Understanding bikeshare mode as feeder to bus: A case study of Chicago’s Divvy system

Yunhu Xiang¹,a, Zhili Xiang²,b*
¹College of Agronomy, Hunan Agricultural University, Changsha, Hunan, China
²College of Landscape Architecture and Art Design, Hunan Agricultural University, Changsha, Hunan, China

Abstract: The bike-share system gives a decent solution to the first- and last-mile problem. And it connects trip origins/destinations and transit stations. However, current research in this area focuses more on metro-bikeshare pattern, and there are still substantial gaps in research in the area of bus-bikeshare pattern. Focusing on Chicago, this study uses Divvy’s location information data to explore the spatial and temporal characteristics of bus-bikeshare transfer trips. Besides, we examine the built environment factors affecting bus-bikeshare transfers. This study uses buffers and time limits to isolate bus-bikeshare transfer trips. Two recognition rules proposed are a maximum transfer time of 20 min and a maximum buffer distance of 100 m. The findings are listed as follows: (1) the average distance and duration of bus-bikeshare trips is 1740.95m and 548.11s; (2) the bus-bikeshare trips show characteristics in different areas, seasons and periods; (3) there is a positive and significant spatial autocorrelation for the bus-bikeshare trips; (4) The bus-bikeshare pattern is influenced by built environment factors in a manner distinct from the bikeshare-only pattern, exhibiting its own unique characteristics.

1. Introduction

In recent years, many issues have attracted more attention, in which transport is one of the greatest concerns. It is reported that transportation is a growing source of global greenhouse gas emissions that contribute to climate change¹. In 2019, global CO2 emissions from transportation accounted for 23 percent of total emissions, and the U.S. transportation sector accounted for 29 percent of all greenhouse gas emissions. Besides pollution, traffic congestion is also a serious problem². It not only affects citizens’ well-being but also causes economic losses and raises a number of social and environmental concerns. In Beijing, commuters spend 46 percent more travel time on the way to work than they would under normal traffic³.

Mass transit is seen as an ideal solution to urban transport problems. It is effective in alleviating urban transport problems and promoting social equity and is also seen as an environmentally friendly approach⁴. Buses are an essential part of mass transit and the critical urban infrastructure. They are popular because of their economic, environmental and health-friendly characteristics. Buses offer the mass-transit capacity, which provides for the urban development.

Meanwhile, bike sharing is one of the most popular mobility methods, which is favored for its convenience, environmental friendliness and other such characteristics. In 2016, the number of trips in the US increased by 25%⁵. As an emerging method of transport, bike sharing has a series of impacts on the mass transit. On the one hand, bike sharing offers a solution to the first- and last-mile problem as the feeder. On the other hand, it competes with buses for trips of short to medium distance⁶.

The integration does not work out as well as expected. It is reported that the bike sharing plays the role as a disruptor. In New York, it is found that there is a significant decline in bus trips along with the implementation of bike sharing system⁷. Although bikeshare competes with bus significantly, the integration has lots of benefit. It can expand the service area of public transportation, promote equity, reduce commuting time and enhance citizens’ well-being⁸. It is clear that the integration of buses and sharing bikes has a great and bright prospect. Although the interest in bus-bikeshare is increasing continuously, the research on the area is scarce and the knowledge about these features is still shrouded. Limited studies have explored the spatial and temporal characteristics, but the total amount of data is not large⁹. Besides, Comprehensive studies on built environment have been sorely lacking. The situation causes obstacles to the formulation of the policies and may lead to the waste of public resources.

In this study, we aim to fill the gap of knowledge. We proposed a data screening method to determine whether a trip is a bus-bikeshare trip by the distance from the bus stop, and then explored the bus-bikeshare transfer patterns from several perspectives. This is aimed to find out the spatial and temporal characteristics of bus-bikeshare
transfer pattern. Furthermore, we explored the built environment factors affecting bus-bikeshare use based on data of Chicago. Finally, according to the analysis, some suggestions have been put forward to improve the coordination between metro and bikeshare.

