BIKEWALK
TOMPKINS

2019 LIME TRIP DATA ANALYSIS

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Prepared by

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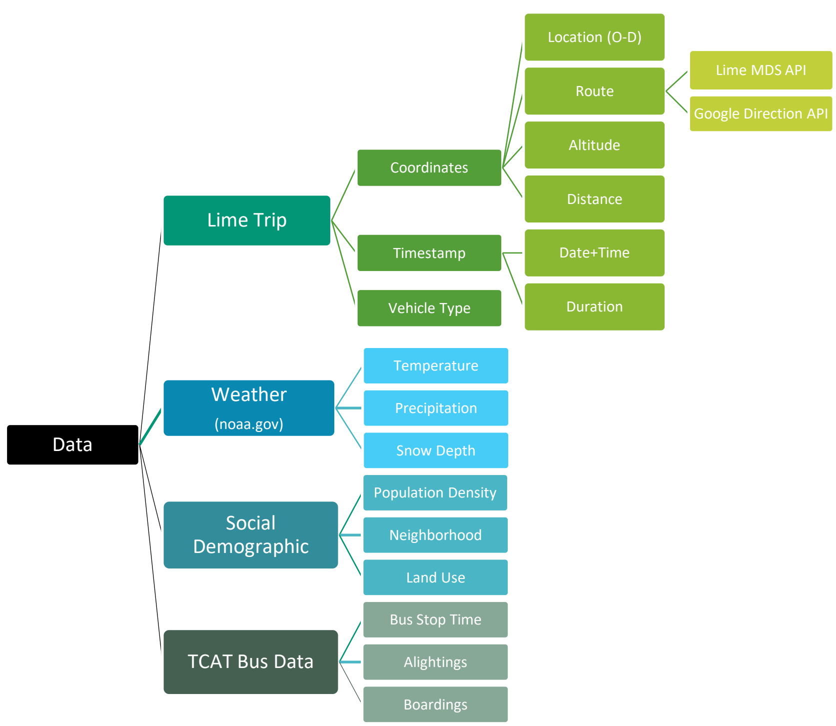
for Bike Walk Tompkins

ABOUT THE DATA

Lime provides trip data exports for all bicycle rides in Ithaca to the City of Ithaca and Bike Walk Tompkins. The data export records the following information for each trip: a unique trip ID number, start coordinates (latitude and longitude), start date and time, end coordinates, end date and time, an estimation of travel duration, and an estimation of distance traveled. **Trip data is devoid of info identifying the user of the bike and the specific bike that was used.** To confirm the integrity of the data, we cross-referenced trips made by Lime users as recorded on the consumer app to the trip data provided by the company. Lime collects GPS and timestamp data from two sources: the GPS module integrated into the lock as well as the user's smartphone. **By cross-referencing trips, we were able to determine that start/end coordinates and time are highly accurate** because they are sourced from the bike's lock. Distance travelled data is not as accurate because it is sourced from users' smartphones. **Therefore, this analysis only uses coordinate data and time data corrected to match Eastern Time.**

Lime separates data exports by **vehicle type**, so this study is able to determine whether a trip was made on a "pedal" bike or "e-bike". Using **time** data, we calculated the duration of each trip and whether the trip was made before they paused the operation on March 17, 2020 due to COVID19. Using **date** data, we also joined weather information including average temperature, precipitation and snow depth with each trip to investigate the impact of weather on Lime bike activity. Furthermore, using **coordinate** data, we calculated the trip distance as the crow flies, the start and end altitude above sea level, and the intersecting census block. This allowed us to determine whether someone rode uphill or downhill and what point of interest, neighborhood, municipality, and county they started and ended their trip. Notably, for **bicycle routes analysis**, Lime MDS API provides **route** data with coordinates and timestamps at each route node for all trips after 2019 Nov 21. For trips before 2019 Nov 21, we inquired the most recommended bicycle route with Google Routing API by setting travel mode as bicycle given each trip's starting and ending locations. Thus this study completed collecting route data for all trips in 2019 to inform how Lime bike activities influenced road traffics. Lastly, for **TCAT Bus-Lime linkage analysis**, bus information in 2019 was provided by TCAT. TCAT bus data including six million records of bus stop details, including the date and time of each stop, with numbers of alighting and boarding passengers for each stop. Join TCAT data with Lime rides data, we were able to estimate the linkage between TCAT and Lime activities. Figure 1 describes the data source, data type and variables.

Figure 1 – Hierarchy of Data Provided by Lime and Data Computed for This Analysis



The data was imported into open sourced Python and QGIS program for analysis. There were 127,999 individual trip records for Lime's vehicles (Lime-E and Pedal) across the Southern Tier between 2019-Jan-1 and 2020-Mar-17 before Lime stopped their operation due to COVID19. 2019 saw 122,617 individual trips and 2020 saw 5,382 individual trip records. For this analysis, we filtered for rides that (1) were in 2019 and (2) started or ended within Tompkins County, which brought the number of records down to 120,751. Lastly, we also filtered out rides that were likely to be short "test rides," defined as all rides that (1) have start and end locations less than **0.05 miles** apart (i.e. the length of an average Ithaca city block) and (2) with a trip duration of less than **3 minutes**. **This leaves us with 100,300 trips to analyze, which is Bike Walk Tompkins' best estimate for the number of rides (ridership) for the Lime system in Tompkins County in 2019.**

Figure 2 - Tompkins County and Municipalities

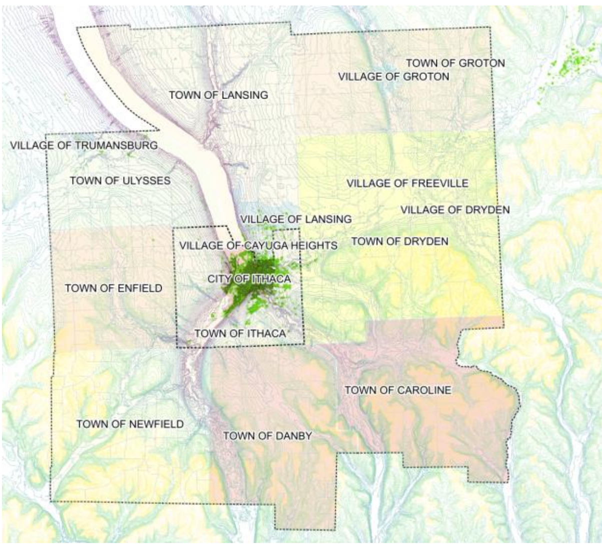


Table 1 – Study Area and Data Filtered

Data Selection	**Total Rides**
All trips between 2019-1-1 to 2020-3-17	127,999
Trips in 2019	122,617
Within Tompkins County	120,751
Longer than 3 minutes and 0.05 mile	100,300

ANALYSIS OF TRIPS BY TRIP START AND END TIME

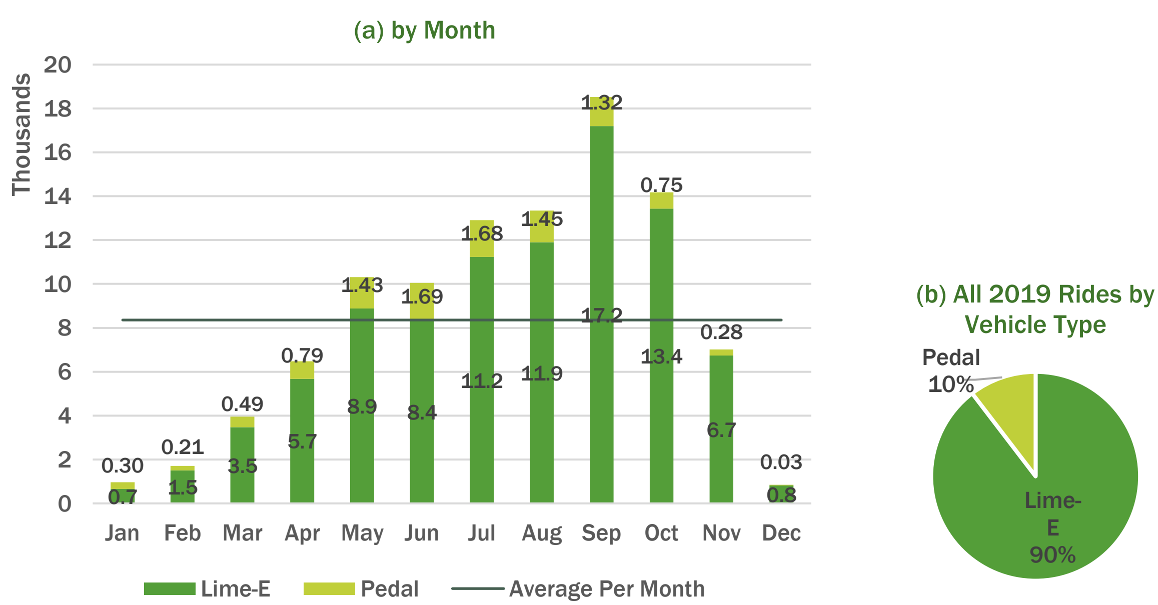
MONTHLY RIDERSHIP

Bicycling use is affected by the seasons, and Lime ridership fluctuation followed the seasons of Ithaca closely. In 2019, Lime had an average ridership of around 8,360 rides per month throughout the year, however its distribution in the four seasons varied a lot. **Figure 3.a** shows that from the starting of Spring (March), the average monthly ridership increased rapidly from about 4,000 to 10,000. During the summer from June until August, the average monthly ride increased to about 12,000. Considering many students had left town for the summer, this ridership is surprisingly high. **In Autumn, with the return of students to Ithaca, Lime's ridership reached its peak at 18,500 in September, increased by about 50% compared to that of summer.** Since October the return of cold weather dramatically brought ridership down to less than 1,000 in December.

Meanwhile, there are two types of bike operated in 2019, namely the Lime-E and Lime Pedal. The former is assisted with electric power while the latter is without electric power and manually ride by manpower. In total there are about 220 Lime-E (only 80-100 in Winter) actively put into operation through the year, while there are about 50 pedal bikes (20 in Winter), of which the number is higher during the summer. **As a result, in Ithaca there are about 20% bikes are pedal and 80% are electric.** Figure 3.b shows that **the ridership between electronic and pedal bikes is not to the proportion of their operation amounts. Though being cheaper, pedal bikes are less popular**, there are only 10,420 rides with pedal bike, contributing to 10% of total trips in 2019. **People prefer the electric bike despite its higher charge per ride.** There are 89,880 rides on Lime-E, constituting 90% of total rides.

In summary, higher ridership figures in the Summer and first half of Fall were likely influenced by ideal weather for bicycling. Lower ridership figures in the latter half of Fall and Winter of the year were likely influenced by less ideal weather, of which a small portion was explained by fewer available bicycles, as more of the fleet (both Lime-E and Pedal) was put into storage during winter.

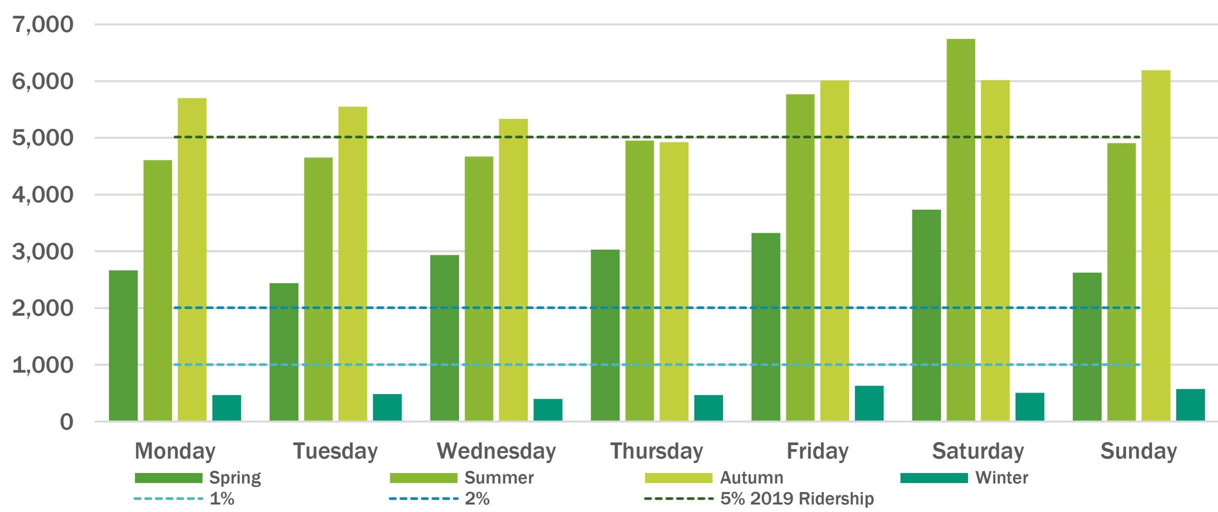
Figure 3 – All 2019 Rides by Month and Vehicle Type.



DAY OF WEEK RIDERSHIP

During summer months, **the Lime system in Tompkins County averaged between 400-450 rides per day**, with a slight increase in rides on weekend days compared to weekdays (see Figure 4). During the fall semester, while the average rides per day increased slightly to **between 450-500**, the most popular days to ride are also on the Fridays and weekends, with a noticeable increase on Sunday. The highest totals for the days of the week during the fall semester can be accounted by the highest ridership from September through October.

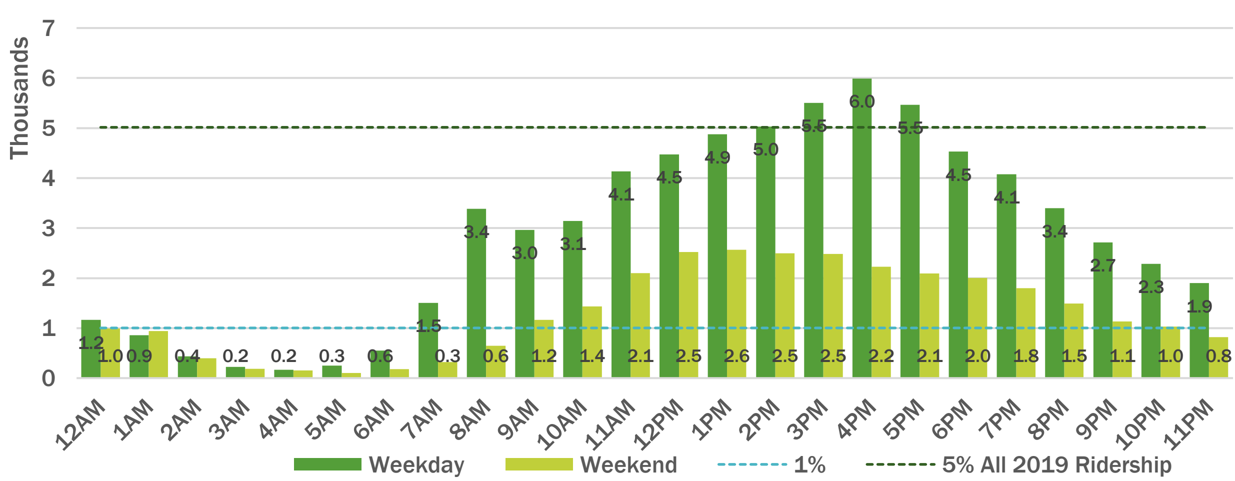
Figure 4 – All 2019 Rides by Day of Week and Season



TIME OF DAY RIDERSHIP

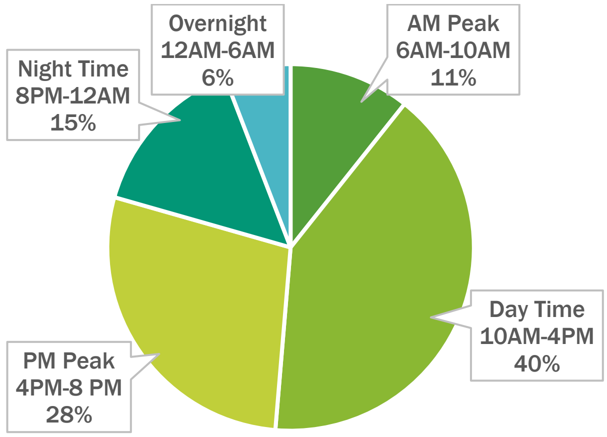
Weekday and weekends see different peak patterns. The weekday peak is at 4 PM while there is no clear sign of AM-peak, although 8AM sees most rides in adjacent hours. This is partially because Lime users can take Lime bike trips one-way. On weekends, activity peaks at 1 PM and steadily decreases after that. Activity after midnight is minimal but still existent, even at 4 AM. Midnight activity between 3AM to 5AM only add up to less than 1,200 trips, accounting for less than 1.5% of total trips. Activity starts to picks up again at 7 AM.

Figure 5 – All 2019 Rides by Hour of Day and Weekday/Weekend



Combining weekday and weekend trips, we see daytime trips between 10AM to 4PM contribute to 40% of all 2019 trips, followed by PM peak (4PM-8PM) during which 28% trips are made. Surprisingly, **night time sees 4% more Lime rides compared to AM peak**. Lastly, overnight rides are still non-negligible, constituting 6% of all rides.

Figure 6 - Distribution of All 2019 Rides by Time of Day



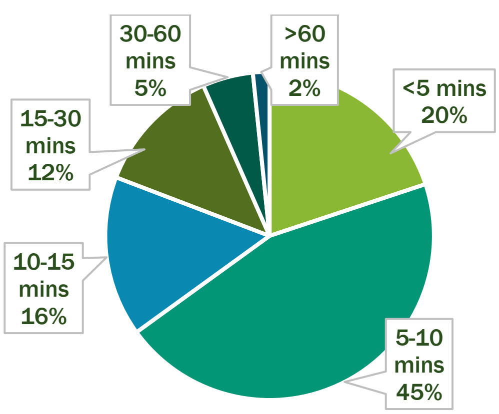
TRIP DURATION

Looking at trip duration data by seasons, by weekday/weekend and by bike types on Figures 7 and 8, there are very distinct patterns in the cycling behaviors. **First, more than 65% trips are shorter than 10 minutes, indicating that a majority of Lime bike trips are highly likely for non-recreational purpose.** Among these short-duration segment, 45% of total rides in 2019 are within 5-10 minutes, and 20% are within 5 minutes, followed by 10-15 minutes trips (16%) and 15-30 minutes trips (12%). **In total trips within half an hour contribute to more than 93% of total rides.** To our surprise, 5% trips are longer than 30 minutes, and 2% are even longer than an hour. We presume these long-duration trips are recreational rides, with a very small portion being cases when the users forget to lock their bikes after a trip (Figure 7a).

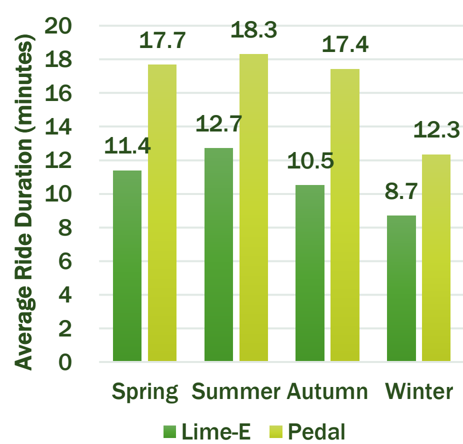
Second, Figure 7.b shows that rides on pedal bikes are 6 minutes longer than those on electric bikes. In next section we will illustrate that the average distance travelled by pedal bike and Lime-E is similar, indicating that **pedal bike users do not necessarily travel longer, instead, they just travel slower.** Moreover, the trip duration in summer is the longest. On average they are 50% longer than rides in winter for both pedal and electric bike rides, indicating that **weather is a significant factor not only influence how many people would use Lime bike, but also how people would use bikeshare.**

Figure 7 – Distribution of All 2019 Lime Rides by Trip Duration

(a) Distribution of All 2019 Trip Durations



(b) Average Trip Duration by Season



Third, in terms of trip duration, there is a clear right-skewed curve with a peak at the 4-minute mark, for both weekday and weekend rides (Figure 8). **The median trip duration is about 7 minutes while the average trip duration is about 12 minutes. The reason for this discrepancy in averages versus medians, as well as the right-skewness of the charts, is due to the higher number of longer rides during the summer and fall.** Table 2 demonstrates this tendency for longer bike rides in summer and fall. It also shows that rides on the electric bikes usually take less time than those on a pedal bike, a pattern also shown in Figure 7b. Presumably, electric bikes travels faster than pedal bikes which are relied on manpower, thus share shorter travel duration on average.

Figure 8 – Distribution of All 2019 Rides from 0 to 30 Minutes

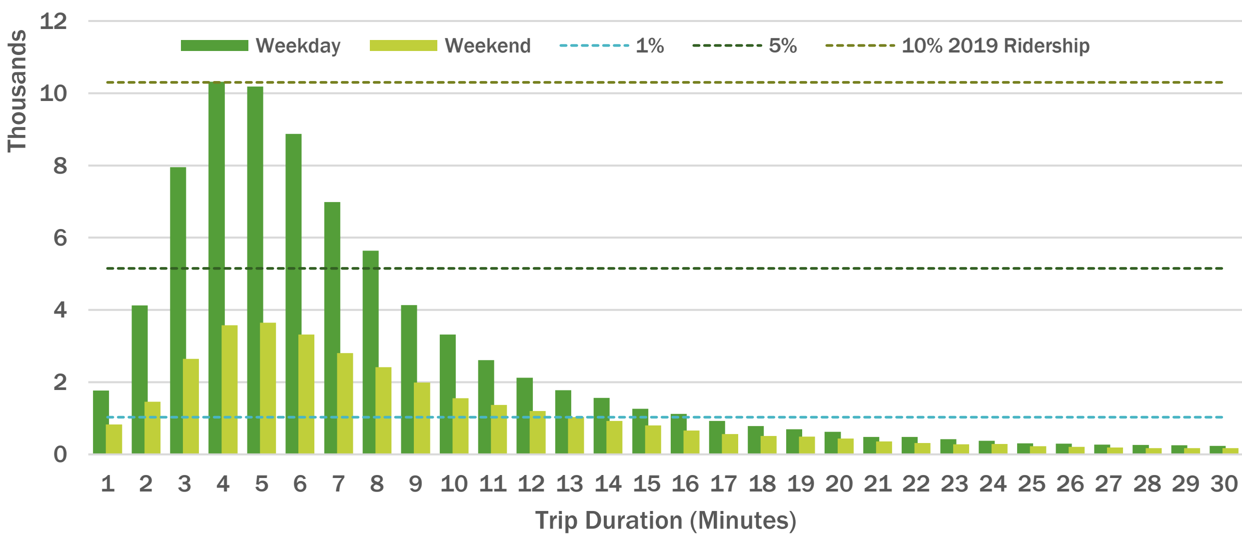


Table 2 – Average Duration of All 2019 Rides by Season (Minutes)

SEASON	Vehicle	Mean	Median	Most Frequent
Spring	Lime-E	11.4	6.8	4.0
	Pedal	17.7	9.8	6.8
Summer	Lime-E	12.7	8.0	5.0
	Pedal	18.3	11.0	6.0
Autumn	Lime-E	10.5	7.0	5.0
	Pedal	17.4	10.0	4.0
Winter	Lime-E	8.7	6.0	5.7
	Pedal	12.3	8.2	9.5
2019 Average	Lime-E	10.9	7.0	4.0
	Pedal	17.0	10.0	5.0
	Both Types	12.3	7.4	5.0

WEATHER

As ride durations and ridership are affected by the seasonality, we start to looking at how specific weather variables, such as temperature, snow depth and precipitation, would influence ridership and travel distance.

