CHEMICAL ENGINEERING TRANSACTIONS
VOL. 89, 2021
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-87-7; **ISSN** 2283-9216
DOI: 10.3303/CET2189029

Changes in Shared Bicycle Usage by COVID-19

Juhyeon Kwak[a], Haram Oh[a], Ilho Jeong[b], Seungheon Shin[b], Donggyun Ku[b], Seungjae Lee[b,*]

[a] Department of Transportation Engineering/Department of Smart Cities, University of Seoul, Korea
[b] Department of Transportation Engineering, University of Seoul, Korea
sjlee@uos.ac.kr

The Seoul Metropolitan Government is promoting and implementing eco-friendly transportation policies covering the revitalization of public transportation, establishment of green transportation promotion areas, and the expansion of shared-bicycle use. With the prevalence of the COVID-19 pandemic, cities worldwide have been paralyzed by lockdowns, the strict implementation of social-distancing policies, and the shutdown of different industry sectors. People's movement and traffic volume have decreased significantly. The pandemic has forced to people change their travel-related decision-making tendencies. Against this backdrop, this study analysed the changes in shared-bicycle traffic in Seoul during the pandemic. This study analyzed the relationship between social distancing levels and shared bicycle usage using regression analysis. This study conducted an analysis of spatially formed clusters through Moran's I test and hotspot analysis. The results indicate that an important correlation between the spread of COVID-19 and shared bicycle use has been found. When social distancing levels increased by one level, the number of shared bicycle rental per day increased by about 10,000 times. As a result of spatial analysis, changes in shared bicycle usage are spatially forming clusters, and Moran's I test showed statistically significant results with a p-value very close to zero. The study results indicate that under special circumstances, government policy plays an important role in promoting green transportation. The use of green transportation is directly related to falling atmospheric pollution in the city. Such transportation can significantly benefit the environment. The government can produce more effective results by considering local characteristics to revitalize eco-friendly transportation.

1. Introduction

The atmospheric environment in cities is continually worsening because of the pollution due to increasing numbers of motor vehicles. Various studies have been conducted toward reducing the environmental pollution due to vehicular transport. Ku et al. (2020) studied low emission zones (LEZs) in Europe and found that while European cities outperform other cities in their application of environmental policies, there was no significant improvement in the application of LEZ policies alone. As regards vehicular energy usage, Yoo et al. (2021) developed a gradient-based path-exploration algorithm to maximize the energy efficiency of electric vehicles (EVs) as an eco-friendly means of transportation. In this regard, shared bicycles in Seoul have emerged as eco-friendly means of transportation that can reduce air pollution, and consequently, study has been conducted on the effectiveness and cost of such facilities. Kim et al. (2020) proposed a cost-estimation method in a feasibility study of facilities for eco-friendly transportation (such as walking and cycling), and Ku et al. (2021) proposed a methodology to consider health benefits for analysing the effectiveness of bicycle-only road projects. In 2020, drastic social changes occurred with the advent of COVID-19. Education has changed so that it can be done online (Novak-Pintarič et al, 2020). Owing to the government's lockdown policy, vehicular traffic reduced drastically. Giacobbe et al. (2020) studied conformity assessment methods using information and communication technologies (ICT) in covid-19 pandemic situations. In Seoul, people adapted to social changes resulting from the social-distancing policy. Against this backdrop, in this study, based on the public-bicycle data available with the Seoul Metropolitan Government, this study analyzed the factors that affected the use of public bicycles after the COVID-19 outbreak and examined the cycle-use characteristics of each region in the city. Throughout this study, spatial characteristics that affect the use of public bicycles were analyzed. The purpose

Paper Received: 22 April 2021; Revised: 16 September 2021; Accepted: 23 November 2021
Please cite this article as: Kwak J., Oh H., Jeong I., Shin S., Ku D., Lee S., 2021, Changes in Shared Bicycle Usage by COVID-19, Chemical Engineering Transactions, 89, 169-174 DOI:10.3303/CET2189029

of this study is to analyze the spatial characteristics and to find ways to activate public bicycles as an eco-friendly means of transportation. Figure 1 shows the flow of this study.

