Identifying Mobility Pattern Changes before and during the COVID-19 Pandemic on Bikeshare Data in Montreal

Xinyu Chen (Ph.D. student), Nicolas Saunier (Supervisor)
Polytechnique Montreal
(Graduate Course Project Report)

Released: July 2022; Updated: August 2022

1 Introduction

Cycling, as a kind of active transport mode, has been demonstrated to not only provide healthy lifestyle to people, but also bring environmental benefits (Kraus and Koch, 2021). As the COVID-19 crisis has led to the important change of transport behavior (Li et al., 2021; Wang and Noland, 2021; Li et al., 2022), cycling is a suitable transport mode for pursuing healthy habits, keeping social distance, and reducing the risk of being infected. Wang and Noland (2021) estimate the changes of both bikeshare ridership and subway ridership in New York City (NYC) before and during the COVID-19 pandemic. Their results demonstrate that both subway ridership and bikeshare ridership plummeted initially; bikeshare ridership has nearly returned to normal while subway ridership remains substantially below pre-COVID-19 levels (Wang and Noland, 2021). Li et al. (2022) discover the spatiotemporal patterns from massive anonymity human mobility (90+ million people) in the United States during the COVID-19 pandemic. Their empirical results demonstrate clear mobility declines and uncover significant disparities in mobility changes between individuals from wealthy regions and lower-income regions when facing the COVID-19 pandemic. According to the APTA Ridership Trends[1], during the COVID-19 pandemic, public transit ridership has risen and fallen rapidly in response to public health alerts across the United States, but the whole ridership level to the resilience of public transit is far below the ridership before the COVID-19 pandemic. The crisis of COVID-19 provides an opportunity to understand the changes of human mobility behavior and rethink our transportation systems over some unplanned events (Osorio et al., 2022).

For the bikeshare systems, we can find some literature and statistics about the characteristics of bikeshare ridership before and during the COVID-19 pandemic. As reported by the United States Bureau of Transportation Statistics[2], bikeshare ridership has decreased by 44% in March, April, and May 2020 compared with the same months in 2019. Teixeira and

[1] https://transitapp.com/APTA

[2] Bikeshare ridership down 44% during COVID-19. https://www.bts.gov/newsroom/bikeshare-ridership-down-44-during-covid-19

Lopes (2020) show that the bikeshare ridership for the months of February and March in 2020 has a significant drop (71%) and an increase on the average trip duration (from 13min to 19min per trip) in NYC as compared with February and March of 2019, providing further evidence of modal substitution during the COVID-19 pandemic. Padmanabhan et al. (2021) not only reveal the fact that the average duration of bike trips increases with the decreased bike trips during the COVID-19 pandemic, but also demonstrate that the effect of COVID-19 on shared-bike trips is diversified in NYC, Boston, and Chicago. Chibwe et al. (2021) demonstrate that the first national lockdown, introduced in March 2020, in England decreased the demand for the London bikeshare system by around 22%. According to a survey[3] from Statistics Canada in 2020, more commuters are walking or cycling to work rather than taking public transit since the onset of the COVID-19 pandemic.

In literature, some works focus on exploring the mobility pattern changes before and during the pandemic, identifying the key factors that motivate bikeshare users, and looking for solutions to stimulate the people's preference for active transport modes (e.g., cycling and walking) (Matekenya et al., 2021; Doubleday et al., 2021; Büchel et al., 2022; Teixeira et al., 2021). This research provides a systematical empirical evidence of bikeshare pattern changes before and during the COVID-19 pandemic. The empirical evidence is analyzed on the Bixi bikeshare data in Montreal. The most important measurements include travel time and trip volume.

2 Goals of this Project

- Process real-world BIXI bikeshare data in Montreal.
- Provide a systematical empirical evidence of mobility pattern changes before and during the COVID-19 pandemic on open bikeshare data in Montreal. Analyze the daily trips and the average travel time.
- Assess lifestyle change over the preference of cycling. Focus on changes in mobility behavior, e.g., commuting at weekday.
- Visualize results and provide a thorough analysis.

3 BIXI Open Data

In this section, we introduce how to process the open BIXI bikeshare data and conduct some preliminary analysis on these data. We also discuss how does the mobility pattern change in terms of trips and average travel time before and during the COVID-19 pandemic.

[3]More commuters now walk or bike to work than take public transit. https://www150.statcan.gc.ca/n1/daily-quotidien/200810/dq200810a-eng.htm

3.1 Dataset

The dataset for the following analysis is from BIXI open data plan[4], and the trip history contains trip records, station information, trip duration, and membership information. In particular, each trip record provides start time, end time, start station, end station, trip duration of each trip, and the membership status of user.[5] It allows us to aggregate trip volume with a certain time resolution and analyze trips and travel time in both spatial and temporal contexts.

Figure 1 demonstrates that the BIXI bikeshare stations in Montreal increased swiftly. As only 22 additional stations appeared in 2020 comparing to 2019, we can see a significant increase of addition stations in 2021, i.e., 209 additional stations comparing to 2019 and 187 additional stations comparing to 2020. Due to the increased stations and docked bikes, bikeshare service can be accessible to more people who are willing to cycle. The increased stations also make more destinations reachable.

Figure 1: Illustration of BIXI bikeshare stations in Montreal during 8 years from 2014 to 2021.

[4] https://bixi.com/en/open-data

[5] Electric BIXI bikes were available since 2020, but the trip history does not provide a certain label to help us identify them from regular bikes.

3.2 Preliminary Analysis

This project aims to analyze the mobility pattern changes of bike trips before and during the COVID-19 pandemic. By doing so, we use the data of two years before the COVID-19 pandemic (i.e., 2018 and 2019) for reference and set two years from 2020 to 2021 as the period during the COVID-19 pandemic. In what follows, we provide a preliminary empirical evidence of mobility pattern changes before and during the COVID-19 pandemic on open BIXI bikeshare data in Montreal.

Table 1 summarizes some basic information of bikeshare trips from 2018 to 2021. In contrast to 2019, the total trips in 2020 are decreased dramatically due to the impact of COVID-19 (e.g., work from home). It shows that the bike trips in 2020 has a significant drop as compared with 2019, i.e.,

$$\frac{5597845 - 3264741}{5597845} \approx 41.68\%,$$

while the bike trip amount of 2021 recovers to the same level as the bike trip amount of 2019.

Figure 2a and Figure 2b plot the pickup trips and dropoff trips on the road network of Montreal, respectively. Since the pickup and dropoff trips on the bikeshare stations are not intuitive for identifying the pattern changes of bike trips, we also take into account the administrative territories of Montreal for visualization.[6] Figure 3a and Figure 3b plot the pickup trips and dropoff trips on the administrative territories of Montreal, respectively. From these visualization results, it is not hard to see the significant reduction of total bike trips in 2020 when comparing to other years. The geographical distributions of bike trips as demonstrated in Figure 3a and Figure 3b show the obvious changes (i.e., trip reduction) of bike trips in Downtown between 2019 and 2021. For other areas, no significant pattern change of bike trips can be revealed between 2019 and 2021.

Table 1 also gives the preliminary statistics of trips done by members and occasionals, respectively. We can see the the drop of bike trips in weekdays and weekends of 2020 when comparing with 2019:

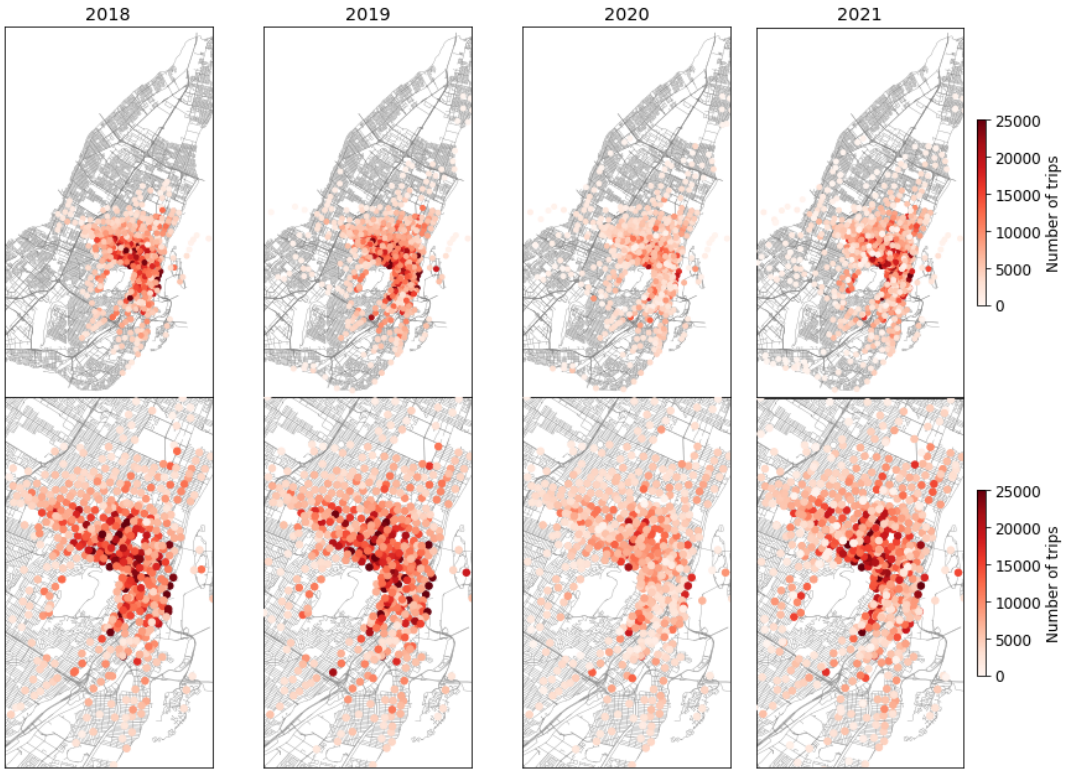
$$\frac{3595191 - 1879459}{3595191} \approx 47.72\%\texttt{(weekday)}, \quad \frac{997592 - 721510}{997592} \approx 27.67\%\texttt{(weekend)},$$

where the reduction of bike trips in weekends is weaker than weekdays.

