IMPACT OF COVID-19 ON ASSOCIATIONS BETWEEN LAND USE AND BIKE-SHARING USAGE

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Abstract. Bike-sharing as a human-centred, zero-emission, sustainable, alternative, and easily accessible transport mode has been implemented globally and consistently contributing to communities and the environment by alleviating consumption of natural sources, traffic congestion, and air pollution, which is considered a solution for future cities. The appearance of Covid-19 significantly impacts public transportation modes, including the bike-sharing system. The intention of this study was to investigate the spatiotemporal impact of the Covid-19 pandemic on associations between urban factors and bike-sharing usage in Los Angeles, United States, by analysing a sizeable actual trip dataset and employing geographically weighted regression (GWR) models. GWR was conducted for examining the varying spatial association between bike infrastructure, public transport, and urban land use factors, and bike-sharing trip volume. The results indicated that bike-sharing usage significantly decreased during the pandemic and essential service as restaurant was found consistently and positively associated with bike-sharing use. GWR provided clear spatial patterns of bike usage based on urban land use and big user databases. The outcomes of this study could inspire policymakers and shared mobility operators to support these safe, sustainable transport alters (such as rebalancing bike stations), help city resilience, and shape a sustainable future of mobility in the post-Covid-19 era.

Keywords. Bike-Sharing; Covid-19; Land Use; Geographically Weighted Regression; Big Data; SDG 11.

1. Introduction

As the bike-sharing system trend rapidly spreads worldwide, this flexible, affordable, easily accessible public mobility has become a solution for the first/last minutes of a daily trip, helping to facilitate the intermodal connection between users' homes and mass public transits within a short mediating distance. (Lahoorpoor et al., 2019; Wu et al., 2019). Over the past decade, many cities have implemented bike-sharing systems considering the benefits of urban sustainability and human health. Using big data-based analysis, Zhang and Mi (2018) identified that bike-sharing helped Shanghai save 8,358 tonnes of gasoline and reduce carbon dioxide and nitrogen oxide emissions by 25,240 tonnes and 64 tonnes respectively, in 2016. Bike-sharing system as an alternative to

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auto-commuting provides environmental and economic benefits which could contribute to future sustainable city strategies. (Martens, 2006).

After the appearance of the Covid-19 pandemic, it has significantly impacted urban mobility modes and travel behaviours around the world (Zafri et al., 2021). The travel restriction and lockdown measurement drastically reduced global and domestic traffic volumes and demands of public transportation (Nikiforiadis et al., 2020; Jenelius and Cebecauer, 2020). Aloi et al. (2020) found that public transport users dropped 93% in Santander, Spain. Much empirical research (Zafri et al., 2021; Abdullah et al., 2020; Jenelius and Cebecauer, 2020; Kubal'ák et al., 2021) points out that the outflow of public transport contains private cars, walking, and cycling. Recent studies examining Covid-19 impacts on traveller's attitudes (Nikiforiadis et al., 2020; Mujahed, 2021) and bike-sharing usage are based on a limited amount of survey results and global quantitative analysis. Respondents of studies showed positive attitudes to bike-sharing transport mode considering hygiene and safety. Few previous studies have quantitatively explored the spatiotemporal impacts on bike-sharing usage by applying actual trip data before and during the pandemic. Wang and Noland's (2021) initial research investigated the bike-sharing usage pattern changes during the pandemic with Citi bike trip data and found reductions of trip volumes associated with mixed, commercial, and other public land use in September 2019 and 2020. Pase et al. (2020) affirmed that socioeconomic factors and bike lane networks contribute to bike-sharing traffic in an area. The lack of related studies is insufficient to understand the changes of quantitative relationships between land use factors and bike-sharing usage and the spatial visualization of associations.