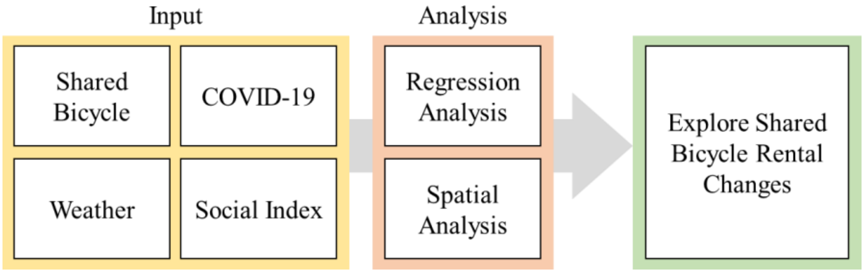

Figure 1: Framework of Study

2. Literature Review

Many researchers have studied the relationships between the various variables related to bicycle use. The main factors affecting bicycle traffic and usage are weather, accessibility to public transportation, and bicycle infrastructure. Since the spread of COVID-19, the use of bicycles has significantly increased. In this regard, Hu et al. (2021) studied the spatiotemporal changes in shared-bicycle use due to the epidemic and compared these data with the counterpart data for other transportation means. Traffic movement was estimated from January to July 2020 using mobile-phone data. It was found that traffic declined significantly during COVID-19. The scale of transport reduction was not constant. When compared with passenger cars, public transportation, walking, and shared bicycles exhibited the smallest decline and fastest recovery rates. The traffic volume increased because of a steady rebound. Kim (2018) investigated the impact of external factors such as weather and holidays on public-bicycle use in Daejeon. A higher temperature corresponded to increased bicycle use. The number of bicycle rentals reduced when the maximum temperature was above 30 °C. There was no significant difference in the number of bicycle rentals between weekends and weekdays, although the number of bicycle rentals decreased on holidays. Sohrabi et al. (2020) developed generalized extreme value (GEV) count models using large digital data that continuously record the status of PBSSs. They considered the time of day, weather, deployment environment, infrastructure, and spatiotemporal dependencies, and predicted the departure and arrival of the number of bicycles per hour at a given station. In this context, Yang et al. (2019) analysed the use of dockless shared bicycles in Nanchang, China, following the opening of new subway lines. They found that the opening of new subway lines increased the demand for dockless shared bicycles by 28 %. The spatiotemporal travel patterns of bicycle travel distance and traffic have changed over time. Zhao et al. (2015) analysed the travel time and trip chain patterns of shared bicycles in Nanjing, China, based on gender and the day of the week using smart-card-based data. They found that residential areas formed the origin points, railway stations formed the destinations. It was also found that more women used a trip chain of shared bicycles than men on weekdays. Xu et al. (2019) reconstructed the visual usage patterns of shared bicycles across different locations using four months of GPS data collected from Singapore's major operators of shared bicycles. According to their analysis, construction-related environmental indicators such as residential density, commercial density, and intersection numbers were found to be correlated with temporal usage patterns, land use and the length of bicycle paths were less affected by these indicators. Wang et al. (2021) compared the shared-bicycle traffic patterns in New York from September 2019 to September 2020 to analyse changes in bicycle-usage patterns. They determined that the number of users gradually increased from April to September 2020, exceeding the number of users before COVID-19. They also found that business travel decreased, leisure travel increased.

3. Methodology

3.1 Open Data

The government of Seoul contributes to research by making available data across various fields to the general public. Park et al. (2020) investigated the impact of social distancing on the public bicycle-sharing system (PBSS) during the COVID-19 outbreak using public data from the Seoul Metropolitan Government. In this study as well, open data from the Seoul Metropolitan Government has been used. The data comprised the public-bicycle-rental history and other relevant information provided by the government. The time range of the data is from January to December 2020, and the spatial range is for Seoul. The relationship between the variables was analyzed using weather-related data and social-distancing policy levels. Various methodologies were used to process these variables in this study. Regression analysis was used to analyze the relationship between the variables. Moran's I method was applied to verify the spatial correlation, and local characteristics were explored via hotspot analysis. Table 1 summarizes the data used in the analysis.