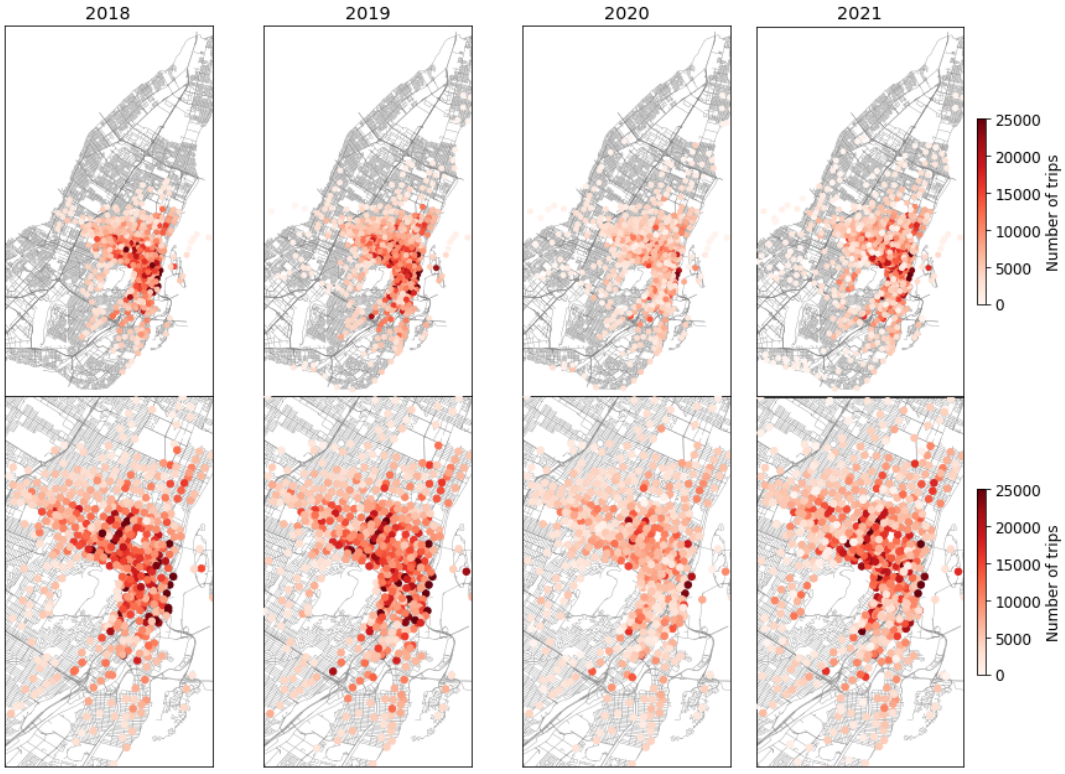
As shown in Table 1, the percentage of trips done by members is about 80% for all four years. It shows that the average travel time of member trips is shorter than the average travel time of occasional trips. Notably, the average travel time has increased to some extent during the COVID-19 pandemic, and the similar finding has also been demonstrated on the bikeshare ridership in NYC (Teixeira and Lopes, 2020). The average travel time of bike trips during 2020 is significantly greater than other years. From 2019 to 2020, the average travel time changes from 13.52min to 15.61min, and it seems to be a significant increase on the trip duration. The increase of average travel time of 2020 can be formally computed as:

$$\frac{936.33 - 811.28}{811.28} \approx 15.41\%.$$

[6]Data of administrative territories of Island of Montreal are avaiable at https://donnees.montreal.ca/ville-de-montreal/anciens-territoires

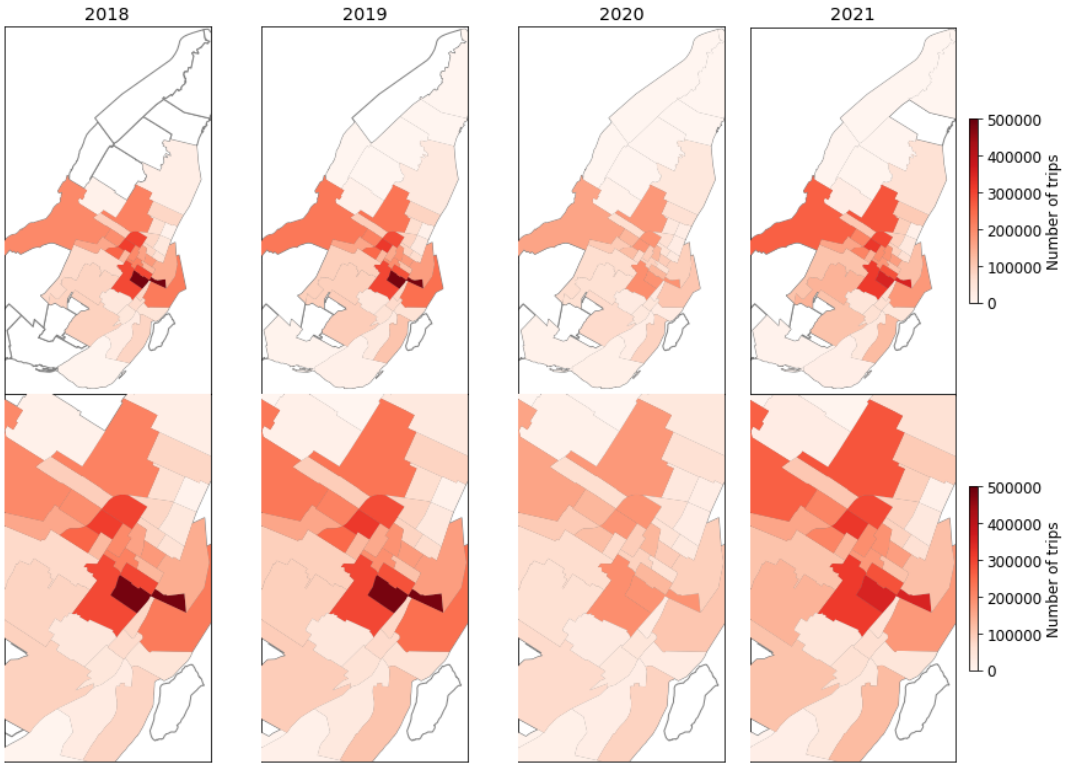


(a) Trip origins

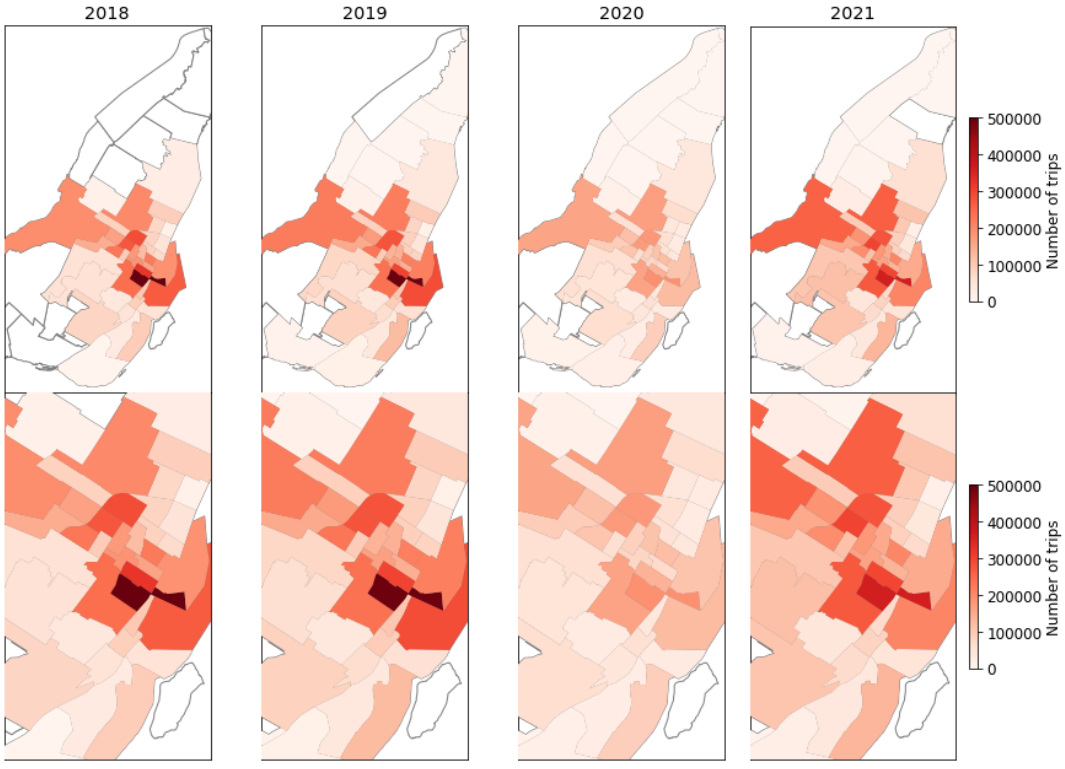


(b) Trip destinations

Figure 2: Visualization of trips of Bixi bikeshare on the road network of Montreal from 2018 to 2021.



(a) Trip origins



(b) Trip destinations

Figure 3: Visualization of trips of Bixi bikeshare on the administrative territories of Montreal from 2018 to 2021.

With respect to the average travel time of weekday and weekend, the increase can be computed as:

$$\frac{836.09 - 726.07}{726.07} \approx 15.15\%\texttt{(weekday)}, \quad \frac{915.99 - 751.31}{751.31} \approx 21.92\%\texttt{(weekend)},$$

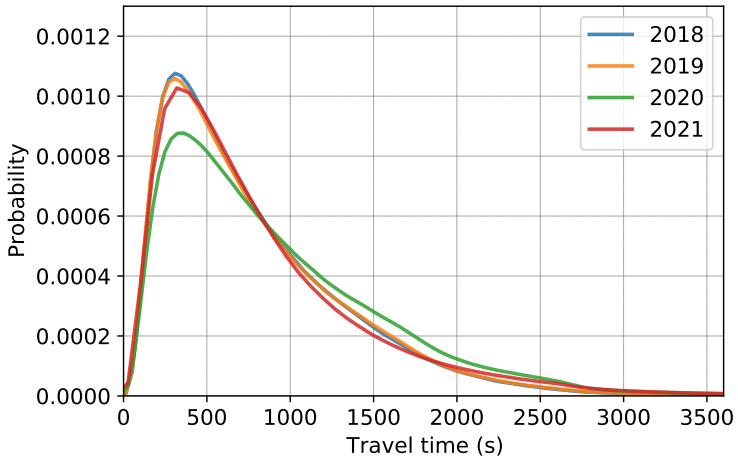
we can see an obvious increase of trip duration of bike trips in weekend.

Table 1: Preliminary statistics of Bixi bikeshare data. We include two important categories. One category is about bike trips of members and occasionals, while another category is about bike trips of members in weekday and weekend.

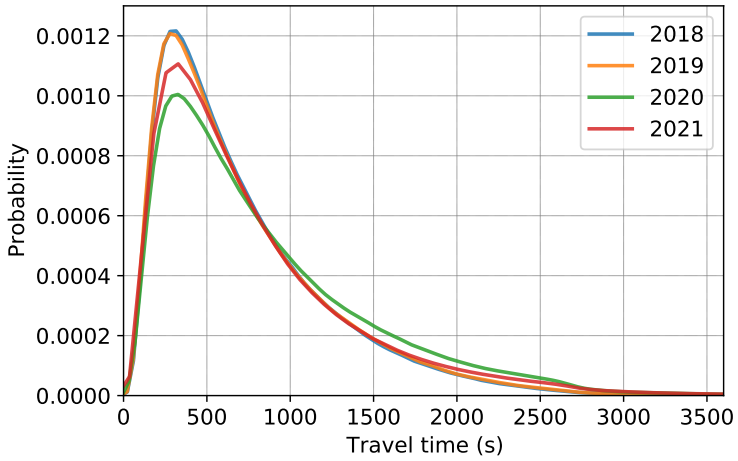
	2018	2019	2020	2021
Stations	552	619	641	828
Total trips	5,277,541	5,597,845	3,264,741	5,490,043
Average travel time (s)	800.68	811.28	936.33	863.88
Members				
Total trips	4,385,520	4,592,783	2,600,969	4,522,011
Trip ratio	83.10%	82.05%	79.67%	82.37%
Average travel time (s)	725.57	731.55	858.25	804.42
Occasionals				
Total trips	892,021	1,005,062	663,772	968,032
Trip ratio	16.90%	17.95%	20.33%	17.63%
Average travel time (s)	1169.99	1175.60	1242.28	1141.61
Weekday (members)				
Total trips	3,429,092	3,595,191	1,879,459	3,309,218
Trip ratio	78.19%	78.28%	72.26%	73.18%
Average travel time (s)	721.35	726.07	836.09	780.53
Weekend (members)				
Total trips	956,428	997,592	721,510	1,212,793
Trip ratio	21.81%	21.72%	27.74%	26.82%
Average travel time (s)	740.68	751.31	915.99	869.61

Figure 4a shows the travel time distributions of all trips in 2018, 2019, 2020, and 2021, respectively. While travel time distributions of trips in 2018 and 2019 are very consistent, they show remarkable differences with travel time distribution of trips in 2020. It demonstrates that the peaks of travel time distribution before the COVID-19 pandemic are higher than the peaks of travel time distribution during the COVID-19 pandemic. There are relatively more trips with longer travel time in 2020 and 2021. Table 1 has also revealed that the average travel time during the COVID-19 pandemic is greater than the average travel time before the COVID-19 pandemic.

