

Assignment 1 - Toronto Bike Share: Analysis on Ridership Behaviour

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Introduction

This report aims to analyze how Toronto Bike Share customer behaviour is affected by various parameters. More precisely, we will take a look at how trip length, which we will soon better define, is affected by these factors.

We will aim to answer the following questions:

- How can we measure the 'length' of trips?
- How are these different definitions of 'length' related to each other?
- Is trip 'length' different for customers who are regular members vs. those who use a temporary pass?
- How do the present season or weather conditions affect trip 'length'?

This report takes some inspiration from the report [Exploring Toronto Bike Share Ridership using Python](https://towardsdatascience.com/exploring-toronto-bike-share-ridership-using-python-3dc87d35cb62) (<https://towardsdatascience.com/exploring-toronto-bike-share-ridership-using-python-3dc87d35cb62>), written by Yizhao Tan.

Abstract

We have provided two definitions for trip length: the trip's duration in seconds, present in the original dataset under `trip_duration_seconds`, and the trip's distance measured as the straight line distance between the trip's start and end stations.

There is a weak positive relationship between these two definitions. There appears to be an exponential relationship, however the data has a lot of variance.

The large majority of trips are performed by members. Trip duration distributions are very different for members and casual users (i.e. those using a temporary pass): casual users tend to go on much longer lasting trips. For trip distance, however, the distributions look very similar in terms of shape.

There were roughly 5 times more trips completed during summer and autumn months compared to winter and spring months. Regardless, for both definitions of trip length the distributions appear to be identical in terms of shape across all four seasons. One can notice how trip durations are on average shorter during winter compared to summer, but these differences are merely a couple of minutes, and could hence be insignificant.

Using meteorological data on the mean temperature and total precipitation for the day each trip was started on, we saw that trips were much more frequent on days with warmer mean temperatures, and on days with no or extremely little precipitation. We noticed tendencies that both trip duration and distance decreased as the daily mean temperature decreased, or as total precipitation increased. However, there is very little to no correlation between the meteorological data and trip length, and so it appears that the tendencies are caused by the underlying trip frequency distributions with respect to mean temperature and precipitation.

Data

This report uses official [Toronto Bike Share ridership data](https://open.toronto.ca/dataset/bike-share-toronto-ridership-data/) (<https://open.toronto.ca/dataset/bike-share-toronto-ridership-data/>) from Q3 and Q4 of 2016, and the entirety of 2017. To accompany this, we will also use [Bike Share station information](https://open.toronto.ca/dataset/bike-share-toronto/) (<https://open.toronto.ca/dataset/bike-share-toronto/>). We will scrape the weather data from the [Government of Canada historical climate database](https://climate.weather.gc.ca/) (<https://climate.weather.gc.ca/>).

Per the [terms and conditions of canada.ca](https://www.canada.ca/en/transparency/terms.html) (<https://www.canada.ca/en/transparency/terms.html>), we are permitted to scrape the data for non-commercial use as long as we:

- exercise due diligence in ensuring the accuracy of the materials reproduced
- indicate both the complete title of the materials reproduced, as well as the author (where available)
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Use of this data for commercial purposes is not allowed without special permission. We will be sure to adhere to these requirements for this report.

Toronto Bike Share Data

First, let us take a look at the Bike Share data.

Out [7]:

	trip_id	trip_start_time	trip_stop_time	trip_duration_seconds	from_station_id	from_station_name
0	712382	1/1/2017 0:00	1/1/2017 0:03	223	7051	Wellesley St E / Yonge St Green P
1	712383	1/1/2017 0:00	1/1/2017 0:05	279	7143	Kendal Ave / Bernard Ave
2	712384	1/1/2017 0:05	1/1/2017 0:29	1394	7113	Parliament St / Aberdeen Ave
3	712385	1/1/2017 0:07	1/1/2017 0:21	826	7077	College Park South
4	712386	1/1/2017 0:08	1/1/2017 0:12	279	7079	McGill St / Church St