Table 1: Summary of Data

Category	Variable	Unit	Information	
Shared-Bicycle	Number of Rental per Day	Rental/day	Mean: 64,767.81	SD: 31,054.87
COVID-19	Social Distancing Level	-	Level: 0, 0.5, 1, 1.5, 2, 2.5, 3	
Weather	Precipitation	mm/h	Mean: 4.51	SD: 14.59
	Wind Speed	km/h	Mean: 8.51	SD: 2.52
	Sunlight Time	h	Mean: 6.18	SD: 3.97
Day of the week properties	Weekend/Weekday	-	Weekend: 1	Weekday: 0
Social Index	Number of Office	-	Spatial Data	

3.2 Regression Analysis

Regression analysis is a statistical methodology for estimating the relationships between a dependent variable and one or more independent variables. Linear regression is a statistical technique that models the relationship between a dependent variable and one or more independent variables as linear relationships. The case of one independent variable is called simple linear regression; for more than one, the process is called multiple linear regression. The basic model for multiple linear regression can be expressed as Eq(1) for each observation.

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_p X_{ip} + \epsilon_i \, , (i = 1, \dots, n) \tag{1}$$

In the formula Eq (1), variables consider *n* observations of one dependent variable and *p* independent variables. Y_i is the i^{th} observation of the dependent variable, X_{ij} is i^{th} observation of the j^{th} independent variable, j = 1, 2, ..., p. The values β_j represent parameters to be estimated, and ϵ_i is the i^{th} independent identically distributed normal error.

Feng et al. (2017) combined historical usage patterns with weather data to predict the demand for rental bicycles available as per the Capital Bikeshare program in Washington, D.C. Demand forecasting for conventional bicycles was conducted using a multi-linear regression model, which included a random forest model and a GBM (Generalized Boosted Regression Models), along with the variables of time and season. The multiple regression model was found to significantly improve the prediction accuracy. Noland et al. (2016) applied Bayesian regression models to investigate the impact of shared-bicycle station utilization on New York's bike infrastructure, population and employment, land use, and user types. Shared-bicycle stations in crowded subway stations and places with many bicycle infrastructure facilities are highly utilized. They found that in densely populated, high-employee-number areas, there were more rentals.

3.3 Spatial Analysis

Moran's I test is a statistical methodology that verifies the spatial autocorrelation of any variable and can be expressed as Eq(2):

$$I = \frac{n \times \left(\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \cdot (x_i - \bar{x})(x_j - \bar{x})\right)}{\left(\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}\right) \times \left(\sum_{i=1}^{n} (x_i - \bar{x})^2\right)} \tag{2}$$

where *n* denotes the number of observation points represented by positions *i* and *j*, x_i and x_j the observations at positions *i* and *j*, $\bar{x}$ the mean of *x*, and w_{ij} the matrix of weights represented based on the spatial proximity of positions *i* and *j*. The *I* value usually ranges between -1 and 1, representing negative autocorrelation for negative numbers and positive autocorrelation for positive numbers. For *I* = 0, it has been shown that arbitrary spatial patterns can exist (Das et al., 2017).

Hotspot analysis is a technique for testing the cluster trends of neighbouring regions within a certain range, and the method can be used to analyse regions with high and low values of certain variables. Parameter G_i^* can be represented as Eq(3):

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}{n-1}}} \tag{3}$$

where x_j denotes the property value at position *j*, $w_{i,j}$ the spatial weight between positions *i* and *j*, *n* the total number of properties, and $\bar{X}$ and *S* are defined as per Eq(4) and Eq(5). G_i^* does not require additional computation to obtain the z-score.