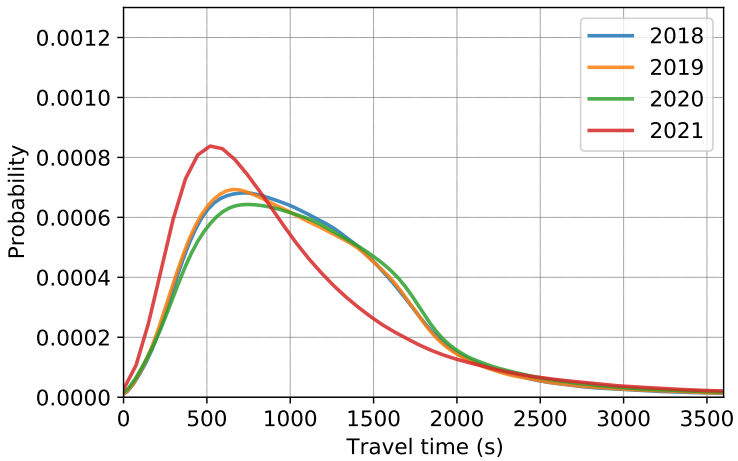
Figure 4b shows the travel time distributions of member trips. The peaks of travel time distribution in 2018 and 2019 are higher than the peaks of travel time distribution during the COVID-19 pandemic (i.e., 2020 and 2021). It seems that there are relatively more trips with



(a) From 2018 to 2021



(b) From 2018 to 2021 (trips done by members)



(c) From 2018 to 2021 (trips done by occasionals)

Figure 4: Histograms of travel time of bikeshare trips.

longer travel time in 2020. Figure 4c shows the travel time distributions of occasional trips. Notably, the characteristics of these distributions are rather different from both Figure 4a (all trips) and Figure 4b (member trips).

4 Mobility Pattern Changes

In this section, we give empirical evidence of mobility pattern changes in the bikeshare system from the perspectives including commuting and cycling lifestyle. First, we analyze the bike trips in weekdays and weekends and identify their differences. In particular, we take into account the commuting trips via the bikeshare system in weekdays and demonstrate their pattern changes. Second, we recognize the lifestyle change for cycling through relatively longer bike trips.

4.1 Weekday and Weekend Cycling Patterns

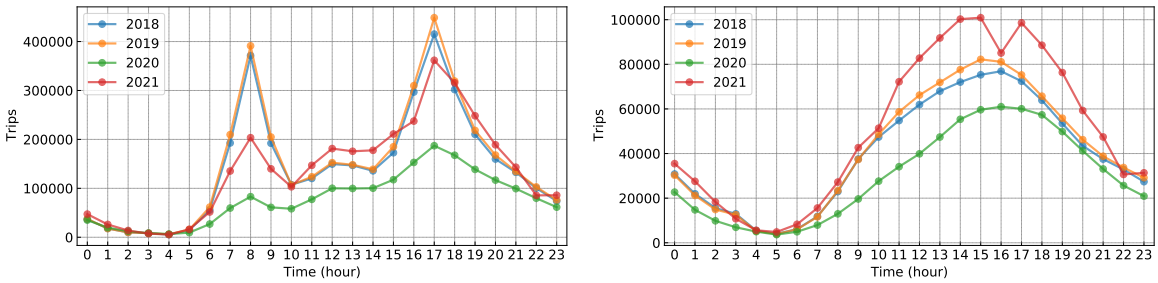
Trips in the bikeshare system include member trips and occasional trips. As summarized in Table 1, a dominant portion of trips was done by members, i.e., $\approx 80\%$ for all four years. As can be seen, members are active users for cycling and contribute most trips in the bikeshare system. To eliminate the impact of occasional trips, we extract the portion of member trips in the following mobility pattern analysis. We intend to identify the mobility pattern change of commuting using these member trips.

Figure 5a shows four hourly aggregated trip volume curves of trips in weekdays of 2018, 2019, 2020, and 2021, respectively. It demonstrates two remarkable peaks for all four years, i.e., one is during the period of 8:00-9:00 and another is during the period of 17:00-18:00. During the off-peak hours, the trip volumes are relatively lower. Therefore, we identify the periods of 8:00-9:00 and 17:00-18:00 as the morning commuting period (i.e., morning peak hour) and the afternoon commuting period (i.e., afternoon peak hour), respectively.

Figure 5b shows four hourly aggregated trip volume curves of trips in weekends of 2018, 2019, 2020, and 2021, respectively. It does not show two peaks as Figure 5a for weekday. As shown in Figure 5b, most bike trips are done in the afternoon (from 12:00 to 18:00) in which people are willing to cycle for activities. This phenomena can also be verified by the relatively longer travel time in 2020 and 2021 comparing to 2018 and 2019 (see Figure 6a and 6b). In particular, people tend to have a relatively longer ride in 2020 at all time periods.

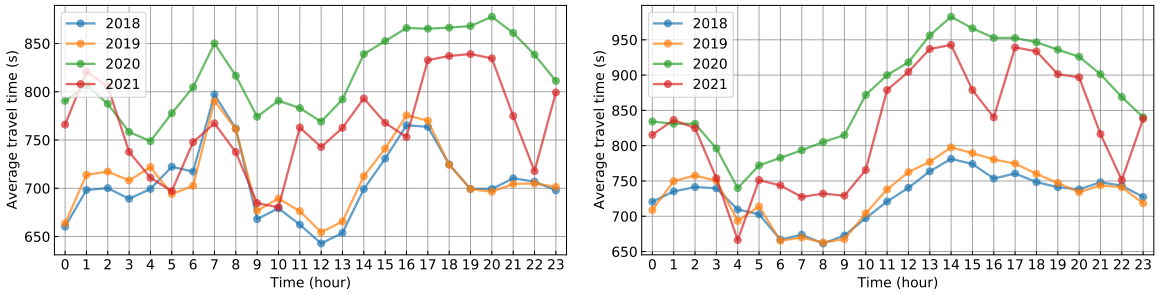
In fact, by analyzing trips (see Figure 5a and Figure 5b) and average travel time (Figure 6a and Figure 6b), these trip curves and average travel time curves of 2018 and 2019 are very consistent. It seems that essential mobility patterns are not changed over two years from 2018 to 2019. But with the crisis of COVID-19, we can observe great changes from either trip curves or average travel time curves in 2020 and 2021. Specifically, Figure 5a depicts a significant reduction of member trips in weekdays of 2020 and 2021 when comparing to 2018 and 2019. Figure 5b demonstrates a remarkable increase of member trips in weekends of 2021 when comparing to 2018 and 2019. These show the pattern changes over cycling in both weekdays and weekends before and during COVID-19 pandemic.

Table 2 summarizes the commuting trips and average travel time of member trips at the peak hours of weekday. Before the COVID-19 pandemic, trips of the afternoon peak hour



(a) Member trips in weekdays (b) Member trips in weekends

Figure 5: Hourly aggregated trip volume curve of member trips.



(a) Weekdays (b) Weekends

Figure 6: Hourly aggregated average travel time curve of member trips.

are greater than the morning peak hour. But the average travel time of both two peak hours is very close. During the COVID-19 pandemic, in contrast to the morning peak hour, there are relatively more people that are willing to ride a bike in the afternoon peak hour. Another remarkable evidence is that the average travel time of the afternoon peak hour is significantly greater than the morning peak hour. It is not difficult to see the cycling preference under the crisis of pandemic, though the total traffic has decreased.

Figure 7a and Figure 7b show the travel time distributions of morning peak hour and afternoon peak hour of member trips, respectively. Referring to Table 2, the average travel time and standard derivation of member trips of afternoon peak hour are greater than morning peak hour. For morning peak hour, we can see that the travel time distribution of 2020 differs from the distributions of other years. For afternoon peak hour, the travel time distributions of both 2020 and 2021 show lower peaks than the distributions of 2018 and 2019. Overall, among these four years, the peak of travel time distribution of 2020 is lowest, showing a great changes of bike trips due to the changed mobility behavior.

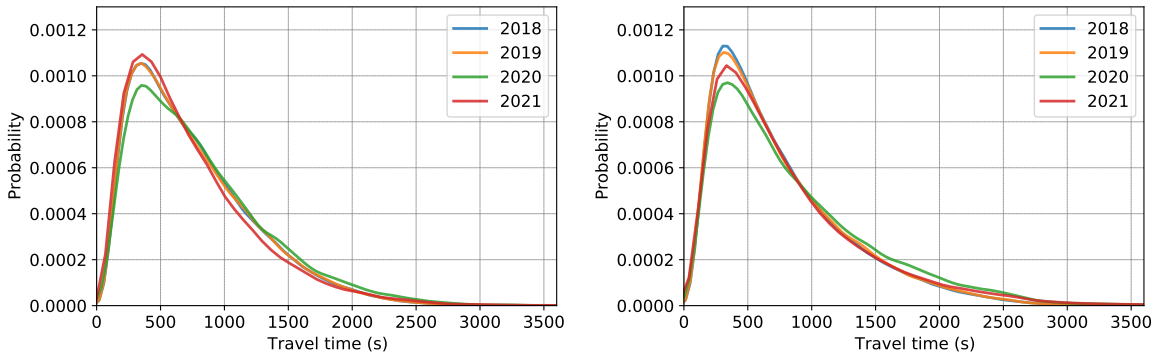
We next analyze the commuting from the spatial context. Figure 8a and Figure 8b show the member trips of the morning peak hour in weekday. As can be seen, the pickup trips are created in most spatial stations, but most of these trips are with the destination of Downtown of Montreal. Figure 10a and Figure 10b show the member trips of the afternoon peak hour in weekday. The pickup trips are mostly created at Downtown, but not as concentrated as Figure 8b. Figure 10b demonstrates the consistent trips with Figure 8a. These findings can verify the commuting of member trips.

Table 2: The commuting trips of members at the peak hours of weekday. The trip rate indicates the portion of trips of peak hours in total member trips. We also include some statistic metrics such as the average travel time, standard derivation, 15% percentile, and 85% percentile.