Out [8]:

	trip_id	trip_start_time	trip_stop_time	trip_duration_seconds	from_station_name	to_station_name
0	53279	2016-07-09 01:03:00	2016-07-09 01:15:00	714	Dundas St E / Regent Park Blvd	Danforth Ave / Ellerbeck St
1	53394	2016-07-09 02:15:00	2016-07-09 02:22:00	417	Riverdale Park North (Broadview Ave)	Dundas St E / Regent Park Blvd
2	58314	2016-07-10 17:04:00	2016-07-10 17:36:00	1904	Dundas St E / Regent Park Blvd	Queen St W / Close Ave
3	60784	2016-07-11 01:45:00	2016-07-11 01:58:00	784	Union Station	Dundas St E / Regent Park Blvd
4	93164	2016-07-18 13:35:00	2016-07-18 13:42:00	443	Front St W / Blue Jays Way	Front St / Yonge St (Hockey Hall of Fame)

Above are shown the first couple of rows in the Q1 2017 and Q3 2016 datasets respectively. The datasets contain the following variables:

`trip_id`: unique identifier for each trip.

`trip_start_time`: date and time of the beginning of the trip.

`trip_stop_time`: date and time of the end of the trip.

`trip_duration_seconds`: the duration of the trip in seconds.

`from_station_name`: the name of the station where the trip began from.

`to_station_name`: the name of the station where the trip ended.

`user_type`: shows whether the user has a Bike Share membership or purchased a temporary pass.

Note that the Q1 2017 dataset also contains the variables `to_station_id` and `from_station_id`, which are not present in the Q3 2016 dataset. Hence, once we get to working with the data, we will omit these columns from the databases they are present in.

There are also several other inconsistencies and issues with the data: note how the trip start and end times are formatted differently in the datasets. We will have to standardize this.

Furthermore, in the data there are strangely short trips that start and end at the same station:

Out [9]:

	trip_id	trip_start_time	trip_stop_time	trip_duration_seconds	from_station_name	to_station_name
363400	2383642	12/31/17 23:46:27	12/31/17 23:46:53	26	Bloor St / Brunswick Ave	Bloor St / Brunswick Ave
363403	2383645	12/31/17 23:49:08	12/31/17 23:49:34	26	Phoebe St / Spadina Ave	Phoebe St / Spadina Ave

Toronto Bike Share considers valid trips to be those that are at least 60 seconds long, so we will exclude trips shorter than this from our analysis. In total, there are nearly 13 000 trips that start and end at the same station, but bare in mind that many of these could be valid trips.

Finally, we will also exclude any trips with missing data, and combine all of the separate datasets into a single big one.

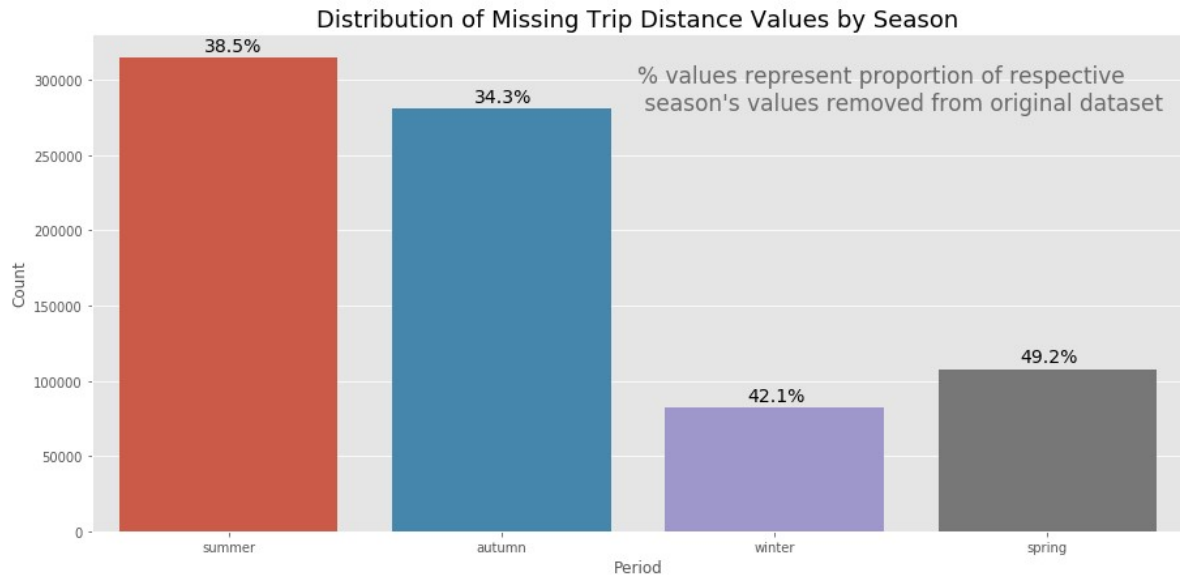
We will create a new column named `season`, representing the season (winter, spring, summer, autumn) the trip took place in based on the month the trip took place on.