The rest of the paper is organized as follows. The second section reviews existing research. On the third section, the paper introduces the study area and the source of data. The fourth part shows that the data handling and methodology. Afterwards, the data analysis results are presented via a series of visualizations. The conclusions and suggestions for future research are summarized in the last section of the paper.

2. Literature review

Bike share programs have been for nearly 60 years. It is widely believed that the earliest bike-sharing program is the White Bike Plan, operated by an environmental organization, the Provos, in 1965, Amsterdam. Today, the bikeshare is more and more accepted by the public, since it is considered as a sustainable, economic, and health-benefited transportation mode[10].

There are many factors that would influence the people’s willingness to use shared bike. According to the previous research, the factors on bike-sharing usage can be grouped into four categories: sociodemographic, natural environment, built environment and bike-sharing perception and satisfaction degree. Also, the social context and transport polices are matter to the usages[11,12]. Zhang et al. employed a multiple linear regression model to examine the influence of built environment focusing on Zhongshan as a case. They found that both trip demand and the ratio of demand to supply at bike stations were positively influenced by population density, length of bike lanes and branch roads, and were negatively influenced by the distance to city center and the number of other nearby stations[13]. But Zhao and Li found that the bike lanes could have negative impact because bike lanes may invite indiscriminate parking[12]. Moreover, some research found that higher temperatures, lower humidity levels, and lower amounts of ground snow were positively correlated with bike ridership. And a positive correlation was observed between the increases of bicycle infrastructure along the path and a decrease of number of intersections with major roads. This is explained by the riders’ sense of security[14].

Although the research about the integrations of bike-sharing and bus is still limited, there are plenty of the literature in the relative area. Martin found that the shared bikes can increase the bus ridership, and the increase is more significant for the electric bicycles. And the increased bus ridership occurred mostly in block groups with a lower median household income, a younger population, lower vehicle ownership rate, and lower homeownership rate[15]. Qiu in 2021 found that the complementary effect between the dockless bikesharing and bus was particularly strong in the urban core and with transit development and employment land use areas, by analyzing the data of Ithaca, NY[9]. However, Campell and Brakewood used the difference-in-differences identification strategy and found that every thousand bikesharing docks along a bus route is associated with a 2.42% fall in daily unlinked bus trips on routes in Manhattan and Brooklyn. They speculated that more bikesharing docks could rise the frequency of using shared bike for the member. But the non-members could increase private cycling trips in lieu of bus trips, influenced by the social atmosphere[7].

In addition to the mutual benefits, the substitution utility of shared bikes for buses should not be overlooked as well. A number of studies label bike sharing as a significant replacement for shorter distance bus journeys[7,16,17]. For environmental and convenience reasons, there is a preference for sharing bikes for a certain amount of time and distance, especially trips that take around 10 minutes. However, the increase in electric bikes will make this competitive effect even more pronounced. Electric bike have faster speed while also being more labor efficient, which makes it tolerable to ride longer distances. This inspired us to increase the maximum distance travelled and the maximum time travelled by screening bus-bikeshare trips in our study[18].

The identification of bikeshare- trips is essential to understand the integration and determinants. There is plentiful research in bus-metro pattern. The usual methods include the field questionnaire survey, interview and the data analyzing. Zhao randomly chose 40 passengers at the metro station in Beijing to get the data[12]. Ma used the smart card data to analyze the bikeshare-metro pattern. It proposed two recognition rules that a maximum transfer time of 10 min and a maximum transfer distance of 300 m[19]. Based on the development of the bike-sharing systems and the open-source database, the common method is counts of the valid use of shared bikes in a certain buffer of the stations. Wang in 2019, Guo in 2020 use the 100 buffer of metro entrances to measure the integrations. However, this area still remains a gap to be filled, especially the integration between bus and bikeshare. As most of the existing research are related to the integration between metro and bikeshare.

