Spatiotemporal analysis of human cycling patterns' changes during weekdays under the COVID-19 lockdown: A case study of London docked shared bicycles

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Summary: The lockdown rules in London indeed change the citizen's mobility and the usage of public transport. Especially, the people's activities based on the docked bicycle system in London shows significant differences. In order to understand the impact of Lockdown rules on the cycling patterns and study the changes in people's intention with this shared bicycle system, our work focuses on the spatiotemporal changes in the daily usage of Santander Cycles, London before and during the lockdown. In this work, we achieved a comprehensive analysis from graph theory and hierarchical clustering, finding that citizens' daily cycling patterns have shown more regional differences after lockdown and also people are prone to use the shared bicycles for leisure purposes. With our current results, we could tentatively provide a basic outline of the new cycling patterns to the public sectors. And also, these new patterns influenced by the pandemic and lockdown rules show great significance to future policymaking.

KEYWORDS: Bike-sharing, Urban mobility, Cycling Patterns, COVID-19 Lockdown

1. Introduction

COVID-19 has brought great changes to citizens' daily lives. In particular, the lockdown rules have changed people's daily transportation choices and their mobility. Traditional modes of urban transport have witnessed a shift during the Lockdown period, illustrated by a drop in the use of motor vehicles with "80% fewer car journeys" being reported on UK roads since the first lockdown starting from 23rd March, 2020 (Barrett, 2020) as well as the "discouragement" in the use of public transportation systems due to the risk of the spread of Covid-19 (Sutton, 2020).

London's docked bicycle sharing systems (BSSs) is the Santander Cycles. This study focuses on the impact to people's mobility in the workdays based on the docked bicycle system data. In section 2, the Santander Cycles data is described. In section 3 the methodology is outline, which involves using Graph theory, Hierarchical clustering and Louvain algorithm to explore the travel mobilities. In section 4 the visualization and

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analysis are illustrated, which contains the specific regional analysis and moving patterns' differences. In section 5, we briefly conclude the results. Moreover, our results provide insights for policymakers and city planners about how to respond to changes to public transport, mainly the tube, or make any improvement to encourage people's usage of shared bicycle systems, as well as how to effectively maintain or improve cities' resilience under the pandemic from the perspective of the shared bicycle systems.

2. Data Description

This study uses the public data from Cycle Hire bike sharing scheme,[*] London. It is derived from the Santander Cycles[†], which is the only dock-based BSS in London. Location data for the bike docking stations were sourced from the TfL website's live feed for Santander cycles (TFL, 2020b). In 2020, the number of recorded bicycle stations is 801, which is equal to the number of 2019.

To analyze the impact of lockdown on people's cycling mobility, we define 23rd March 2020, the first- lockdown starting date as the milestone, then extract the weekdays in four periods of weeks of both 2019 and 2020. The data information is shown in **Table 1.**

Table 1 Summary of the Data

Date	Number of Bicycles	Number of Trips	Description
21st Jan, 2019-25th Jan, 2019	10, 194	122, 528	Normal time and before lockdown
25th Mar, 2019-29th Mar, 2019	160, 446	10, 782	Normal time and before lockdown
06th May, 2019-10th May, 2019	138, 397	10, 401	Normal time and before lockdown
01st Jul, 2019-05th Jul,2019	210, 321	9, 809	Normal time and before lockdown
20th Jan, 2020-24th Jan, 2020	9737	138345	Before Lockdown
23rd Mar, 2020-27th Mar, 2020	8919	53763	During 1st Lockdown(early period)
04th May, 2020-08th May, 2020	10395	128731	During 1st Lockdown(Middle period)
29th Jun, 2020-03rd Jul, 2020	9577	155504	During 1st Lockdown(Late period)

3. Methods

In this section the methodology is described, which uses methods from graph theory to pre-processing the data and combine the regional bicycle traffic flow in a graph structure. As the bicycle patterns show a typical geospatial characteristic, we also present the two

[*] https://cycling.data.tfl.gov.uk/
[†] https://tfl.gov.uk/corporate/terms-and-conditions/santander-cycles

clustering methods: 1) Louvain algorithm method is used to extract the most popular urban areas during the weekdays from the usage of these bicycle system; 2) hierarchical clustering method is used define the hub station groups based on the in and out station flows.