First, higher temperature is associated with increased ridership, such a positive effect is stronger in electric bike segment than that of pedal. For example, Lime-E ridership increases faster than pedal ridership when temperature increases from 0F to 68F. Conversely, Lime-E ridership also decreases faster when the temperature continues to increase from 50F to 86F. That said, electric bike users are more sensitive to temperature changes than pedal bike users do. One assumption is since Lime-E charges more than pedal bike, its users are likely to be less sensitive to price but more sensitive to the comfortableness of a given service. As another illustration, in the extreme cold days (0-32F), pedal bike rides have both higher ridership and longer average distance compared to that of electric bike trips.

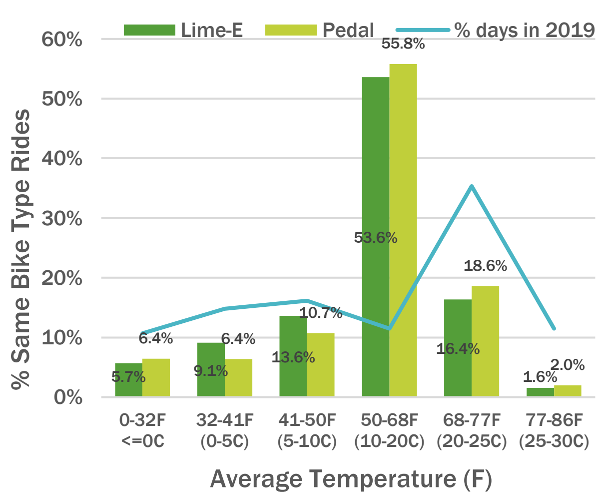
Second, **a small group of people consistently rely on pedal bikes even in Winter.** For example, there are 6% rides when the temperature is below 32F (0C) in both bike types, with an average distance per ride at about 0.6 miles. It indicates that **people still rely on Lime bike to make short distance trips even in freezing weather. Additionally, the ridership of pedal bike for the temperature segment of 0-32F and 32-41F are consistently 6.4%, or on average 15 rides per day, accumulating to 1340 rides.**

Third, **while the cold temperature clearly suppresses the ridership, it seems that the warmer temperature does not induce ridership** (Figure 9.a). The largest portion of rides happen in the 50-68F temperature segment. Though it is not considerable warm and only takes about 11% of the days in 2019, or 40 days, it saw more than 50% of the total rides in 2019. One reasonable explanation could be, the amount of rides is largely due to the return of students in the Fall semester. Though the temperature in summer looks like comfortable for biking and it contributes to 35% of 365 days in 2019, it only sees about 17% of total rides. All other temperature segments saw less ridership to their proportions.

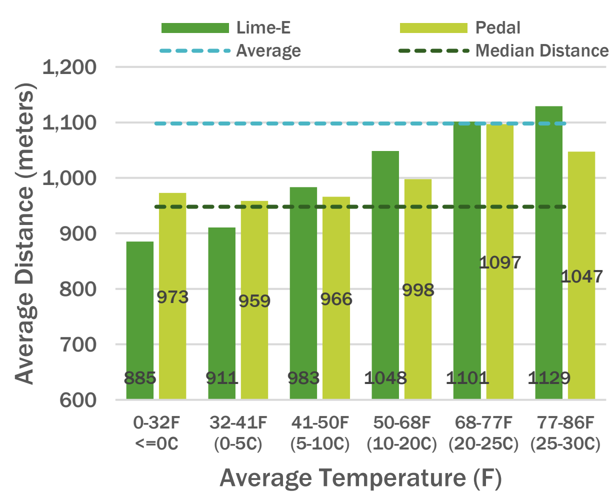
Lastly, regarding the travel distances, the average is about 0.68 while the median is 0.62 mile. As a result, there are more longer distance rides. Figure 9.b shows that the average ride in the cold weather segment is 0.12 mile shorter than the annual average. Interesting enough, pedal bike rides are 0.06 mile longer than Lime-E.

Figure 9 – Ridership and Average Ride Distance by Temperature

(a) Ridership by Temperature



(b) Mean Distance by Temperature

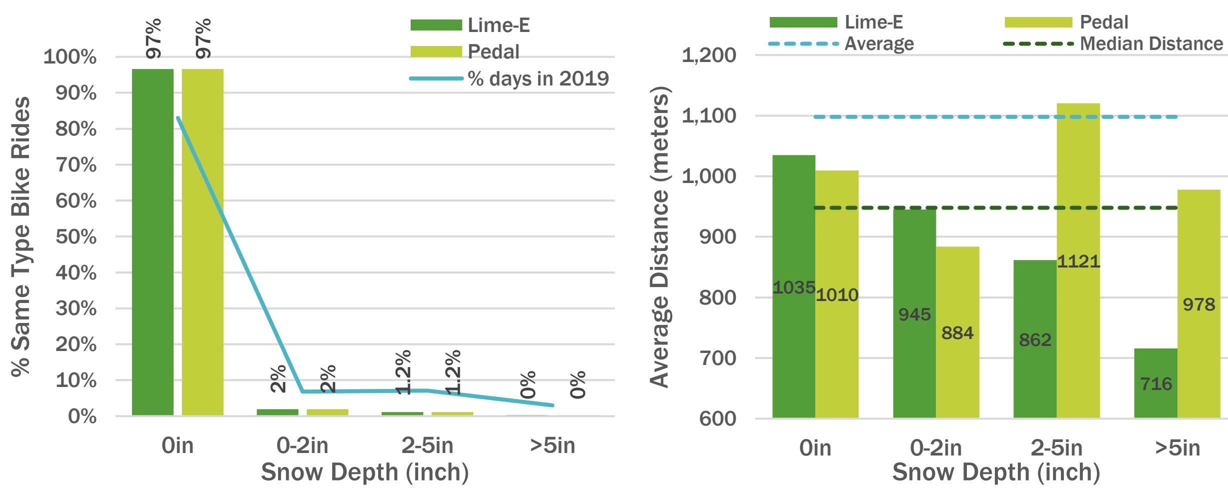


Snow is a strong indicator of bike activity and negatively influence Lime bike ridership (Figure 10). First, almost all Lime trips (96%) happen when there is no snow, sleet, or ice on the ground according to the definition of snow depth

(Figure 10.a). Second, the average distance of electric bike trips decreases rapidly when snow depth increases, being consistent with the statement that Lime-E rides are more sensitive to bad weathers. For instance, when snow depth is larger than 5 inches, the average distance for Lime-E trip is 400 meters shorter than the average trip. Third, the average distance of pedal bike trips increase in such bad weather when the snow depth is 2-5 inches or even greater than 5 inches (Figure 10.b), That said, the pattern might reveal that at least partial portion of pedal bike users consistently relied on Lime while Lime-E users behave more similar to the average users. It supports previous statement that pedal bike users are more endurable with bad weathers.

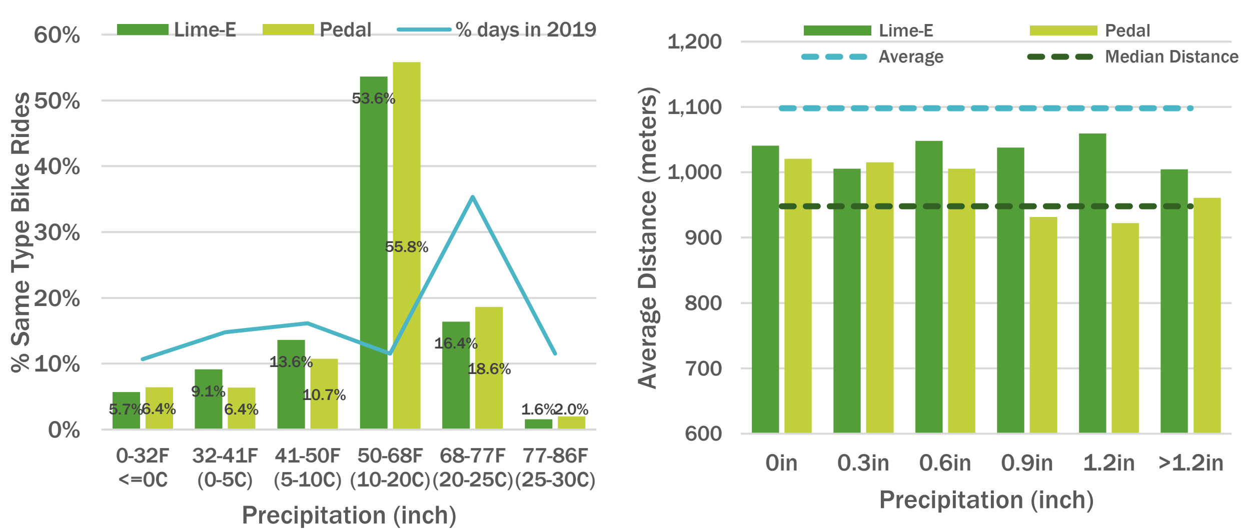
Figure 10 –Ridership and Average Ride Distance by Snow Depth

(a) Ridership by Snow Depth (inch) (b) Average Distance by Snow Depth (inch)



Precipitation also negatively affect Lime ridership with a smaller magnitude compared to snow. More than half of the rides (about 55%) in 2019 happen when there is no rain, and about one third happen when the rain is minor less than 0.3 inch. Unlike snow depth, rain influences the average distance of pedal bike rides greater than that of eletric bike rides. In other words, pedal bike users are more sensitive to rainy weather than eletric bike users.

Figure 11 – Ridership and Average Ride Distance by Precipitation



ANALYSIS OF TRIPS BY START AND END COORDINATES

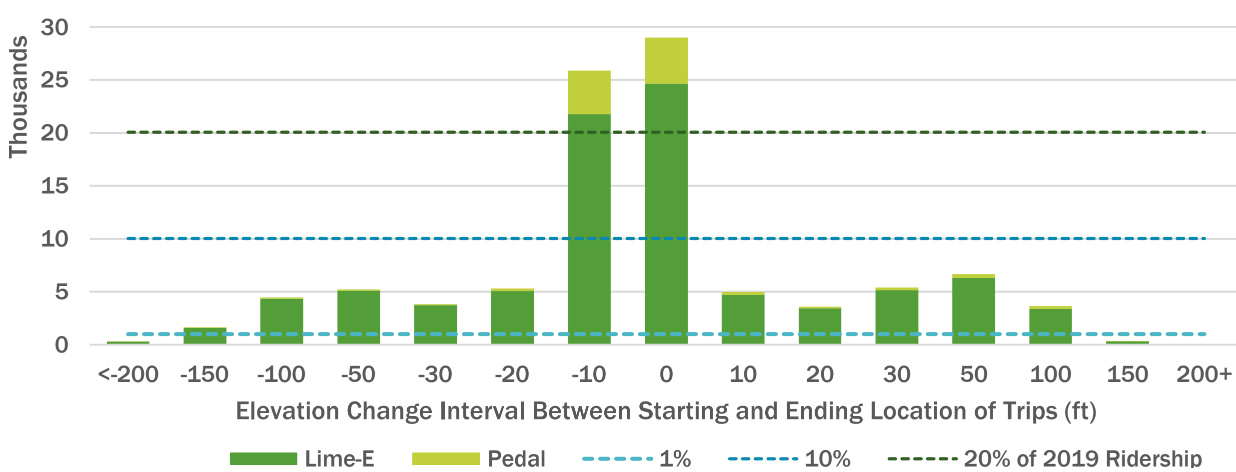
ELEVATION CHANGE

The topography in Ithaca Urbanized Area is not easy for cyclist. For reference, the elevation change from downtown to Stewart Avenue is 170 feet, followed by 260 feet to Eddy St, and 325 feet to College and Dryden (see Table 2). The introduction of Lime-E pedal-assist electric bikes in 2018 was to address the difficulty of bicycling up the steep hills of Ithaca. **First, most Lime riders did not use the bikes to go up or down Ithaca's steep hills, and there are more going down trips than going up rides.** More than 70% of rides went up or down less than 20 feet in elevation change. As another illustration, the rides with absolute elevation change for less than 10 feet (-10 to 10 feet) constitute about one third of the total ridership (Figure 12). Second, **while there are more trips going downhill than uphill, 2019 data also shows that in Lime-E segment, the discrepancy of the ridership between downhill trips and uphill trips was smaller than that of Pedal bike segment, indicating that Lime-E increase riders mobility against the slopes.** Among Lime-E rides that changed 50-100 feet in elevation, there were more uphill trips than downhill.

Table 3 - Comparison of Elevation Above Sea Level and Change in Elevation

Intersection	Elevation (ft)	Change
Buffalo at Aurora	410	-
University at Ithaca City Cemetery	465	55
Buffalo at Stewart	580	170
College at Mitchell	650	240
Buffalo at Eddy	670	260
College at Dryden	735	325
Cornell Arts Quad	805	395
Five-Point Intersection (Rt 366)	845	435
East Hill Plaza	935	525

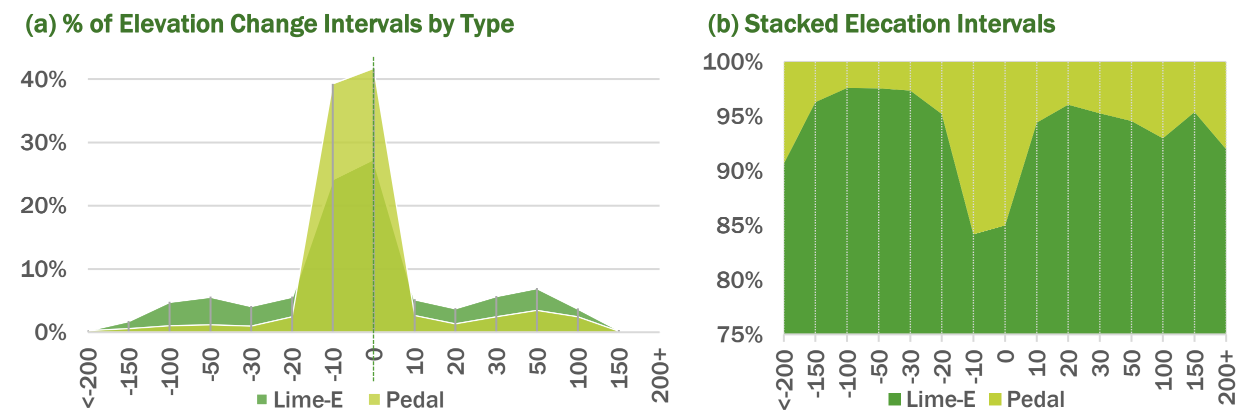
Figure 12 – All 2019 Rides by Elevation Change Intervals (Counts)



The electric bike non-negligibly increases riders mobility against the slopes. First, comparing electronic and pedal bike users, the latter has rides that are more concentrated on flat elevation change interval segments than the former. To be more specific, about 80% of pedal bike rides go up or down for less than 10 feet in their pick-up and drop-off elevation change, while the percentage for Lime-E rides is only 50% (Figure 13.a). Second, more than 10%

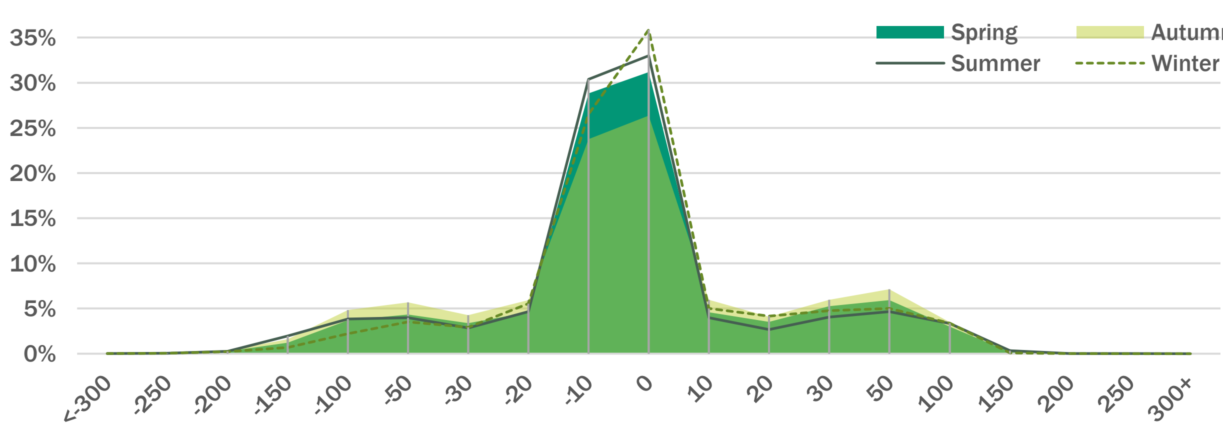
Lime-E trips go up or down for more than 50 feet, while the percentage for its pedal counterpart is less than 5%. In other words, **electric bike trips have wider range of elevation change interval, indicating that Lime-E bikes increase people's mobility against the terrain in Tompkins County.** The stacked diagram in Figure 13.b reveals how electronic bike helps people move around against the slops in a very clear way. Within the 20-200 feet elevation change segments, Lime-E rides contributes to **more than 95% of the total trips**. Considering that the total ridership between Lime-E to Pedal is 90% and 10%, it is fair to say that electric bike is more popular when dealing with slopes. Third, it is also interesting to see more pedal bike users going up than going down, since the percentage of 30-100 feet segment is much higher than that of -30 to -100 feet segment. Our hypothesis is that pedal bikes are lighter so people may intuitively thought they are easier to climb slopes.

Figure 13 – 2019 Rides by Elevation Change Intervals (Percentage)



There is also a seasonality in the elevation changes. **Autumn has the largest ridership of steep-slope rides, followed by Spring and Summer.** In 2019 Fall, more than 25% of the rides in 2019 climb up or go down in the 20-200 feet interval. **Winter has the least percentage of steep slope rides.** Our hypothesis is that during the fall and spring semesters, Cornell students are back. Given the topography of Cornell campus and its relationship to Downtown and Collegetown, there are more rides need to go uphill or downhill. Moreover, Autumn has higher portion than Spring could be explained by the fact that the weather in Fall in general is better, which creates more bike events, as a result, the portion of steep-slope rides are just higher than the Spring.

Figure 14 – 2019 Rides by Elevation Change Intervals by Seasons



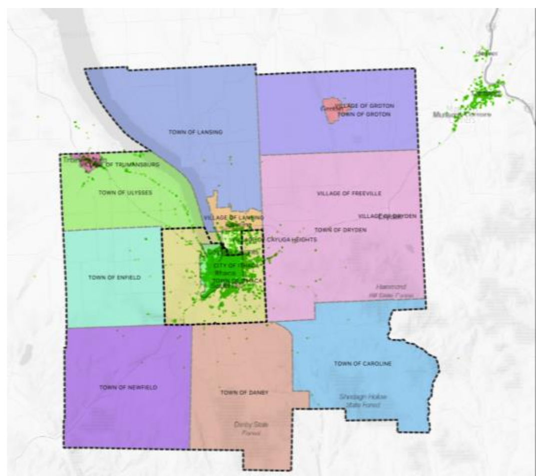
TOMPKINS COUNTY MUNICIPALITIES & POLITICAL BOUNDARIES

Most trips started and ended within the City of Ithaca, but Lime also operates in the Villages of Trumansburg and Dryden. Since the bicycles can be ridden past municipal boundaries, some riders have used them to go to neighboring municipalities that are not served by Lime such as the Village of Cayuga Heights and the Town and Village of Lansing. The only local municipality that was not been visited by a Lime vehicle in 2019 is the Town of Groton.

Given the high number of rides within the City of Ithaca, **the rest of this analysis will focus on rides happening within the City's boundaries and its immediate surroundings** (the Ithaca Urbanized Area). The urbanized area includes the City of Ithaca, Town of Ithaca (including the Village of Cayuga Heights), Village of Lansing, and the hamlets of Varna and Etna.

Table 4 – All 2019 Trip Starts and Ends by Tompkins County Municipalities

Start Municipality	**Trip Starts**	**Trip Ends**
City of Ithaca	92,521	93,346
Town of Ithaca	6,904	6,431
Town of Lansing	378	196
Town of Ulysses	336	245
Town of Dryden	127	70
Town of Danby	13	4
Town of Enfield	12	9
Town of Caroline	5	-
Town of New Field	4	-
within Tompkins	**100,300***	**100,300***

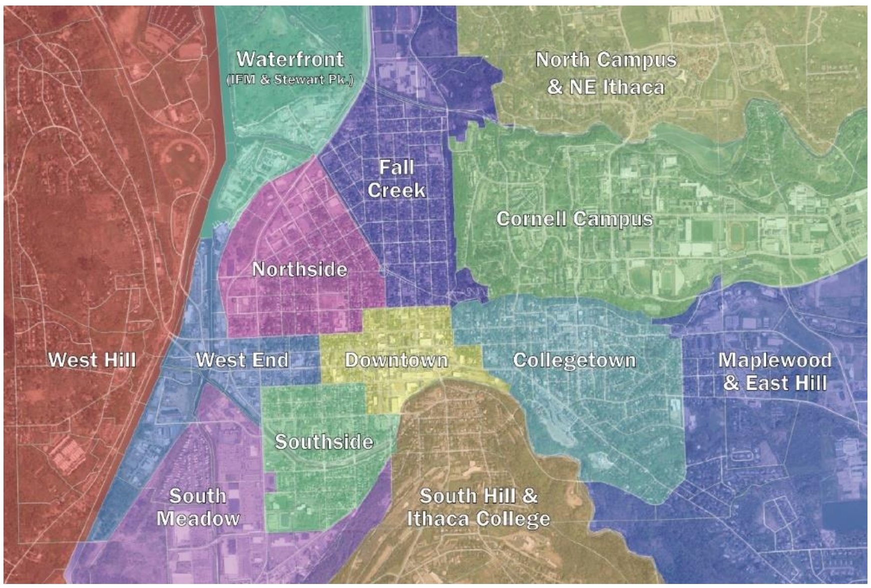


* only includes trips that started or ended within Tompkins County

ITHACA URBANIZED AREA

To understand the use of Lime within the City of Ithaca and surrounding urban and suburban neighborhoods, we separated the Urbanized Area of Ithaca into 13 distinct neighborhoods to be able to count the number of rides starting and ending in each neighborhood (see Figure 15). While some neighborhoods are consistent with the general community consensus of their boundaries (ex. Fall Creek, Southside), other neighborhoods used in this analysis are an amalgamation of different neighborhoods and even municipalities. This is because the number of Lime rides would be too low to be noticeable if these amalgamated areas were subdivided into the actual neighborhoods.