To conclude, evident from the previous research that focused on the relationship between bikeshare and transit, the study of comprehensive bikeshare-transit has well-established, diverse methodologies. Many works have been conducted by scholars to analyze the integration between shared bikes and other mass transit. However, the area of the bus-bikeshare pattern is still remained to be investigated. Therefore, we believe that the research on the bus-bikeshare pattern is workable and meaningful.

3. Study area and data

3.1. Study area

Chicago, located in the shore of Lake Michigan, has an area of 606.2 km², with the most population city in Illinois and the third-most population in the United States. According to the census, there is a population of 2,746,388 in Chicago. The Chicago area has one of the highest gross domestic products (GDP) in the world, generating $753.1 billion in 2022. Also, it is the center of the Chicago metropolitan area and a major tourist destination. In 2022,
Chicago received nearly 46 million visitors. Just like many other large cities, Chicago is suffering from urban problems, brought by the development. Air pollution, traffic congestion, and other problems like these all give embarrassing setbacks to the city.

Chicago owns the second largest public transportation system in the United States, serving the city of Chicago and 35 nearby suburbs. The CTA bus system, whose distribution is demonstrated in Fig 1, consists of over 140 routes that cover about 2,230 route miles and carry about 800,000 passengers on an average weekday. The base fare for a bus ride is $2.25. Divvy is Chicagoland’s bike share system across Chicago and Evanston. There are over 600 stations in Chicago totally, of which number is still increasing. It offers 3 kinds of bike for choosing, Classic bike, Scooter, and Ebike. Based on the type and the membership, divvy has the different pricing strategies for the users, illustrated in Table 1. Also, the divvy offer the member. Divvy's membership is $130.90 per year, and there is a student discount that a year's membership for students is only $105.90.

![Fig. 1. The distribution of residents and bus station in Chicago](image1)

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The pricing strategies of Divvy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single ride</td>
</tr>
<tr>
<td>Classic bike</td>
<td>$1 unlock</td>
</tr>
<tr>
<td></td>
<td>+$0.17/min</td>
</tr>
<tr>
<td>Scooter</td>
<td>$1 unlock</td>
</tr>
<tr>
<td></td>
<td>+$0.42/min</td>
</tr>
<tr>
<td>Ebike</td>
<td>$1 unlock</td>
</tr>
<tr>
<td></td>
<td>+$0.42/min</td>
</tr>
<tr>
<td>Fee</td>
<td>$16.50/day</td>
</tr>
</tbody>
</table>

3.2. Data and identification

Through Chicago's BSS, Divvy Bikes (https://www.divvybikes.com/), we investigated data on Chicago's shared bike trips in 2022, with data including trip start time, start coordinates, bike type, and user category. The Divvy database contains 4,149,350 pieces of the bike-sharing trips information. At the same time, we obtained GIS data of local bus stop distribution in Chicago and GIS data of local EPA demographic social attributes. The EPA demographic social attributes contain a variety of socioeconomic characteristics, including income, households, gender, races, and employment density.

We performed data cleaning to obtain reliable bus-bikeshare transfers data. Firstly, we removed data that were obviously problematic, for instance, durations that were zero or minus. Since the BSS data could not provide the distance of the trip, we used ArcMap’s line-tracking interval function to calculate the distance between the starting points to reflect the actual riding distance to some extent.

Secondly, we filtered the bus-bikeshare trips from the data. Our definition of bike-bikeshare transfers is that (1) the starting point or the end point of a trip is located within a radius of 100 m around a bus stop, as shown in Fig 2; (2) the time is greater than 1 minute and less than 20 minutes; (3) the distance between the starting point and the end point is more than 100 m and less than 9500 m. And we got 2,818,414 pieces valid trips data.

Followed the previous study, most bike-transit trips take less than twenty minutes [18]. And the duration less than one minutes are more likely to invalid data, as the unlocking and locking would waste most of the time. Moreover, the distance is also an important reference for the identification, since the too short distance may indicate that the trip is only bike-using. On the other hand, the much long distance is also should be excepted. The speed of the bike is limited. Therefore, it should be caused by some unforeseen circumstance or the device error.