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \tag{4}$$

$$S = \frac{\sum_{j=1}^{n} w_{i,j}\, x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{\sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2}} \tag{5}$$

Positive large values of G_i^* correspond to a larger “hotspot” region, on the other hand, negative small G_i^* values correspond to smaller “coldspot” regions (Zhang and Tripathi, 2018).

Researchers in various fields are applying these methods to conduct spatial analysis. In this context, Yuan et al. (2017) identified spatial clusters and spatial outliers using Moran's I technique to determine the distribution patterns of rare materials in London soil. Concha et al. (2017) used Moran's I technique to determine the spatial autocorrelation of pH and Cr in natural water regions. Zhang and Tripathi (2018) used methods such as Global Moran's I and Getis-Ord Gi* statistics to determine $PM_{2.5}$ hotspots in eastern Thailand and identify spatial correlations of lung cancer cases, mortality, and $PM_{2.5}$ regions.

4. Results

4.1 Regression Analysis

In this study, ‘R Studio’ software was used for regression analysis. Simple regression analysis was performed by setting the number of public-bicycle rentals as the dependent variable and the level of social distancing as the independent variable. The results of the simple regression analysis showed that whenever the level of social distancing policy increases by one, the number of public-bicycle rentals increases by a factor of 10,140, which positively affects the environment. The P-value was also shown to be statistically significant. Table 2 shows the results of simple regression analysis.

Table 2: Result of Simple Regression Analysis

	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	51,566	2,639	19.542	<2e-16 ***
Level of Social Distancing policy	10,140	1,641	6.179	1.73e-09 ***

Bicycle rental and use are affected by various variables such as weather and infrastructure. Multiple regression analysis was performed by adding the related variables. The data were analysed by applying stepwise techniques that selected only high explanatory variables. Precipitation was considered to have a constant effect on bicycle use beyond a certain threshold. So, precipitation above the threshold is reflected in the same effect. The analysis results showed that the social-distancing level, precipitation level, and average wind speed were significant variables, and even when other variables were added, the social-distancing level still acted as a significant variable. Table 3 shows the results of multiple regression analysis.

Table 3: Results of Multiple Regression Analysis

	Estimate	Std.Error	t value	Pr(>|t|)
Intercept	67,880.5	5,210.0	13.029	<2e-16
Social Distancing Level	9,976.9	1,518.3	6.571	1.74e-10
Precipitation	-30,540.5	4,184.7	-7.298	1.86e-12
Wind Speed	-1,252.7	584.4	-2.143	0.0327

4.2 Spatial Analysis

In this study, ‘ArcGIS’ software was used for spatial analysis. By applying Moran's I test, spatial autocorrelation in increasing shared bicycle usage in 2020 has been checked. This can identify whether changes in the use of shared bicycles form a spatial cluster. Given a z-score of 12.2645 and p-value of 0, there is a <1 % likelihood that this clustered pattern could be the result of random. There is a spatial correlation and spatially clustered pattern in the use of shared bicycles. Figure 2 show the results of the Moran's I test.