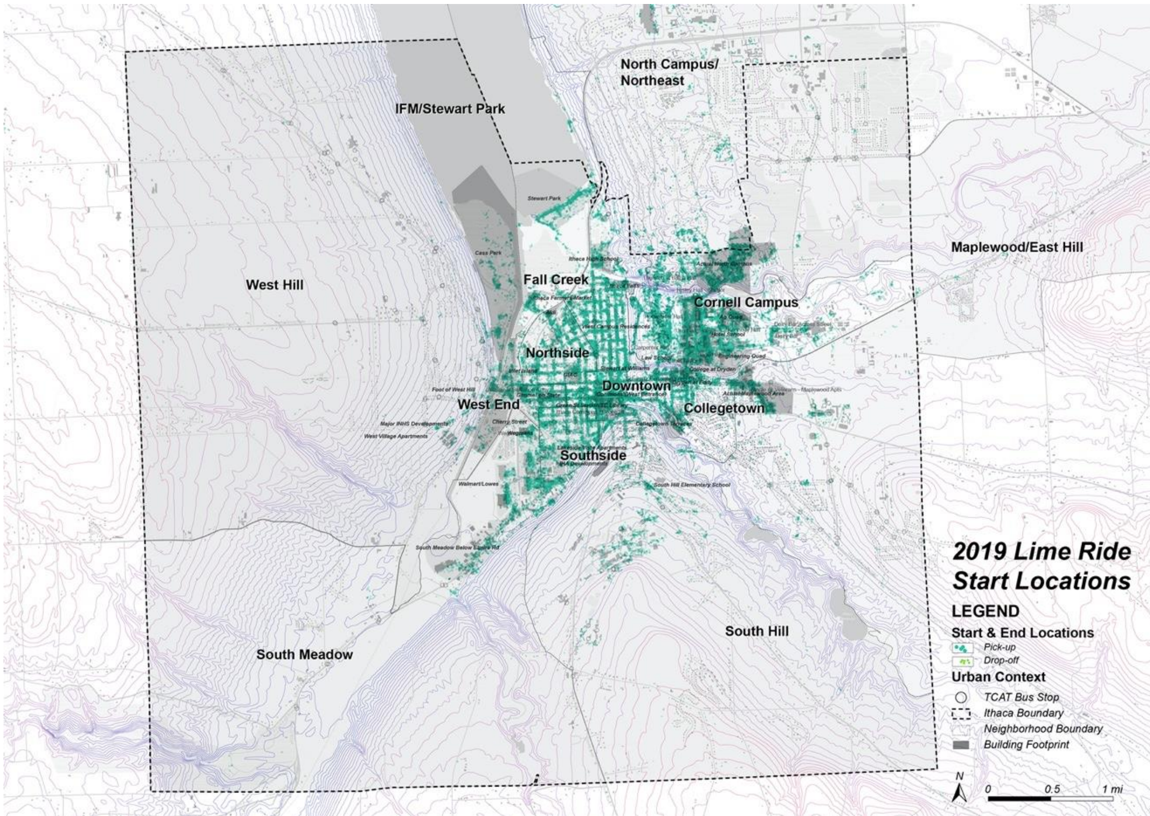
Figure 15 - Map of Ithaca Urbanized Area Neighborhoods for Lime Analysis



Using QGIS, a geographical information system (GIS) program, we create Lime bike pickup and drop-off location plots with Tompkins and Ithaca context as well as heatmaps. As evidenced by Figure 16, nearly all streets in the flats of Ithaca (Downtown, Fall Creek, Northside, and Southside) have been visited at least once by a Lime Bike. We also see Cornell Campus and Collegetown are busy with both trip starts and ends. Besides, the Waterfront, South Hill & Ithaca College and Maplewood also see active bike usage. Figure 17 is the heatmap generated from QGIS, these maps show not only **downtown Ithaca** as a very strong hub of activity, but also highly active are **Cornell Campus and Collegetown**. **These three neighborhoods stand out from the 13 neighborhoods in the Ithaca Urbanized Area, followed by West State Street corridor, Stewart Park, Wegmans, the Ithaca Farmers Market, and TCAT bus stops with frequent service, among other areas.**

Moreover, comparing the trip start and end locations, while they are almost identical in Figure 16, the heatmaps in Figure 17 reveal places of the unbalanced needs, e.g. where they have a lot more pick-ups than drop-offs or the other way around. **For example, Maplewood is only a hot spot for trip starts while Stewart Park, Cayuga Waterfront Trail, Walmart and Wegmans are only more popular for trip ends**. The remainder of this report will go into details about the unbalanced bike flows between places and neighborhoods.

Figure 2 – All 2019 Trip Start and End Locations



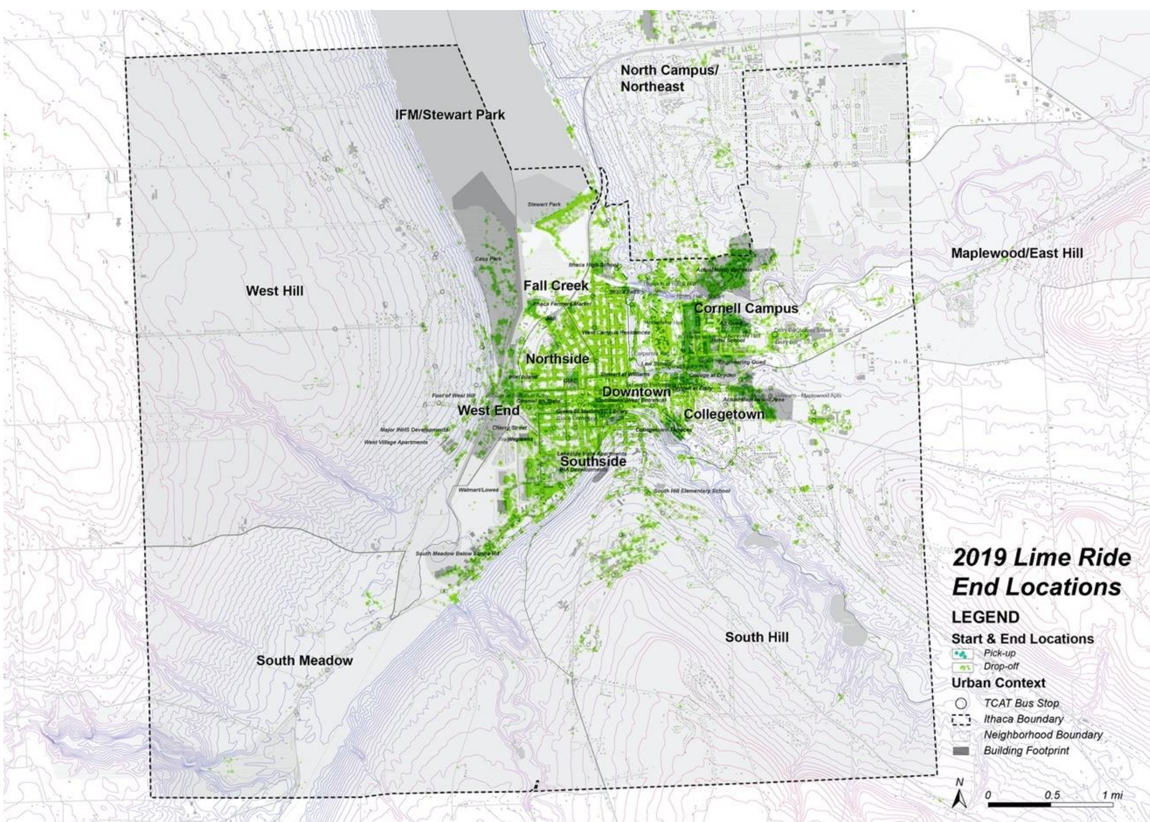
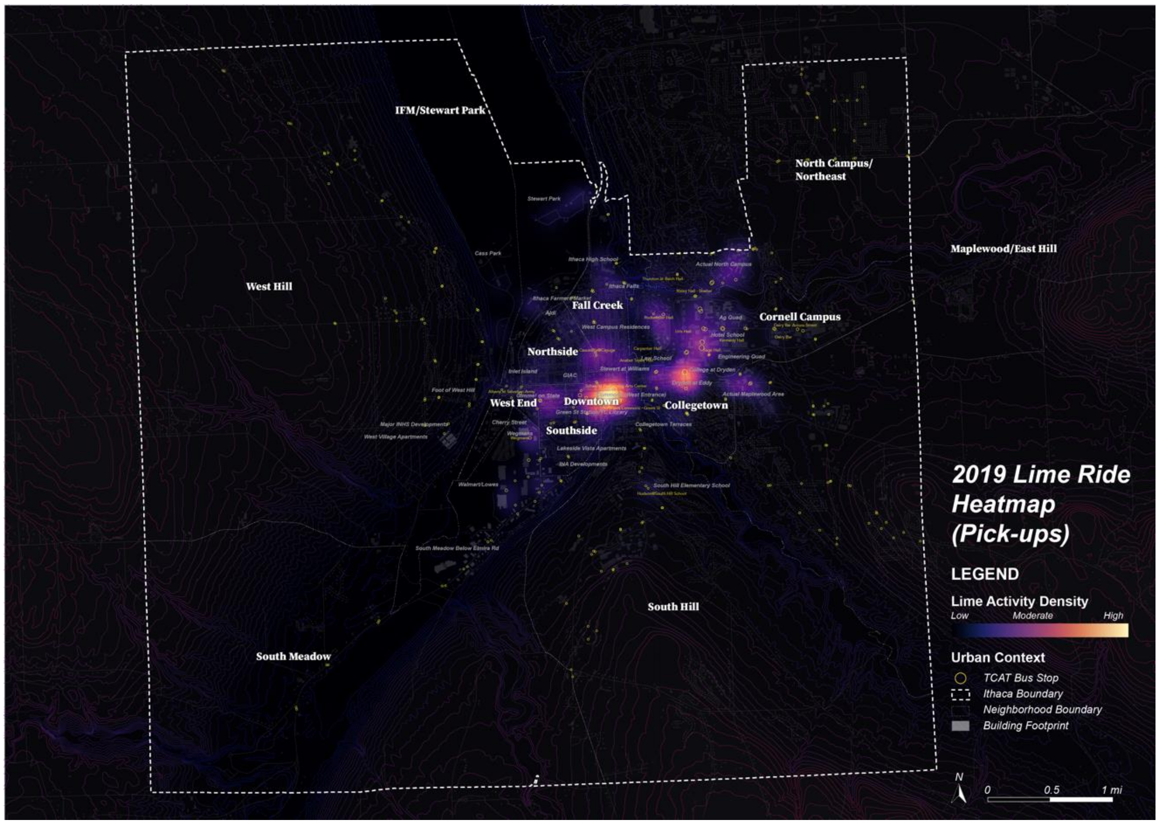
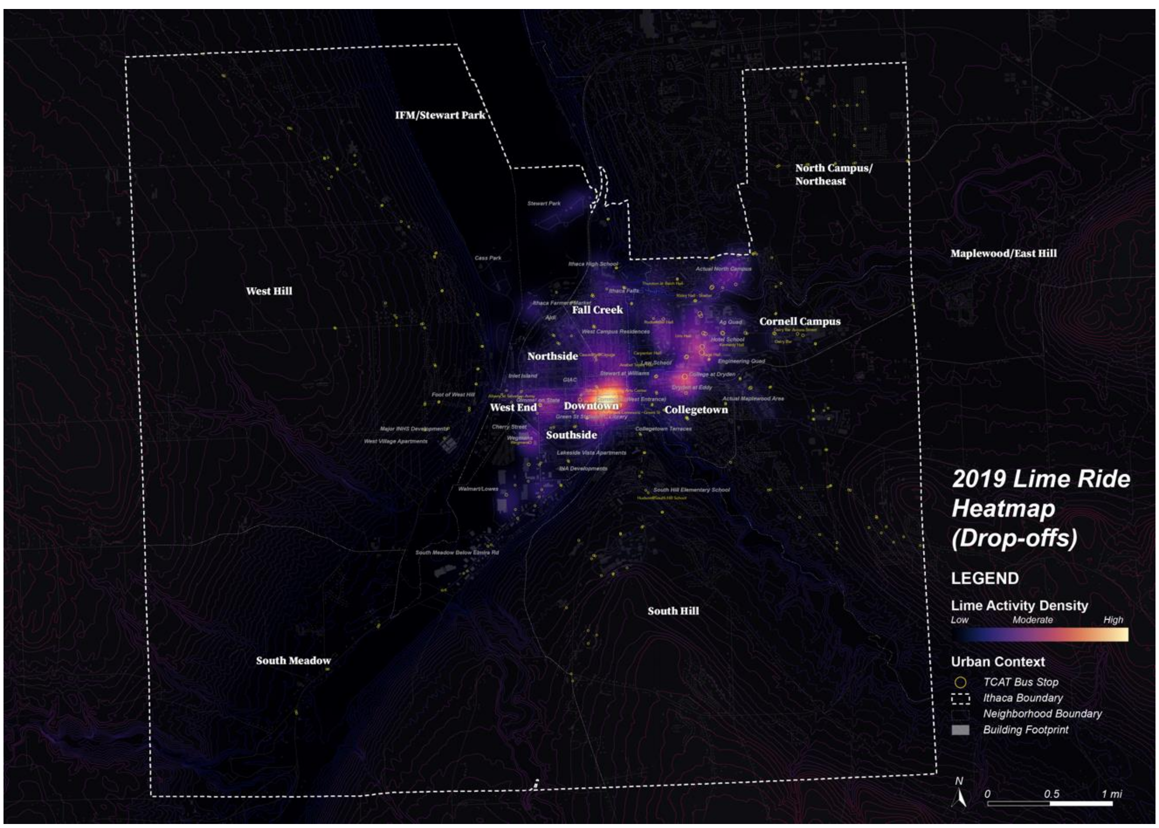


Figure 17 – Heat Map of All 2019 Trip Starts and Ends





BY NEIGHBORHOOD BY SEASONS

Table 5 ranks the thirteen neighborhoods by number of trips started within them in 2019. Of note is the difference between trips taken in spring, summer, autumn and winter. **Notably, although Lime do not officially place bike in Cornell campus, instead they put bikes on East Hill starting from 2018 fall, campus related trips start to be dominant in the Ithaca Urbanized Area.**

While Cornell Campus, Downtown, Fall Creek and Collegetown remain at the top four regarding both total rides and seasonal sums, we see very different patterns in summer compared to autumn when students are back. For example, Downtown has the most ride starts in summer and Cornell Campus only ranks the third, while in Autumn Cornell Campus has almost twice the ride starts than Downtown. **In general, Lime bike activity in and around campus, student residence, and recreational attractions show clear seasonal fluctuation.** In fall semester there are more rides from Cornell Campus, Collegetown and Maplewood than that of downtown, while in summer downtown and recreational site Stewart Park gain more starting trips.

Table 5 – All 2019 Trip Starts by Neighborhood by Season

Trip Start Neighborhood	Spring	Summer	Autumn	Winter	Start Total
*Cornell Campus**	3,408 (2)	4,625 (3)	9,853 (1)	514 (2)	18,400 (1)
Downtown	3,913 (1)	7,237 (1)	5,698 (2)	728 (1)	17,576 (2)
Fall Creek	2,794 (3)	4,903 (2)	4,223 (4)	415 (3)	12,335 (3)
Collegetown	2,332 (4)	3,391 (4)	5,433 (3)	393 (4)	11,549 (4)
*North Campus/Northeast**	1,123	2,363	3,472 (5)	168	7,126 (5)
Northside	1,287 (5)	2,568 (5)	1,702	254	5,811
South Meadow	1,029	2,219	1,710	211	5,169
West End	1,283	2,097	1,466	248	5,094
Maplewood/East Hill	937	1,479	2,038	270 (5)	4,724
Southside	839	1,608	1,245	180	3,872
IFM/Stewart Park	774	1,869	728	12	3,383
South Hill	639	896	1,464	93	3,092
West Hill	390	944	545	35	1,914
Total Rides Starting in the Ithaca Urbanized Area	**20,748**	**36,199**	**39,577**	**3,521**	**100,300**

* Lime not actively placing bikes in these neighborhoods during the indicated season; numbers in the bracket present their descent ranking in the corresponding column.

Figure 18 shows the seasonality by neighborhoods, revealing at least two types of neighborhood, the "campus-related" and "local-related" (Figure 18.a). On one hand, Downtown, Fall Creek, Northside, West End, South Meadow and many other neighborhood have their greatest numbers of rides in summer and also more rides in spring than autumn. Since these neighborhood accommodate or serve more locals, we assume the rides are related with local usages. One the other hand, Cornell Campus stands out with the greatest amount of rides in fall, along with with Collegetown, North Campus, Maplewood, and South Hill who have more trips in fall than spring. These five neighborhoods are campus or where more students residence live. The discrepancy between these two types of neighborhood is clearly shown in the 100% stacked area chart (Figure 18.b) where campus-related neighborhoods are highlighted by the jagged pattern in the Autumn segment.

Figure 18 –Trip Starts by Neighborhood by Seasons in 2019

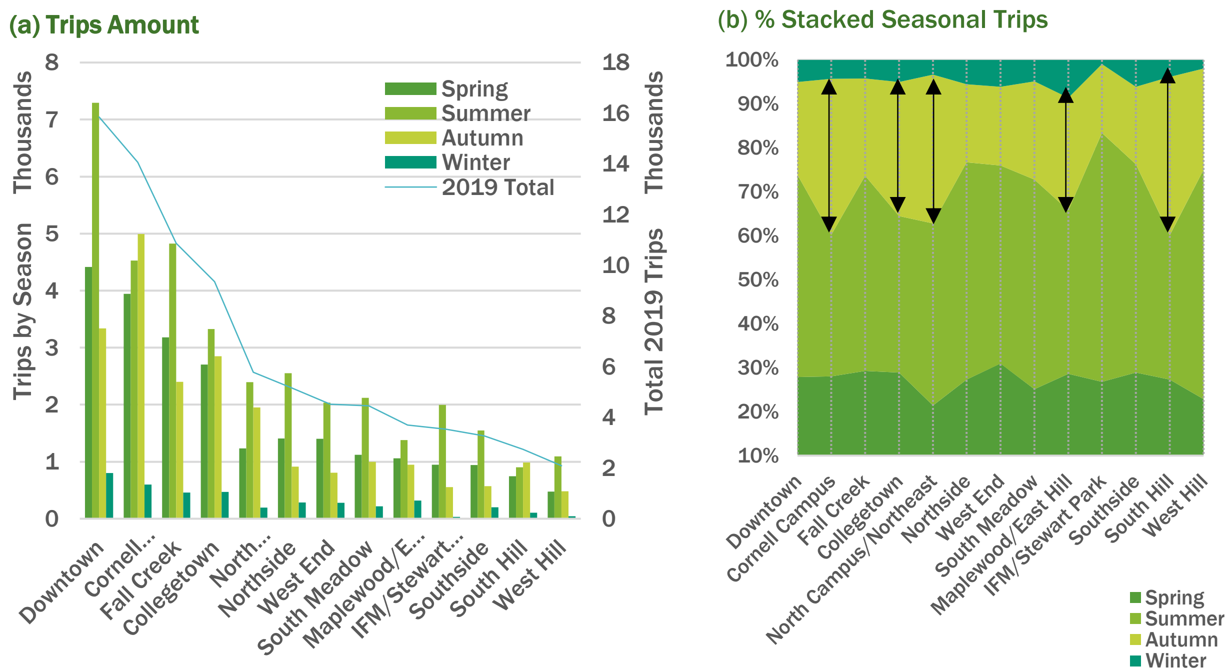


Table 6 shows the descent ranking of trip ends, the pattern is similar to trip starts. First, Downtown and Cornell Campus flip the 1st and 2nd places in summer and autumn. Second, they both remain top three with Fall Creek in all columns. Third, campus related neighborhoods have comparable amount of rides in autumn while recreational attraction places also have comparable numbers in summer compared to trip starts in Table 5.

Table 6 – All 2019 Trip Ends by Neighborhood

Neighborhood	Spring	Summer	Autumn	Winter	End Total
*Cornell Campus**	3,445 *(2)*	4,624 *(2)*	10,236 *(1)*	651 *(1)*	18,956 *(1)*
Downtown	3,702 *(1)*	6,620 *(1)*	5,615 *(2)*	551 *(2)*	16,488 *(2)*
Fall Creek	2,825 *(3)*	4,846 *(3)*	4,678 *(3)*	444 *(3)*	12,793 *(3)*
Collegetown	1,772 *(4)*	2,660	4,117 *(4)*	253	8,802 *(4)*
*North Campus/Northeast**	1,297	2,621	3,733 *(5)*	197	7,848 *(5)*
South Meadow	1,313	2,779 *(5)*	2,267	303	6,662
Northside	1,502 *(5)*	2,823 *(4)*	1,908	329 *(4)*	6,562
West End	1,446	2,270	1,693	277	5,686
Southside	945	1,818	1,500	225	4,488
IFM/Stewart Park	872	2,153	862	25	3,912
South Hill	667	987	1,402	127	3,183
Maplewood/East Hill	476	935	965	96	2,472
West Hill	450	981	607	41	2,079
Total Ride Ends	**20,712**	**36,117**	**39,583**	**3,519**	**99,931**

* Lime not actively placing bikes in these neighborhoods during the indicated season

The seasonality of ending rides is similar to starting rides. **We identify the "campus-related" ones with more autumn trips and "local" with more summer and spring trips.** With students coming back, rides in autumn in Cornell Campus doubled compared to summer trips. Two types of pattern are clearly shown in Figure 19.b, where the campus-related neighborhoods are highlight with the jagged peaks of stacked percentage of rides in autumn, while Stewart Park see its peak in summer. Those places, including Cornell Campus, Collegetown, North Campus, South Hill and Maplewood, have gained lots of ridership in Autumn. On the other hand, we see IFM/Stewart Park Stands out with Summer ridership peak, while Downtown has similar ridership for Summer and Autumn.