Thirdly, we join the data with each census block in Chicago to get the number of bus-bikeshare trips within each census block. So we are allowed to perform analysis on the impact of built environment on bus-bikeshare trips in the certain area.

![Fig. 2. The bus-bikeshare pattern identification](image2)

4. Methodology

To realize the feature of the bus-bikeshare pattern, several models were used to analyze. Firstly, we employed multiple linear regression model to examine the statistical relations between the duration and factors. Those factors include membership, area, period and bike type. The area was divided into two part, urban area and suburban area. The urban area includes Loop, Near North side, Near West Side and Near South side, which is the commercial, financial, political, cultural and tourist center of Chicago. To capture the daily temporal variations, we broke down the trips into seven different periods based on trip start time, i.e., Night (0:00–7:00), Morning Rush (7:00–9:00),
Morning (9:00–11:00), Noon Rush (11:00–13:00), Afternoon (13:00–17:00), Afternoon Rush (17:00–21:00), and Evening (21:00–24:00). Also, we divided the year into four parts based on the climate, i.e., Spring (March to May), Summer (June to August), Autumn (September to November), Winter (December to February). Because these variables are categorical, the statistical relationship is clearly nonlinear. The multiple linear regression model is shown in Equation 1.

\[ Y_s = \beta_0 + \sum \beta_i X_{ai} + \varepsilon \]  

where \( s (=1, 2, 3, \ldots) \) is an index to represent each bike trip, \( \beta_0 \) is a constant, \( \varepsilon \) is the random error or random disturbance and it is a random variable whose distribution is independent of the independent variable. \( X_{ai} \) and \( \beta_i \) are the categorical variables and their corresponding coefficients.

We carried out the standard multiple linear regression analysis using SPSS. We firstly ran the regression analysis in which all predictors were entered into the model, and examined the output to know which independent variables contribute significantly (p < 0.05) to the model's ability to predict the outcome. Based on these important independent variables, we reran the multiple linear regression analysis using a Forward (stepwise) method that adds each significant (p < 0.05) variable step by step, which was done by SPSS automatically and stopped when all the significant variables were included in the model.

Secondly, we also used Cross-tabulation table analysis to demonstrate the specific characteristics of the bus-bikeshare trips in a certain dimension. Meanwhile, we carried Chi-Squared test of independence, to ensure that the two categorical variables are related to each other. The Chi-Squared test is shown in Equation 2.

\[ X^2 = \sum \frac{(O - E)^2}{E} \]  

where \( O \) is the observed frequency, \( E \) is the expected frequency.

Finally, we employed some model to make the special statistical analysis. The Global Moran’s I was used to measure spatial autocorrelation, to show how closely related the bus-bikeshare trips in their locations in space. The Local Moran’s I is used to reveal the spatial patterns.

Geographically weighted regression (GWR) is also used to analyze how the relationship between the bus-bikeshare trips and built environment varies across space. Before that, we analyze the data to avoid the multicollinearity. The built environment data include income, households, gender, races, and employment density. This analysis was run by SPSS. And all the special statistical analysis were carried by ArcGIS Pro.

5. Result and analysis

5.1. General characteristics of bus-bikeshare pattern

The average distance and duration of bus-bikeshare trips is 1740.95m and 548.11s. Fig 3 illustrates the distribution of the transfer frequency. It can be seen that trips lasting around five minutes have the highest frequency. Table 2 illustrates that the duration is influenced by the trip’s membership, area, period, season and bike type. That is, these categorical variables have different characteristics, at least in terms of duration. Because there is a linear relationship between distance and duration and duration is got directly based on the Divvy, the variable, distance, is not discussed in this section.
Table 2

