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IMPACTS OF THE COVID-19 PANDEMIC ON DEMAND OF PUBLIC BIKE SYSTEM AND ITS CORRELATION WITH URBAN LIFE

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ABSTRACT:

Public bike systems provide the flexibility of bike-usage that users can rent and return a bike freely at any station. The convenience of the bike-travel system, however, may turn into a disadvantage of demand-supply imbalance in the bike inventory. The recent spread of the COVID-19 pandemic has changed the mobility demands due to the lockdowns which restrict the business operating hours and transit services. Therefore, investigating the impacts of the pandemic on the urban social life patterns with the bike usage is an important issue for the bike demand prediction and the improvement of the public bike system service.
This research aims to investigate the correlation between the public bike demand and social environment factors during the pandemic applying a multivariate linear regression model to public bike usage data in Seoul, Korea. The results show some promising findings to further promote shared mobility services through policy and marketing strategies. It is noteworthy that the transport disruptions during the pandemic have made a spillover effect from taxi and public transit to bike as an alternative transport mode. The lockdown has restricted the range of activity and resulted in the decrease of the taxi demand, so the number of taxis. On the other hand, the correlations of the geography, meteorology, and date with the bike demand have shown consistency. Therefore, supply of extra bike facilities to improve the system service should be determined based on more accurate demand prediction considering lifecycle-related factors.

1. INTRODUCTION

With the rise of urban issues and shared economy, public bike systems have been implemented worldwide as shared mobility. Public bike systems provide the flexibility of bike-usage that users can rent and return a bike freely at any station. The convenience of the bike-travel system, however, may turn into a disadvantage of demand-supply imbalance in the bike inventory. Therefore, maintaining the bike inventory based on the bike demand by station is an important issue facing public bike systems within the paradigm of the shared economy(Lee et al., 2020).

To contain the spread of the COVID-19 pandemic, many countries have restricted the business operating hours and transit services. As a result, mobility patterns in urban life have been significantly changed(Pase et al., 2020 and Kim, 2021). This research aims to investigate the correlation between the public bike demand and social environment factors during the pre- and post- COVID-19 pandemic.

2. IMPACTS OF PRE- AND POST- COVID-19

The study has been conducted using Seoul, where the largest floating population exists in South Korea. The first COVID-19 case was detected in Seoul in January 2020. Therefore, the time-series public bike usage data was collected from April 2019 to December 2021(total 33 months) to cover both pre- and post-COVID-19 period.

2.1 Seoul Public Bike System

Seoul's public bike-sharing system has been launched in 2015 with over 20,000 bikes and 1,290 stations. The system was grown to more than 40,500 bikes and 2,600 stations by 2021. Bike users can rent and return their share bike at any station regardless of the district. Therefore, all 25 districts of Seoul have been included in the analysis site as illustrated in **Figure 1**. Seoul has been operating the station-based bike sharing system of which the fare is about $30 per year in membership. Due to its competitive fare and the high-quality maintenance system, it is a widely used transport mode compared to other transport modes(Cho et al., 2021 and Kapuku et al., 2022).

The data of hourly bike use are available at Seoul's Open Portal Source (www.data.go.kr). As shown in **Figure 2**, the daily bike use in Seoul increased periodically over time. It seems intuitive that the impact of the pandemic has promoted the bike demand. Less bike uses are observed during the summer months (Jul-Aug) and the winter months (Dec-Feb) due to too warm and too cold temperature for outdoor activities.