Figure 19 –Trips End by Neighborhood by Season in 2019

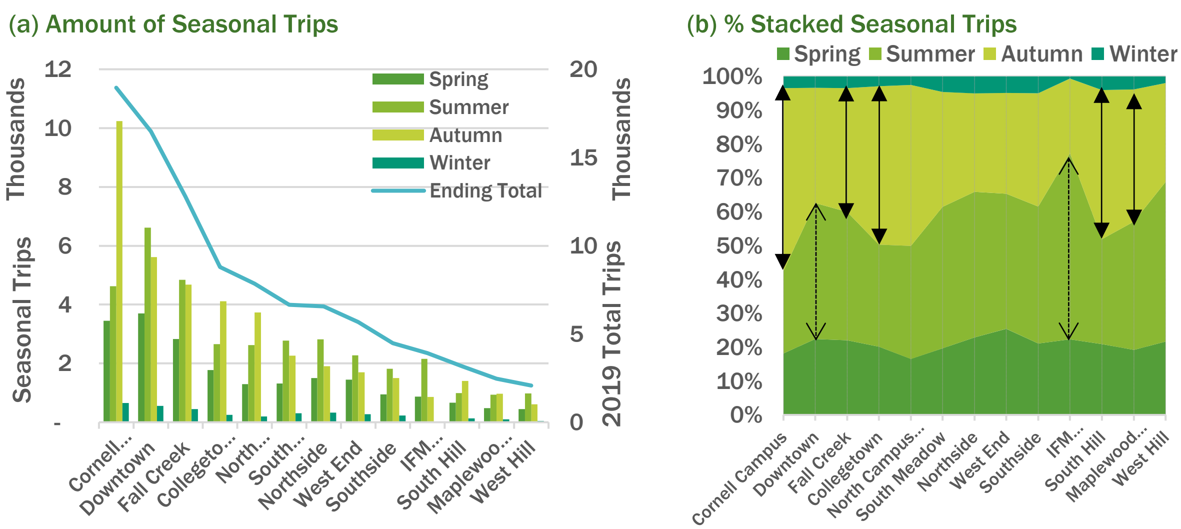
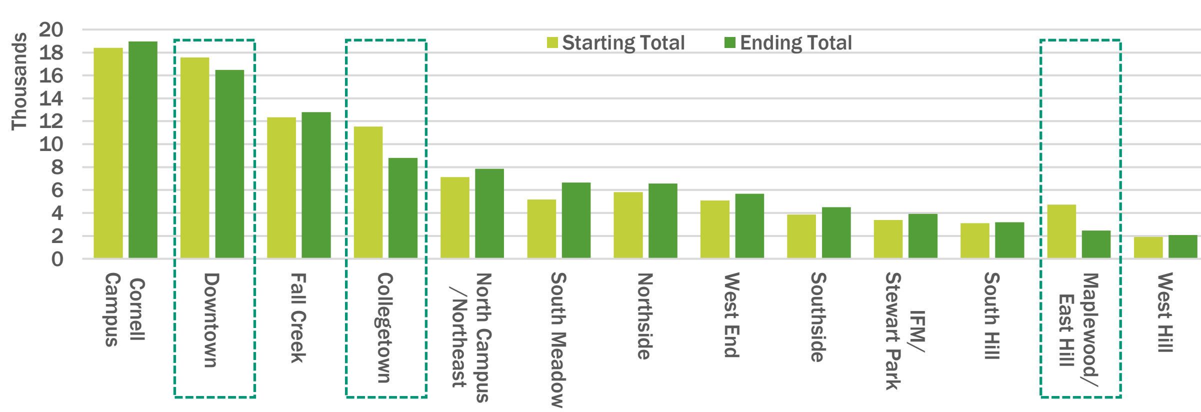


Figure 20 shows the discrepancy of starting and ending trips by weekday and weekend. **The unbalanced demand between bike pick-up and drop-off widely exists.** While on average there is about a thousand rides' difference per neighborhood, some neighborhoods have more trip starts while some are the other way around. **Only three out of thirteen neighborhoods, namely Downtown, Collegetown, and Maplewood have more total pick-up rides than drop-offs, while all other neighborhoods have more ending trips than starting ones.** This provides implications for future rebalancing operation. Bikeshare operator might consider distribute and rebalance more bikes to these three more demanding neighborhoods in order to meet the pick-up demand there from adjacent neighborhoods where the drop-off number is larger than pick up demand, meaning there are surplus of bikes available.

Figure 20 – 2019 Total Trip Starts and Ends by Neighborhood



BY NEIGHBORHOOD BY WEEKDAY/WEEKEND

Figure 21 shows the weekend-weekday discrepancy of starting trips by neighborhood. It also reveals the pattern of "college" and "local" neighborhoods. First, except for Cornell Campus, on average all other neighborhoods have about 150 more starting trips daily during a weekend than a weekday. Second, notably, this discrepancy is extremely large for Steward Park and Downtown. The daily demand is 3 times larger during a weekend than a weekday for Steward Park. Downtown has 500 more trips during weekend than a weekday. In Figure 21.b, the jagged pattern highlight Cornell Campus and Maplewood are busier with starting trips during weekday while Stewart Park has an opposite pattern.

Figure 21 – 2019 Daily Trip Starts by Neighborhood by Weekday/Weekend

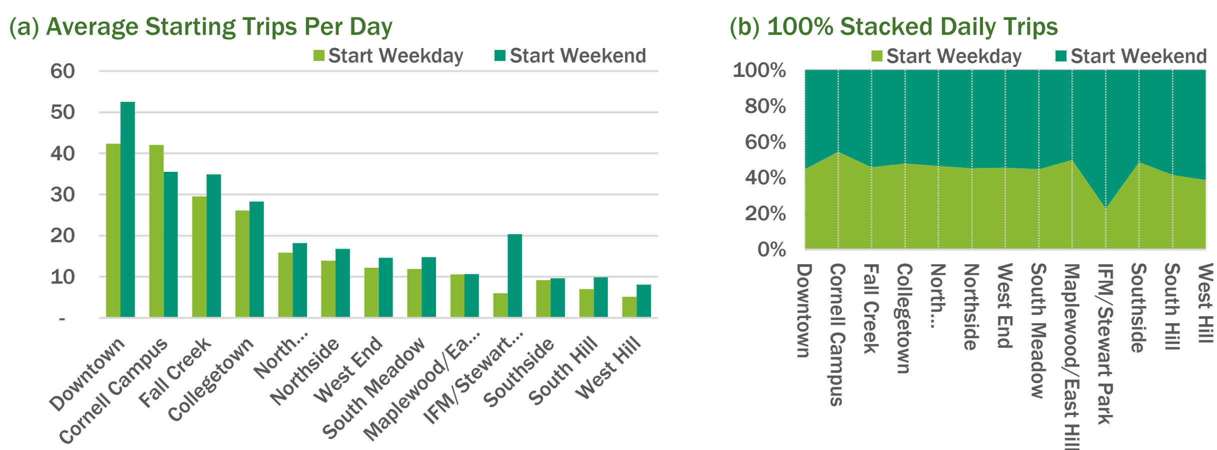


Figure 22 shows the weekend-weekday discrepancy of ending trips by neighborhood. In general the pattern is opposite to its counterpart of starting trips. **Except for Stewart Park, on average all other neighborhoods have about 30%-50% more ending trips per day during a weekend than a weekday. Such a discrepancy is extremely large for Cornell Campus and Downtown.** The daily demand is about 3 times larger (about 1,500 more trips) during a weekday than a weekend for Cornell Campus. Downtown has about 1,000 more trips during weekday than a weekend (Figure 22.a).The jagged pattern on Figure 22.b highlight Cornell Campus and Stewart Park with their opposite patterns.

Figure 22 – 2019 Daily Trip Ends by Neighborhood by Weekday/Weekend

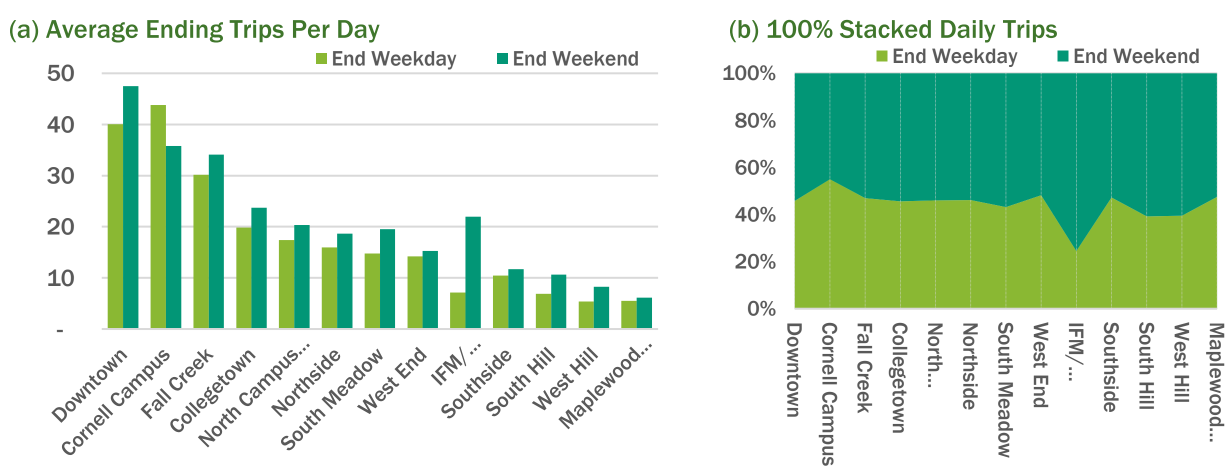
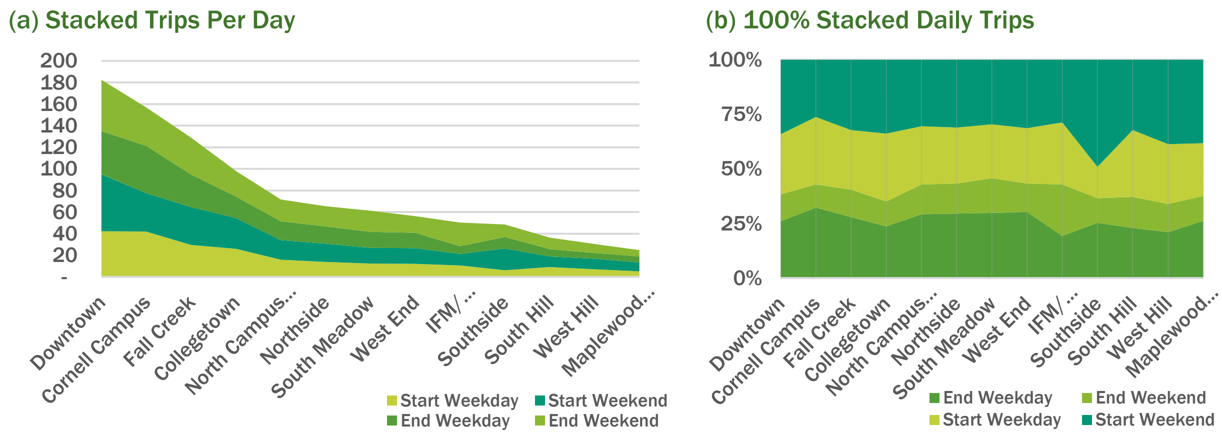


Figure 23 summarizes the discrepancy of daily trips starting and ending in each neighborhood in the Ithaca Urbanized Area by weekday and weekend. We identify two neighborhood, the Cornell Campus and Stewart Park to represent the very distinct patterns. **Cornell Campus, as an important study/work place, the average daily drop-off during a weekday is 3 times larger than weekends. Stewart Park, on the other hand, has three times more daily pickup demand on weekends than weekdays. Such a discrepancy pattern is important for future bikeshare operation and maintenance for Tompkins County.**

Figure 23 – 2019 Daily Starting and Ending Trip by Neighborhood by Weekday/Weekend



BY POINT OF INTERESTS (POI)

Ride ends in 2019 are aggregated at Census Block level and spatially joint with the point of interests (POI) data to identify the specific attractions and places that people visit on Lime bikes. The POIs we include in this report is shown in Figure 24, including Cornell and Ithaca College campus, commercial and education amenities and recreational parks. Table 7 shows the total number of rides in 2019 that ended on POIs' block, with average trips per day by weekday/weekend and by seasons. **It is a surprise to see that Cornell Campus, Downtown and Stewart Park take over the Top 10 most attracting blocks in Ithaca Urbanized Area. They are followed by either shopping attractions such as Wegmans, Ithaca Farmers Market, Walmart, or student residence such as Maplewood Area from the top 20**. Compared to the top 10 in 2018, it indicates that **though Lime does not distribute bikeshare in Cornell Campus, since Ithaca is a college town, campus related bike activity is increasingly dominant.**

Figure 24 – POIs in Ithaca Urbanized Area

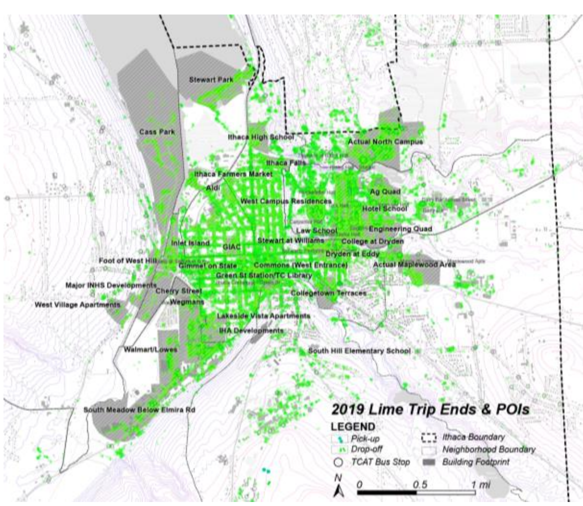
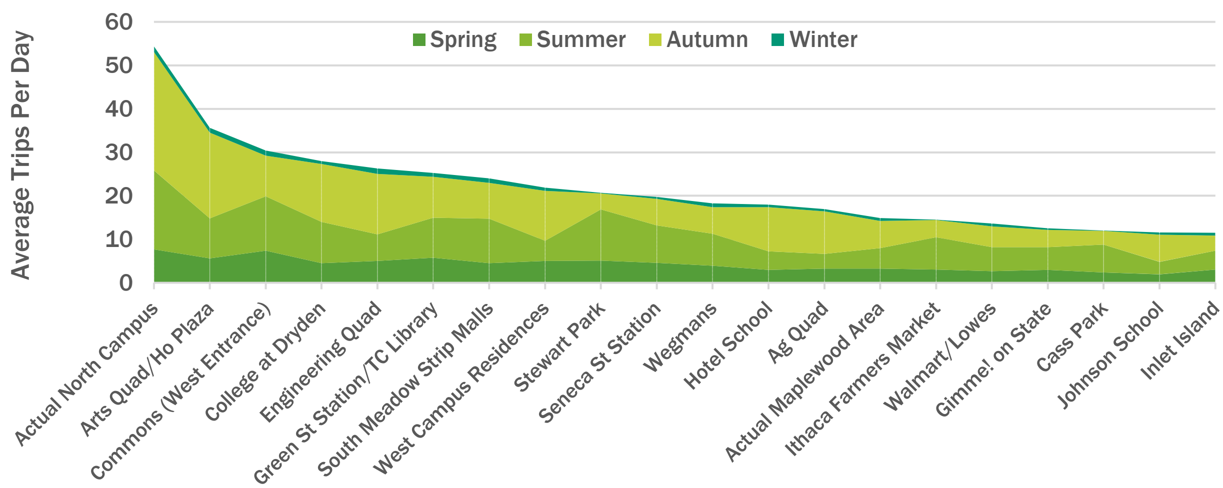


Table 7 – Top 20 Points of Interests (POIs) for Trip Ends in 2019

		Sub Total 2019		Average Per Day					
	Trip End POIs	Sum	% Total	Weekday	Weekend	Spring	Summer	Autumn	Winter
1	Actual North Campus	4757	4.7%	13	14	8	18	27	1
2	Arts Quad/Ho Plaza	3117	3.1%	10	6	6	9	20	1
3	Commons (West Entrance)	2658	2.7%	7	9	7	13	9	1
4	College at Dryden	2451	2.4%	7	8	4	10	13	1
5	Engineering Quad	2298	2.3%	7	5	5	6	14	1
6	Green St Station/TC Library	2210	2.2%	6	6	6	9	9	1
7	South Meadow Strip Malls	2104	2.1%	6	6	5	10	8	1
8	West Campus Residences	1913	1.9%	5	7	5	5	11	1
9	Stewart Park	1811	1.8%	4	8	5	12	4	0.1
10	Seneca St Station	1728	1.7%	5	6	5	9	6	0.5
11	Wegmans	1598	1.6%	4	6	4	7	6	1
12	Hotel School	1570	1.6%	5	3	3	4	10	1
13	Ag Quad	1484	1.5%	5	2	3	3	10	1
14	Actual Maplewood Area	1304	1.3%	4	4	3	5	6	1
15	Ithaca Farmers Market	1267	1.3%	1	11	3	7	4	0.0
16	Walmart/Lowes	1196	1.2%	3	4	3	5	5	1
17	Gimme! on State	1098	1.1%	3	3	3	5	4	0.4
18	Cass Park	1053	1.0%	2	5	2	6	3	0.1
19	Johnson School	1010	1.0%	3	2	2	3	6	0.5
20	Inlet Island	1007	1.0%	3	3	3	4	3	1
	Sub total	*37634*	*37.5%*	*103*	*119*	*85*	*151*	*180*	*14*

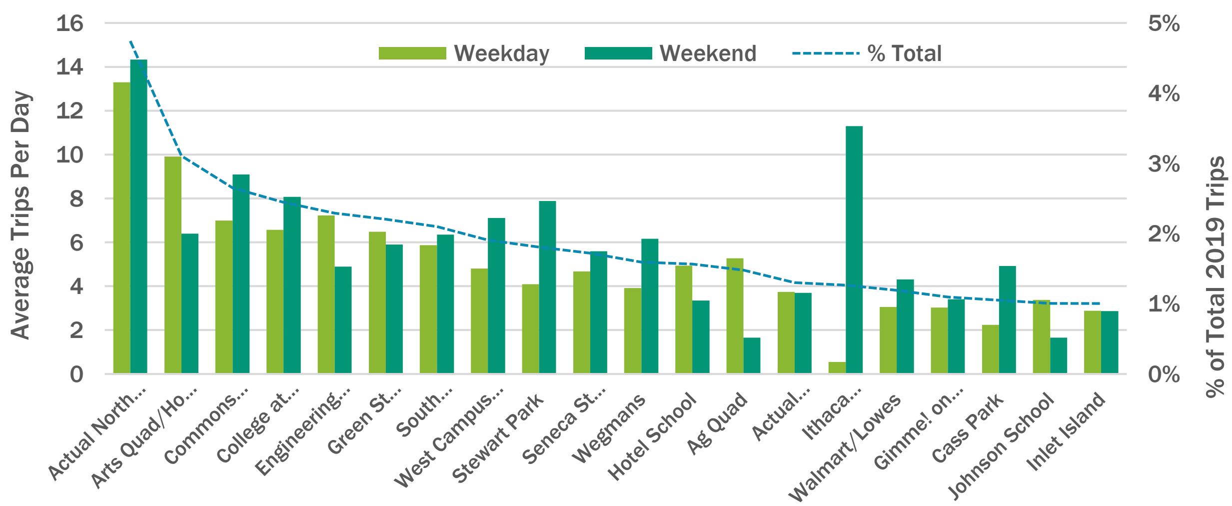
Figure 25 demonstrates a seasonal fluctuation pattern similar to previous neighborhood analysis. Identified by either summer or fall drop-off peaks, places that are campus-related, local or recreational related stand out from the jagged pattern. For instance, **local places such as Commons (West Entr), TC Library, Strip Malls, Farmers Market, and recreational places such as Stewart Park and Cass Park gain their greatest ridership in summer.** On the other hand, campus related places such as North Campus, Arts Quad, Ag Quard, and student residence Maplewood gain their largest portions of rides in Autumn when students are back in town.

Figure 25 – All 2019 Trip Ends at Selected Points of Interests (POIs) by Season



Similarly, Figure 26 shows a weekly fluctuation pattern in the weekday and weekend which is also similar to previous neighborhood analysis. **Campus where students have classes see 40-80% more rides during weekday than weekend** (e.g. Arts Quad, Engineering Quad, Ag Quad, and Johnson School)**. While local and recreational areas gain a lot more rides during the weekend** (e.g. Commons, Stewart Park, Cass Park), **Ithaca Farmer Market stands out with an extremely skewed demand in weekend.** During the weekend it has 11 trips on average per day, while less then 1 trip visit it during the weekday. It is also interesting to see that for campus places where students resides, e.g. North Campus, West Campus Residences, and Maplewood, there are a few more or even rides during the weekend than weekday.

Figure 26 – All 2019 Trip Ends at Selected Points of Interests (POIs) by Weekend/ Weekday



ORIGIN-DESTINATION FLOWS

GENERAL SYSTEM FLOW

By comparing total trip starts and ends in each neighborhood, we can understand the general flows of Lime riders in Ithaca. Generally there are spatial and temporal patterns of unbalanced flows, in other words, for certain neighborhoods, they might have more incoming rides than going out within a certain time frame. As a rule of thumb, from this comparison, we find that **trips that originate in neighborhoods on top of a hill** (e.g. Collegetown, Maplewood & East Hill) **generally do not return.** Similarly, there is an **outward flow of rides from the downtown core to outlying neighborhoods** (i.e. Northside, Southside, South Meadow), as Lime places more bikes in the downtown core, and some people may choose a different mode of transportation for their return trip.

Table 8 compares the differences between trip starts and ends for the thirteen neighborhoods in summer and autumn 2019. **It reveals the shifts in the discrepancy of origin-destination (OD) rides.** First, all neighborhoods see shifted magnitude in the OD discrepancy. Downtown has more starting trips in summer while Cornell Campus gains end rides in fall. **Second, most neighborhoods have consistent sign of discrepancy, except for South Hill which has shifted sign from more trip ends in summer to more strip starts in Autumn.** Third, two types of neighborhoods are identified by their outstanding origin or destination trips. **On one hand, Maplewood/East Hill and Collegetown consistently see a lot more trip starts**, **marked as O-type neighborhood. On the other hand, South Meadow, Southside and Stewart Park consistently attract about 15-30% more trips ends than starts, identified as D-type.** Notably, their gaps are the largest during autumn when students are back. In summary, attentions should be put to Fall Creek, Collegetown, These spatial and temporal shifts in trip starts and ends raise challenges for bikeshare rebalancing. We hope the analysis can shed light on the operation strategies.