3.1 Graph Theory and Construction of Station Groups

Graph theory is derived from discrete mathematics, representing a pair of relationships between two entities. A graph is a collection of nodes, which may be docking stations, connected by edges, which could represent weighted flows or spatial connectivity. (Guze, S., 2015) For the docked bike-sharing systems, the initial nodes are the stations and the edges are the trips connecting each pair of two stations. Thus, the weight in the whole network is defined by the number of flows that start or end at the nodes, whilst the degree is the number of edges that connect with the node.

The first step is to construct station groups by clustering nearby stations. This step reduces the total number of stations, making local patterns simpler to interpret. Inspired by Yang et al.(2020) and Francesco et al.(2020), we firstly define 122 clusters of the total 801 stations according to the around proportion with Yang et al.(2020), then use a hierarchical clustering method based on the stations' spatial distances. After that, we find the geospatial center as the node representing the individual cluster. So, with this method, we can tentatively get a distribution map of small-scale clusters, shown in Fig.1, which can help us to analyze the 'hub' areas of in or out traffic flow.

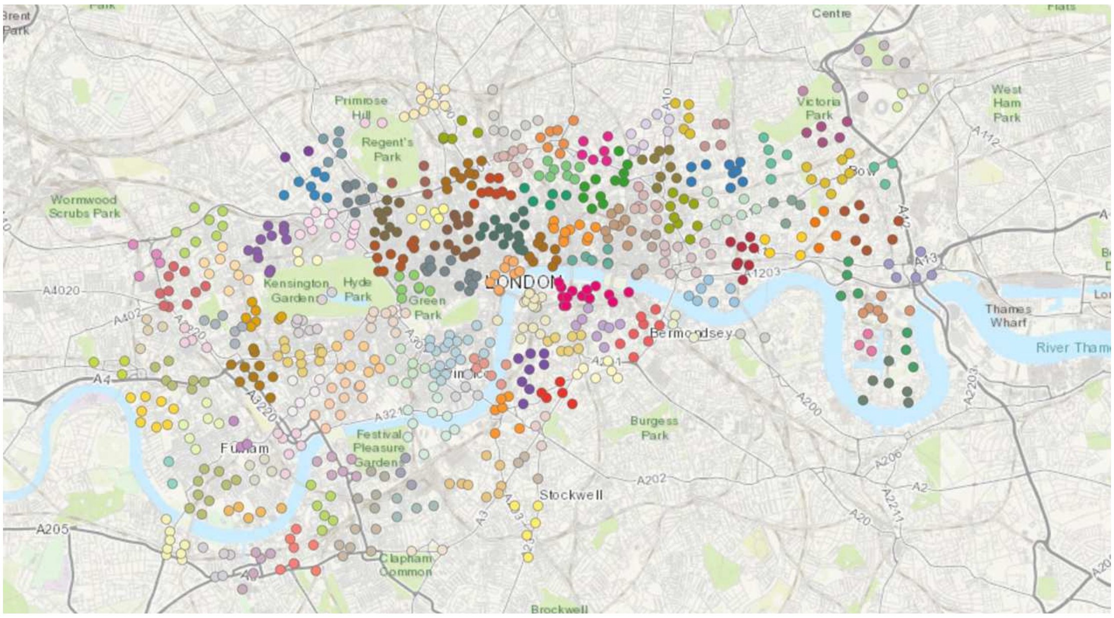


Figure 1 Clusters of the whole docked bicycle system

3.2 Louvain algorithm

Louvain algorithm was first proposed by Vincent D.Blondel et al.(2008) as a fast unfolding method to detect subgraphs in a network. It is a heuristic algorithm with modularity optimization. In our study, this method is used to divide the whole network community into several densely linked subcommunities and compare the changes of these communities. That is, the number of trips within subcommunity structures is higher than those between subcommunities.