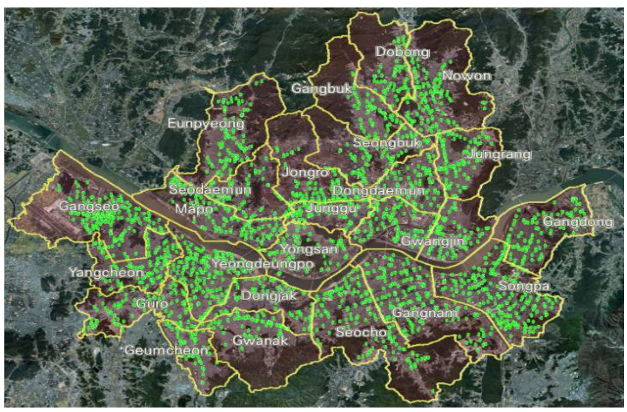

Figure 1. Spatial Distribution of Public Bike Stations in Seoul

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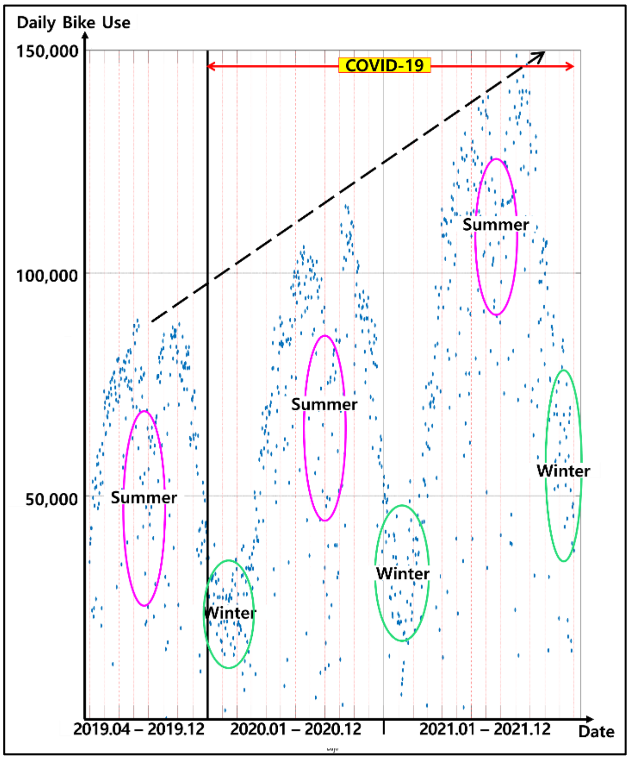

Figure 2. Daily Bike Use in Seoul (2019.04 – 2020.12)

2.2 Social Environment Factors

Social environment factors are considered to investigate the correlation of bike demand with urban life. The social environment factors have been tested including: (i) supplement of bike facilities, (ii) availability of alternative transport mode, (iii) COVID-19 case numbers, (iv) geography information, (v) meteorology data, and (vi) date-related data.

Bike facilities are the maintenance service of the system that supply bike road, stations, and stands to satisfy the bike demand. The supplement has been increased steadily. The extension level of the facility should be balanced to the bike demand considering the shared economy. The data are available at Seoul's Open Portal Source (www.data.go.kr).

Monthly data of the number of taxi drivers are selected as the availability of the alternative transport mode. The pandemic has decreased the number of the drivers as illustrated in **Figure 3**. It is representative that mobility patterns in urban life have been significantly changed. The data are obtained from Korea National Joint Conference of taxi Association (www.taxi.or.kr).

Daily data of COVID-19 confirmed cases are the most crucial social factors that indicate the severity of the pandemic. The confirmed cases of Seoul and national scale are publicly shared. The daily confirmed cases are shown in **Figure 4**. The data are provided by Central Disaster Management Headquarters (ncov.mohw.go.kr).

The bike usage largely depends on the environment conditions such as geography information, meteorology data, and date-related data. Average slope of district in Seoul ranges from 1.2 to 5.6%, which provides condition on the bike riding. There are four distinct seasons in Korea so that the monthly average temperature ranges from -7 to 30℃. Furthermore, preference of bike usage could depend on time of day, day of the week, or holidays. The listed data are available at Seoul's Open Portal Source (www.data.go.kr). A total 18 social environment factors are selected and some sample datasets are provided in **Table 1**.