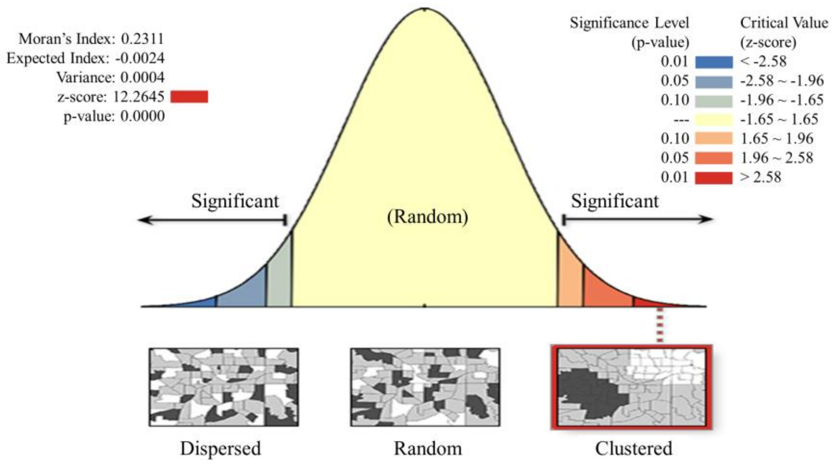

Figure 2: Result of Moran's I Test

Local characteristics were analyzed through hotspot analysis. In particular, the use of shared bicycles has rarely increased in Gangnam-gu and Jung-gu, but it has increased significantly in Yeouido and other western regions. Gangnam-gu and Jung-gu are known to contain concentrated work areas with a particularly large number of workers and businesses. When the same analysis was conducted based on the number of businesses, the 'hotspot' of the number of offices was distributed similarly to the 'coldspot' of shared bicycle use. Figure 3 shows the results of hotspot analysis. Yeouido Park, which lies in the western part of Seoul, has a large population and allows outdoor leisure activities. The Han River flows through this area, which showed a particular increase in the use of public bicycles. In areas with a large number of businesses, the use of public bicycles did not increase significantly since the COVID-19 outbreak. This result indicates that social changes and government policies do not significantly affect the use of public bicycles in work districts.

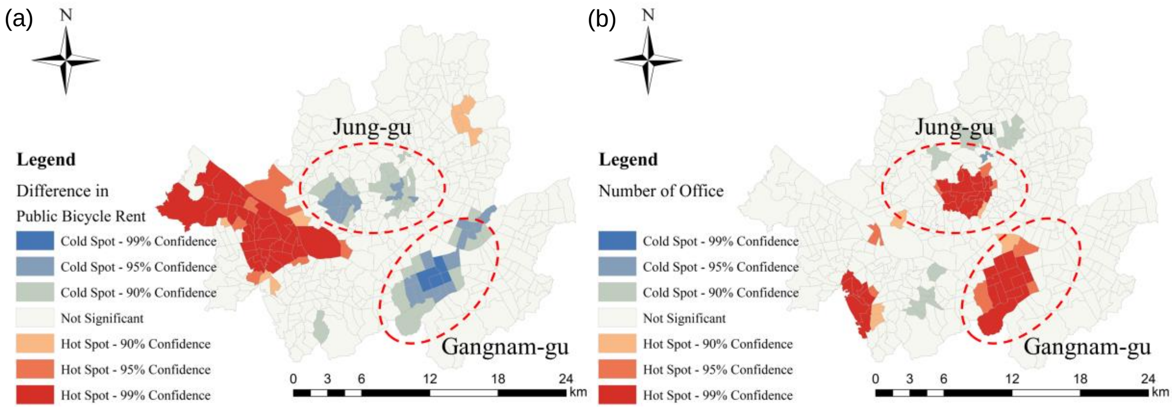

Figure 3: Results of hotspot analysis (a) Difference in public-bicycle rental and (b) Number of offices

5. Conclusions

According to this analysis, the level of social distancing policy acted as a statistically significant variable affecting the use of shared bicycles in Seoul. The results of the regression show that the average number of shared bicycle rental per day increases by 9,977 as the social distancing level increases by one step. The change in public-bicycle usage in 2020 (when compared with 2019) exhibited a spatially clustered pattern. It is suggesting the existence of local characteristics. The unusual social situation relating to the pandemic and government policies influenced the use of public bicycles, and this use varied depending on the spatial characteristics of each region. The effect of policies on bicycle use was found to be greater in areas with many businesses and in areas with large populations that allowed leisure activities. These results suggest that government policies based on social situations can significantly impact the choice of transportation. Active government intervention can significantly contribute to the revitalization of a city's atmospheric environment and promote eco-friendly transportation. The government's establishment of policies considering local characteristics to promote eco-friendly transportation can yield significant environmental benefits. When the government considers the regional characteristics of a city and suggests policies appropriate for the spatial characteristics of each region, eco-friendly transportation in the city can become more effective, leading to the development of eco-friendly cities.

Acknowledgments

This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (2019K1A4A7A03112460).