Modularity Q, which is a major evaluation concept for community detection (M. E. J. Newman, 2006), is defined as follows.

$$Q = \sum_i (e_{ii} - a_i^2)$$

Where e_{ii} is the ratio of the number of trips within the specific community to the whole number of trips of the network, and a_i represents the fraction of edges that connect to vertices in the community i.

Then, the Louvain algorithm will follow the next steps with two phases. It initially deems each node as an individual community. For an individual node, the algorithm will try to allocate it to the neighborhood communities, calculating changes of modularity as ΔQ. The node will be automatically assigned to the community where it causes the maximum change of modularity. This phase will end when all the nodes find their finalized community. Then, each of the new communities is going to be shaped a new node, and the new network will repeat the initial step until the whole graph's modularity remains steady.

The changes of modularity, ΔQ can be calculated by the following function.

$$\Delta Q = \left[\frac{\sum in + k_{i,in}}{2m} - \left(\frac{\sum tot + k_i}{2m}\right)^2\right] - \left[\frac{\sum in}{2m} - \left(\frac{\sum tot}{2m}\right)^2 - (\frac{k_i}{2m})^2\right]$$

In this function, where $\sum in$ is total weights of the lines within the target community, $\sum tot$ is the sum of the weights of the lines incident to nodes in the target community, k_i is the sum of the weights of the links incident to the reallocated node, $k_{i,in}$ is the sum of the weights of the links from the reallocated node to the nodes in the target community, and m is the sum of the weights of all the links in the network.(Vincent D. Blondel et al.,2008)

The first part of this function represents the modularity of a specific community when having the node i , while the second part is the former modularity of the same community as the node i is not added. After doing the formula method simplification, the former formula can be a simpler and also a more understandable one.

$$\Delta Q = \left[\frac{k_{i,in}}{2m} - \frac{\sum tot\, k_i}{2m^2}\right]$$

4. Results and Analysis

4.1 Spatiotemporal changes of the 'hub' areas

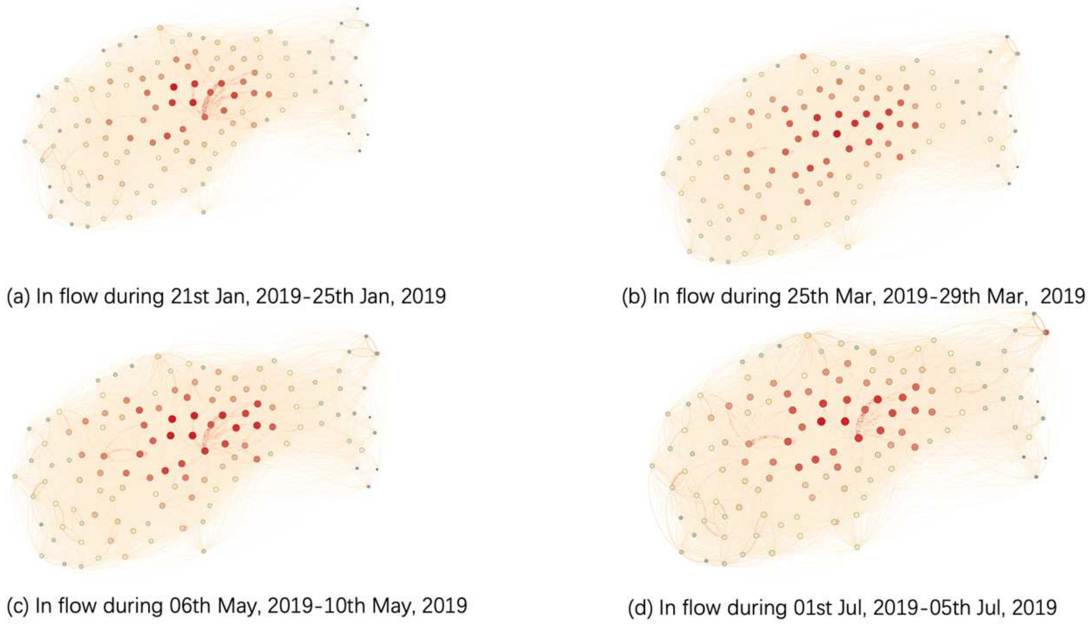
The usage of the shared bicycle system can be regarded as two actions, namely refilling and removal. As 3.1 described above, we visualize the in-flow(Fig 2.(a) &(b)) and out-flow(Fig 3. (a) &(b)) with the number of trips. The bigger and darker the node is, the more trips have been into or out of this area. The edges are the number of trips between each pair of nodes, which can help us to conduct a flow analysis.