This paper aims to address the research gap by analysing the Covid-19 impacts on the association between urban land use and shared bike ridership by comparing actual trip data during pre-Covid-19, highest morbidity period, and after vaccination implementation in Los Angeles County, United States. The study addresses several questions on how shared trip volumes changed compared to pre-Covid-19 time; how land-use factors were associated with ridership in three study periods; how the associations vary between different locations. The research employed global regression models and Geographically Weighted Regression models to investigate shared mobility patterns further to quantify trip information and provide spatial visualization. This presented method of modelling allows researchers to visualize raw data from open-source platforms and helps policymakers to improve bike-sharing system implementation regarding spatial variations to create more efficient and smarter cities.

2. Methodology

2.1. STUDY AREA

The study area covers Downtown Los Angeles (DTLA), Santa Monica, and North Hollywood, including 214 bike-share stations. All three neighbourhoods have flat road slopes, high population density, young age population, and influential economic activities in Los Angeles County, with plenty of time and sufficient sunshine having a minor weather influence on bike riding relatively. Moreover, Los Angeles County experiences the most severe Covid-19 pandemic having most Covid-19 cases nationwide and is one of the first few counties issuing "Stay at home" orders. With unique pandemic experience, multimodal transportation implementation, and data availability, Los Angeles County is a valuable study area with bike-sharing system development potentials.

2.2. DATA RESOURCE

The shared bike trip data was provided by Bicycle Transit Systems managing the Metro Bike Share program in Los Angeles and making trip data available to the public through their open portal. The raw dataset was downloaded in April 2021, containing information about the trip origin, destination, start time, end time, duration, and trip route category (one way or round trip). The data included three time periods which correspond to pre-Covid-19 time, the highest test rate, and decrease of morbidity with the beginning of vaccination, ranging from December 2019 to January 2020, December 2020 to January 2021, and February 2021 to March 2021. According to a report from the Los Angeles County Department of Public Health, the average daily new cases reached the peak from December 14th, 2020, to January 29th, 2021. Regarding shared bike as the first/last-mile transportation, 500m radius buffers around bike stations were applied and the Thiessen-polygon method was introduced into the study to avoid the buffer zone overlapping issue. The Thiessen-polygon defined edges to make all locations in partitioned areas closest to area centres that ensured buffer zone not overlapped and urban data in areas not double-counted (Rhynsburger, 1973). Figure 1 shows Thiessen-polygon buffers created in ArcGIS 10.7 with clear boundaries.

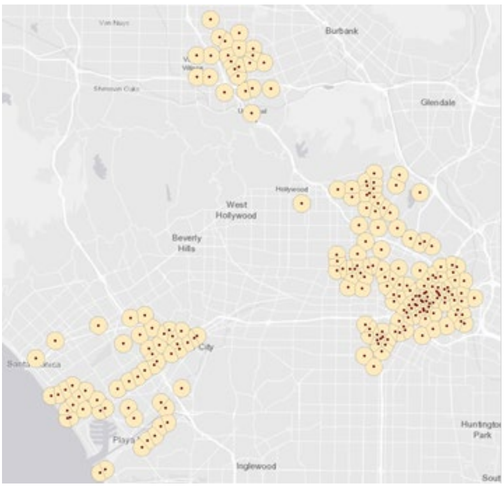

Figure 1. Bike stations with 500m Thiessen-polygon buffers in study areas

The original dataset contained a total of 103746 bike shared trip records, constituted by 50307 trips, 25170 trips, and 28269 trips, respectively. Due to the lack of actual trip route information, the calculation of trip distance was based on longitudes and latitudes of start points and endpoints. There was filtration of trips' unrealistic durations and distances that lasted less than 1 minute or longer than 1440 minutes and shorter than 100m or more prolonged than 50,000m. The round-trip removal was removed from the raw dataset considering the accuracy of trip distance calculation and ensuring actual bike usage. The actual working data were 42255 trips, 17892 trips, and 19932 trips, respectively, after the data cleaning process.