<table>
<thead>
<tr>
<th>Factors</th>
<th>Coefficient</th>
<th>P</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membership</td>
<td>-0.156</td>
<td>0.000</td>
<td>-264.902</td>
</tr>
<tr>
<td>Area</td>
<td>0.119</td>
<td>0.000</td>
<td>202.292</td>
</tr>
<tr>
<td>Period</td>
<td>0.060</td>
<td>0.000</td>
<td>101.903</td>
</tr>
<tr>
<td>Season</td>
<td>-0.054</td>
<td>0.000</td>
<td>-92.633</td>
</tr>
<tr>
<td>Bike type</td>
<td>-0.040</td>
<td>0.000</td>
<td>-68.461</td>
</tr>
</tbody>
</table>

\[ F = 26387.351 \]

5.2. Membership characteristics of bus-bikeshare pattern

The trips of member users are much more than the casual users. Table 3 and Table 4 illustrate that the member riders would have shorter distance and duration in trips by about 100 m and 90 s. In additional, they prefer to use the classic bike. The member riders may have more regular route instead of occasional or arbitrary use. This can explain why the member riders have lower intensity of single use of shared bikes. And it is reasonable that a higher percentage of non-members use electric bikes, as the higher speeds and convenience increase the duration and the distance they ride. Also, the preference for classic bike by member riders may be due to economic factors. Divvy offers member riders more than 30 minutes of free time with classic bike. By contrast, the electric bikes are only free for unlocking.

Table 3

<table>
<thead>
<tr>
<th>Membership</th>
<th>Distance(m)</th>
<th>Duration(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casual</td>
<td>1802.39</td>
<td>606.40</td>
</tr>
<tr>
<td>Member</td>
<td>1708.58</td>
<td>517.40</td>
</tr>
<tr>
<td>Total</td>
<td>1740.95</td>
<td>548.11</td>
</tr>
</tbody>
</table>

\[ \text{Distance} \ P < 0.001, \ F = 4713.235 \]
\[ \text{Duration} \ P < 0.001, \ F = 66278.711 \]

Table 4

<table>
<thead>
<tr>
<th>Bike type</th>
<th>Percentage of membership</th>
<th>Percentage of bike type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic bike</td>
<td>40.2%</td>
<td>28.1%</td>
</tr>
<tr>
<td>Docked bike</td>
<td>3.8%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Electric bike</td>
<td>56.0%</td>
<td>39.2%</td>
</tr>
</tbody>
</table>

\[ P < 0.001, \chi^2 = 110204.114 \]

5.3. Area characteristics of bus-bikeshare pattern

Table 5 shows that both duration and distance are longer in urban area. And in urban area, there is a preference for classic bikes while electric bikes in the suburbs. Similarly, in the terms of membership, there are more member users in urban area while non-member in suburban area. This phenomenon may be due to the more availability of shared bikes placed in urban areas. At the same time, traffic conditions in urban areas can be worse during peak hours, which may promote the use of shared bikes and increase interest in subscription membership\(^{[6,3]}\).

Table 5

<table>
<thead>
<tr>
<th>Area</th>
<th>Distance(m)</th>
<th>Duration(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1772.55</td>
<td>576.91</td>
</tr>
<tr>
<td>Suburban</td>
<td>1707.29</td>
<td>517.42</td>
</tr>
<tr>
<td>Total</td>
<td>1740.95</td>
<td>548.11</td>
</tr>
</tbody>
</table>

\[ \text{Distance} \ P < 0.001, \ F = 2519.204 \]
\[ \text{Duration} \ P < 0.001, \ F = 32343.369 \]

Table 6

<table>
<thead>
<tr>
<th>Bike type</th>
<th>Percentage of area</th>
<th>Percentage of bike type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic bike</td>
<td>51.1%</td>
<td>53.3%</td>
</tr>
<tr>
<td>Docked bike</td>
<td>1.5%</td>
<td>59.1%</td>
</tr>
<tr>
<td>Electric bike</td>
<td>47.4%</td>
<td>49.7%</td>
</tr>
</tbody>
</table>

\[ P < 0.001, \chi^2 = 4448.088 \]
Table 7 Cumulative percentage of membership by different area