We will go into more detail about this later, but we also would like to find out what is the physical distance between the start and end stations. To do so, we will use the Bike Share stations data and use their coordinates.

The coordinates are represented in WGS longitude and latitude, so we can use the [Haversine formula](https://en.wikipedia.org/wiki/Haversine_formula) (https://en.wikipedia.org/wiki/Haversine_formula) to compute the distance between two stations. Conveniently, a Python package called `haversine` exists just for this purpose. We will store trip distance in meters in a new variable named `trip_distance`.

It turns out that there are many inconsistencies with the station names, too. For example, a station name can be represented both as 'Lake Shore Blvd' and 'Lakeshore Blvd'. This is a big problem: when computing distances between stations, we were unable to do so for nearly 800 000 trips - about 40% of our dataset. We are still left with data for over a million trips, which is sufficient for our analysis, so we will not try to correct this issue.

We can take a look at where trip distance is missing with regard to the time period the trip is in:



We can see how we are removing more values from trips that took place during summer and autumn, however proportionately we have not taken away as many values from those seasons. Instead, we have disproportionately taken away more values from winter and spring trips.

This is not great because there is a 15% swing in the proportion of values removed from spring and autumn data. However, there is not much we can do: spelling inconsistencies are notoriously difficult to fix, so this limitation is simply something we will have to keep in mind when doing analysis - we will still exclude trips with missing trip distance data from our analysis.

Weather Data

We will scrape the data from Canada's historical climate database for each day from July 1st 2016 to December 31st 2017 - the time period we are analysing our Bike Share data on. The data is presented in [neat tables](https://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=51459&timeframe=2&StartYear=1840&EndYear=2019&Day=22&Year=2017&Month=1#) (https://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=51459&timeframe=2&StartYear=1840&EndYear=2019&Day=22&Year=2017&Month=1#) that are really easy and fast to go through using Pandas. We will scrape each day's mean temperature in degrees Celcius, and each day's precipitation in millimeters.