Table 8 –Trip Starts, Ends, and Percentage Difference by Neighborhood

Neighborhood	**Summer Trip Starts**	**Summer Trip Ends**	**% Difference**	**Autumn Trip Starts**	**Autumn Trip Ends**	**% Difference**
Downtown	7,237	6,620	-8.5%	5,698	5,615	-1.5%
Fall Creek	4,903	4,846	-1.2%	4,223	4,678	**10.8%**
Cornell Campus	4,625	4,624	-0.02%	9,853	10,236	3.89%
Collegetown	3,391	2,660	**-21.6%**	5,433	4,117	**-24.2%**
Northside	2,568	2,823	9.9%	1,702	1,908	**12.1%**
North Campus/Northeast	2,363	2,621	**10.9%**	3,472	3,733	7.5%
South Meadow	2,219	2,779	**25.2%**	1,710	2,267	**32.6%**
West End	2,097	2,270	8.2%	1,466	1,693	**15.5%**
IFM/Stewart Park	1,869	2,153	**15.2%**	728	862	**18.4%**
Southside	1,608	1,818	**13.1%**	1,245	1,500	**20.5%**
Maplewood/East Hill	1,479	935	**-36.8%**	2,038	965	**-52.6%**
West Hill	944	981	3.9%	545	607	**11.4%**
South Hill	896	987	**10.2%**	1,464	1,402	-4.2%

Actually, since Lime expanded into East Hill neighborhoods in the fall 2018, the area has saw the strong downhill flow from Collegetown and Maplewood, and this flow has strengthened further in 2019. These downhill rides ended in downtown, replacing the outward flow from that neighborhood that was seen in the summer. Outlying neighborhoods in the Flats, however, are still net receivers of rides. These patterns become more apparent in the next subsection.

NEIGHBORHOOD-TO-NEIGHBORHOOD FLOW

Using the start and end locations, with 13 neighborhoods defined in our spatial analysis, rides could be counted amongst a possible 169 (13 x 13) neighborhood origin-destination (O-D) pairs. Tables 9 shows the top 10 neighborhood O-D pairs rank by the total number of Lime bike trips in 2019. **Again we see a seasonal shifting pattern, with more flows in summer between local-recreational neighborhoods while there are more flows in fall between campus related neighborhoods.** On one hand, although Cornell Campus is dominant in Summer and Autumn, other campus related O-D pairs (e.g. Cornell Campus - North Campus) also gains about 12% autumn flows compared to summer. One the other hand, local neighborhood pairs such as Fall-Creek-Downtown loses about 2/3 of its summer rides (Table 9). By comparing the seasonal O-D flows in Table 9, we can see that the top four greatest amount of Lime rides in any season happen either within or in-between three neighborhoods, namely Cornell Campus, Downtown and Fall Creek. In total they made up about 20% of Lime rides.

Table 9 – Top 10 Neighborhood O-D Pairs

Neighborhood O-D Pair	**Rank**	**Spring**	**Summer**	**Autumn**	**Winter**	**Sub Total**	**% Total**
Within Cornell Campus	1	1,625	1,662	2,172	288	5,747	6.7%
Downtown- Fall Creek	2	1,006	1,527	716	203	3,452	4.0%
Collegetown- Cornell Campus	3	984	977	1,223	183	3,367	3.9%
Fall Creek- Downtown	4	1,009	1,480	694	146	3,329	3.9%
Within Fall Creek	5	989	1,388	821	130	3,328	3.9%
Downtown- Downtown	6	832	1,388	567	110	2,897	3.4%
Cornell Campus- North Campus	7	664	956	1,061	98	2,779	3.2%
North Campus - Cornell Campus	8	581	929	1,071	92	2,673	3.1%
Cornell Campus- Collegetown	9	815	776	910	109	2,610	3.1%
Downtown- Northside	10	539	840	305	106	1,790	2.1%
Sub-Total		**9,044**	**11,923**	**9,540**	**1,465**	**31,972**	**37.4%**

Table 10 lists the top ten neighborhood pairs in the summer and fall 2019. As mentioned before, summer and fall see very different Lime user activity between local, recreational and Cornell campus related purposes. **The biggest change is the rides that happen within the Waterfront neighborhood, composed of the Ithaca Farmers' Market and Stewart Park. While this O-D pair had the ninth highest ridership in the summer, it was ranked 28th in the fall and therefore not on Table 10.** It shows the how concentrated recreational rides are in the summer. **Another big change is that rides from Collegetown to Cornell Campus move from the 6th in the summer to become the 2nd most frequent O-D pair in the fall, demonstrating the bike flows generated when students are back.**

Moreover, Lime rides in the autumn are more spread out than in the summer.**While the top 10 O-D pairs made up nearly 34% of all rides within the Ithaca Urbanized Area in the summer, the top 10 O-D pairs in the fall only made up 27% of all rides.** The reasonable cause of the more dispersed rides in autumn is because of the increasing usage of Lime starting and ending in neighborhoods on East Hill during fall semester.

Table 10 - Top 10 Neighborhood Pairs

(a) 2019 Summer

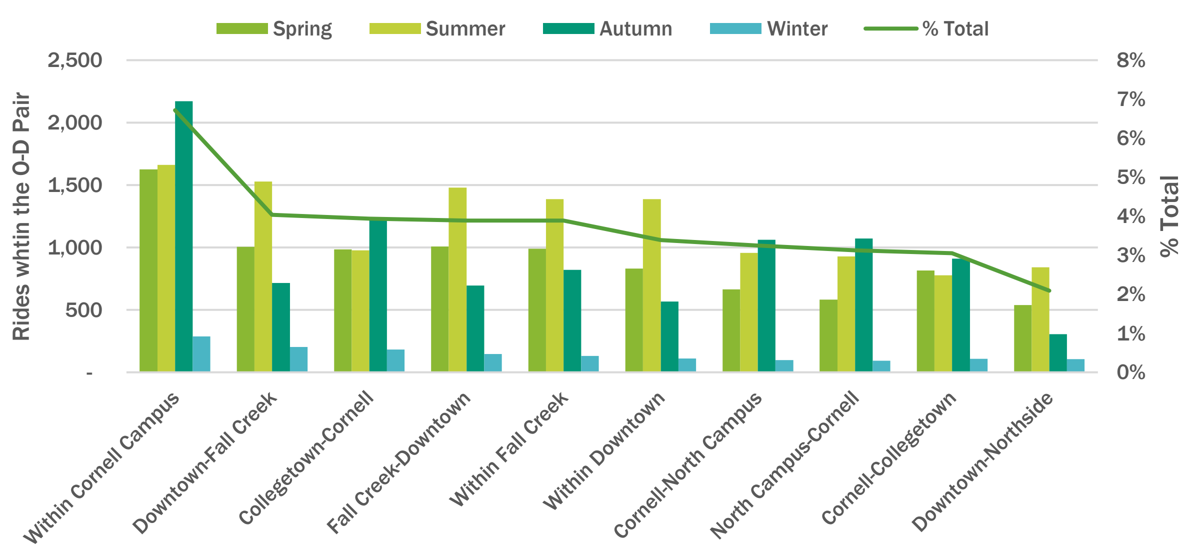
Neighborhood O-D Pair	**Summer**	**% total**
Within Cornell Campus	1,662	4.6%
Downtown-Fall Creek	1,527	4.3%
Fall Creek-Downtown	1,480	4.1%
Within Fall Creek	1,388	3.9%
Within Downtown	1,388	3.9%
Collegetown-Cornell	977	2.7%
Cornell -North Campus	956	2.7%
North Campus -Cornell	929	2.6%
Within IFM/Stewart Park	904	2.5%
Downtown-Northside	840	2.3%
sub-total	**12,051**	**33.6%**

(b) 2019 Fall

Neighborhood O-D Pair	**Autumn**	**% total**
Within Cornell Campus	2,172	6.1%
Collegetown-Cornell	1,223	3.4%
North Campus-Cornell	1,071	3.0%
Cornell-North Campus	1,061	3.0%
Cornell-Collegetown	910	2.5%
Within Fall Creek	821	2.3%
Downtown-Fall Creek	716	2.0%
Fall Creek-Downtown	694	1.9%
Within North Campus/Northeast	573	1.6%
Downtown	567	1.6%
sub-total	**9,808**	**27.3%**

Figure 27 shows the seasonality in the top 10 neighborhood O-D flows. Again we identified two types of O-D pairs that fluctuates with the season changes. Neighborhood pairs with largest rides in the autumn are all related to Cornell campus, e.g. the rides solely within Cornell Campus, or rides between Collegetown-Cornell and between Cornell-North Campus. Otherwise, summer rides contribute to the greatest ridership for other neighborhood pairs that related to Downtown and Fall Creek. **Tied back to the previous neighborhood analysis, Cornell, Downtown and Fall Creek are the top three neighborhood with the most rides, as a result it is consistent that the most busiest O-D pairs happen either within or between them.**

Figure 27 – Top 10 Neighborhood O-D Pairs



Figures 28 shows spatially the Lime trips amounts by the thickness of the edges for each neighborhood O-D pairs in each season in 2019. The chord diagrams on Figure 29 provide a representation of the ridership on all neighborhood

O-D pairs in the each season respectively and aggregately. These chord diagrams can be accessed online at https://www.bikewalktompkins.org/2018-lime-analysis

Figure 28 – Lime Bike Trips Between Neighborhood O-D Pairs in 2019

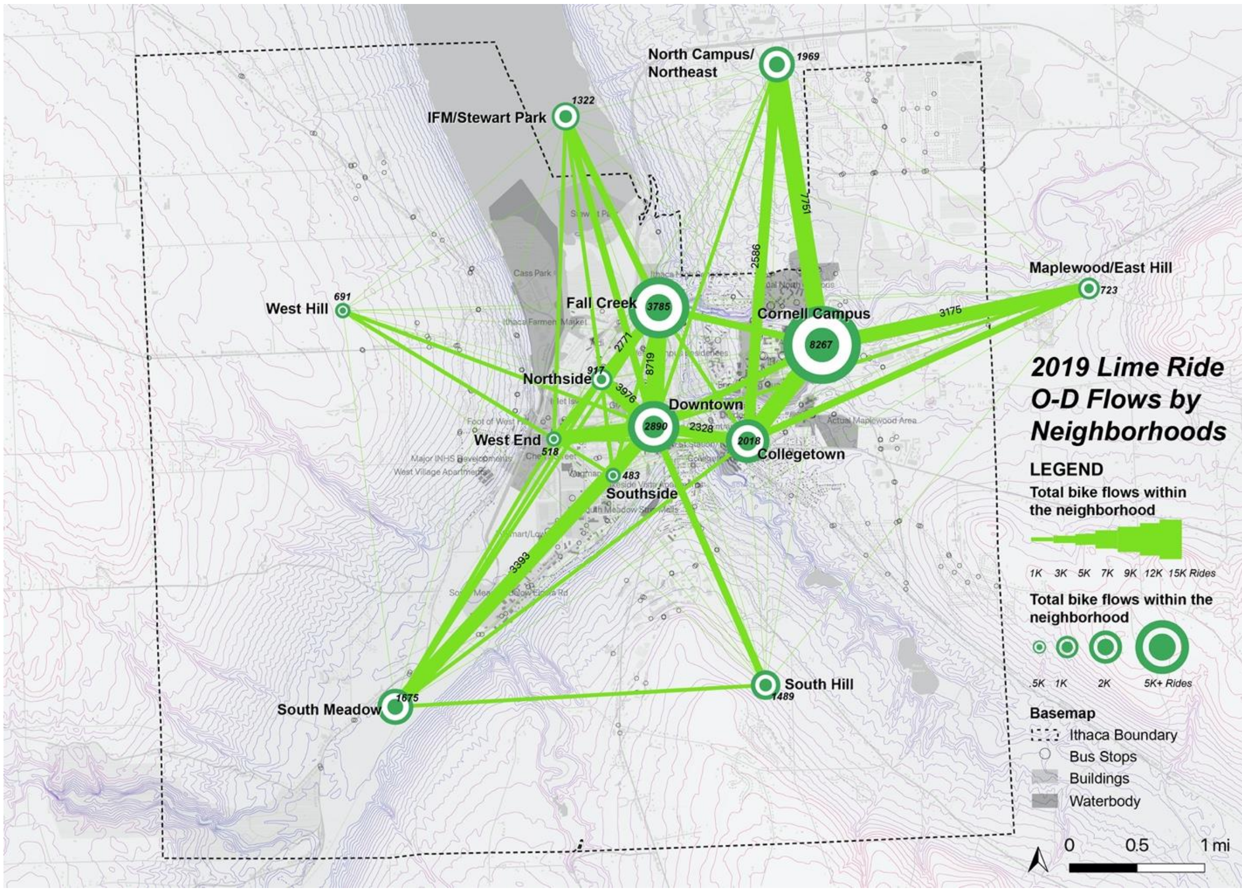


Figure 28 –2019 Lime Bike Trips Between Neighborhood O-D Pairs by Spring, Summer, Autumn and Winter

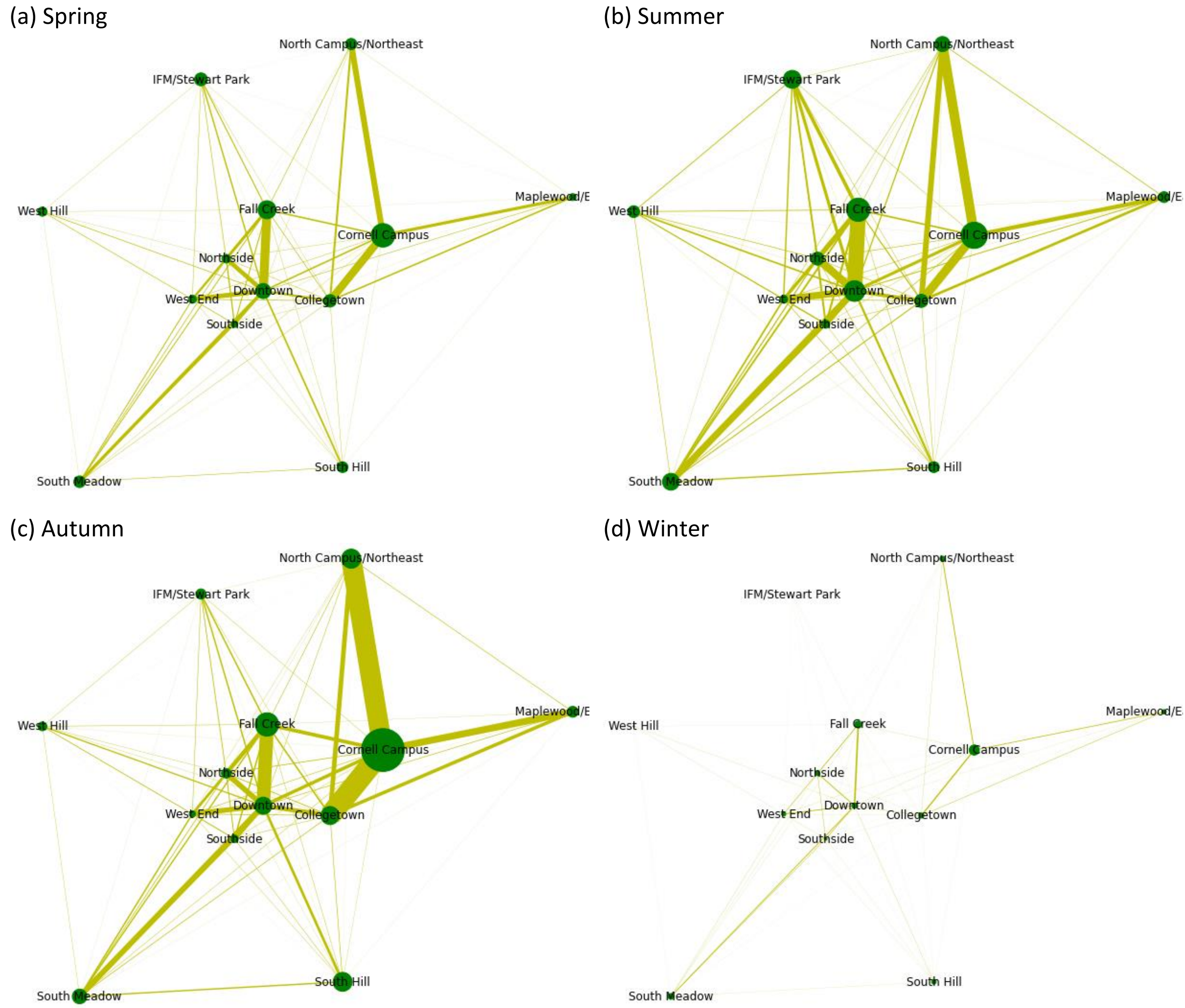


Figure 29 – Chord Diagram of Neighborhood Origin-Destination Pairs in 2019

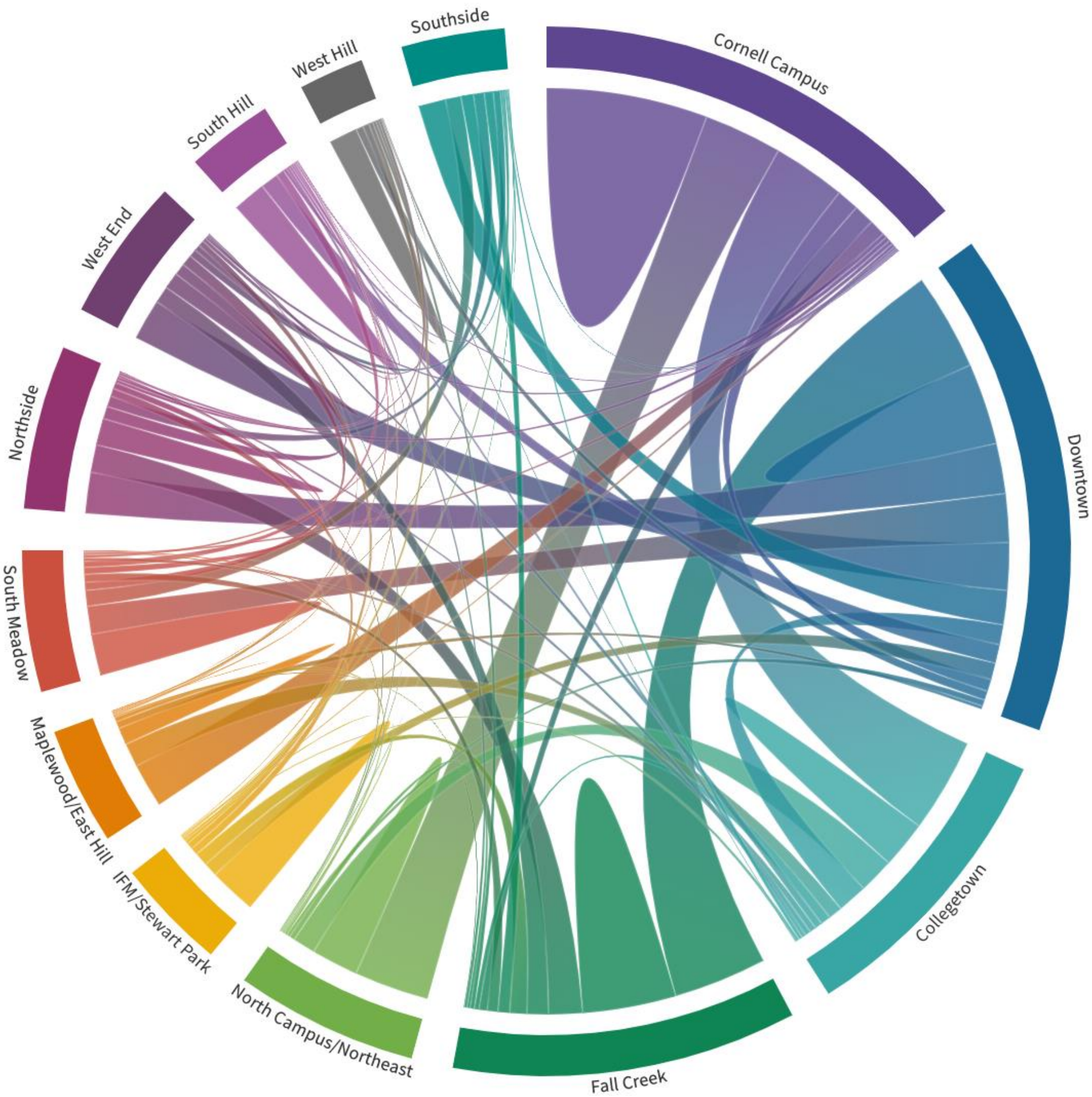
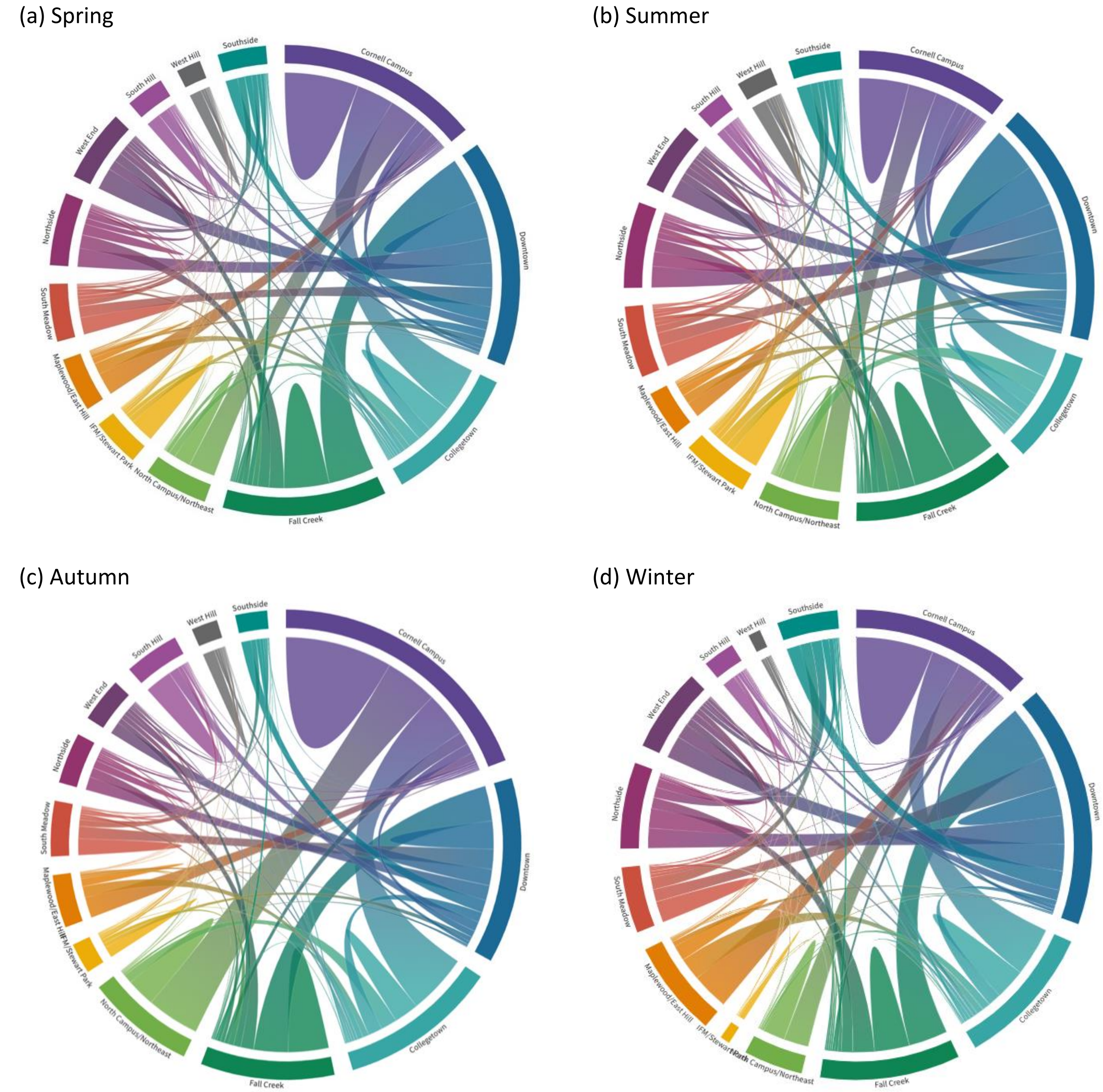


Figure 29 – Chord Diagram of Neighborhood Origin-Destination Pairs by Season



NEIGHBORHOOD-TO-NEIGHBORHOOD SPATIAL FLOW

FRAMEWORK

This section builds the hybrid street-by-street Lime ride traffic flow model based on multi-sourced data including (a) actual route records from Lime API and (b) Google Direction API routes. Limited by the fact that Lime API only provides actual routes data between Nov 21 2019 to March 17 2020, we take the returned best route from Google by feeding the O-D coordinates data of each trip between Jan 1 2019 to Nov 20 2019 to Google Direction API by setting "bicycle" as the travel mode. We then combine the proxy routes with actual route data and thus we have either proxy route or actual route data for every single trip in 2019.