<table>
<thead>
<tr>
<th>Membership</th>
<th>Percentage of area</th>
<th>Percentage of membership</th>
<th>Urban</th>
<th>Suburban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casual</td>
<td>32.0%</td>
<td>47.8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Member</td>
<td>68.0%</td>
<td>53.6%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( P < 0.001, \chi^2 = 8514.160 \)

5.4. Period characteristics of bus-bikeshare pattern

The Fig 4 demonstrates the bus-bikeshare trips time distribution. The bus-bikeshare trips are concentrated in the daytime and there is peak time at 8:00, 12:00, 17:00. In terms of distance, it peaks in night period and evening period, and then drops to the bottom at noon rush period and rises again, as it is illustrated in Fig 5 and Table 8. This may be due to the fact that at nighttime, the rest of the public transport services are less available. Bike-sharing is a more accessible and economical option, so commuters with longer distances tend to use bike-sharing. Meanwhile, people use the shared bikes for lunch breaks and meals in noon rush period. It will reduce the distance travelled due to the need to continue working in the afternoon.

In terms of duration, shown in Fig 6 and Table 8, it would be lower at nighttime and eventually rises gradually, peaking during the afternoon rush. At midnight, commuting is more about getting to your destination faster.

While in morning rush period and morning period commuters have more stringent time requirements. However, in noon rush period, afternoon period, afternoon rush period and evening period, the time requirement decreases, the commuters could be more easily and tourists are more likely to be active in these period, so duration increases.

Table 8 Distance and duration by different period

<table>
<thead>
<tr>
<th>Period</th>
<th>Distance(m)</th>
<th>SD</th>
<th>CI(95%)</th>
<th>Duration(s)</th>
<th>SD</th>
<th>CI(95%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>night</td>
<td>1857.58</td>
<td>1217.083</td>
<td>1852.30-1862.86</td>
<td>515.50</td>
<td>275.675</td>
<td>514.30-516.70</td>
<td>204024</td>
</tr>
<tr>
<td>Moring rush</td>
<td>1793.04</td>
<td>1143.192</td>
<td>1788.86-1797.22</td>
<td>520.96</td>
<td>270.876</td>
<td>519.97-521.95</td>
<td>287632</td>
</tr>
<tr>
<td>Morning</td>
<td>1688.03</td>
<td>1090.471</td>
<td>1683.53-1692.53</td>
<td>522.06</td>
<td>276.228</td>
<td>521.92-523.19</td>
<td>225668</td>
</tr>
<tr>
<td>Noon rush</td>
<td>1635.55</td>
<td>1035.629</td>
<td>1631.76-1639.34</td>
<td>536.38</td>
<td>280.475</td>
<td>535.35-537.41</td>
<td>286635</td>
</tr>
<tr>
<td>Afternoon</td>
<td>1699.32</td>
<td>1058.538</td>
<td>1696.87-1701.76</td>
<td>556.20</td>
<td>281.482</td>
<td>555.56-556.85</td>
<td>722414</td>
</tr>
<tr>
<td>Afternoon rush</td>
<td>1756.49</td>
<td>1067.351</td>
<td>1754.20-1758.78</td>
<td>566.35</td>
<td>279.099</td>
<td>565.75-566.95</td>
<td>833700</td>
</tr>
<tr>
<td>Evening</td>
<td>1820.33</td>
<td>1136.273</td>
<td>1815.95-1824.71</td>
<td>558.37</td>
<td>278.628</td>
<td>557.30-559.45</td>
<td>258341</td>
</tr>
<tr>
<td>Total</td>
<td>1740.95</td>
<td>1091.395</td>
<td>1739.68-1742.23</td>
<td>548.11</td>
<td>279.126</td>
<td>547.78-548.44</td>
<td>2818414</td>
</tr>
</tbody>
</table>

Distance: \( P < 0.001, F = 1467.276 \)
Duration: \( P < 0.001, F = 2092.022 \)

The result in Table 9 shows that the proportion of members reach the peak in morning rush period and in morning period, probably because more morning and am commuters have this fixed route. Whereas in the midday peak to midnight, the proportion gradually decreases. In the midday peak to the evening peak, this may be due to those without fixed routes and the rise in the use of shared bikes by tourists. In the evening to midnight, bike sharing is a good commuting option and those without a membership may choose bike sharing for financial reasons. There are more users of electric bikes in evening period and night period, which may be because that users at this
time are more tired and have a greater need to get to their destinations quickly. These matches the distribution of bus-bikeshare trips in the terms of duration and distance.