		Trips	
		8:00-9:00	17:00-18:00
Number (ratio) of trips	2018	371,235 (8.47%)	415,217 (9.47%)
	2019	391,241 (8.52%)	448,709 (9.77%)
	2020	82,963 (3.19%)	187,071 (7.19%)
	2021	203,506 (4.50%)	361,641 (8.00%)
Average travel time (s)	2018	761.83	763.63
	2019	761.33	770.02
	2020	816.60	865.35
	2021	737.44	832.78
Standard deviation of travel time (s)	2018	487.54	538.44
	2019	491.58	544.41
	2020	535.87	643.15
	2021	524.21	726.83
15% percentile of travel time (s)	2018	290	275
	2019	288	273
	2020	307	288
	2021	269	278
85% percentile of travel time (s)	2018	1272	1309
	2019	1274	1326
	2020	1362	1503
	2021	1230	1408

To visualize the bike trips more intuitively, we also consider to project the bikeshare stations and aggregate the corresponding bike trips on the administrative territories of Montreal. Figure 9a and Figure 9b show the geographical distribution of member trips of morning peak hour on the administrative territories of Montreal, while Figure 11a and Figure 11b refer to the member trips of afternoon peak hour on the administrative territories of Montreal. From Figure 9a and Figure 9b, we can see significant pattern changes in terms of morning peak hour, and most frequent areas in 2018 and 2019 are less highlighted in 2020 and 2021. It seems that people are less likely to ride a bike for commuting in 2020 and 2021 than before the COVID-19 pandemic, and this finding can also be verified in Figure 5a (i.e., a lower trip peak in the morning peak hour). By checking out Figure 9a and Figure 9b, the most frequent areas in 2018 and 2019 are also highlighted in 2021.

In addition, we analyze the member trips in weekend. Figure 12a and Figure 12b show the member trips of the afternoon in weekend. It does not show any great differences between pickup trips and dropoff trips, which is different from the trips at peak hours of weekday. Fig-



(a) Morning peak hour

(b) Afternoon peak hour

Figure 7: Histograms of travel time of member trips of two peak hours in weekday. Here, we identify 8:00-9:00 and 17:00-18:00 as the morning peak hour and the afternoon peak hour, respectively.

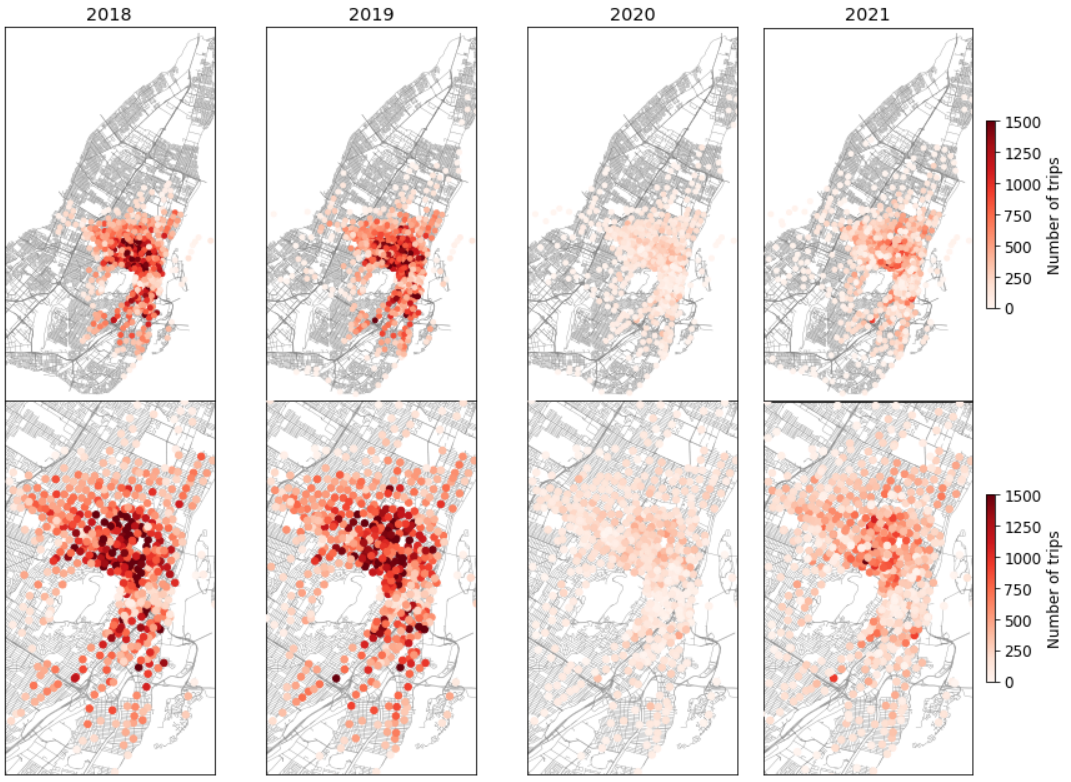
ure 13a and Figure 13b show the member trips on the administrative territories of Montreal in weekend. As can be seen, the most frequent areas in 2018 and 2019 are more highlighted in 2021. Note that the trips created in weekend are also with relatively longer travel times when comparing to weekday (see Table 1). From Figure 5b, most of member trips in weekend are done during the afternoon, which also demonstrate the cycling preference of people for health benefits.

4.2 Lifestyle Change for Cycling: Longer Trip Means A Lot

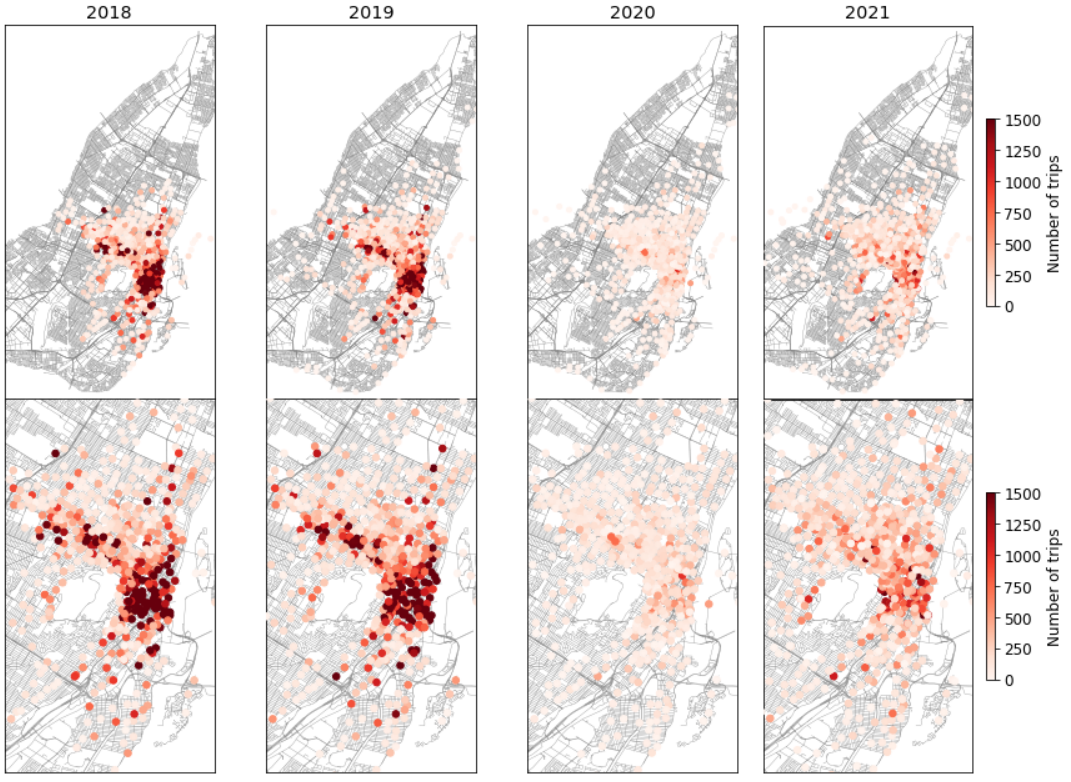
Recall that the bikeshare stations, as a kind of infrastructure, has been substantially increased (see Figure 1). To make fair and comparable analysis, we only take into account 552 bikeshare stations (corresponding to 2018) for the following analysis. Through analyzing travel time of member trips, it is possible to reveal the preference of cycling underlying bikeshare data. Notably, since the start station ID and end station ID of 2021 do not match the station ID of 2018, we only consider 2018, 2019, and 2020 for analysis.

Table 3 summarizes the commuting trips and travel time of member trips within 552 stations in weekday. Comparing to Table 2, it exhibits the consistent trip rates between 552 stations and 619 stations for 2019. In 2019, the average travel time of trips over 552 stations is a little smaller than the average travel time of trips over 619 stations. In 2020, the trip rates between 552 stations and 641 stations are even same. The average travel time of trips over 552 stations is a little smaller than the average travel time over 641 stations, while the average average travel time in 2020 is greater than both 2018 and 2019. These may demonstrate that people are willing to ride a bike with relatively longer travel times in 2020.

Figure 14a and Figure 14b show the travel time distribution of member trips at peak hours. It is not hard to see that the average travel time of afternoon peak hour is greater than morning peak hour. Observing travel time distributions corresponding to different years, the distributions in 2018 and 2019 are completely coincident. This implies no mobility pattern changes from 2018 to 2019. The peak of travel time distribution in 2020 is lower than other two years, but there are relatively more trips with longer travel times. This illustrates