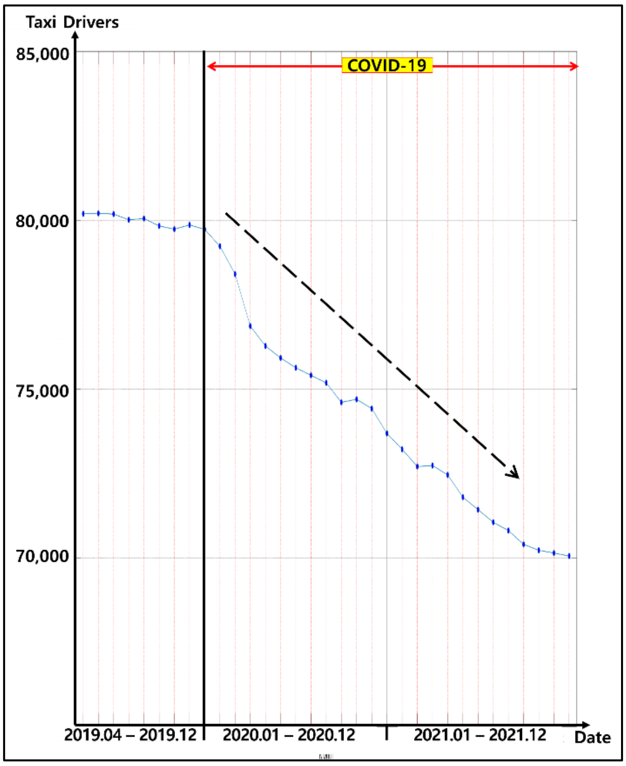

Figure 3. Number of Taxi Drivers in Seoul (2019.04 - 2020.12)

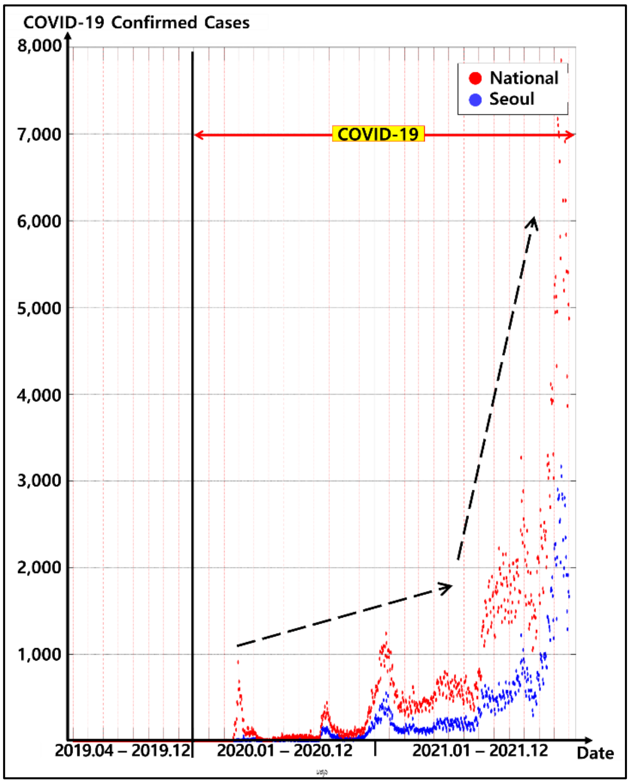

Figure 4. Number of COVID-19 Confirmed Cases in Korea

Variables		Time of Day 29 Sep 2021			
		08-09	09-10	10-11	11-12
Hourly Bike Use in Gangnam		38	7	16	54
Bike Facility	1. Bike Road Length(km)	90.0			
	2. Bike Stations	138			
	3. Bike Stands	1,668			
Alternative Mode	4. The number of Taxi Drivers	70,398			
COVID19	5. Confirmed in Seoul	1,051			
	6. Confirmed in Korea	2,881			
	7. Deaths in Korea	10			
Geography	8. Park Area (m^2)	7,769			
	9. Average Slope (%)	2.18			
Meteor-ology	10. Temperature (C)	20.9	21.1	20.9	21.1
	11. Rain fall (mm)	0.1	3.7	3.7	1.1
	12. Wind speed (m/s)	0.7	4.1	2.4	2.3
	13. Humidity (%)	98	97	98	94
	14. Snow (cm)	-	-	-	-
	15. Cloud (10-quantile)	10	10	10	10
Date	16. Time of Day (0 – 23)	8	9	10	11
	17. Day of the week (1–7, Monday-Sunday)	3	3	3	3
	18. Holiday (0, 1)	0	0	0	0