Additionally, using the neighborhood origin-destination pair data and some logical assumptions, we also build a schematic diagram of the flow of Lime rides between neighborhoods that accounts for the trips that were made between two neighboring neighborhoods but also the trips that traversed through those two neighborhoods to go someplace else. The remainder of this sections covers both models. We will start with the schematic diagram.

SCHEMATIC FLOW DIAGRAM

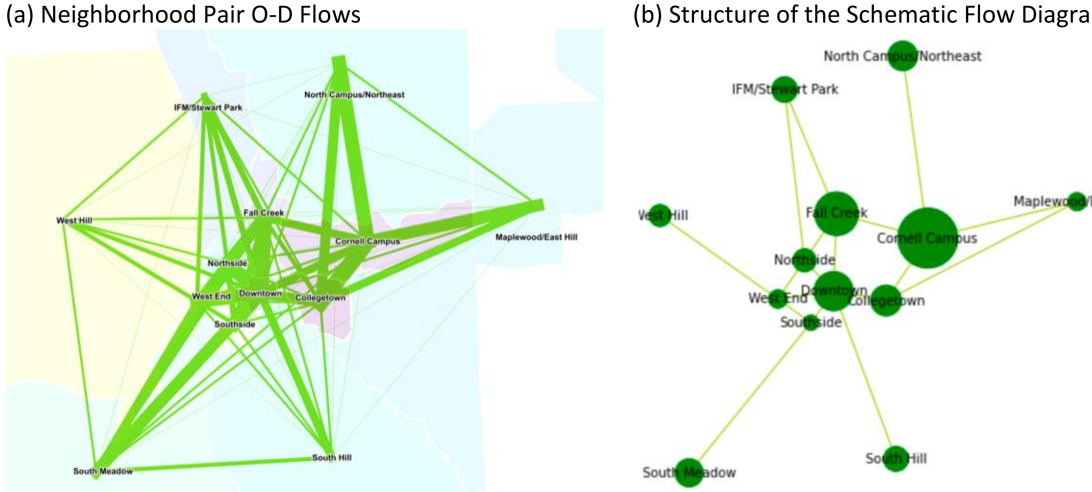
The schematic diagram on Figure 30b is built on Python. Each node represents a neighborhood and takes the coordinates of its geographical centroid location. Two nodes are directly connected if only there is an edge between two nodes. The size of the node is visualized by the number of rides within itself to give a sense of how popular the neighborhood is. Figure 30a shows the O-D flows between the neighborhood pairs. The O-D traffics would be assigned to the edges in the schematic diagram to count the actual accumulated bike flow volume.

To build the diagram, two assumptions were made. First, the thirteen neighborhoods are connected in a geographically relevant way as described on Figure 30b. For example, all trips originating from West Hill and going somewhere else will use the link between West Hill and West End (and traverse through the West End) to get to their destination neighborhood. **Second, all rides will take the path with the smallest sum costs between their originating neighborhood and destination neighborhood.** In cases where a neighborhood O-D pair has several paths with the same number of links, we chose the path that followed the most "logical" geographic orientation. For example, this analysis assumes that all rides that go from Cornell Campus to Waterfront will connect through Fall Creek instead of a longer route or a steep route. Therefore, a limitation of this analysis is that it cannot account for rides that may have taken a more circuitous path. The limited geographic data provided by Lime prevents us from accounting for longer routes.

Figure 30 – Schematic Diagram of Links Between Neighborhoods

(a) Neighborhood Pair O-D Flows

(b) Structure of the Schematic Flow Diagram



With those assumptions in place, we assigned each of the 169 possible neighborhood origin-destination pairs a specific "path" of connecting neighborhood links and counted the occurrences of each link. Tables 11 and 12 show the top 10 neighborhood links in the summer and fall, respectively, based on this analysis. As expected, the Collegetown-Cornell link is at the top three for all four seasons and it ranks the first by the annual total. In second and third place, however, is the Downtown–Fall Creek and Southside–Downtown links. The spatial analysis reveals the influence of trips between South Meadow and neighborhoods north and east of Downtown on the Downtown–Southside link.

Table 11 – Top 10 Neighborhood Links by Trips by Season in 2019

Neighborhood	**Spring**	**Summer**	**Autumn**	**Winter**	**Total Trips**	**% Total**
Collegetown-Cornell	2,813	4,136	3,269	419	10,637	12.4%
Downtown-Fall Creek	2,995	4,832	2,163	427	10,417	12.2%
Southside-Downtown	2,477	4,549	2,006	512	9,544	11.2%
Cornell-North Campus	1,899	3,722	2,917	256	8,794	10.3%
Downtown-Collegetown	1,894	3,179	1,770	273	7,116	8.3%
Southside-South Meadow	1,781	3,338	1,612	370	7,101	8.3%
Within Cornell Campus	1,625	1,662	2,172	288	5,747	6.72%
Downtown-Northside	1,442	2,346	841	306	4,935	5.8%
West End-Downtown	1,465	2,130	946	276	4,817	5.6%
Northside-Fall Creek	1,203	1,870	874	214	4,161	4.9%

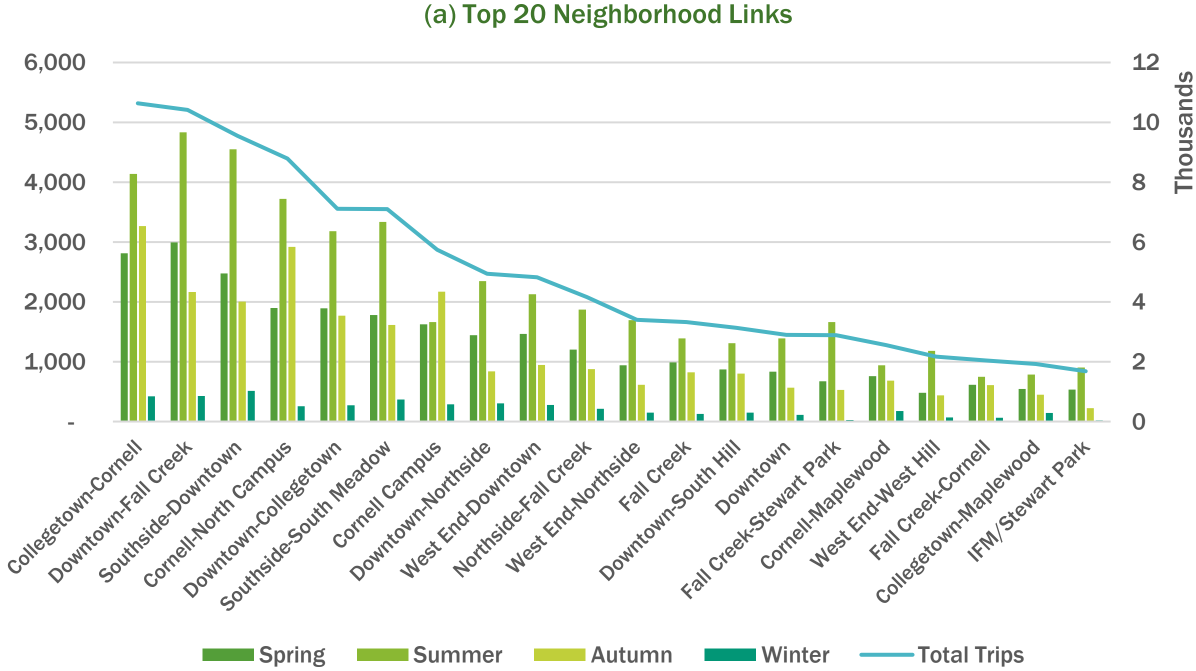
Table 12 – Top 10 Neighborhood Links (Summer)

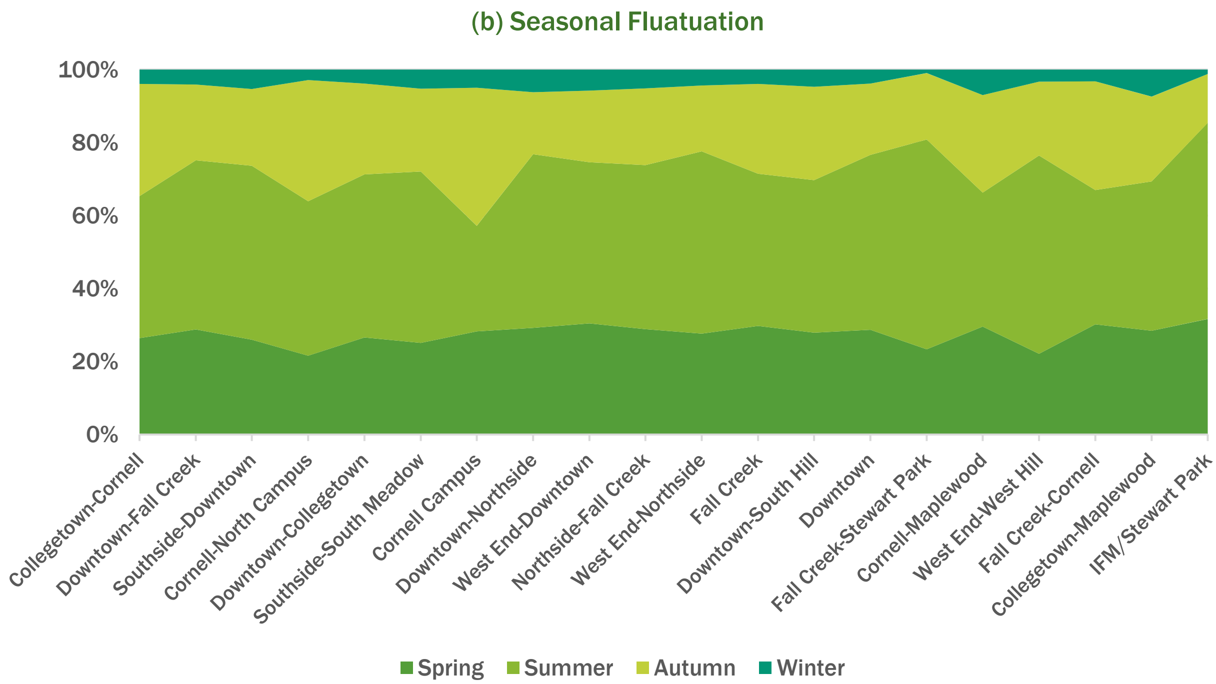
Neighborhood	**Summer**	**% Total**
Downtown-Fall Creek	4,832	22.1%
Southside-Downtown	4,549	20.8%
Collegetown-Cornell	4,136	18.9%
Cornell-North Campus	3,722	17.0%
Southside-South Meadow	3,338	15.2%
Downtown-Collegetown	3,179	14.5%
Downtown-Northside	2,346	10.7%
West End-Downtown	2,130	9.7%
Northside-Fall Creek	1,870	8.5%
West End-Northside	1,696	7.7%

Table 12 – Top 10 Neighborhood Links (Fall)

Neighborhood	**Autumn**	**% Total**
Collegetown-Cornell	3,269	14.9%
Cornell-North Campus	2,917	13.3%
within Cornell Campus	2,172	9.9%
Downtown-Fall Creek	2,163	9.9%
Southside-Downtown	2,006	9.2%
Downtown-Collegetown	1,770	8.1%
Southside-South Meadow	1,612	7.4%
West End-Downtown	946	4.3%
Northside-Fall Creek	874	4.0%
Downtown-Northside	841	3.8%

Figure 31 –Top 20 Links Between Neighborhoods





By combining the numerical results of the analysis with the network structure shown from Fig.30(b), we can create a graphical representation of the total Lime ride flows amongst the 13 neighborhoods. The thickness of the lines between neighborhoods is representative of the estimated number of trips for each neighborhood link, and the thickness of the node is representative of the number of trips that happened solely within that neighborhood. We can see from Figure 32 that **the Fall Creek–Downtown–Southside–South Meadow** axis and **the North Campus-Cornell Campus-Collegetown-Downtown** corridor both carry a significant proportion of Lime rides in 2019**.** The former axis is laid on the Ithaca Flats and the latter covers a wide range of elevation changes. Other strong links across both seasons include the **Downtown–West End** and the **Downtown–Northside** links.

Figure 32 – Total Lime Traffic Volume Between Neighborhood Links in 2019

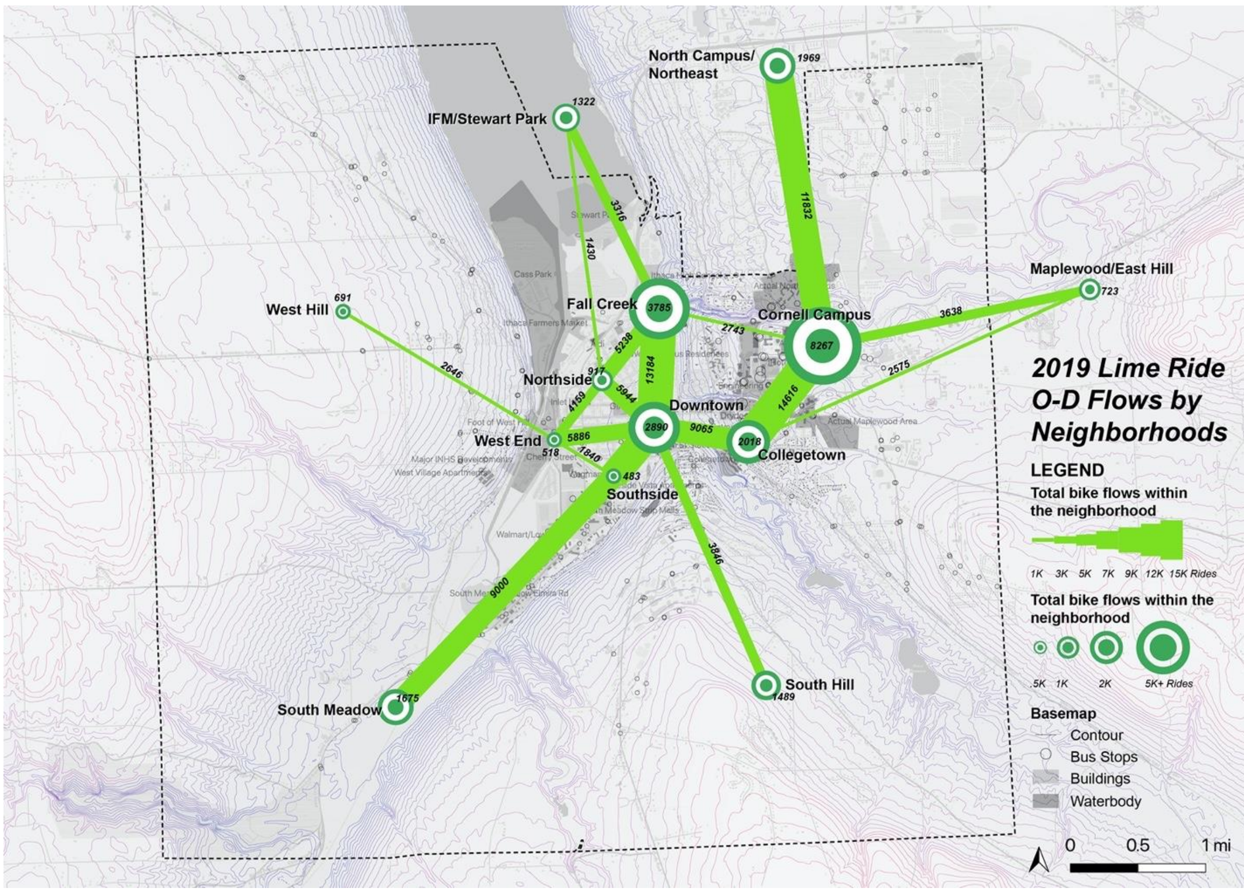
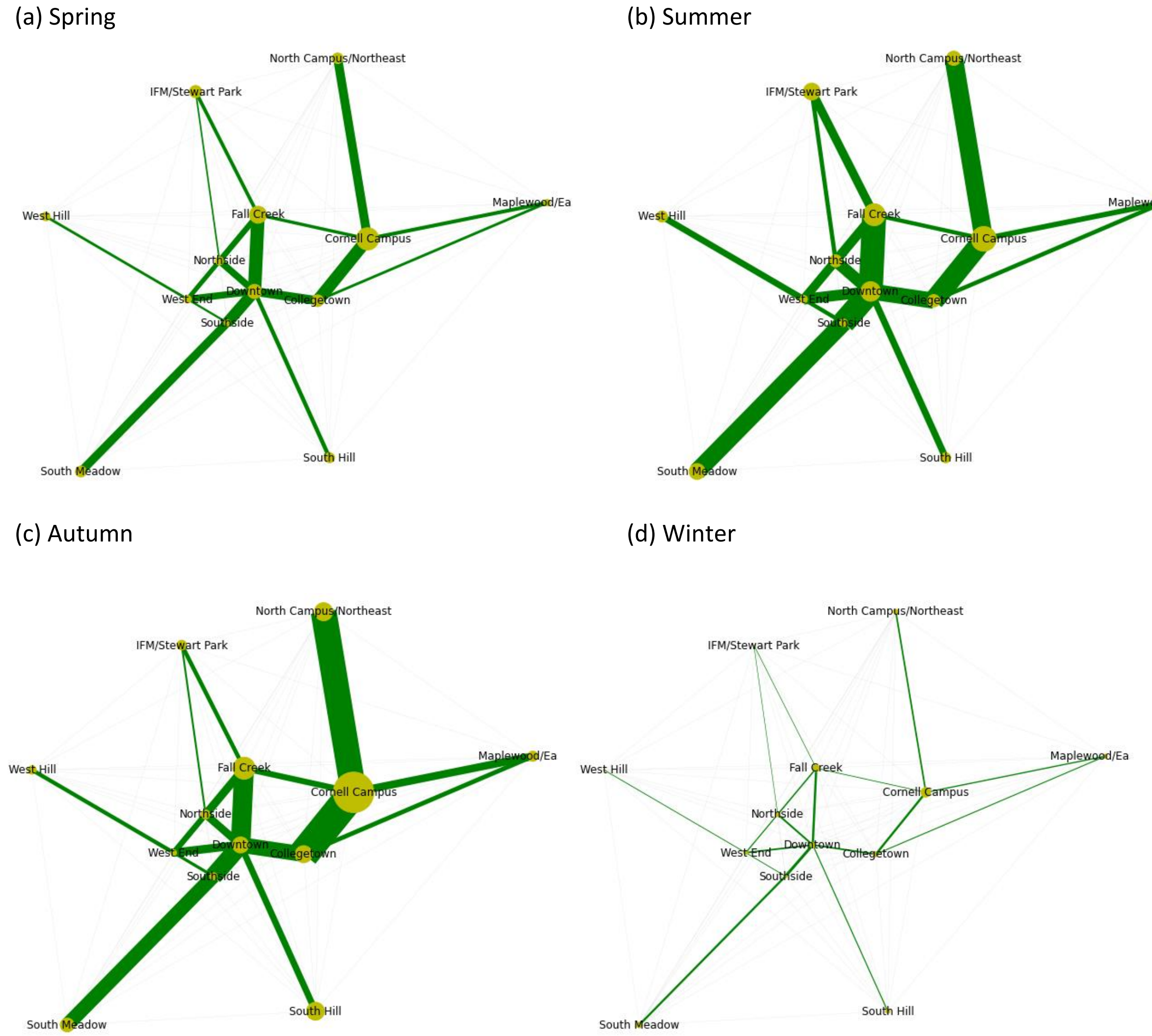


Figure 33 shows the total Lime traffics in the neighborhood links in each season in 2019. It is a spatial visualization of Table 11. We can see that **the Fall Creek–Downtown–Southside–South Meadow axis** and **the North Campus-Cornell Campus-Collegetown-Downtown both carries a significant proportion of Lime rides in every season, especially for summer and fall with large amount of traffic exceeding other links.** Moreover, the latter is typically strong in autumn as a result of returning students. Secondary links that show consistency between summer and fall include the Fall Creek–Northside–West End axis, West End-West Hill, Downtown-South Hill, and Maplewood-Collegetown and Maplewood-Downtown.