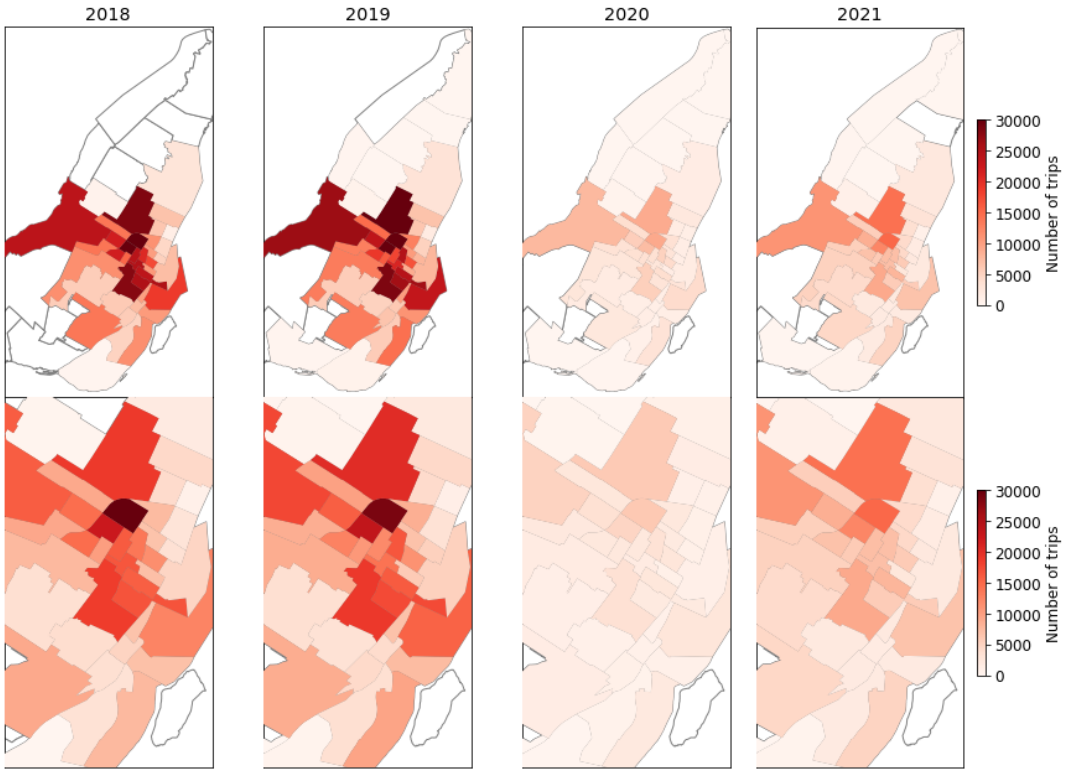


(a) Trip origins

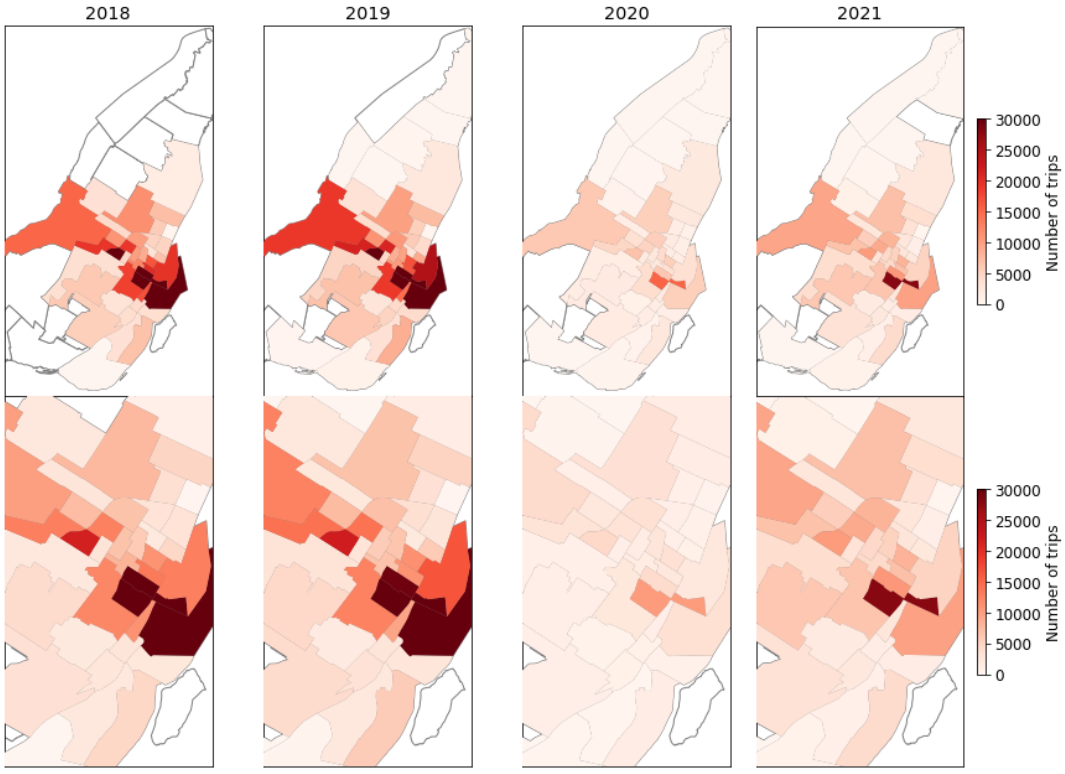


(b) Trip destinations

Figure 8: Visualization of member trips of the morning peak hour at weekday on the road network of Montreal from 2018 to 2021.

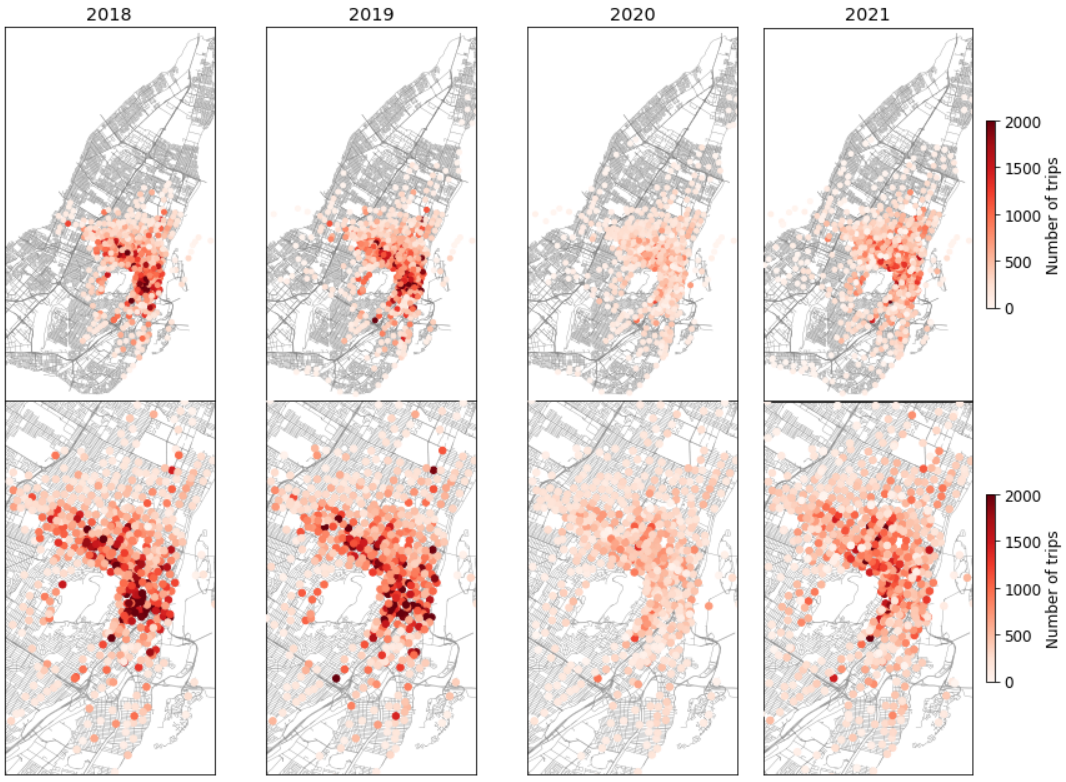


(a) Trip origins

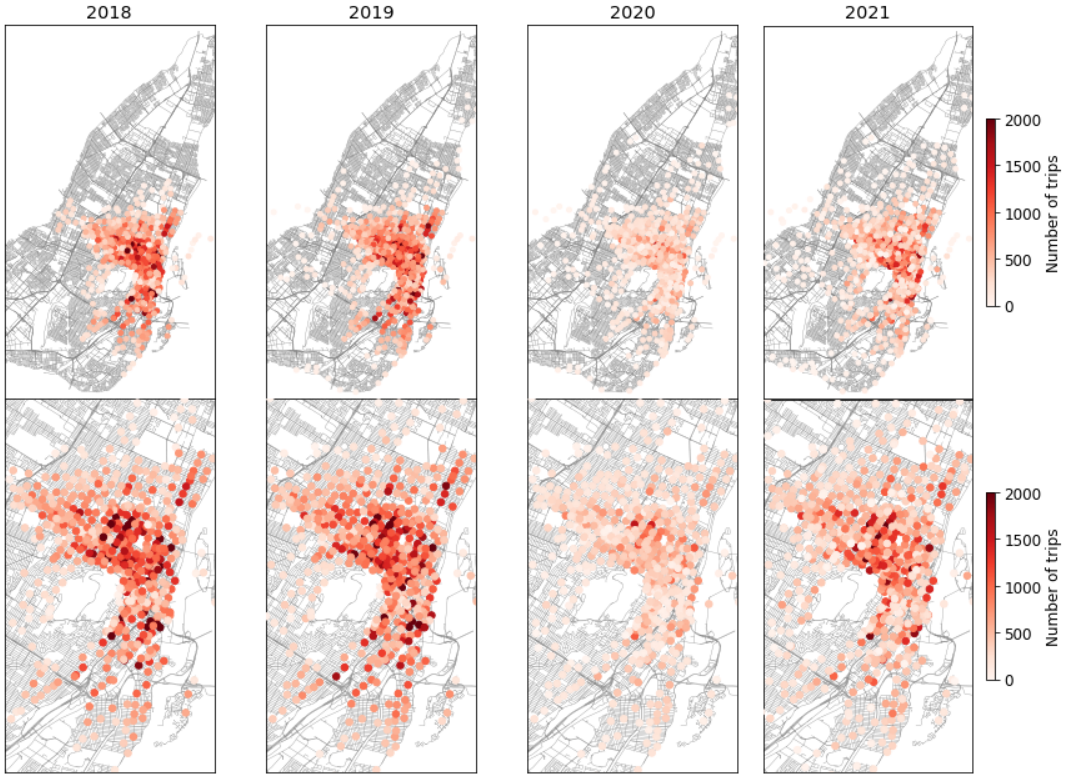


(b) Trip destinations

Figure 9: Visualization of member trips of the morning peak hour in weekday on the administrative territories of Montreal from 2018 to 2021.