Table 1. Example of Bike Use and Social Environmental Data in District Gangnam on 29 Sept. 2021

3. STATISTICAL ANALYSIS APPROACH

3.1 Multivariate Linear Regression Model

According to the concept of this research, a multivariate linear regression model is developed to identify correlations between the public bike demand and the social environment factors. The multivariate model is promising for the network-level analysis where there are large number of stations(Ashqar et al., 2021). The formulation is expressed in **Equation (1)**:

$$y_i(\mathrm{t}) = \sum_{f\in F} \beta_i^f X_i^f(t) + \varepsilon_i(t),\ \ \varepsilon_i \sim N(0,\Sigma), \quad (1)$$

where $y_i(t)$ = bike demand of district i at time t;
β_i^f = estimated coefficient of variable f of district i;
$X_i^f(t)$ = variable f of district i at time t;
$\varepsilon_i(t)$ = error of district i at time t, which follows multivariate normal distribution;
I = a set of 25 districts in Seoul;.
F = a set of social environment variables.

The bike demand of district i at time t, $y_i(t)$, is set as a $(i \times t)$ matrix. District i is a component of a set I of 25 districts in Seoul. Variable f of district i at time t, $X_i^f(t)$, is set as a $(i \times t)$ matrix. Here, variable f is a component of a set F of social environment variables. $\varepsilon_i(t)$ indicates an unobservable error of district i at time t, which is set as a $(i \times t)$ matrix. The error is assumed to be a normal distribution with zero mean, and Σ is the standard deviation. Then the estimated coefficient of variable f of district i, β_i^f, is set as a $(i \times f)$ matrix.

To compare the precise relative impacts of the variables, the z-score normalization method has been applied each variable to scale values with mean 0 and standard deviation 1 as shown in **Equation (2)**:

$$X_i^{f\prime}(\mathrm{t}) = \left(X_i^f(\mathrm{t}) - \mu_i^f\right)/\sigma_i^f \quad (2)$$

where $X_i^{f\prime}(\mathrm{t})$ = normalized variable f of district i at time t;
μ_i^f = mean value of variable f of district i;
σ_i^f = standard deviation of variable f of district i;

3.2 Coefficient Estimation using Gradient Descent Method

The gradient descent method is an iterative first-order optimization algorithm used to find optimal coefficient. It is widely used in machine learning area to minimize cost function. The cost function and the gradient descent method for multiple variables are applied to investigate the appropriate coefficients as expressed in **Equation (3)** and **(4)**, respectively:

$$J(\beta) = J\left(\beta_1^1, \beta_1^2, \dots, \beta_i^f\right) = \frac{1}{2I}\sum_{i=1}^{I}(y_i - \hat{y}_i)^2 \quad (3)$$

$$\beta_i^f := \beta_i^f + \alpha \frac{\partial}{\partial \beta_f} J(\beta) \quad (4)$$

where $J(\beta)$ = cost function with the estimated coefficients β;
y_i = estimated bike demand in district i;
$\hat{y}_i$ = observed bike demand in district i;
α = learning rate of 0.001;

Using the gradient descent method with iterations, the estimated coefficients of variables of each district converge into local minimum. Maximum iteration counts are set as 10,000 for not being converged.

4. EFFECTS OF SOCIAL ENVIRONMENT FACTORS ON PUBLIC BIKE DEMAND

The modelling results of public bike usage estimation by district are given in **Table 2** and **3**. The correlations between the increase/ decrease rates of the bike demand and the social environment factors have been estimated. The results indicate that those factors have varying levels of effect on bike demand.