References

Castro C. C., Portacio T. G., Mendoza D., Pajaro C. M., Herrera R. F., Lambis-Miranda H. A., 2017, Spatial analysis about structural patterns of fate of chromium (VI) in relation to ph at natural sea water bodies, Chemical Engineering Transactions, 57, 391-396.

Das M., Ghosh S. K., 2017, Measuring Moran's I in a cost-efficient manner to describe a land-cover change pattern in large-scale remote sensing imagery, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(6), 2631-2639.

Feng Y., Wang S., 2017, A forecast for bicycle rental demand based on random forests and multiple linear regression, In 2017 IEEE/ACIS 16th International Conference on Computer and Information Science (ICIS), 101-105.

Giacobbe F., Bemporad E., 2020, Conformity Assessment of Pressure Equipment during Coronavirus Disease Emergency: Risks and Opportunities, Chemical Engineering Transactions, 82, 55-60.

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, 102997.

Kim S., Na Y., Na S., Ku D., Lee S., 2020, Cost Estimation Methods in Feasibility Studies on Eco-Friendly Transportation Facilities, Chemical Engineering Transactions, 78, 247-252.

Kim K., 2018, Investigation on the effects of weather and calendar events on bike-sharing according to the trip patterns of bike rentals of stations, Journal of transport geography, 66, 309-320.

Ku D., Bencekri M., Kim J., Lee S., Lee S., 2020, Review of European Low Emission Zone Policy, Chemical Engineering Transactions, 78, 241-246.

Ku D., Kwak J., Na S., Lee S., Lee S., 2021, Impact Assessment on Cycle Superhighway Schemes, Chemical Engineering Transactions, 83, 181-186.

Lee J. W., Lee W. J., 2007, A study on the characteristics of disparity between autonomous districts in Seoul, Journal of Korea Planning Association, 42, 81-94.

Noland R. B., Smart M. J., Guo Z., 2016, Bikeshare trip generation in New York city, Transportation Research Part A: Policy and Practice, 94, 164-181.

Novak-Pintarič Z., Kravanja Z., 2020, The Impact of the COVID-19 Pandemic in 2020 on the Quality of STEM Higher Education, Chemical engineering transactions, 81, 1315-1320.

Sohrabi S., Paleti R., Balan L., Cetin M., 2020, Real-time prediction of public bike sharing system demand using generalized extreme value count model, Transportation Research Part A: Policy and Practice, 133, 325-336.

Seoul Institute, 2018, Regional gap by sector in Seoul (5) Businesses and workers, Seoul Institute <www.si.re.kr/node/60810> accessed 20.07.2021.

Wang H., Noland R., 2021, Changes in the pattern of bikeshare usage due to the covid-19 pandemic, Findings, 18728.

Xu Y., Chen D., Zhang X., Tu W., Chen Y., Shen Y., Ratti C., 2019, Unravel the landscape and pulses of cycling activities from a dockless bike-sharing system, Computers, Environment and Urban Systems, 75, 184-203.

Yang Y., Heppenstall A., Turner A., Comber A., 2019, A spatiotemporal and graph-based analysis of dockless bike sharing patterns to understand urban flows over the last mile, Computers, Environment and Urban Systems, 77, 101361.

Yoo N., Ku D., Choi M., Lee S., 2021, An Eco-friendly Path Guidance Algorithm for Electric Vehicle, Chemical Engineering Transactions, 83, 217-222.

Yuan Y., Cave M., Zhang C., 2018, Using Local Moran's I to identify contamination hotspots of rare earth elements in urban soils of London, Applied geochemistry, 88, 167-178.

Zhang H., Tripathi N. K., 2018, Geospatial hot spot analysis of lung cancer patients correlated to fine particulate matter (PM2. 5) and industrial wind in Eastern Thailand, Journal of Cleaner Production, 170, 407-424.

Zhao J., Wang J., Deng W., 2015, Exploring bikesharing travel time and trip chain by gender and day of the week, Transportation Research Part C: Emerging Technologies, 58, 251-264.