Acquisition of land use, built environment, and urban infrastructure information was through OpenStreetMap (OSM) API, including primary roads, secondary roads, university area, commercial area, park area, industrial area, and retail area. Bus stops, metro stations, healthcare facilities, restaurants, and schools emerged from the points of interest (POIs) dataset from OSM API. Healthcare facilities consisted of clinics, doctors, and hospital POIs information. Data on sharing bike dock numbers per each bike station were from Bicycle Transit Systems open portal. The bikeway information came from the City of Los Angeles Hub API as open data. Furthermore, calculating all other land uses and built environment density indicators was based on previously mentioned numbers within ArcGIS buffer areas.

2.3. MODEL BUILD

The study first conducted a backward stepwise regression for each period to examine the relationship between trip frequencies with all variables. The method started with all variables included in the model, eliminated the least significant variable, and refitted in the statistical model until the most substantial explanatory variables got selected for all three models. The collinearity diagnostics were conducted simultaneously to ensure no intercorrelation was present on the multi-collinearity potentials between independent variables.

Second, the study employed Geographically Weighted Regression (GWR) models to investigate the spatial autocorrelation between variables which provided a local regression showing the spatial relationship (Fotheringham et al., 2002). Compared with global regression, the local statistic is not based on a single value but considered and examined the coefficients of variables in the vicinity of locations within the study area. Given by Fotheringham et al., the GWR model is shown as:

$$y_i = a_0(u_i, v_i) + \sum_k^m a_k(u_i, v_i)\, x_{ik} + \varepsilon_i \quad (1)$$

where y_i is the trip frequency in i Thiessen-polygon buffer; $a_0(u_i, v_i)$ is the intercept parameter at i location; x_{ik} is an independent (kth) variable at i location; $a_k(u_i, v_i)$ is the local coefficient of kth variable; ε_i is the random error at i location; m is the number of independent variables. Based on the equation (1), the estimated local coefficient of each location can be different within the study area which can preserve spatial relationship heterogeneity in this study. The large size of trip data can calibrate some bias and make standard errors lower during GWR estimation process (Fotheringham et al., 2002). The observed indicator closer than the location has a stronger influence than farther data. That can be presented as,

$$\hat{a}(u_i, v_i) = [X^T W(u_i, v_i) X]^{-1} X^T W(u_i, v_i) y$$

where, $\hat{a}$ is the estimation of a; $W(u_i, v_i)$ is a n × n matrix of geographical weighting of data at i location; y is the dependent variable.

3. Results

This study was to investigate how the pandemic impacts the association between bike-sharing usage and land use. Table 1 presented the summarized usage pattern of bike-sharing from Dec 2019 to Jan 2020 (Pre-Covid), Dec 2020 to Jan 2021 (Peak), and Feb 2021 to March 2021 (Early vaccination). It was noted that high bike sharing usage was recorded before the pandemic. The lowest trip volume occurred during the second "Stay at home" order period with significantly declined trip numbers. Accompanied with implementing vaccination and slight order release, bike-sharing usage began to increase. However, the trip volume was reduced during the pandemic, the trip duration and trip distance steadily increased. The trend might project that people were more likely to choose bike-sharing instead of shared riding (i.e., Uber and Lyft) concerning the unwillingness to stay with strangers in a private small automobile.

Table 1. Summary statistics for trip records in Los Angeles, United States.

	Pre-Covid (total 42255 trips)	Peak (total 17892 trips)	Early vaccination (total 19932 trips)
Trip duration (minute)			
Mean	17	28	32
Medium	10	16	16
Std. Dev.	50.7	71.9	83
Trip distance (meter)			
Mean	1389.6	1834	2013.3
Medium	1082.1	1309.2	1508.6
Std. Dev.	1040.8	1732.2	1836.7