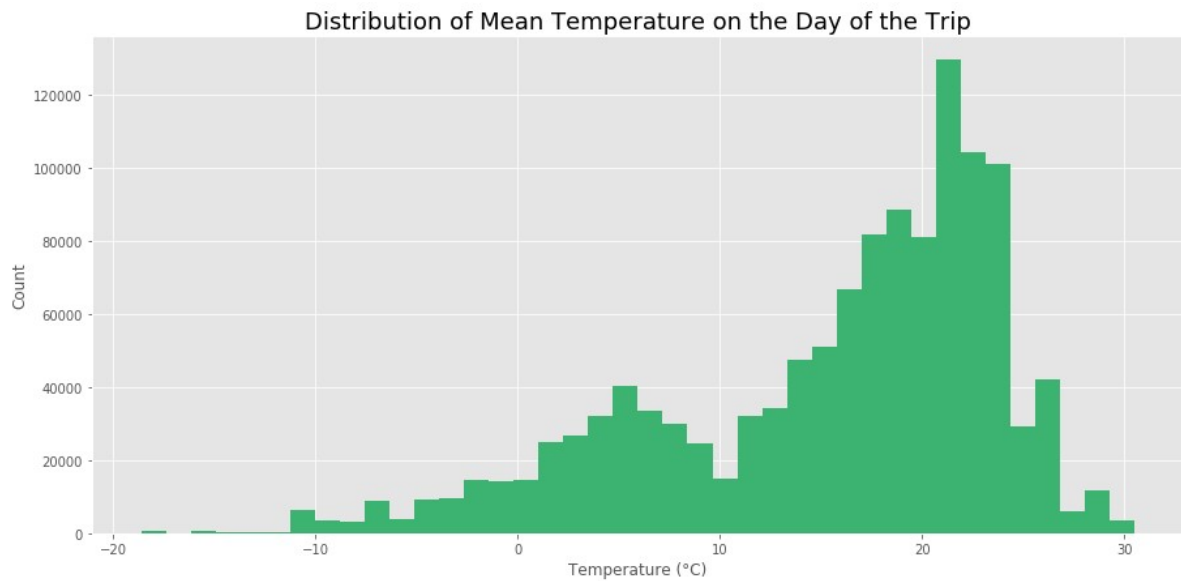
First, we will create a dictionary of the form:

```
{YEAR:
  {DAY: (mean_temp, precipitation)
  }
```

Data is not available for all days, in which case we will input the appropriate value as NaN.

Then, we iterate through our entire Bike Share dataframe, and get the mean temperature and precipitation data for each trip from our lookup dictionary. We will store the mean temperature in `mean_temp` and the total precipitation in `precipitation`.

Now, let's take a quick glance at how these newly created variables distribute. First, `mean_temp`:

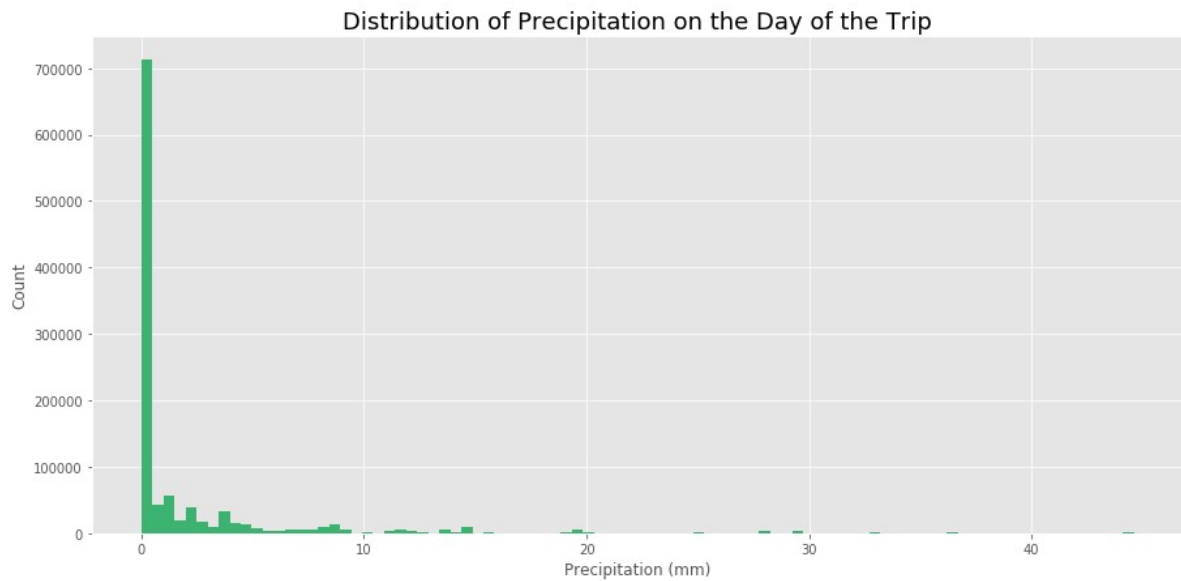


Out [20] :

	Mean Temperature on the Day of the Trip (°C)
count	1226735.0
mean	15.5
std	8.6
min	-18.6
25%	10.4
50%	18.1
75%	21.9
max	30.5

We can see that the distribution has two dominant modes: one centered around 20°C, and the other around 5°C. The distribution is left-skewed with an overall mean temperature of 15.5°C.