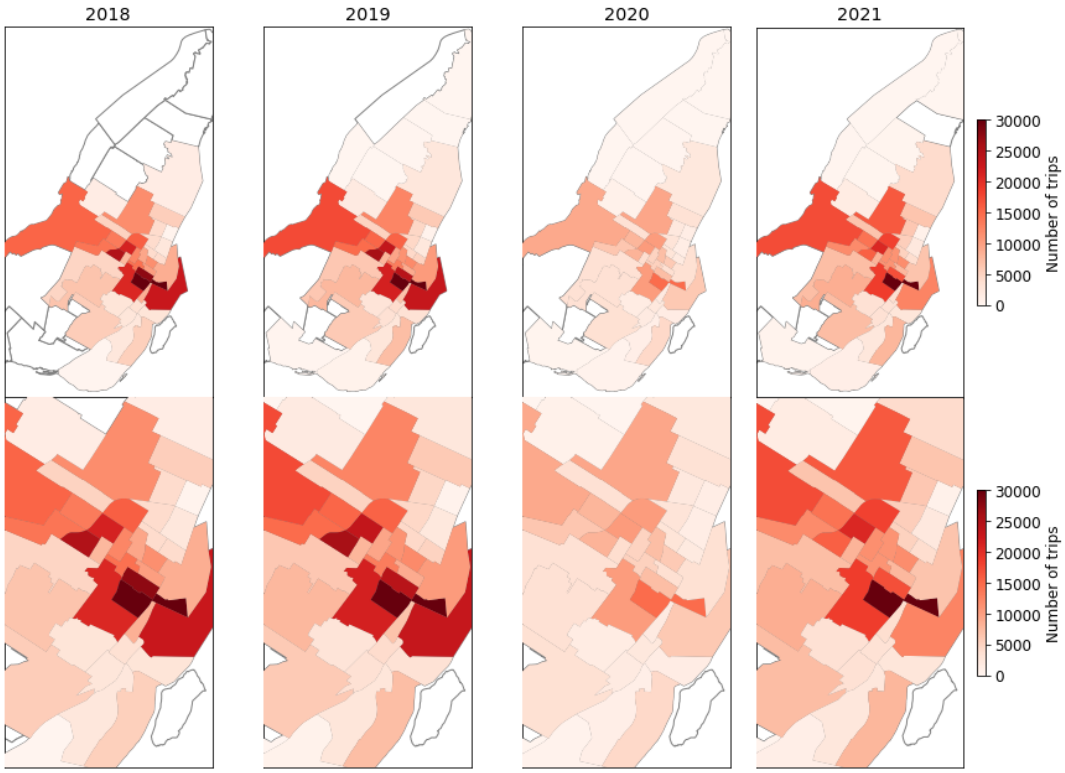


(a) Trip origins

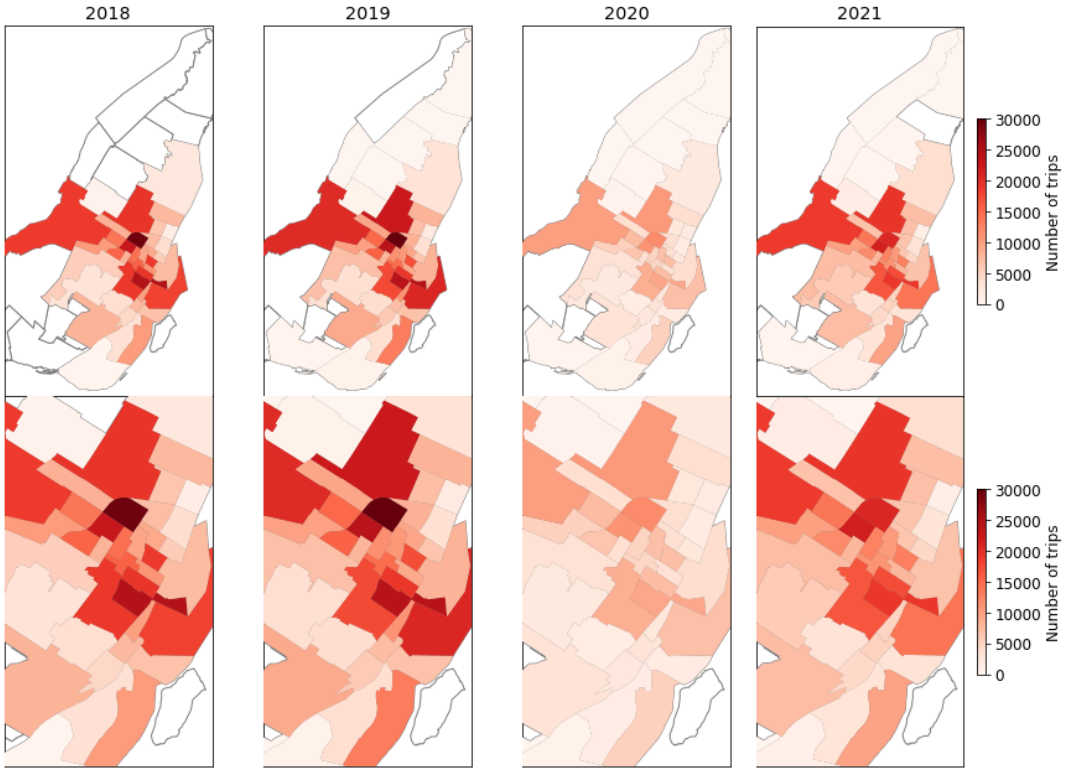


(b) Trip destinations

Figure 10: Visualization of member trips of the afternoon peak hour at weekday on the road network of Montreal from 2018 to 2021.

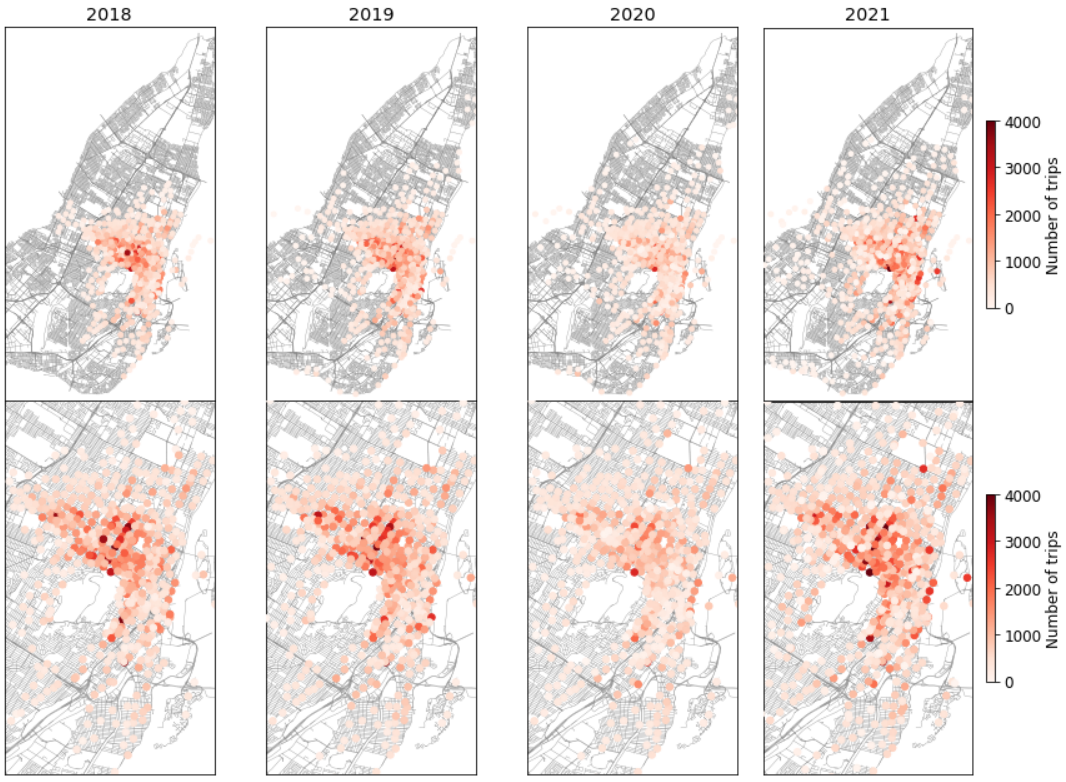


(a) Trip origins

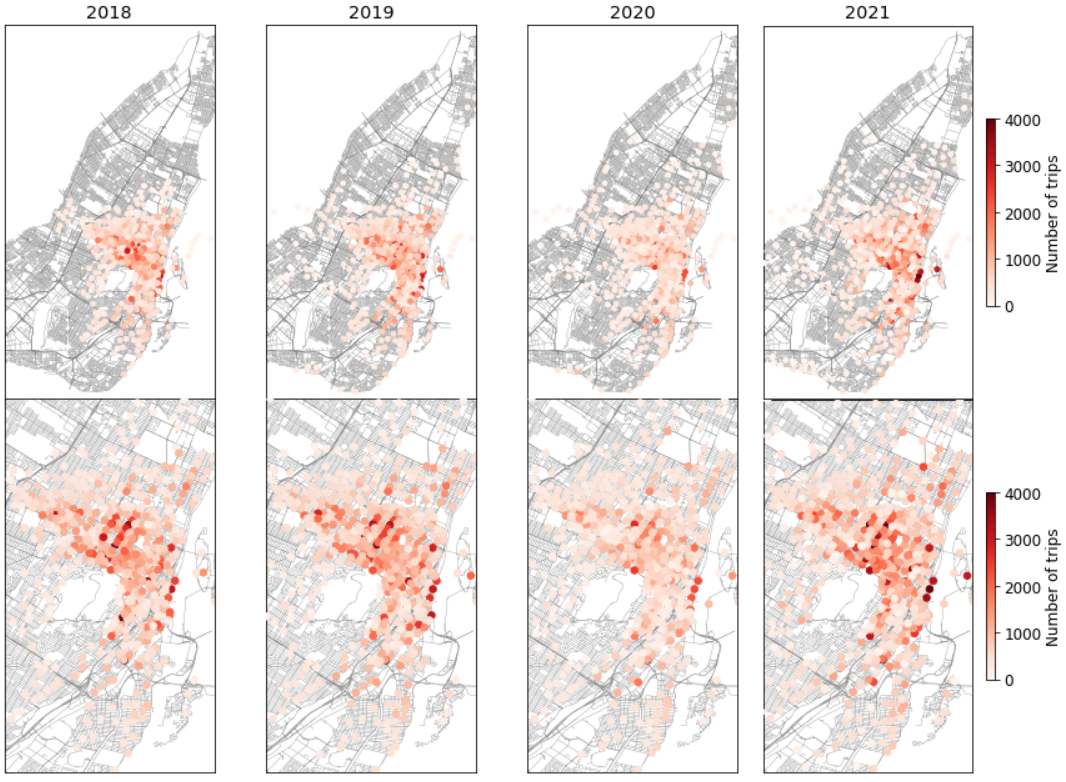


(b) Trip destinations

Figure 11: Visualization of member trips of the afternoon peak hour at weekday on the administrative territories of Montreal from 2018 to 2021.