3.1. STEPWISE LINEAR REGRESSION MODEL AND VARIABLES

Three backward stepwise linear regression models by SPSS for different study periods were employed to examine the impact of Covid-19 on the association between sharing usage and land use, which could avoid multicollinearity problems and select the most influential explanatory indicators in the models. Table 2 presents the output of three models corresponding to different periods. The outcomes for peak time and early vaccination period had more similarity, mainly possessing the same predicators in final models, excluding primary road density. Additionally, bike path density, industrial area density, retail area density, school density, university density, and healthcare POIs density were eliminated from all three models. The backward stepwise linear regression results demonstrated that commercial area density and restaurant POIs density significantly correlated with bike-sharing usage. The centre of the commercial area usually limits automobile accessibility and parking spaces that can attract people to choose shared bikes. It was perceived that restaurant as essential service keeping high significance level which might be related to food pick-up services and people more likely to choose closer restaurants. Nevertheless, the park area density variable was excluded during the pandemic to reduce the rate of people going out only for leisure and recreation reasons to avoid exposure to Covid-19 in large crowds.

Table 2. Backward stepwise linear regression output

Explanatory variables	Pre-Covid		Peak		Early vaccination	
	Coef.		Coef.		Coef.	
Bike dock density	.320	-***	.239	-***	.223	-**
Bike path density						
Primary road density	.148	-**			-.204	-**
Secondary road density			-.199	-***	-.298	-***
Intersection density			.147	-***	.180	-***
Bus stop density			.173	-**	.184	-*
Metro rail station density	-.097	-*				
Commercial area density	.205	-***	.189	-**	.231	-*
Industrial area density						
Retail area density						
Park area density						
University density	.141	-***				
School POIs density						
Restaurant POIs density	.162	-***	.262	-***	.214	-***
Healthcare POIs density						

Coef. = coefficient; "-" = retain variable in the model; $*p\leqslant 0.1$; $**p\leqslant 0.05$; $***p\leqslant 0.01$.

3.2. LAND USE AND BIKE-SHARING USAGE IN GWR MODELS

One of the primary aims of this study was to understand the pandemic impact on the association between urban land use and bike-sharing usage locally. GWR has been extensively used and proved a better fit for exploring predicators' spatial heterogeneity than global regression models (Fotheringham et al., 2002; Lu et al., 2014; Zhang et al., 2016). To further examine the variation of the local coefficients before the pandemic and during the pandemic, three GWR models with land use factors and other explanatory variables were applied to different study periods, respectively.

Figure 2 and figure 3 present the local coefficients of restaurant POIs density and commercial area density in three GWR models, considering the significant association between these two explanatory variables and bike sharing usage in the results of backward stepwise linear regression models. The local coefficients of restaurant POIs density appeared to positively associate bike-sharing use both before and through the pandemic. Before the pandemic, the spatial distribution of the strongest association was observed near the downtown area. The distribution became polycentric in the peaked period, centred on west Santa Monica and the whole North Hollywood area. During the early vaccination period, the centre of positive association moved from the west side of Santa Monica to the east. Regarding the local coefficients of commercial area density, the association was relatively weak compared with restaurant POIs density. Unexpectedly, the spatial distribution maps before and during the morbidity peak shared similarities that Santa Monica and North Hollywood were clustered to have strong associations and showed a decreased trend to the downtown area. It offers a weak negative association near Santa Monica, and the trend generally fell from north to south after vaccination implementation.

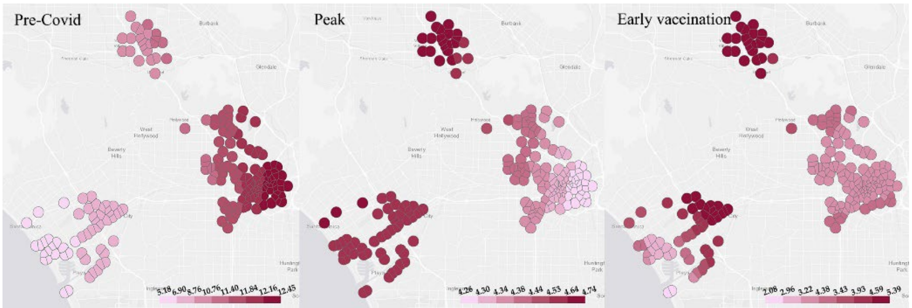

Figure 2. Restaurant POIs density spatial distribution of coefficients in three periods

