of eco-friendly passenger travel modes*. Korea Transportation Institute.
- Lai, C. C., Shih, T. P., Ko, W. C., Tang, H. J., & Hsueh, P. R. (2020). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and corona virus disease-2019 (COVID-19): The epidemic and the challenges. *International Journal of Antimicrobial Agents*, *2020*(55), Article 105924.
- Lei, Y., & Ozbay, K. (2021). A robust analysis of the impacts of the stay-at-home policy on taxi and city bike usage: A case study of manhattan. *Transport Policy*, *110*, 487–498.
- Li, W., Tian, L., Gao, X., & Batool, H. (2019). Effects of dockless bike-sharing system on public bike system: Case study in Nanjing, China. *Energy Procedia*, *158*, 3754–3759.
- Li, H., Zhang, Y., Zhu, M., & Ren, G. (2021). Impacts of COVID-19 on the usage of public bicycle share in London. *Transportation Research*, *150*, 140–155.
- Márquez, L., & Soto, J. (2021). Integrating perceptions of safety and bicycle theft risk in the analysis of cycling infrastructure preferences. *Transportation Research*, *150*, 285–301.
- Marshall, S., & Banister, D. (2000). Travel reduction strategies: Intentions and outcomes. *Transportation Research*, *34*(5), 321–338.
- Nikitas, A., Tsigidinos, S., Karolemeas, C., Kourmpa, E., & Bakogiannis, E. (2021). Cycling in the era of COVID-19: Lessons learnt and best practice policy recommendations for a more bike-centric future. *Sustainability*, *13*(9), 4620.
- Parker, M. E., Li, M., Bouzaghrane, M. E., Obeid, H., Hayes, D., Frick, K. T., Rodríguez, D. A., Sengupta, R., Walker, J., & Chatman, D. G. (2021). Public transit use in the United States in the era of COVID-19: Transit riders' travel behavior in the COVID-19 impact and recovery period. *Transport Policy*, *111*, 53–62.
- Pucher, J., & Buehler, R. (2008). Making cycling irresistible: Lessons from The Netherlands, Denmark and Germany. *Transport Reviews*, *28*(4), 495–528.
- Sangveraphunsi, T., Fukushige, T., Jongwiriyaturak, N., Tanaksaranond, G., & Jarumaneeroj, P. (2022). Impacts of the COVID-19 pandemic on the spatio-temporal characteristics of a bicycle-sharing system: A case study of pun pun, Bangkok, Thailand. *PLoS One*, *17*(8), Article e0272537.
- Santander, C., Audenhove, F. J. V., Jouron, A., Phillips, S., & Gopal, V. (2022). Rethinking bike-sharing performance. <https://www.adlittle.com/fr/node/24083>. (Accessed 27 June 2022).
- Seo, I.-J., & Cho, J. (2021). Changes in Seoul's public bike usage patterns before and after COVID-19. *Journal of the Korea Big Data Society*, *6*(2), 139–149.
- Seoul Metropolitan Government. (2023). *Report on the traffic speed of seoul*. <https://www.seoul.go.kr/main/index.jsp>. (Accessed 30 May 2023).
- Seoul Open Data Square, data.seoul.ac.kr/ last accessed 22.05.05.
- Shin, S. H., & Cho, S. (2022). A Study on the influence factors on the change of shared mobility utilization due to COVID-19: New town residents. *Journal of Korean Society of Transportation*, *40*(2), 230–244.
- Song, Y., Preston, J. M., & Ogilvie, D. (2017). New walking and cycling infrastructure and modal shift in the UK: A quasi-experimental panel study. *Transportation Research*, *95*, 320–333.
- Teixeira, J. F., & 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*, Article 100166.
- Wang, C., Horby, P. W., Hayden, F. G., & Gao, G. F. (2020). A novel coronavirus outbreak of global health concern. *The Lancet*, *395*, 470–473.
- Yoon, Y.-C., & Cho, B.-Y. (2014). A study on the development of tashu public bike in daejeon metropolitan city. *Social Science Research*, *25*(2), 591–608.
- Zhang, Y., & Mi, Z. (2018). Environmental benefits of bike sharing: A big data-based analysis. *Applied Energy*, *220*(15), 296–301.