![Fig. 6. The average of the duration of bus-bikeshare trips in different period](image)

**5.5. Season characteristics of bus-bikeshare pattern**

In the terms of season, bus-bikeshare trips are most concentrated in the summer, while they are least concentrated in winter. This may be related to the temperature and other climatic factors. According to the previous study, bike share ridership seems to be at its highest whenever the perceived temperature is between 20 to 30 degrees Celsius. Lower temperature ranges of 0 to 10 and 10 to 20 degrees are still positively correlated [14].

And this trend is shown in the *Fig 7*. It can be seen that the number of trips is roughly consistent with the temperature curve. Also, the greater efficiency of electric bicycles during the summer months may increase the usage of shared bicycles during the high temperature period.

![Fig. 7. The bus-bikeshare trips date distribution](image)

**5.6. Spatial characteristics of bus-bikeshare pattern**

The *Fig 8 (a)* shows that the bus-bikeshare trips are mainly located in the central area of Chicago and the nearby areas. In addition to this, the number of bus-bikeshare trips are significantly higher in Washington Park, South Side. This may be due to there are many parks and universities, and it is reported that parks could promote the use of bike share [12]. Besides, universities could increase the number of people most interested in bike share in the area [20], and student discount from Divvy promote the use of shared bike by college students for travelling. Additionally, the area has a high crime rate, which may lead riders who would otherwise use private bikes to use shared bikes [8].

According to the, *Fig 8 (b)* and *Table 10*, it is concluded that there is a positive and significant spatial autocorrelation for the bus-bikeshare trips. And the high value block where the bus-bikeshare transfer is popular are more likely to be near the area with the high value. This phenomenon occurs in central and peri-central urban areas with a high distribution of trips. And so is the low value block, which occurs in the northwestern, southwestern, and southern parts of Chicago, centered on the Northwest Side and Southwest Side. This may be because better services and a build environment suitable for cycling will promote an increase in the number of trips in the area. Besides, the areas have the similar infrastructure which may have positive impact on bus-bikeshare trips. In addition, people's choice of bike sharing to appear will be influenced by the surrounding atmosphere, which will promote the aggregation of trips [20].
5.7. The relationship between bus-bikeshare trips distribution and the built environment

5.7.1. Employment density and households

Generally, higher employment density and household represent a more densely populated area, which would increase people's use of shared bikes. However, employment density and household have different impacts on bus-bikeshare transfer, as shown in Fig 9. Employment density has a negative impact on bus-bikeshare transfer, with the impacts radiating out from the center of the city. This may be due to the better transport services in these regions. People could go straight to their destination instead of using a shared bike for the last kilometer.

Household has a positive impact on bus-bikeshare transfer, with more significant impacts in West Side, Central Chicago and North Side. This may be because these areas have a high population density along with higher employment density but have below-average infrastructure development and incomes for their residents. This means that residents in these areas may be more inclined to use bike sharing as a convenient and affordable way to get around.
5.7.2. Income

Overall, like Fig 10 shows, the effect of the number of low-wage people on bus-bikeshare transfer is negative, most pronounced in North Side and decreasing towards the periphery. There is a weaker positive effect in Southwest Side, Far Southwest Side, and Far Southeast Side. The effect of the number of middle-wage people on bus-bikeshare transfer is negative and is most pronounced in North Side. In the airport area, South Side, Far Southwest Side and Far Southeast Side, the effect is not significant. The effect of the number of high-wage people on bus-bikeshare transfer is positive, most pronounced in Central Chicago, with the effect gradually diminishing as one moves away from the center. There is a weaker negative effect in Far Southwest Side and Far Southeast Side.