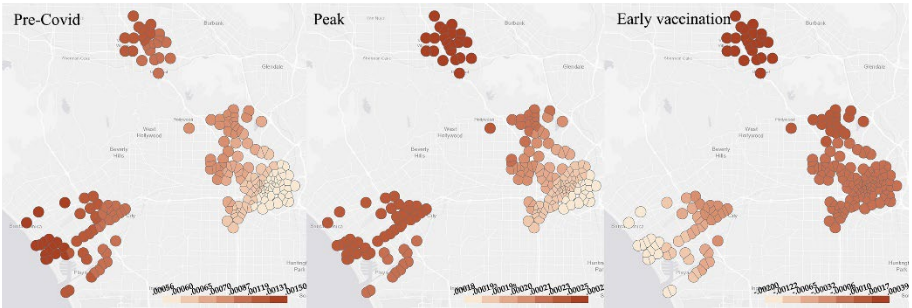

Figure 3. Commercial area density spatial distribution of coefficients in three periods

In general, the restaurant POIs density had a continuous significant positive contribution to bike-sharing usage throughout three study periods. It implies that restaurants attract more customers who prefer to ride shared bikes. Neighbourhoods near restaurants might be challenging to find parking spaces, and parking fees are usually higher than in other areas. Although the coefficients during the Covid-19 pandemic are relatively lower than before, food services as an essential need are still a strong reason for people coming outside and keeping demand for shared bikes. The discrepancy of spatial distribution might cost from the business closure and the decrease of commute population in the downtown area. The insignificant and negative coefficients of commercial density might have two reasons. First, most people were working from home, leading to fewer work-related trips, and unwilling to have nonessential outdoor activities to avoid contact with crowds. Second, due to the government orders and policies, commercials were kept closed through the most severe period to reduce gathering possibility. According to the results, North Hollywood and Santa Monica have a bigger potential to increase bike-sharing usage due to the considerable number of restaurants and commercial areas so expanding bike numbers in the areas might be considered as a rebalancing suggestion. Therefore, the study of the pandemic impact on the association of land use and bike-sharing in GWR models is worth discussing, which projects the spatial variation of different land-use factors. Thus, it gives clear visibility of how bike-sharing demand and spatial pattern change due to Covid-19.

3.3. OTHER VARIABLES

Bike dock density was the only significant factor other than land-use-related factors remaining in all three globe regression models. As figure 4 shows, most local shared bike dock density coefficients indicated a strong positive association with bike-sharing usage before or during the pandemic. In the pre-Covid and the peaked period, strong associations were observed around the downtown area, where a larger commuting population with smaller street block scales had. After vaccination coming out, the local coefficients tended to decrease from Santa Monica to northeast orientation, and the downtown area had consistently high local coefficient values. It is noteworthy that the North Hollywood region showed relatively weaker associations in all GWR models. It might be due to less shared bike docks installation and larger block scales. The number of shared bike docks and essential infrastructures encourage bike-sharing usage in all three areas. Hence, North Hollywood deserves significant bike dock infrastructure improvement after the pandemic to increase shared bike usage.

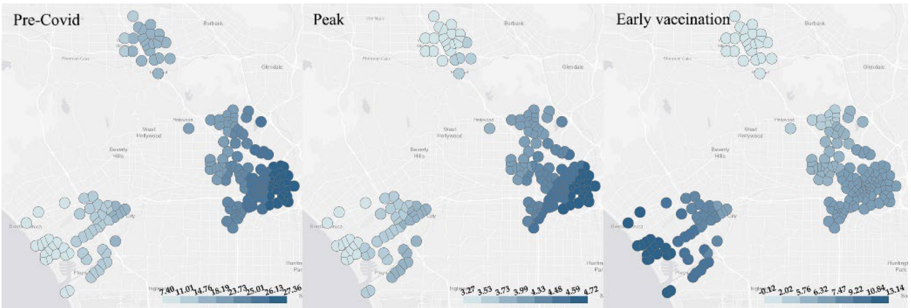

Figure 4. Bike dock density spatial distribution of coefficients in three periods

The results of backward regression models showed that secondary road and intersection density were both highly significant after the appearance of Covid-19. Figures 5 showed the spatial distribution of secondary road density local coefficients after the appearance of the Covid-19 pandemic. The secondary road density had a weak and negative association with bike-sharing usage in all study areas, reflecting that the secondary roads were not fit for bike-sharing users in Los Angeles.