In 2019(Fig 2.(a), Fig 3.(a)), we could find that a regular cycling pattern during the weekdays from central London to the city of London. From the tentative trend, we could summarize that the major purpose of this daily pattern during normal time is related to daily commuting.

In 2020, we could see a totally different trend. Before the lockdown rules, the 'hub' areas of the refilling action were typical in central London, namely near Waterloo station, Holborn station, and between Oxford Circus and Tottenham Court Road Station. The most significant trip flows were the connections within the Waterloo Station, Holborn, and the City of London. Other parts of the city showed no major refilling patterns. But for the first week of lockdown, the patterns have a major change. Although people were still prone to use the docked station nearby Waterloo Station and Oxford Street, the areas around the Victoria Station and Hyde Park attracted more people during the weekdays.

Furthermore, the flows between Hyde Park and Kensington Gardens and within the Olympic Park were more significant than normal days. Due to lockdown travel, we can find more trips within the same node, especially those docked stations located nearby parks or gardens. These new patterns show a similarity with the fourth week we examined. Moreover, when the lockdown rules have taken place around one month, in early May, the usage of the whole city's station showed a more balanced trend, aside from the four major hub areas, the other nodes of the public bicycle systems had a greater size as well.

For the removal action and outflows to each specific node (Fig3.), we can find that the patterns before lockdown are consistent with the refilling actions, especially the hub areas and the flows within them. That is, during the normal days, the typical outflows on weekdays were the trips starting from Waterloo Station area to the Holborn area or the City of London. In early May, the most popular start station areas were still centered within the Waterloo Station, Victoria Station, Hyde Park as well as along Oxford Street. However, compared with the situation in the first week of lockdown, the usage of the station nearby Bayswater had a clear increase. With the temporal changes, the start stations nearby Hyde park have become more important, and the trips within the Olympic Park have increased significantly.



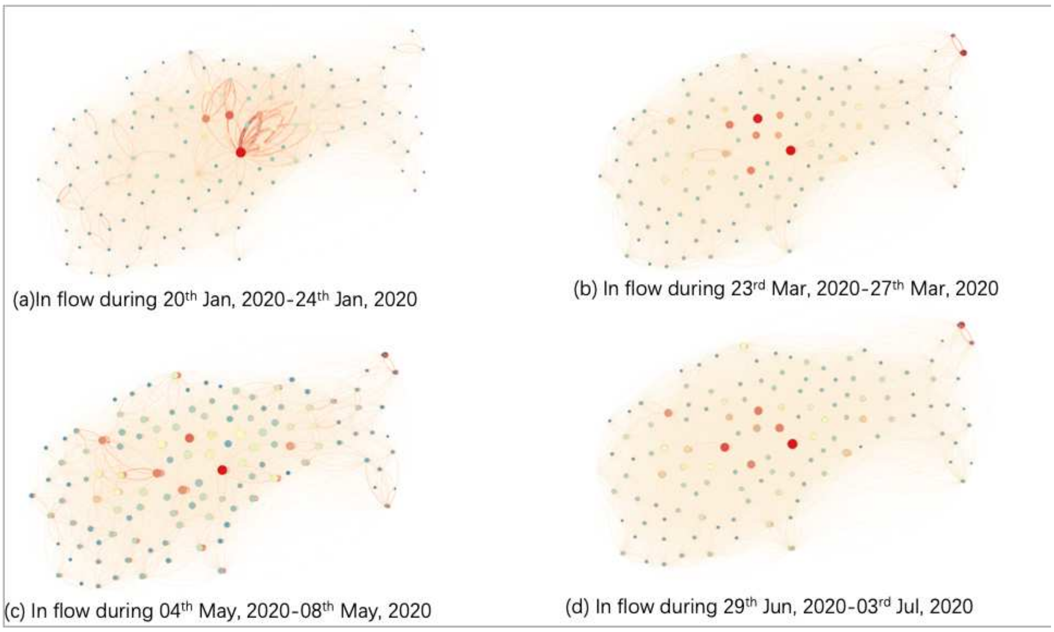
(a) In flow during 21st Jan, 2019-25th Jan, 2019