The spatial distribution of the impact of low- and middle-income groups on bus-bikeshare transfer roughly overlaps with that of Household. This may be due to the special built environment factors of the area, such as high employment density and poor infrastructure. They may prefer to walk to the destination straight. The promotion of bus-bikeshare transfer by higher income groups is documented by other researchers [20], and presenting such a spatial distribution may be due to more bikeshare services in the region.

5.7.3. Gender and race

In terms of gender, the effect of the number of males on bus-bikeshare transfer is positive, demonstrated in Fig 11 (a). The effect is most pronounced in the Lincoln Park area, north of Central Chicago, and diminishes towards the periphery. This distribution may be due to the area being dominated by the service sector, where men are less restricted in their use of cycling.

In terms of race, illustrated Fig 11(b) in impacts are more pronounced in areas close to Lake Michigan, but the northern and southern regions show different impacts. Impacts are negative in the north and positive in the south. This may be related to the different income levels of different ethnic groups. Local whites generally have higher incomes than blacks. According to the Census Bureau data, the median household income for whites in Chicago in 2019 was $79,000, versus blacks' median income of $32,000, a difference of $47,000, with whites making 2.47 times more than blacks. In the north area where there are more whites, more whites mean more low- and moderate-income people, while in the South, more whites means more high-income people.

6. Conclusion

Bike sharing has a bright future, since it has received popularity due to its environmentally friendly and convenient features. In order to ensure that the shared bicycle service can operate efficiently, it is important to understand the characteristics of shared bicycles in different states of use. This paper explores the bike sharing as the feeder to the bus by mining big data. We propose a method to identify bus-bikeshare trips. Then, the characteristics of trips are analyzed using mathematical and spatial modelling, and the built environment factors affecting trips are explored. The findings can be summarized as follows: (1) There is a positive and significant spatial autocorrelation for the bus-bikeshare trips. And the duration is influenced by the trip’s membership, area, period, season and bike type; (2) the trips of member users are much more than the casual users and the member riders would have shorter distance and duration in trips. Duration and distance are longer in the urban area, and there is a preference for classic bikes and more member in urban area; (3) the bus-bikeshare trips are concentrated in the daytime, and at night distance would be longer while
Duration would be lower. And the bus-bikeshare trips are most concentrated in the summer; (4) employment density and the number of low wage and med wage have the negative impact on bus-bikeshare transfer, while the number of households, high wage and male have the positive impact on bus-bikeshare transfer.

Understanding the pattern’s characteristics in this study has the potential to benefit the encouragement and
management of the integrated usage of bus-bikeshare transfer. A more flexible and economical membership pricing strategy might promote bus-bikeshare transfer. Additionally, adapting bus and bike sharing services based on the characteristics, such as appropriately increasing the distances between passages through bus stops in the region and placing a certain number of shared bicycles, could further improve the efficiency of both and reduce the waste of public transport resources. Moreover, the placement of shared bicycles can also be adjusted according to the season. For example, in the winter, the number of bicycles placed around the bus station can be appropriately reduced. This could reduce the maintenance costs of the bikes. Besides, adjusting the pricing strategy to different times of day may also be a desirable option. Bus-bikeshare transfer time distribution is clearly less used in morning rush, morning and noon rush. Therefore, a tidal pricing strategy with different tides in the morning and evening may be able to promote user usage.

Though the results in this study are inspiring, several limitations must be noted. Firstly, there is still room for improvement in this paper with respect to the identification of bike-share pattern. The current identification may lump some bikeshare-only trip into the bike-share trip category as well, which will inevitably cause some interference with the results. Combining more identification methods (e.g. questionnaires, interviews, etc.) can further improve the accuracy of identification. Secondly, analyzing for a single region and a single bike-sharing brand may make the results obtained less representative. Therefore, there is still more work waiting to be done for this area of bus-bikeshare transfer.

References