4.1 Supplement of Bike Facility

The coefficients of bike related facilities show either positive or negative correlation by districts. The positive values indicate that the supplement of the bike facility have promoted people to ride bikes in the districts. The negative values in other districts imply that bike facilities could have been oversupplied over the bike demand level in the districts.

For example, the coefficients of the bike road length, stations, and stands in the district Gangnam have been estimated as 0.008, 0.082, and -0.078, respectively. The positive signs of the bike road and the number of stations indicate that these facilities have been appropriately supplied with the increase rate of bike demand. On the other hand, the negative sign of the bike stands shows that the it might have failed to predict the demand accurately. The stands in the district might have been oversupplied or not been improved relative to the increase rate of the bike demand.

4.2 Availability of Alternative Mode

The estimated coefficients of the number of taxi drivers are consistently negative in all 25 districts. The number of the drivers has been steadily decreased during the pandemic as shown in **Figure 3**. Moreover, a COVID-19 lockdown in Seoul has restricted operating hours of the public transport services except bike. Therefore, the results could be interpreted that the public bike has been encouraged to use as an alternative transport mode. This finding of transport mode shift shows a part of change in the daily life cycle that influenced by the pandemic.

4.3 Severity of COVID-19

Increasing number of confirmed cases in Seoul has positive correlation with bike usage. One implication could be suggested that there has been an increase in bike usage by subways or bus users as the virus spreads, in order to avoid or minimize contact with the confirmed cases during rush-hour.

However, the bike demand has negative correlation with the numbers of confirmed and death cases across South Korea. This could imply that the spreading speed of infection across the nation outrates the increasing rate of bike demand in the city.

4.4 Geography Information

Park area and slope in few districts have been estimated to have correlation with the bike demand. With the respective of park area, the district Gangbuk and Gwanak have the second and third largest park area out of 25 districts, respectively. Nevertheless, the coefficients have been estimated as 0.138 and -0.133, respectively. This indicates that the park area has less correlation with the bike demand. The estimated results of the slope also have shown same interpretation. Therefore, it could be interpreted that people care less about the characteristics of geography in districts.

	Bike Facility			Alter.	COVID-19			Geography	
Districts	Bike Road Length	Bike Stations	Bike Stands	Taxi drivers	Seoul	National		Park Area	Slope
					Confirmed	Confirmed	Death		
Dobong	-0.924	0.122	-0.072	-0.074	0.026	-0.018	-0.022	-	-
Dongdae-mun	-0.040	0.438	-0.391	-0.060	0.052	-0.046	-0.026	-0.034	-
Dongjak	-0.032	-0.240	0.238	-0.054	0.061	-0.049	-0.015	-	-
Eun-pyeong	-4.857	17.60	-18.31	-4.499	3.459	-3.472	-0.976	60.52	-
Gangbuk	-0.354	-0.051	0.134	-0.061	0.045	-0.035	-0.018	-	0.342
Gang-dong	-0.023	0.397	-0.385	-0.076	0.058	-0.050	-0.017	-	-
Gang-nam	0.008	0.082	-0.078	-0.015	0.094	-0.086	-0.002	-	-
Gangseo	-0.015	0.082	-0.053	-0.087	0.058	-0.037	-0.031	-	0.418
Geum-cheon	-1.642	0.119	-0.011	-0.072	0.074	-0.057	-0.029	-	-
Guro	-0.040	-0.045	0.103	-0.061	0.082	-0.066	-0.022	-	-
Gwanak	-0.070	0.186	-0.125	-0.041	0.052	-0.043	-0.019	0.138	-
Gwang-jin	0.018	0.222	-0.228	-0.034	0.063	-0.056	-0.010	-	-
Jongro	-9.031	23.39	-19.05	-2.666	9.443	-7.398	-1.881	-	52.98
Junggu	-10.09	28.44	-26.63	-3.911	7.087	-5.089	-1.846	-	-
Jungrang	-7.098	-12.03	14.26	-5.148	3.324	-2.630	-1.305	-	-
Mapo	0.010	-0.048	0.040	-0.041	0.083	-0.077	-0.003	-	0.264
Nowon	-0.034	0.085	-0.050	-0.049	0.042	-0.029	-0.016	-0.133	-
Seocho	-0.032	0.010	0.002	-0.034	0.065	-0.064	-0.001	0.003	-
Seodae-mun	-0.008	0.160	-0.130	-0.037	0.063	-0.055	-0.015	-	-
Seong-buk	0.149	-0.236	0.236	-0.062	0.068	-0.055	-0.018	-	-
Seong-dong	-0.031	0.050	-0.082	-0.070	0.070	-0.071	-0.004	-	-
Songpa	0.003	0.266	-0.263	-0.047	0.072	-0.069	-0.011	-	0.344
Yang-cheon	-0.092	0.429	-0.362	-0.085	0.054	-0.044	-0.026	-	-
Yeong-deungpo	2.632	-36.62	30.92	-17.05	19.96	-14.89	-3.614	-	-97.33
Yongsan	3.986	-25.36	24.04	-3.948	4.467	-3.621	-0.538	-96.65	-