(b) In flow during 25th Mar, 2019-29th Mar, 2019

(c) In flow during 06th May, 2019-10th May, 2019

(d) In flow during 01st Jul, 2019-05th Jul, 2019

Figure 2(a) In flow of the whole docked bicycle system in 2019



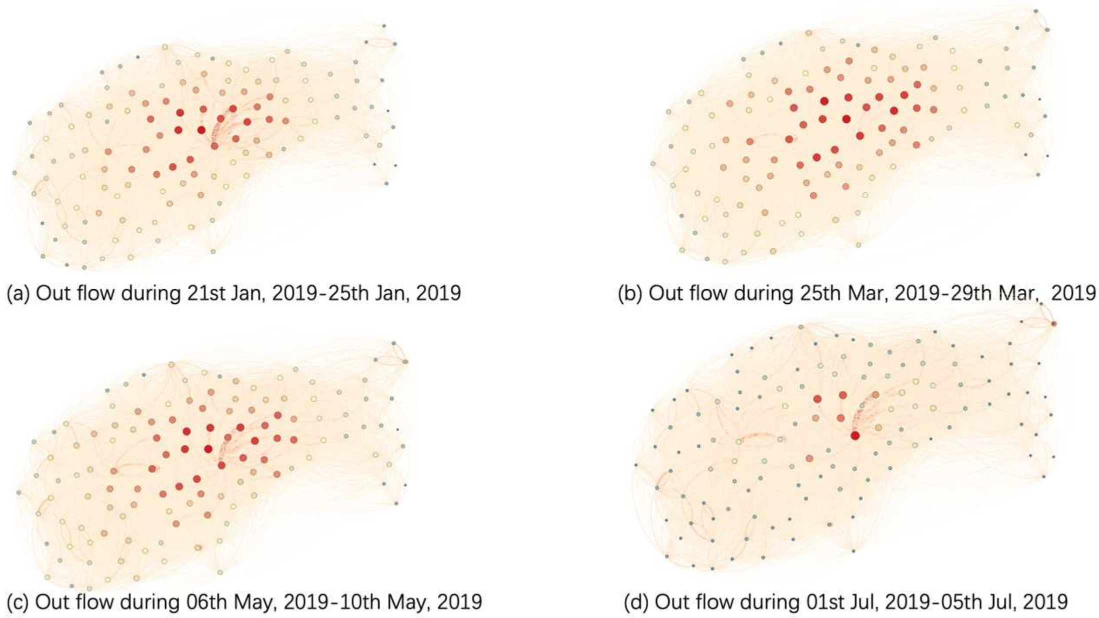
(a)In flow during 20th Jan, 2020-24th Jan, 2020