As previously stated, note that links within neighborhoods on East Hill and between these neighborhoods and the flats of Ithaca are affected by the elevation changes. As a result the Lime-E is assumed to play an important role for riders on these links. **Back in 2018 once bicycles were placed on East Hill neighborhoods, a clear pattern emerges where many of the trips that start on the hill end up in the flats.** We also see trips along the Collegetown–Cornell–North Campus axis particularly well-suited to the Lime-E pedal-assist electric bikes.

Figure 33 – Network Analysis Result of Trip Volume Between Neighborhoods by Season



TRAFFIC VOLUME ANALYSIS

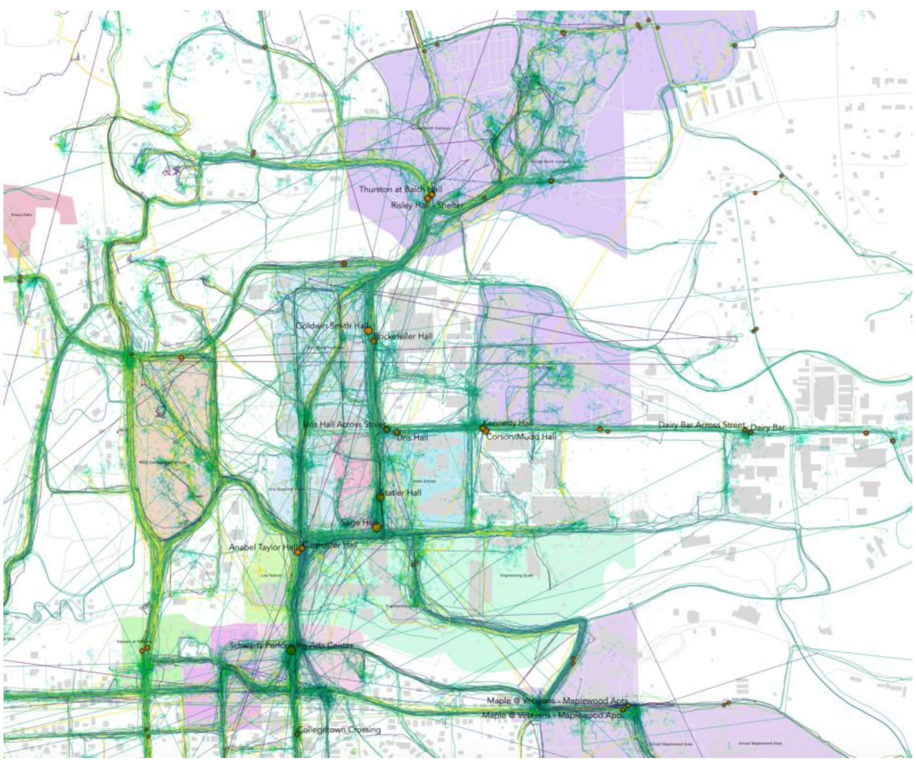
As mentioned before, we also build the hybrid street-by-street Lime traffic model based on (a) actual route records from Lime API and (b) Google Direction API routes. Due to data availability issues, Lime only make route data after Nov 21 available, as a result we are only able to scrape the actual routes data between Nov 21 2019 to March 17 2020 before Lime pauses their operation in Ithaca. Figure 34 shows the route data in the available period with a base map of Ithaca Urbanized Area and POIs blocks.

With these actual route data, we see the similar pattern regarding traffics in or between neighborhoods that have been covered by previous trip start and end analysis. Additionally, we also notice at least two new findings in much more details on how Lime users utilize the streets and recreational ways. **First, almost all recreational trails have been visited by Lime users, for example the Cayuga Waterfront Trail, the East Ithaca Recreational Way, and the South Hill Recreational Way. Second, though Lime is not formally operated in Cornell Campus, there are many Lime rides trespassing all the bike-able or walkable trails, paths, and sidewalks in the campus**, such as the Art Quad, the Agri Quad, and so on. Figure 34.b details these trespassing trips and we hope this map illustrates how creative Lime riders could be. These in-detail examination of Lime routes provide insights for biking and pedestrian transportation planning.

Figure 34 – Visualization of Actual Bike Routes between Nov-21-2019 to Mar-17-2020

(a) Actual Lime Bike Routes in Ithaca Urbanized Area

(b) Actual Lime Bike Routes in Cornell Campus Arts Quad



Each route data would contain multiple points' coordinates in order to complete the full path. However, due to Lime technology issues with their GPS lock, a partial route data missed interval point coordinates. As a result, there are straight lines fluttering across the space on Figure 34. **To fix the missing interval node issue, we applied Google Snap to Road API to generate best-guess coordinates for those actual route data** with missing data. Meanwhile, note that Lime only have route data available between Nov 21 to Dec 31 2019 for 2019. **Regarding the trips before Nov 21, we generate proxy routes using the best routing navigated from Google Direction API.** In brief we input the O-D coordinates of each Lime trip between Jan 1 2019 to Nov 20 2019 to the API and set "bicycle" as the travel mode. Google will return the best route for biking, taking into consideration of the travel distance, travel time, slopes and the traffic conditions. In this way we completed all route information with either actual route or proxy route data for every single trip for the 100,300 rides in 2019.

On top of the networks, we overlay the TCAT bus stops with their total alighting/boarding passengers in 2019 on Figure 35. It provides a detailed investigation for the rides behaviors and implications for traffic management planning. **First, busier streets are also where have more bus passengers.** We will dig into the relationship between TCAT and Lime later. Second, East Ave, Thurston Ave, College Ave, Campus Rd, East Buffalo St and Cayuga St are amongst the most popular routes Lime user would take. **Third, while streets in Cornell Campus, Downtown and Fall Creek attract large amount of Lime traffic, recreational trails are also non-negligible.**

Figure 35 –Total Lime Bike Traffic Volume in 2019

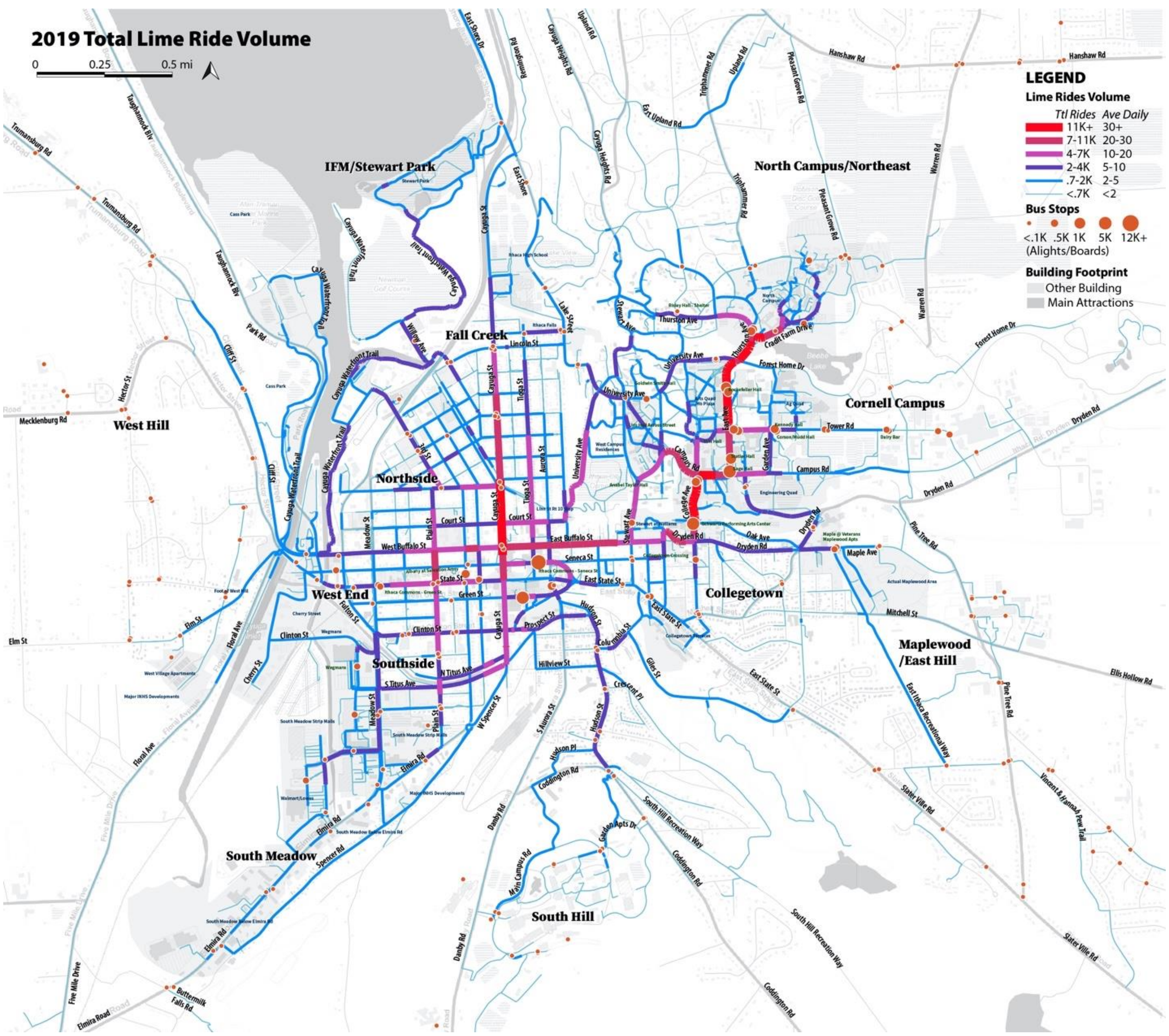
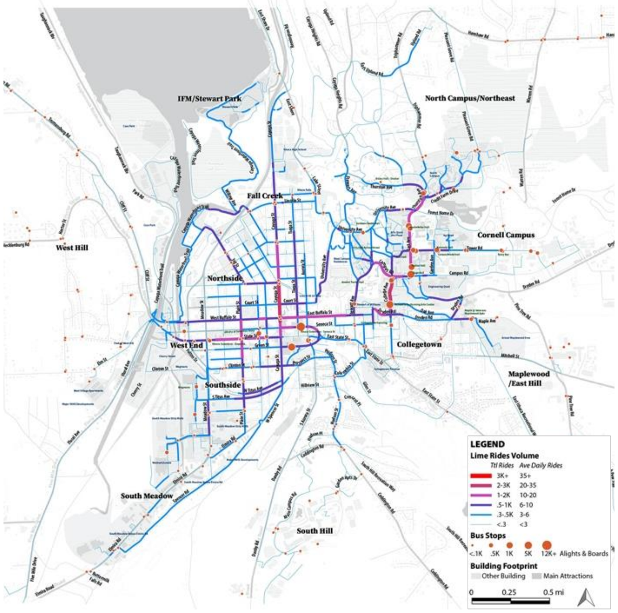


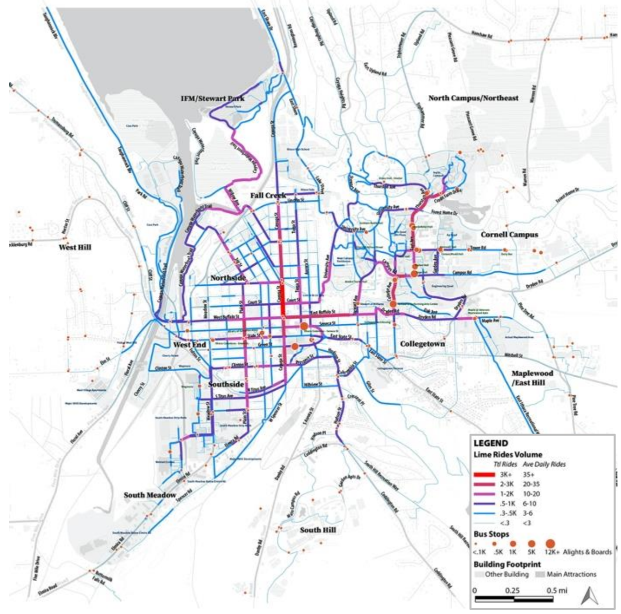
Figure 36 compared the Lime bike flows on each street in the four seasons in 2019. Spring has moderate number of rides, and Cayuga St, Buffalo St in Downtown, along with College Ave, College Rd and East Ave in Cornell Campus stand out as Lime bike corridors with significantly more rides. During the summer, since waterfront neighborhoods and downtown attract more bike rides, the downtown corridor and recreational trails have gained much more Lime rides while Cornell region does not see big changes. In fall with students coming back and as the weather goes worse, recreational trips decrease to moderate while campus rides continue to grow. During the winter, only very few rides still remain in the main corridors of downtown and Cornell campus.

Figure 36 – Aggregated Volume of Lime Bike Rides by Four Seasons in 2019

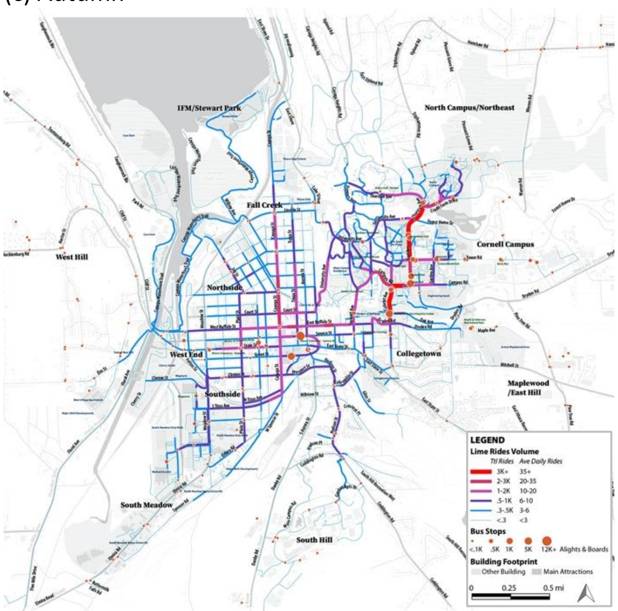
(a) Spring



(b) Summer



(c) Autumn



(d) Winter

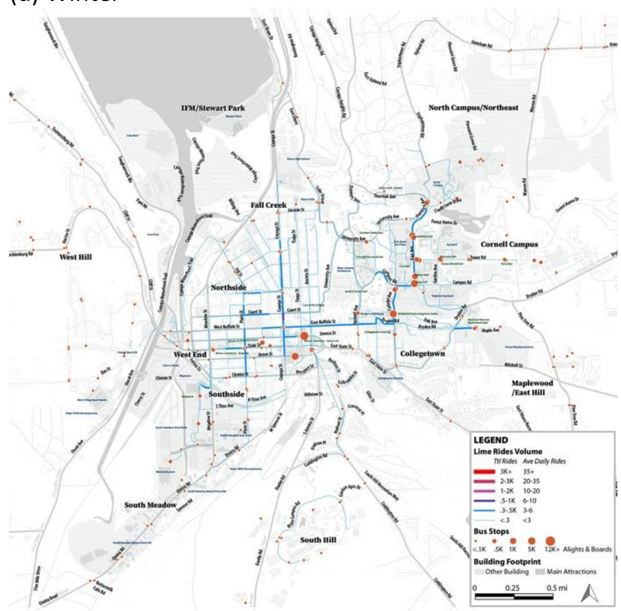


Table 13 and 14 summarizes the top 10 street segments that has the most Lime rides by seasons and by yearly total. Notably, there are similar patterns in the summer versus autumn to that of AM peak versus day time. In general, we see that during weekdays or during AM peak hours, there would be more Lime trips on the roads within Cornell Campus, Collegetown or MapleWood area, while during weekends or daytime, there will be more Lime traffic on streets in the Downtown, Fall Creek and other neighborhoods. It reveals the commute pattern of Cornell students, stuffs and Ithaca local residents.

Table 13 – Top 10 Streets with Most Average Daily Lime Traffic in 2019

Neighborhood	Street	Sub-Total	Spring	Summer	Autumn	Winter
Downtown	**North Cayuga St.**	71.2	16.2	30.2	22.1	2.7
Cornell Campus	**East Ave**	66.5	15.7	26.2	22.0	2.6
Cornell Campus	**Thurston Avenue**	40.9	5.7	12.5	21.6	1.1
Downtown	**East Buffalo St.**	63.0	14.2	25.5	20.2	3.1
Collegetown	**College Ave**	47.8	9.3	14.8	21.9	1.8
Downtown	**West State St.**	42.2	5.8	14.1	21.3	1.0
Cornell University	**Campus Rd.**	39.6	8.1	17.3	12.8	1.4
Cornell Campus	**East Avenue**	39.2	8.3	13.2	16.2	1.4
Northside	**North Cayuga St.**	51.1	11.8	20.5	17.0	1.8
Collegetown	**East Seneca St.**	34.1	7.6	13.3	11.8	1.4

Table 14 – Top 10 Streets with Most Lime Traffic in 2019 by Time of Day

Neighborhood	**Street**	**Overnight**	**AM Peak**	**Day Time**	**PM Peak**	**Night Time**
Downtown	South Albany Street	397	758	2,645	2,107	1,164
Downtown	North Cayuga Street	494	539	2,490	1,846	1,037
Downtown	East Buffalo Street	399	562	2,272	1,720	1,035
Downtown	West State Street	332	557	2,041	1,690	1,047
Maplewood/East Hill	Oak Avenue	279	969	1,899	1,192	585
Downtown	North Tioga Street	322	466	1,521	1,427	862
Collegetown	Oak Avenue	228	702	1,849	1,025	500
Southside	South Albany Street	179	444	1,655	1,250	621
Cornell Campus	Thurston Avenue	108	543	1,676	1,001	469

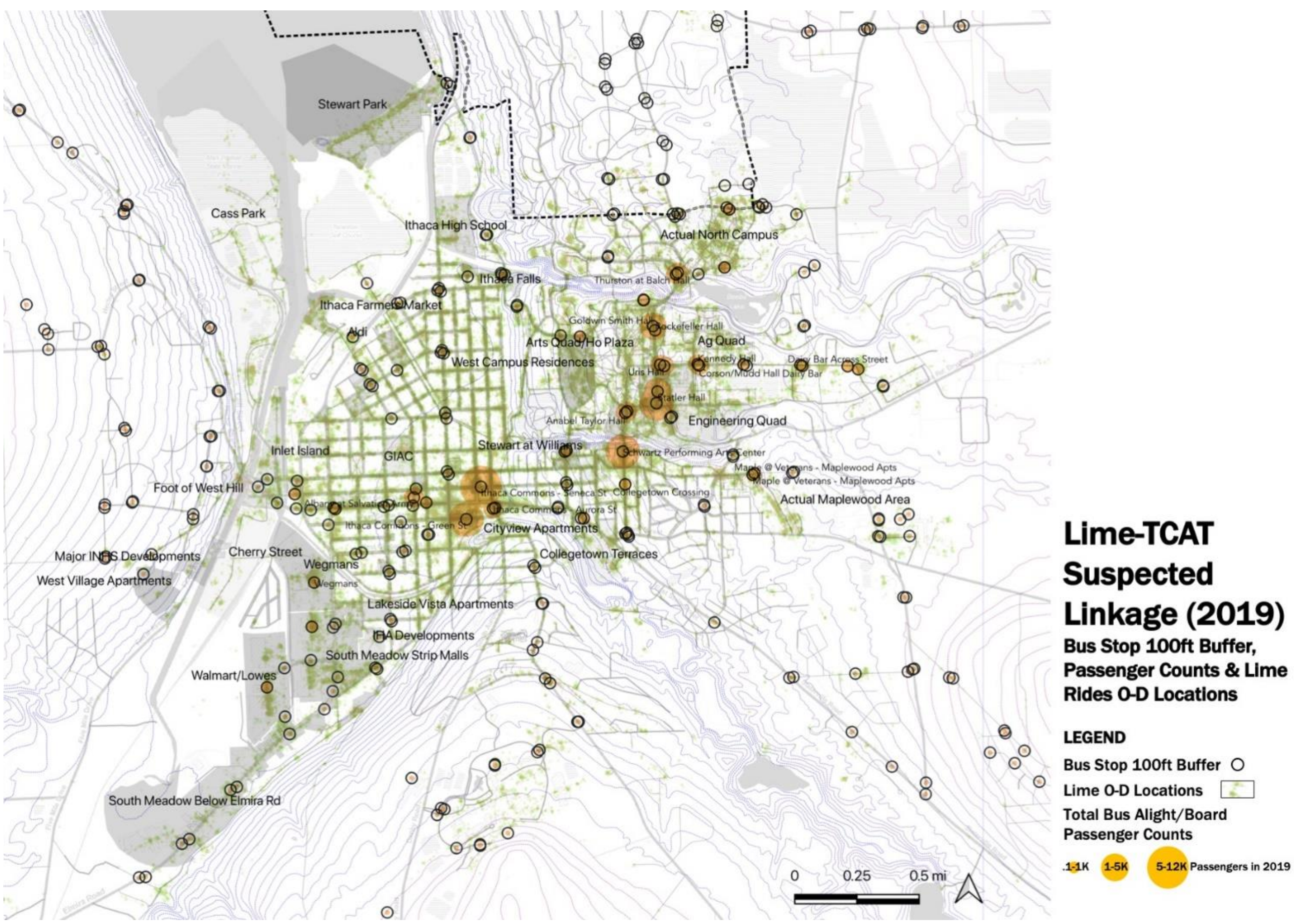
LIME-TCAT LINKAGE

ASSUMPTION AND FRAMEWORK

Bikeshare has been advocated to help people get to the public transit easier thus tackling the "Last Mile" issue by a few studies in transportation literature. A study conducted in Washington, DC, and Minneapolis, Minnesota found that users in less densely-developed areas often used bike share to access transit, as opposed to users in the dense urban core who used bike share to get to transit faster and replaced some transit trips with bike share (Martin & Shaheen, 2014). More recent system-level analysis of Capital Bikeshare stations indicated that increasing bike-share trips by 10% would contribute to a **2.8%** increase in Metrorail ridership (Ma et al., 2015). A most recent report (Graehler Jr et al., 2019) revealed that bikeshare has a positive effect on subway ridership increasing it **by 6.9%** with data from 2002-2018 in seven large U.S. cities including Boston, Chicago, New York City, San Francisco and Washington, DC.