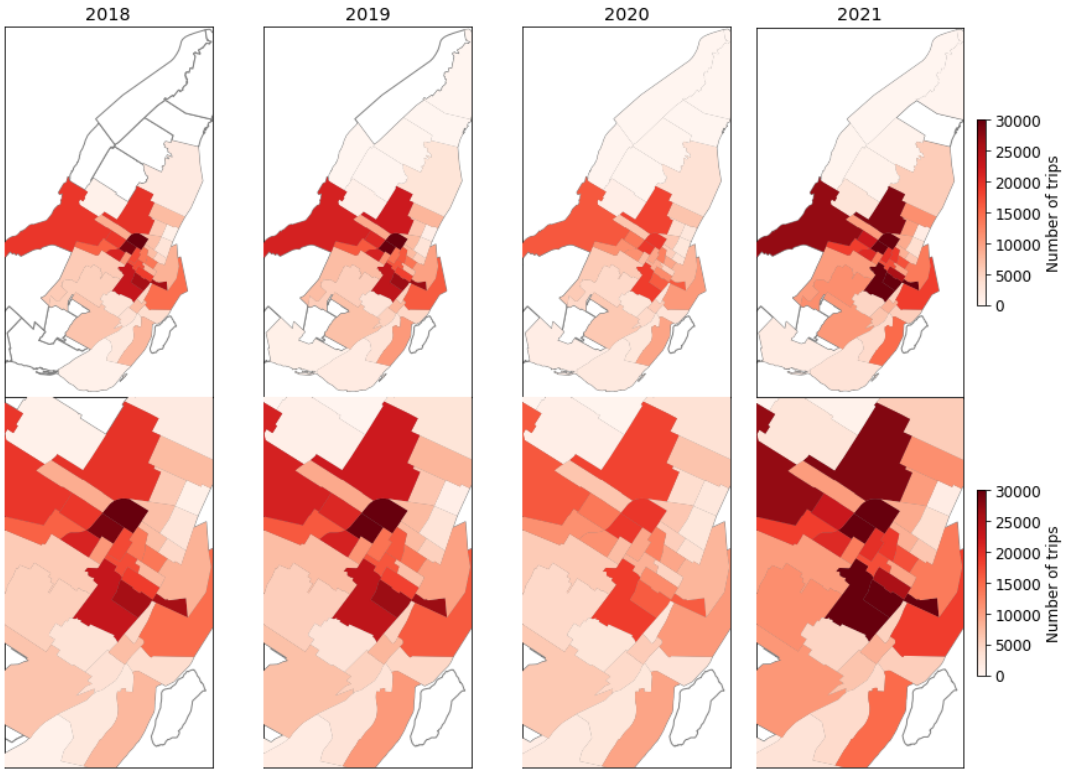


(a) Trip origins

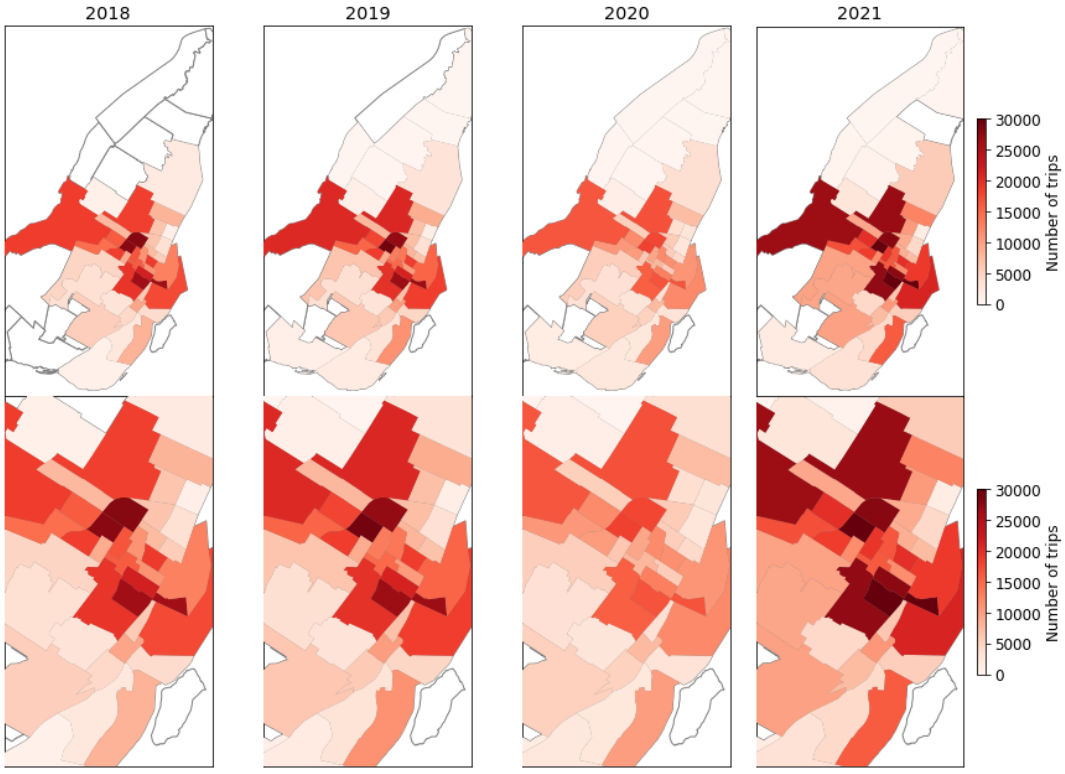


(b) Trip destinations

Figure 12: Visualization of member trips of the afternoon (12:00-18:00) at weekend on the road network of Montreal from 2018 to 2021.



(a) Trip origins



(b) Trip destinations

Figure 13: Visualization of member trips of the afternoon (12:00-18:00) at weekend on the administrative territories of Montreal from 2018 to 2021.

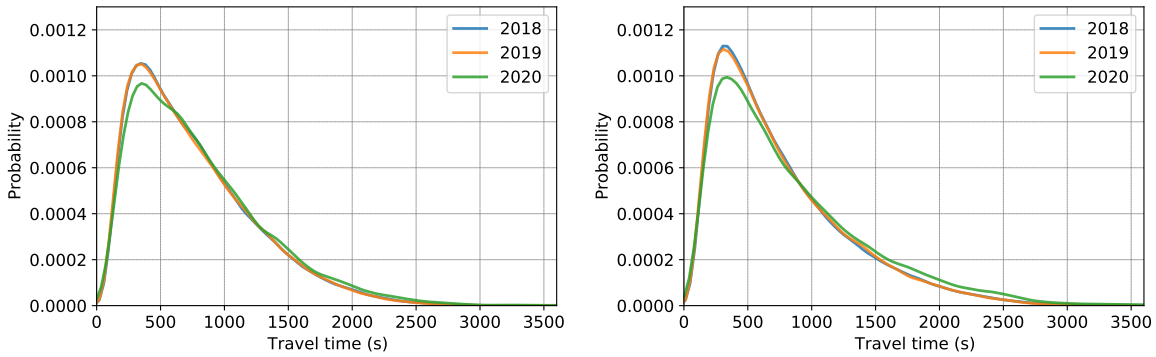
Table 3: The commuting trips of member trips (within 552 stations) at the peak hours of weekday. The trip rate indicates the trips of peak hours in total trips within 552 stations. We also include some statistic metrics such as the average travel time, standard derivation, 15% percentile, and 85% percentile.

		Trips	
		8:00-9:00	17:00-18:00
Number (ratio) of trips	2018	371,235 (8.47%)	415,217 (9.47%)
	2019	364,190 (8.50%)	413,590 (9.65%)
	2020	77,190 (3.20%)	173,608 (7.19%)
Average travel time (s)	2018	761.83	763.63
	2019	759.40	761.59
	2020	806.77	843.40
Standard deviation of travel time (s)	2018	487.54	538.44
	2019	488.84	537.76
	2020	526.83	626.56
15% percentile of travel time (s)	2018	290	275
	2019	286	270
	2020	304	283
85% percentile of travel time (s)	2018	1272	1309
	2019	1272	1310
	2020	1343	1459

that, during the COVID-19 pandemic, people are willing to ride a bike for their commuting with relatively longer distances.

To analyze the bike trips with relatively longer travel time, we filter the member trips with travel time greater than 20min and 30min of commuting in weekdays. Figure 15a and Figure 15b show the member trips with travel time greater than 20min of the morning peak hour in weekday on the administrative territories of Montreal, while Figure 16a and Figure 16b correspond to the member trips with travel time greater than 30min of the morning peak hour in weekday. Despite the significant reduction of bike trips in 2020 as shown in Figure 15a, it demonstrates similar pickup trip patterns among 2018, 2019, and 2020. As shown in Figure 15b, the dropoff trip patterns of 2020 are quite different from 2018 and 2019, and there are more highlighted areas in 2020 than 2018 and 2019. By using 30min as another threshold, Figure 16b shows more highlighted areas in 2020 that have not been highlighted in 2018 and 2019. These findings demonstrate the pattern changes of dropoff trips from 2018 to 2020.

For the afternoon peak hour, the member trips are visualized in Figure 17a, Figure 17b, Figure 18a, and Figure 18b, respectively. By using the travel time threshold as 20min, the pickup trip patterns of 2020 are quite different from 2018 and 2019, and we can see more highlighted areas in 2020 than 2018 and 2019. However, the dropoff trip patterns of 2020 do not show any great differences. These findings can also be observed in Figure 18a and



(a) Morning peak hour

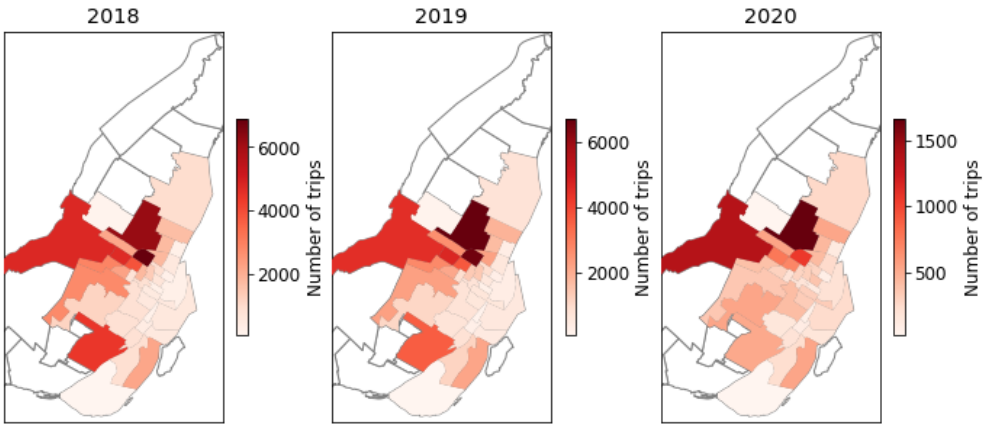
(b) Afternoon peak hour

Figure 14: Histograms of travel time of member trips (within 552 bikeshare stations) of two peak hours in weekday. Here, we identify 8:00-9:00 and 17:00-18:00 as the morning peak hour and the afternoon peak hour, respectively.

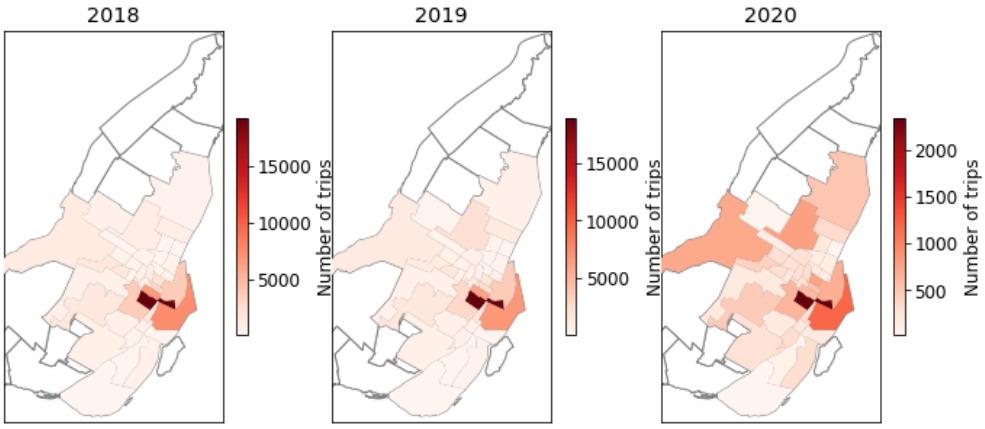
Figure 18b for the travel time greater than 30min. Therefore, we can summarize the pattern changes of pickup trips from 2018 to 2020.

5 Conclusion

In this report, we give a thorough empirical analysis for identifying mobility pattern changes before and during the COVID-19 pandemic on open bikeshare data in Montreal. Through processing data, there are about 80% trips that are created by members, and these member trips are representative for exploring the mobility change before and during the COVID-19 pandemic. By analyzing commuting trips in the peak hours of weekday, it demonstrates that there are more people that are willing to cycling for the afternoon peak hour than the morning peak hour in 2020 and 2021. The average travel time of member trips for commuting and weekend's cycling in 2020 and 2021 is greater than both 2018 and 2019. Both trips and average travel time of 2018 and 2019 do not show any differences, which demonstrate no mobility pattern change over two years. By conducing spatial analysis, It is not hard to conclude that the pandemic leads to a sequence of mobility changes over commuting and attitude for healthy lifestyle. This report provides an empirical analysis for bikeshare system in Montreal and reveals some findings of cycling behavior, and it can help decision-making processes in the bikeshare system.