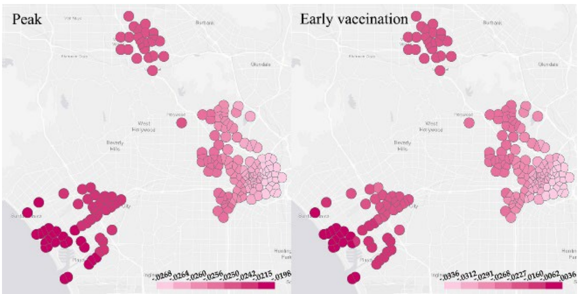

Figure 5. Secondary road density spatial distribution of coefficients in peak and early vaccination period

Figure 6 displays the local coefficients of intersection density. The presence of intersections negatively affected bike sharing usage. Roads with more intersections were not preferable for bike-sharing riders and were challenging to navigate while riding a bike.

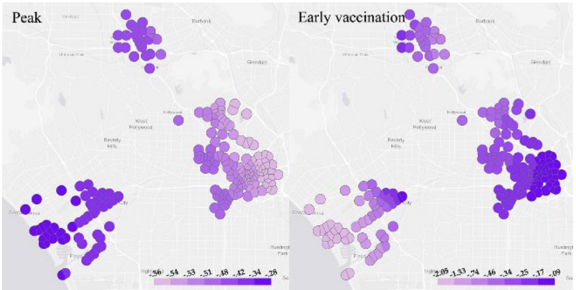

Figure 6. Intersection density spatial distribution of coefficients in peak and early vaccination period

4. Discussion and Conclusions

This study aimed to investigate how the Covid-19 pandemic impacted the association between land use and bike sharing usage in Los Angeles. It contributes to the literature by analysing the influence of bike infrastructure, public transportation, and urban land use on trip volumes covering 3 different periods. Intuitively, the demand for bike-sharing was expected to drop after the Covid-19 pandemic appearance in general, but the trip volume was gradually increasing after releasing the lockdown order. The purpose of cycling might shift from work-related commute to more prolonged recreation or essential needs. Shared bikes might become a potential substitute for buses in medium-distance trips. The results of GWR revealed the spatial heterogeneity of the impact of land-use factors and other urban infrastructure variables on ridership in Los Angeles. GWR modelling as a tool can provide direct local urban analysis for spatial relationships of various urban database. This meaningful methodology presents a clear way to visualize spatial correlations of urban data and can be applied to other locations. GWR could overcome the limitations of global regression models which could the Hence, the results of the study could inspire policymakers and planners on how to implement bike-sharing system effectively based on spatial heterogeneity and make specific strategies for different locations. The pandemic negatively impacts bike-sharing demand and influences the spatial association between bike facilities, public transport accessibility, essential needs destination, open space, and bike-sharing system usage. According to the results, increasing bike dock quantity would strongly encourage commuters to ride shared bikes, releasing local traffic and contributing to sustainable city strategies. Riders are more like to avoid intersections and roads with large automobile volumes. While rebalancing existing bikes or installing new bike stations, policymakers and operators might consider ridership safety, essential needs for food services, groceries, and recreation destinations.

However, the pandemic still rages through countries; the current paper's main limitations concerning the timing of data collection are based on a limited period, in which individuals constantly change their travel behaviours and attitudes on sharing transportation. Simulating and proposing implementation suggestions quantitatively based on this study results would be included in future study to provide further comparison. Besides, due to the specific bike station locations in Los Angeles, the usage pattern is centralized in specific areas. More broadly, additional data and surveys in other cities need further investigation.

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