Table 2. Estimation Results of Correlation between Bike Use and Social Environmental Data by District in Seoul (1)

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4.5 Meteorology Data

Most meteorology variables have shown consistent correlation with the bike demand over the 25 districts as given in **Table 3**. The results are reasonable since bike is the most weather-exposed transport mode.

The increase in temperature, for example, has positive correlation with the bike demand. Noting that there are four distinct seasons in Korea, warm temperature might encourage people to ride bike. The results show acceptable correlation except the summer months (Jul-Aug) which is too warm temperature for outdoor activities. The coefficients of other weather conditions such as rain fall, wind speed, or humidity have been estimated consistent all over the districts.

4.6 Date-related Data

The coefficients of time of day are found all positive, which indicates that people tend to ride bike more in the afternoon, or after work. With the perspective to the day of week, the estimation results have shown positive indicating that they prefer riding the mobility on later days in the week. However, the negative coefficients of the holiday reveal that bike usage on weekends or holidays is discouraged.

4.7 Summary of the Estimation Results

The results show some promising findings to further promote shared mobility services through policy and marketing strategies. The social environment factors were found to have either positive or negative relationship with the bike demand.

Some districts are found to have oversupplied bike facilities due to misprediction of bike demand. One of the main causes of the misprediction is the change in urban life during the pandemic. As the impact of COVID-19, the transport mode shift to bike has been shown with the change in the service of the alternative modes. The number of taxis has steadily decreased and the lockdown has restricted public transport services except bike. On the other hand, the correlations of the geography, meteorology, and date have shown consistency with the bike demand.

5. CONCLUSION

This research shows how COVID-19 influenced on the usage of public bike service in Seoul. Mobility patterns in urban life have been significantly changed. It is noteworthy that the transport disruptions during the pandemic have made a spillover effect from taxi and public transit to bike as an alternative transport mode. Therefore, supply of extra bike facilities should be determined based on more accurate demand prediction considering lifecycle-related factors to improve public bike service.