Knowing how bike-share programs affect the public transit ridership allows transit agencies to develop programs that caters to specific audiences. This section examines to what extent Lime bikeshare system in Ithaca Urbanized Area is linked to the public transit, i.e. the TCAT bus stations. **Two types of linkage activities are assumed, namely (1) ride a Lime bike to get to bus station to board a bus, or (2) alight from a bus stop and ride a Lime bike to a final destination.** We acquire from TCAT 5.6+ million bus stop records with numbers of boarding and alighting passengers at each stop given each stop date and time. Joining the 100,300 Lime rides data and TCAT bus stop records, we were able to quantified these two types of suspected Lime-TCAT linkages.

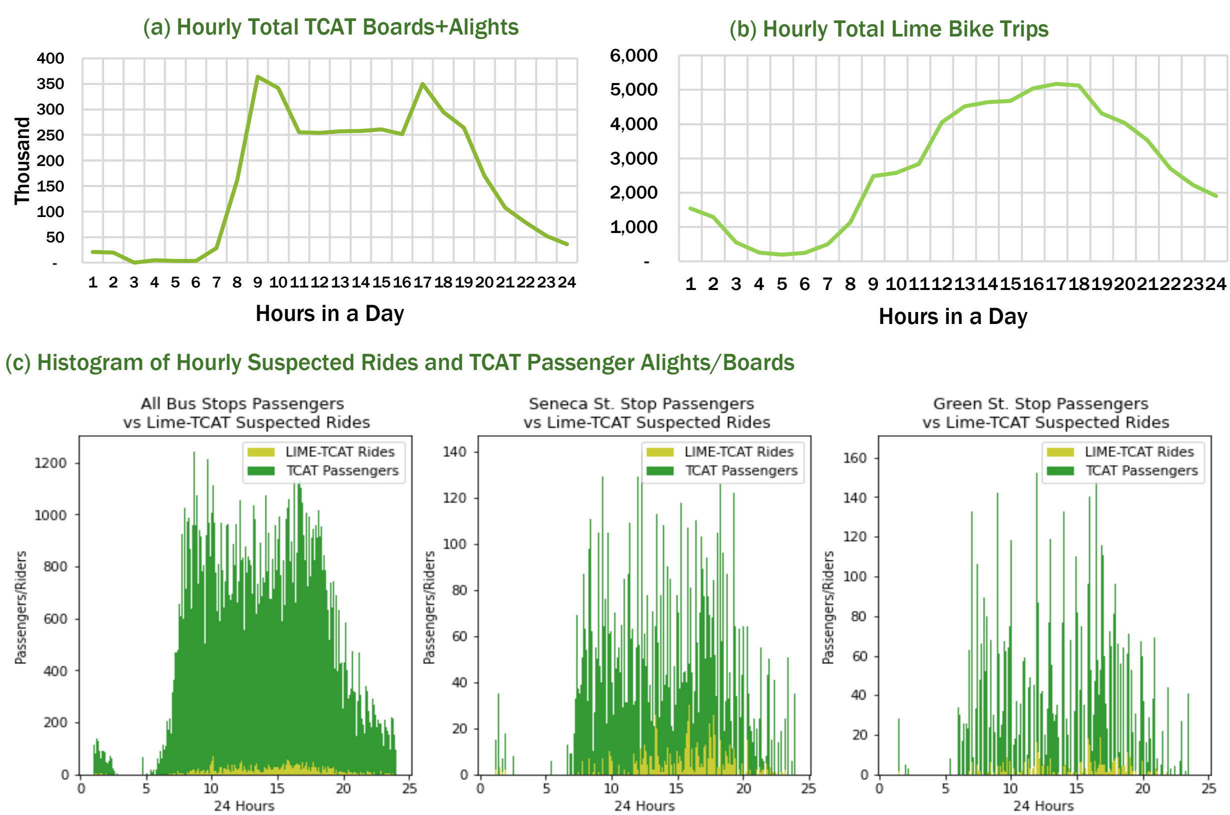
Figure 37 – TCAT Bus Stop Passenger Volumes and Lime Activity in 2019



We make three assumptions about the travel behavior of linkage rides and define two variables to capture the behavior, namely **the search radius and time window**. First, the search radius is the distance between Lime bike pickup or drop off location from a bus stop. **We assume linkage rides would naturally stop or start close enough to the bus stop, and the search radius is set at 100 feet**. Second, the time window is the time gap from a bike drop-off to bus stop time or from bus stop time to a bike pick up. **We assume linkage trips would have a relative short but also enough long time window, such that the rider has enough time to lock the bike and board a bus without waiting for the bus for too long.** Neither the rider has to look for a bike too long after they alighting from the bus. **We set the time window as 5 minutes.** Third, only if there are enough passengers boarding or alighting the bus, a potential ride meets the first two conditions can be a suspected linkage. **In other words, we filter out the potential rides that happen within the time frame and search radius, but do have any people getting on of getting off the bus correspondingly. In the end, any trip meets these three criteria is defined as a suspected ride.**

We conduct explanatory analysis on the total hourly ridership of Lime bike and TCAT Passengers in an aggregated level as well as per station. **The preliminary analysis reveal the strong correlation between Lime riders close to bus stops and around stop times. First, Lime rides and TCAT bus have distinct peak hour patterns.** TCAT users have morning and evening peaks while Lime usage has a more concentrated peak during late afternoon and evening (Figure 38 a & b). Given their very different peak hour patterns, our hypothesis is that if we observe morning peak rides around bus stop locations, it is reasonable evidence to justify the suspected linkages. **By just looking at Lime rides within the search radius of 300ft of bus stops, such suspected linkages during the morning peak hour do show up on Fig. 38(c). The bike rides density increases around the time when there are more bus passengers alight or board from the bus stops** (Figure 38.c). Additionally, we found such correlation is shown typically strong around certain popular bus stops such as Seneca St stop and Green St stop.

Figure 38 – TCAT Bus Stop Passenger Volumes and Lime Activity in 2019



With above framework and explanatory analysis, we conduct further investigation. We (1) found the percentage of suspected rides is just a function of the time-window and search radius, (2) quantified the percentage of suspected

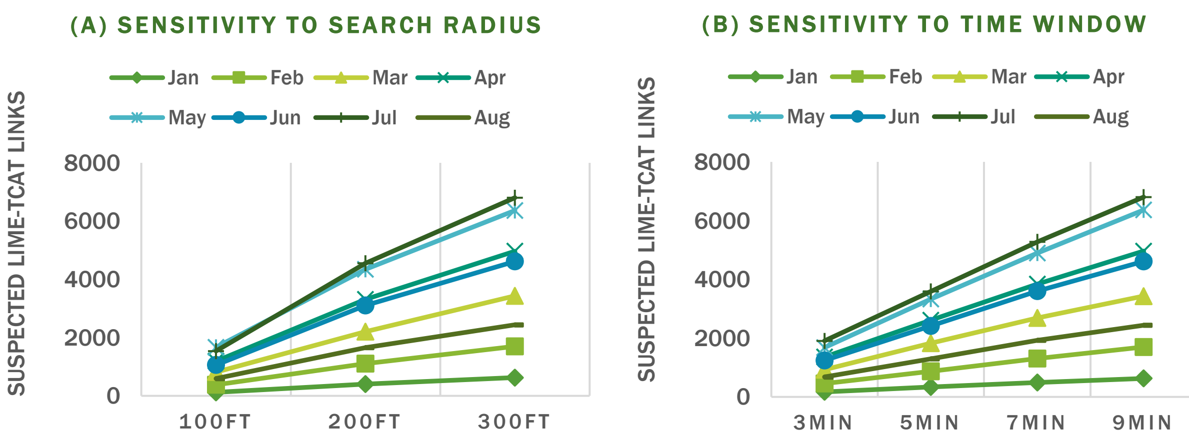
Lime-TCAT linage rides in 2019 using 100 ft and 5 minutes as the criteria, and (3) build a linear regression model to investigate the statistic relationship between suspected rides and bus ridership. Specific method description and pseudo code is detailed in Appendix. The remainder of this section will discuss the findings in details.

FINDINGS AND DISCUSSION

SENSITIVITY TO TIME WINDOW AND SEARCH RADIUS

First, as a rule of thumb, **there is a linear relationship between the number of identified suspected trips, the time-window and search radius**. While for the final analysis we set the search radius at 100 ft and time window at 5 minutes, we also test different range of 3, 5, 7 and 9min and the search radius of 100, 200 and 300f. We found the amount of suspected Lime-TCAT linkage trips identified is positively linear to the size of time-window or search radius (Figure 39). As a result, the assumptions we made about the 5 minutes time window and 100 ft search radius can be easily scaled to other ranges with the slope we identified in Figure 39. **The percentage of suspected trips range between 5%-50% of the total Lime trips, or 0.5%-3% TCAT alights/ boards that are likely to be the connecting bike rides, given different time-window (3-9 minutes) and radius (100-300 ft).**

Figure 39 – TCAT Bus Stop Passenger Volumes and Lime Activity in 2019



PERCENTAGE OF LIME-TCAT LINKAGE RIDES

Using the three criteria mention before, we joint the 100,300 lime bike rides with about 5.6 million bus stop records to count the numbers of inbounding out-bounding Lime rides. Inbounding rides are defined as bike trips with drop off location within 100 ft and 5 minutes before the bus stop. Out-bounding rides are those whose pick-up time are within 5 minutes after the bus stops and pick-up locations within 100ft of the bust stop.

The analysis result in Table 5 reveals that **with all three criteria together, 4,317 rides, or 4.3% Lime trips are suspected linkage rides to TCAT bus stop.** These suspected Lime-TCAT rides satisfy the criteria of have either start or end within 100ft of a bus stop location and either 5 minutes after or before the bus stop time when there is at least enough passengers board or alight from the bus. **Third, using the amount of suspected rides divided by the total TCAT passengers that alight or board which is 6 millions in 2019, we found at least 0.07% of the total passenger boards or alights from TCAT buses are suspected to be linked to a Lime ride.**

Moreover, just with the criteria of the 100ft search radius, about 9.0% Lime trips have started and 9.1% Lime rides have ended within the radius. We also found at least 50% of Lime rides in 2019 happened within 300 feet and 9 minutes of a TCAT board or alight. While these findings do not reveal the contribute of Lime bikeshare to the percentage of public transit ridership change, it sheds light on how many people potentially use Lime to access the public transit in Ithaca. It also reveals the highly spatially overlap of Lime and TCAT coverage. Additionally, the percentage of potential linkage in ridership is also consistent with literature in magnitude around 4% if we set the search radius larger at 300ft and time window at 5 minutes.

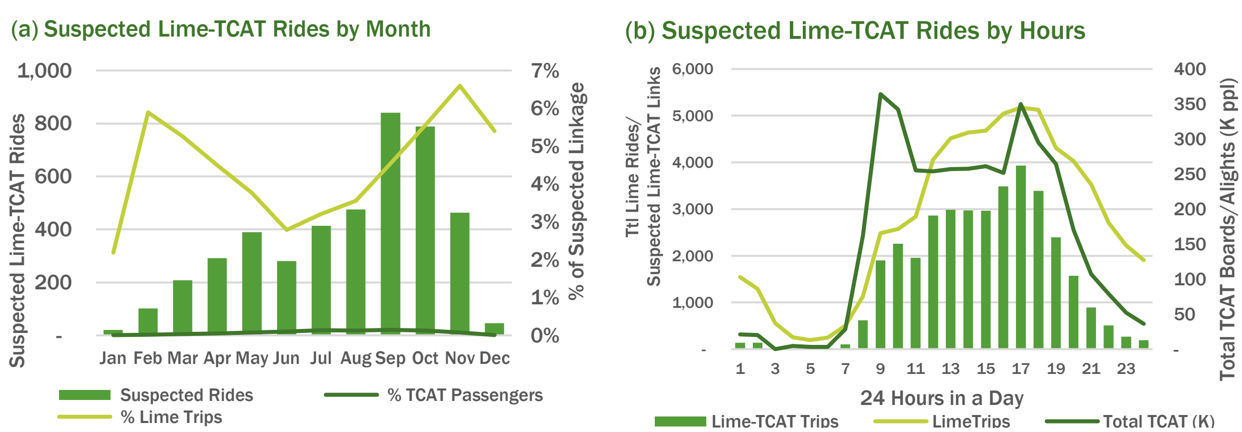
Table 15 – Suspected Lime-TCAT Linkage Rides by Month in 2019

	Suspected Linkage Rides	Ttl Lime Rides	Ttl TCAT Passenger	% Ttl TCAT Alights/ Boards Passenger	% Ttl Lime Rides
Jan	21	960	427,057	0.00%	2.2%
Feb	101	1,714	664,273	0.02%	5.9%
Mar	208	3,956	691,059	0.03%	5.3%
Apr	291	6,474	618,424	0.05%	4.5%
May	389	10,318	492,157	0.08%	3.8%
Jun	280	10,047	270,887	0.10%	2.8%
Jul	414	12,909	299,094	0.14%	3.2%
Aug	475	13,348	376,139	0.13%	3.6%
Sep	841	18,518	578,681	0.15%	4.5%
Oct	788	14,185	608,006	0.13%	5.6%
Nov	463	7,019	588,308	0.08%	6.6%
Dec	46	852	418,663	0.01%	5.4%
sub-total	**4,317**	**100,300**	**6,032,748**	**Ave: 0.07%**	**4.3%**

STATISTIC EVIDENCE

So far we discuss the relationship between the Lime ride density around a bus stop' location and bus schedule. Figure 39 summarizes the relationship in an aggregated level. Diagram (a) shows that the percentage of suspected rides in TCAT total passenger alight/boards is relatively consistent throughout the year while its percentage in total Lime rides drops a lot during the summer. This is reasonable because as previously discussed, a large portion of summer Lime rides are for recreational purposes to the waterfront or downtown. As a result, its percentage see a large drop due to less commute rides connecting to public transit. On the other hand, since TCAT passengers also decrease in summer, then the drop in linkage rides does not affect linkage rides percentage in total bus passengers. Chart (b) shows the total suspected linkage rides by hour and compares it with the overall trend in Lime rides and TCAT bus passengers. Unlike Lime trends, the suspected rides have more flatten volume change from 9AM to 7PM.

Figure 39 – Suspected Lime-TCAT Linkage by Month



Above analysis is based on our assumptions about potential linkage ride behaviors on their ride attributes with relationship to bus stops. We can also build a regression model to statistically test is the amount of TCAT bus passengers at each bus stop significantly associated with the amount of Lime rides around the bus stop. In other words, we build a regression model to ask, keep other neighborhood, weather, time of day variables the same, will there be more Lime rides around the bus station when there is a bus coming that would have more passengers getting on or off the bus. If so, how many Lime rides are associated with how many passengers.

To build the model, we set 300 ft as the search radius, and construct a new database that joining bike rides with bus stops. We use Lime ride density around each bus stop per hour as the independent variable, and use the neighborhood attribute, time variable, weather attribute, and bus stop passenger numbers in each hour as the independent variables.

Neighborhood attributes include neighborhood names, residence population density of the bus stop, and working population density of the bus stop. Time attributes include whether the ride happen in weekend/weekday and what hour of the day. Weather attributes include the average temperature and precipitation. Bus stop passenger count is the total bus passengers alight or board in each hour from that bus stop location.

The model achieve a R-square of 0.729, meaning our model captures (or explains) about 73% of the data variance. All attributes are significant except for the average temperature, precipitation, and the neighborhood of Maplewood. Thus we found the significant statist relationship between total passengers and Lime rides around the bus stops. To interpret the model, we can say that keep all other variables equal, if there are a hundred more bus passengers get on or get off the bus at the bus stop, we are likely to see 1.2 more rides either start or end within that hour at least 300ft close to the bus stop. Regression results can be seen from the Appendix.

APPENDIX- DETAILED METHOD AND DATA

Appendix 1. Search Framework and Pseudo Code

1. Lime Dropoff + TCAT Boarding

which calculates possible bike trips from other places to the bus stop to get on the bus. The conditional criteria are as follows: bike drop-off time (t.dp) is within the time-window (t.w) before the bus stop time (t.bs), and the drop-off location is within the search radius of the bus stop, e.g.:

Bus stop time (t.bs) - time window (t.w) < Lime drop-off time (t.dp) < bus stop time (t.bs)

Distance (d) between Lime Drop-off & bus stop < search radius (r.s)

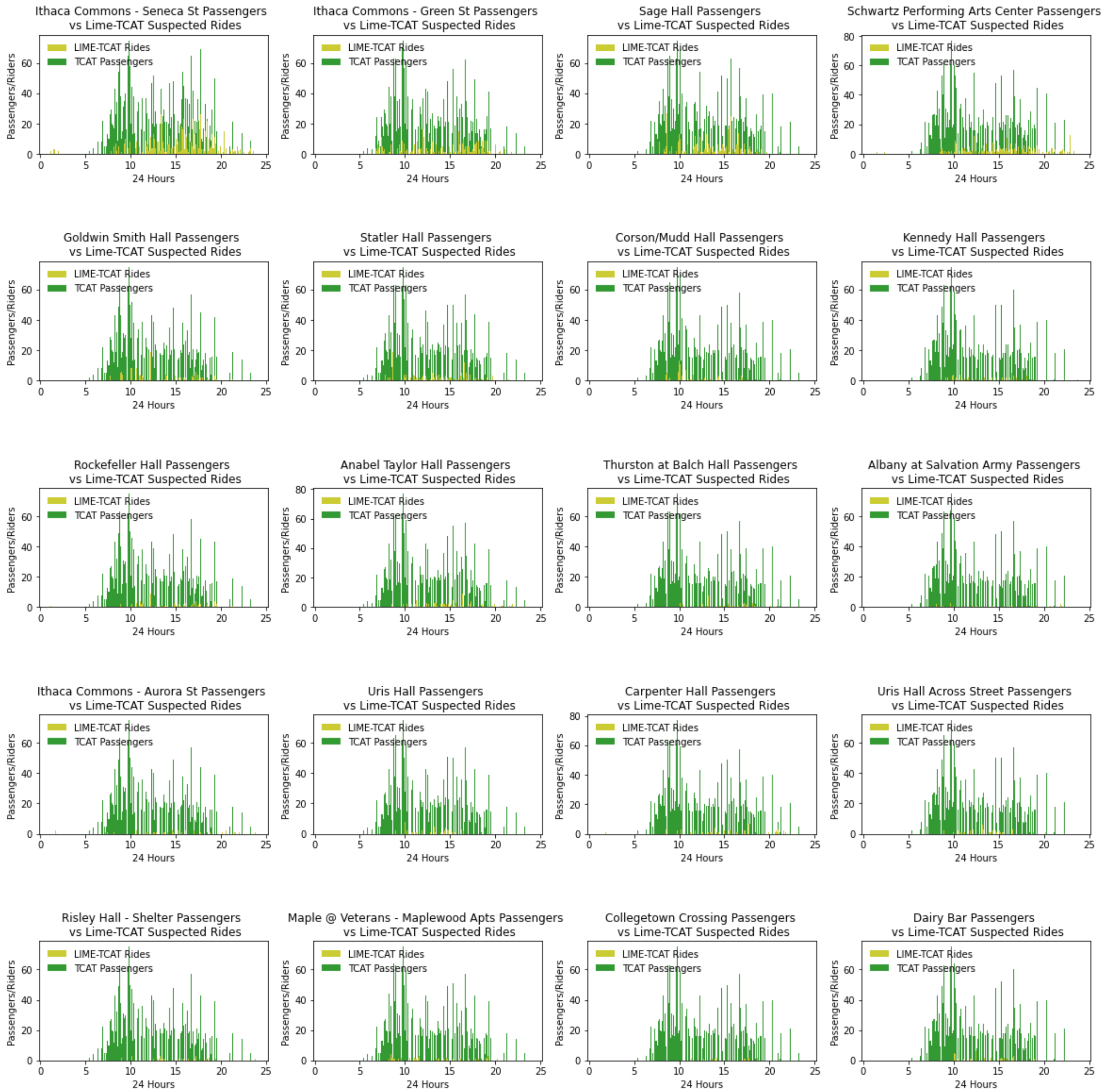
2. TCAT Alighting + Lime Pickup:

which calculates possible bike trips that were TCAT passengers alight from a bus stop to pick up a LimeBike. The conditional criteria are as follows: bike pickup time (t.pk) is within the time-window (t.w) after the bus stop time (t.bs), and the dropoff location is within the search radius of the bus stop, e.g.:

Bus stop time (t.bs) < LimeBike pickup time (t.pk) < Bus stop time (t.bs)+time window (t.w)

Distance (d) between LimeBike pickup & bus stop < search radius (r.s)

Appendix 2. TCAT Passengers and Suspected Rides Per Bus Stop



Appendix 3. Regression Result

MODEL:	OLS		ADJ. R-SQUARED:	0.729
METHOD:	Least Squares		F-statistic:	1.55E+04
DATE:	Mon, 7 Sep 2020		Prob (F-statistic):	0
TIME:	8:51:09		Log-Likelihood:	-6.42E+05
NO. OBSERVATIONS:	100,300		AIC:	1.28E+06
DF MODEL:	Residuals:	100,300	BIC:	1.28E+06
DF		12		
COVARIANCE TYPE:	Non robust			
	coefficient	**std err**	**t**	**P>|t|**
INTERCEPT	-1017.7705	30.604	-33.256	0
NGBR[T.DOWNTOWN]	3192.6197	86.789	36.786	0
NGBR[T.MAPLEWOOD/EAST HILL]	2002.6809	1853.122	1.081	0.28
NGBR[T.NORTH CAMPUS/NORTHEAST]	1382.3089	50.84	27.189	0
NGBR[T.NORTHSIDE]	2092.195	524.868	3.986	0
NGBR[T.SOUTHSIDE]	4744.8204	32.263	147.065	0
NGBR[T.WEST END]	2040.0435	200.146	10.193	0
WEEKEND	-1017.7705	30.604	-33.256	0
BUS_HOURS	13.1577	2.662	4.944	0
AVERAGE TEMPERATURE	-0.9386	0.753	-1.247	0.212
PRECIPITATION_INCH	63.5053	37.232	1.706	0.088
POP DENSITY	-0.0624	0.003	-19.707	0
WORK DENSITY	0.0045	0	20.801	0
TOTAL BUS PASSENGER	0.0123	7.86E-05	156.679	0
OMNIBUS:	7268.585	Durbin-Watson:	1.575	
PROB(OMNIBUS):	0	Jarque-Bera (JB):	9346.548	
SKEW:	-0.885	Prob(JB):	0	
KURTOSIS:	2.658	Cond. No.	1.20E+20	