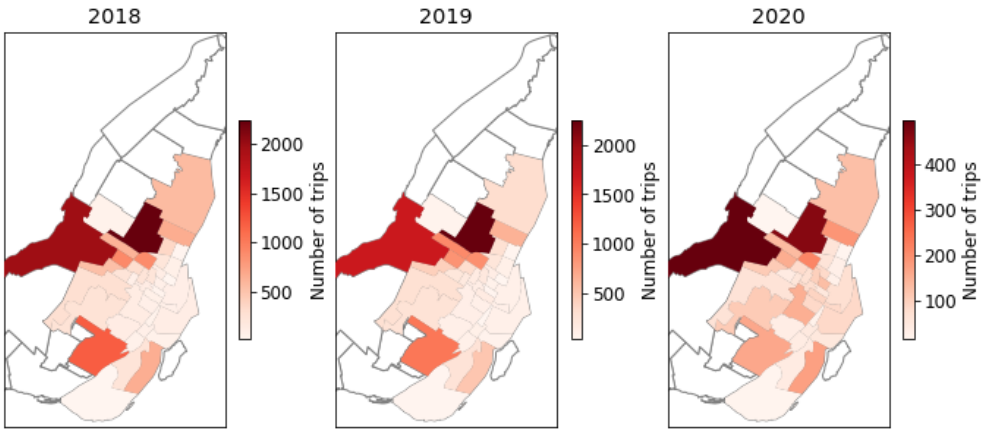


(a) Trip origins

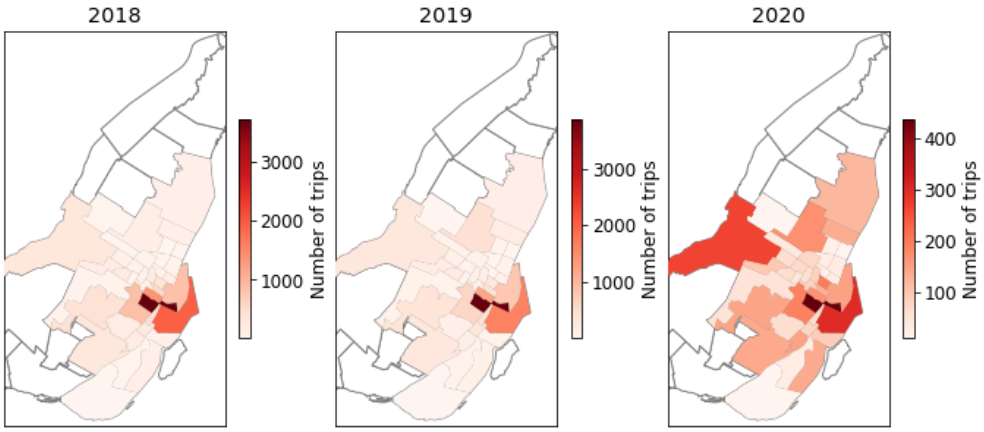


(b) Trip destinations

Figure 15: Visualization of member trips with travel time greater than 20min of the morning peak hour in weekday on the administrative territories of Montreal from 2018 to 2020.

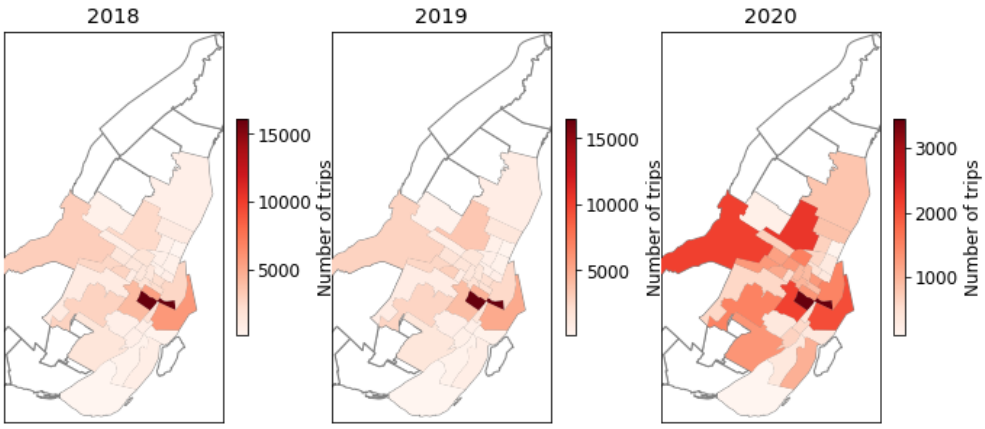


(a) Trip origins

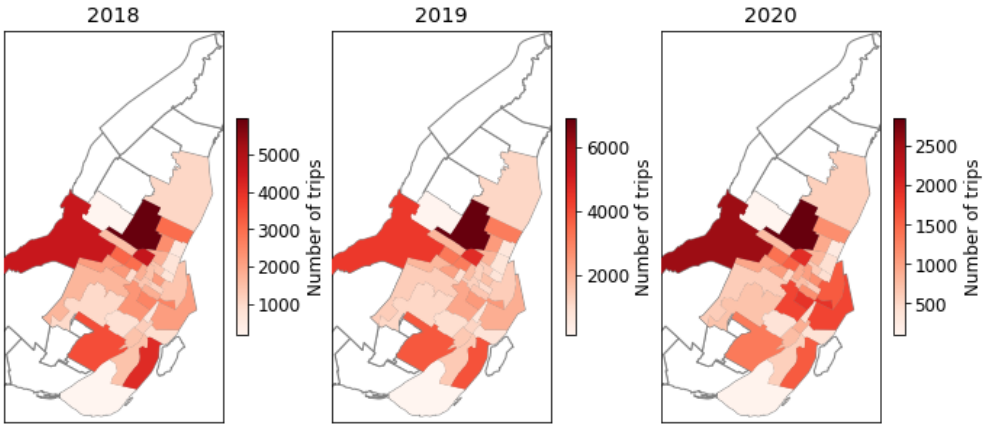


(b) Trip destinations

Figure 16: Visualization of member trips with travel time greater than 30min of the morning peak hour in weekday on the administrative territories of Montreal from 2018 to 2021.

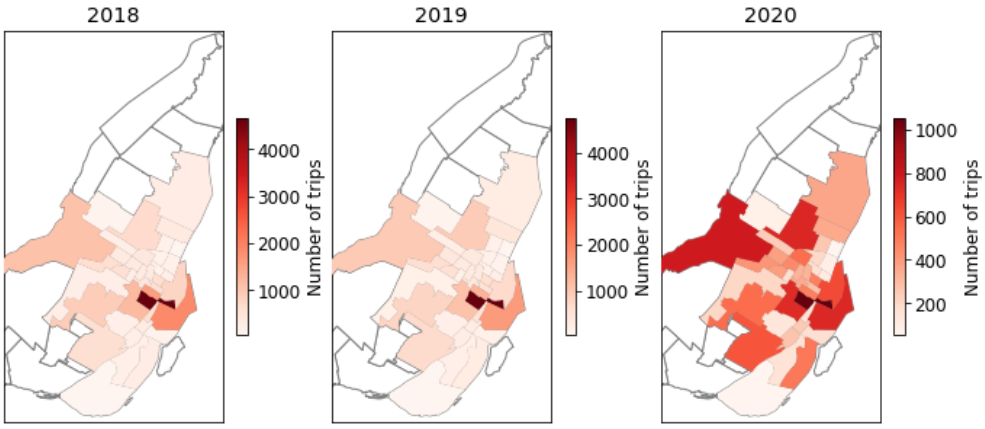


(a) Trip origins

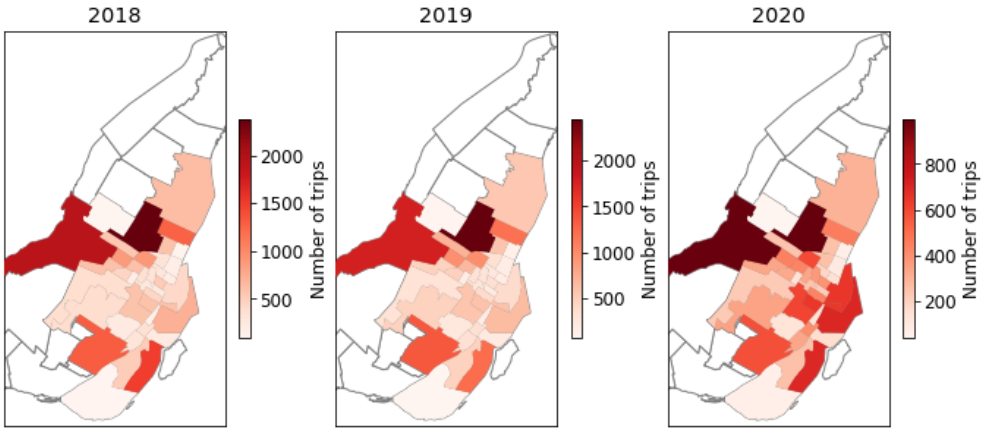


(b) Trip destinations

Figure 17: Visualization of member trips with travel time greater than 20min of the afternoon peak hour in weekday on the administrative territories of Montreal from 2018 to 2020.



(a) Trip origins



(b) Trip destinations

Figure 18: Visualization of member trips with travel time greater than 30min of the afternoon peak hour in weekday on the administrative territories of Montreal from 2018 to 2021.

Appendix

Supplementary Material

- Geobase of the road network in Montreal is available at https://donnees.montreal.ca/ville-de-montreal/geobase.
- Open Montreal transport data is available at https://donnees.montreal.ca/collections/transport.
- Counts of bicycles of cycle lanes are available at https://donnees.montreal.ca/ville-de-montreal/velos-comptage.
- GeoPandas 101: Plot any data with a latitude and longitude on a map: https://towardsdatascience.com/geopandas-101-plot-any-data-with-a-latitude-and-longitude-on-a-map-98e01944b972

Acknowledgement

Xinyu Chen would like to thank the following researchers for providing helpful discussion:

- Zhanhong Cheng (Ph.D., McGill University): Suggestion for Geospatial data visualization tools.
- Xiaowei Gao (Ph.D. student, University College London): Discussion about possible directions for exploring cycling behaviors.

References

Büchel, B., Marra, A. D., Corman, F., 2022. Covid-19 as a window of opportunity for cycling: Evidence from the first wave. Transport policy 116, 144–156.

Chibwe, J., Heydari, S., Imani, A. F., Scurtu, A., 2021. An exploratory analysis of the trend in the demand for the london bike-sharing system: From london olympics to covid-19 pandemic. Sustainable Cities and Society 69, 102871.

Doubleday, A., Choe, Y., Busch Isaksen, T., Miles, S., Errett, N. A., 2021. How did outdoor biking and walking change during covid-19?: A case study of three us cities. PLoS one 16 (1), e0245514.

Kraus, S., Koch, N., 2021. Provisional covid-19 infrastructure induces large, rapid increases in cycling. Proceedings of the National Academy of Sciences 118 (15), e2024399118.

Li, A., Zhao, P., Haitao, H., Mansourian, A., Axhausen, K. W., 2021. How did micro-mobility change in response to covid-19 pandemic? a case study based on spatial-temporal-semantic analytics. Computers, Environment and Urban Systems 90, 101703.

Li, W., Wang, Q., Liu, Y., Small, M. L., Gao, J., 2022. A spatiotemporal decay model of human mobility when facing large-scale crises. Proceedings of the National Academy of Sciences 119 (33), e2203042119.

Matekenya, D., Espinet Alegre, X., Arroyo Arroyo, F., Gonzalez, M., 2021. Using mobile data to understand urban mobility patterns in freetown, sierra leone.

Osorio, J., Liu, Y., Ouyang, Y., 2022. Executive orders or public fear: What caused transit ridership to drop in chicago during covid-19? Transportation Research Part D: Transport and Environment 105, 103226.

Padmanabhan, V., Penmetsa, P., Li, X., Dhondia, F., Dhondia, S., Parrish, A., 2021. Covid-19 effects on shared-biking in new york, boston, and chicago. Transportation research interdisciplinary perspectives 9, 100282.

Teixeira, J. F., Lopes, M., 2020. The link between bike sharing and subway use during the covid-19 pandemic: The case-study of new york's citi bike. Transportation research interdisciplinary perspectives 6, 100166.

Teixeira, J. F., Silva, C., e Sá, F. M., 2021. The motivations for using bike sharing during the covid-19 pandemic: Insights from lisbon. Transportation research part F: traffic psychology and behaviour 82, 378–399.

Wang, H., Noland, R. B., 2021. Bikeshare and subway ridership changes during the covid-19 pandemic in new york city. Transport policy 106, 262–270.