(b) In flow during 23rd Mar, 2020-27th Mar, 2020

(c) In flow during 04th May, 2020-08th May, 2020

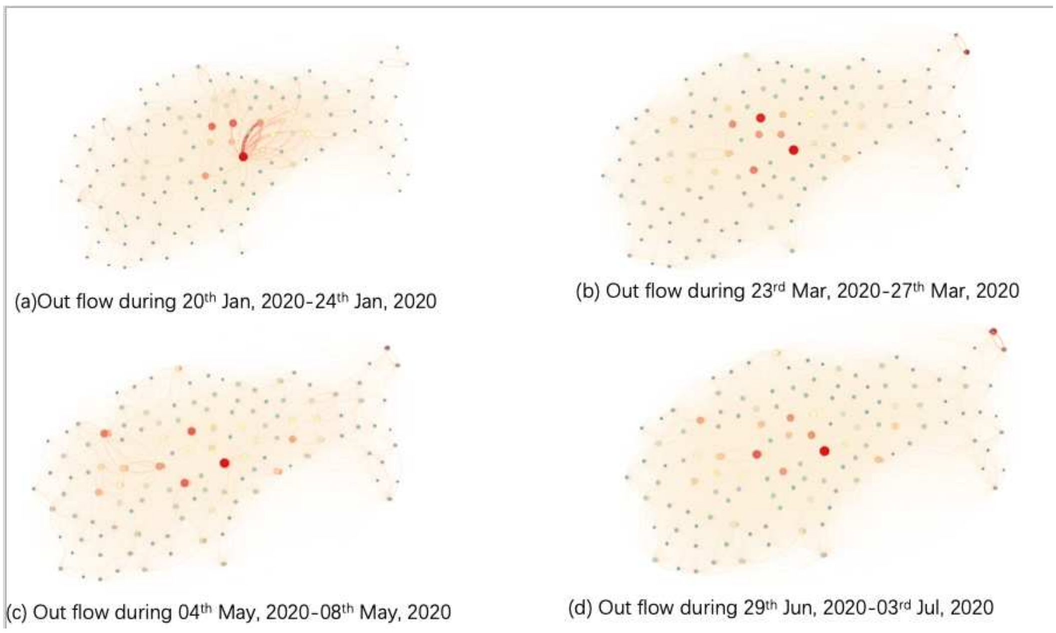
(d) In flow during 29th Jun, 2020-03rd Jul, 2020

Figure 2(b) In flow of the whole docked bicycle system in 2020



(a) Out flow during 21st Jan, 2019-25th Jan, 2019
(b) Out flow during 25th Mar, 2019-29th Mar, 2019
(c) Out flow during 06th May, 2019-10th May, 2019
(d) Out flow during 01st Jul, 2019-05th Jul, 2019