Districts	Meteorology						Date		
	Temp.	Rain	Wind	Humid	Snow	Cloud	Time of Day	Day of Week	Holi-day
Dobong	0.107	-0.023	0.025	-0.065	0.001	-0.012	0.048	0.002	-0.007
Dongdae-mun	0.124	-0.031	0.023	-0.066	-0.002	-0.023	0.077	0.002	-0.030
Dongjak	0.116	-0.020	0.031	-0.062	0.001	-0.021	0.046	0.001	-0.005
Eun-pyeong	7.250	-1.623	1.934	-3.977	0.005	-1.128	2.694	0.114	-0.568
Gangbuk	0.124	-0.027	0.024	-0.071	0.000	-0.020	0.070	0.002	-0.012
Gang-dong	0.109	-0.023	0.028	-0.061	0.000	-0.013	0.040	0.002	-0.015
Gang-nam	0.150	-0.023	0.041	-0.111	0.003	-0.011	0.021	-0.006	-0.015
Gangseo	0.102	-0.019	0.028	-0.057	-0.001	-0.011	0.041	0.004	-0.028
Geum-cheon	0.137	-0.024	0.031	-0.077	-0.003	-0.023	0.056	0.002	-0.060
Guro	0.129	-0.023	0.031	-0.074	-0.001	-0.018	0.053	0.003	-0.025
Gwanak	0.115	-0.023	0.023	-0.052	0.000	-0.025	0.080	0.005	-0.011
Gwang-jin	0.126	-0.025	0.029	-0.075	0.002	-0.021	0.076	0.002	-0.007
Jongro	12.06	-1.953	3.424	-10.41	0.047	-0.340	1.337	-0.138	-4.516
Junggu	8.085	-1.247	2.085	-6.815	-0.008	-0.153	1.371	0.000	-3.259
Jungrang	7.687	-1.814	1.656	-4.095	-0.020	-1.219	4.397	0.075	-0.836
Mapo	0.131	-0.016	0.040	-0.094	0.004	-0.010	0.030	0.000	-0.006
Nowon	0.101	-0.019	0.030	-0.068	0.002	-0.007	0.038	0.000	-0.010
Seocho	0.122	-0.018	0.042	-0.089	0.004	-0.008	0.016	-0.001	-0.006
Seodae-mun	0.116	-0.025	0.026	-0.061	-0.001	-0.021	0.037	0.000	-0.016
Seong-buk	0.119	-0.028	0.024	-0.062	-0.001	-0.022	0.072	0.000	-0.016
Seong-dong	0.135	-0.022	0.038	-0.101	0.003	-0.011	0.046	-0.002	-0.006
Songpa	0.114	-0.021	0.037	-0.080	0.002	-0.008	0.027	0.000	-0.003
Yang-cheon	0.091	-0.019	0.026	-0.057	-0.001	-0.008	0.033	0.005	-0.017
Yeong-deungpo	30.92	-4.189	8.651	-20.60	0.520	-3.196	8.842	-0.363	-3.280
Yongsan	7.457	-0.817	2.630	-5.676	0.235	-0.363	0.971	-0.053	0.589

Table 3. Estimation Results of Correlation between Bike Use and Social Environmental Data by District in Seoul (2)

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REFERENCES

Ashqar, H. I., Elhenawy, M., Rakha, H. A., Almannaa, M., House, L., 2021: Network and station-level bike-sharing system prediction: A San Francisco bay area case study. *Journal of Intelligent Transportation Systems*, 1-11.

Cho, J. H., Ham, S. W., Kim, D. K., 2021: Enhancing the accuracy of peak hourly demand in bike-sharing systems using a graph convolutional network with public transit usage data. *Transportation Research Record*, 2675(10), 554-565.

Kapuku, C., Kho, S. Y., Kim, D. K., Cho, S. H., 2022: Modeling the competitiveness of a bike-sharing system using bicycle GPS and transit smartcard data. *Transportation Letters*, 14(4), 347-351.

Kim, K., 2021: Impact of COVID-19 on usage patterns of a bike-sharing system: Case study of seoul. *Journal of transportation engineering, Part A: Systems*, 147(10), 05021006.

Lee, E., Son, B., Han, Y., 2020: Optimal Relocation Strategy for Public Bike System with Selective Pick-Up and Delivery. *Transportation Research Record*. 2674(4):325-336. doi:10.1177/0361198120912232

Pase, F., Chiariotti, F., Zanella, A., Zorzi, M., 2020: Bike Sharing and Urban Mobility in a Post-Pandemic World. *IEEE Access*, vol. 8, pp. 187291-187306. doi: 10.1109/ACCESS.2020.3030841.