Figure 3(a) Out flow of the whole docked bicycle system in 2019

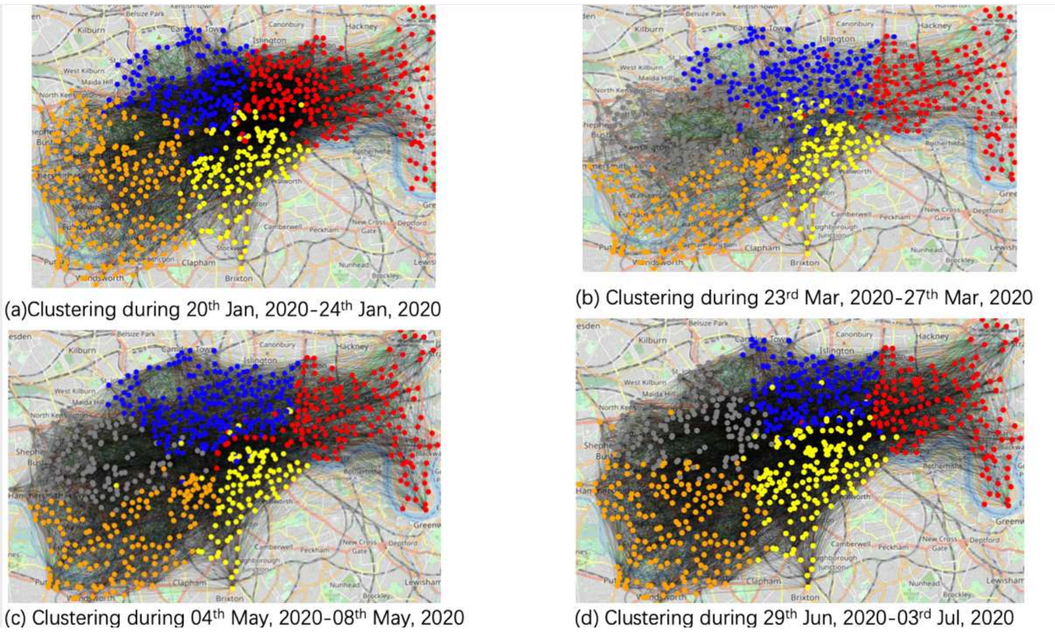


(a)Out flow during 20th Jan, 2020-24th Jan, 2020
(b) Out flow during 23rd Mar, 2020-27th Mar, 2020
(c) Out flow during 04th May, 2020-08th May, 2020
(d) Out flow during 29th Jun, 2020-03rd Jul, 2020

Figure 3(b) Out flow of the whole docked bicycle system in 2020

4.2 Connectivity analysis

In this part of analysis, the results of the connectivity analysis are presented. It can be seen that the docked-bicycle system has a geospatial change under the lockdown rules(Fig 4.).



(a)Clustering during 20th Jan, 2020-24th Jan, 2020

(b) Clustering during 23rd Mar, 2020-27th Mar, 2020

(c) Clustering during 04th May, 2020-08th May, 2020

(d) Clustering during 29th Jun, 2020-03rd Jul, 2020

Figure 4 Clustering with Louvain Algorithm of the whole docked bicycle system in 2020

In the first research week, the whole London was divided into four parts. The red part contains the Olympic Park and Limehouse regions, connected with the blue part, which mainly included King's Cross and City of London, and yellow part, which was the Southwark and Kennington regions. Moreover, the large orange community covered Hammersmith Borough, City of Westminster, Kensington and Hyde Park.

With the lockdown rules have a full effect, the clearest change occurred within the orange community with people have much shorter trip patterns. Thus, the original orange part has less connective, and was especially separated into to two parts, grey one covering Kensington and Hyde Park, orange one covering Fulham and Chelsea, separately. Furthermore, during the first week of lockdown, the whole graph showed a significant sparse situation in the working days. It can draw a direct conclusion that the majority of citizens followed the policies.

In the weekdays of the week starting from 4th May 2020, the cycling activities have nearly back to normal again, as the whole network became density. Especially, the user mobility of the red part had transitioned towards longer trips along the river on the East-West axis, indicating a closer connection with the central London. Moreover, in the June, the yellow part clearly extended to the orange, blue and red part, showing that the Southwark regions more strongly connected with the City of Westminster as well as the north side of the river. And also, the orange part enlarged along the North-South axis letting the grey part became much thinner in this direction. Thus, we can assume that the cycling patterns around Hyde park may not a big difference, while the cycling activates in Earl's Court, Hammersmith and Chelsea had a stronger connectivity with Kensington than with Southwark.

5. Conclusion

In this study, we analyze the spatial patterns of the public docked sharing bicycles during the weekdays before and during the lockdown. It can conclude that before the lockdown users were prone to use this public transport as a commuting method, especially the in and out flow's hub stations were always in the key transport area, such as Waterloo Station, Holborn, and the City of London. Nevertheless, during the first lockdown, restricted by the traffic control and work for home rules, people chose to use the Santander bicycles as a leisure method. Thus, the destination and orientation were more nearby the parks and leisure regions, finding that Hyde Park, Bayswater as well as Olympic Park have become attractive areas. Moreover, the lockdown rules indeed decreased the usages of public bicycles and also made people riding much shorter distances.

6. Biography

Xiaowei Gao is the first-year PhD student at the SpaceTimeLab for Big Data Analytics (http://www.ucl.ac.uk/spacetimelab), University College London. His research interests include spatiotemporal data mining in cycling, sustainable public transport development, and transport policy.

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Huanfa Chen is a Lecturer (Teaching) in Spatial Data Science and Quantitative Methods at Centre for Advanced Spatial Analysis, University College London. His research interests include spatial optimization, agent-based modelling, transport behaviour studies.

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