Secondly, precipitation:

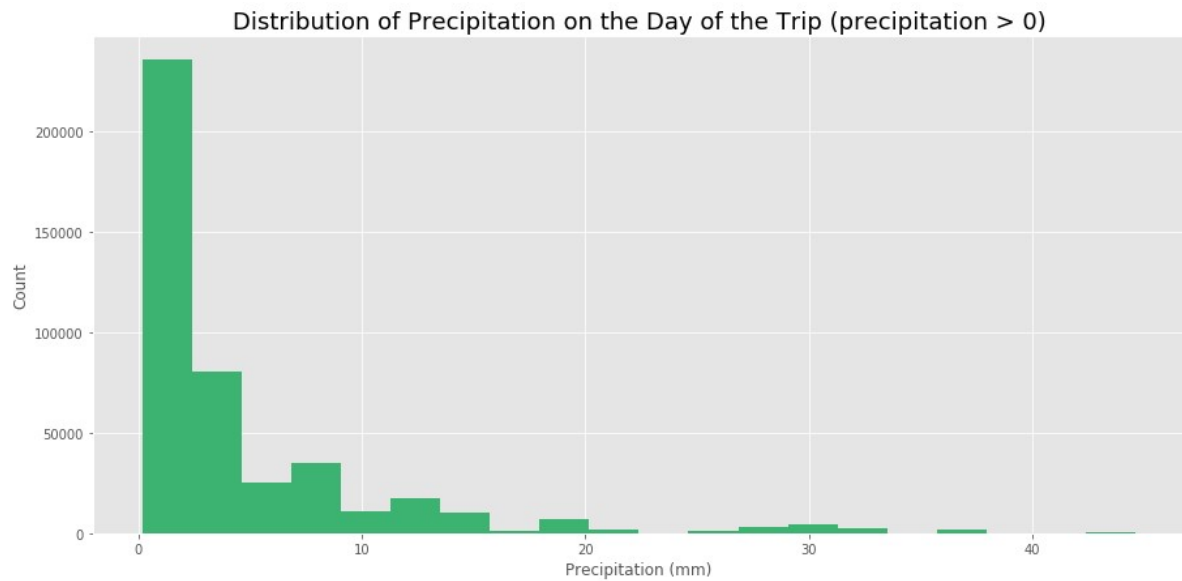


Out [22] :

	Precipitation on the Day of the Trip (mm)
count	1073240.0
mean	1.9
std	4.7
min	0.0
25%	0.0
50%	0.0
75%	1.4
max	44.6

We can see that over 50% of the trips have been recorded on days without precipitation. The mean daily precipitation in Toronto is 2.18mm (<https://en.climate-data.org/north-america/canada/ontario/toronto-53/>), while the mean for this distribution is 1.9, suggesting that Bike Share users embark on trips more frequently on days with very little or no precipitation.

Let's take a closer look at trips that were started on days that had precipitation to get a better look at the rest of the distribution:



Out [24] :

	Precipitation on the Day of the Trip (mm) [precipitation > 0]
count	437747.0
mean	4.7
std	6.4
min	0.2
25%	0.6
50%	2.2
75%	5.4
max	44.6

We can see that the distribution is still very right-skewed when we remove trips on days without precipitation, further suggesting that Bike Share users prefer little or no precipitation.

After all of our modifications, this is what the dataset looks like:

Out [25]:

	trip_id	trip_start_time	trip_stop_time	trip_duration_seconds	from_station_name	to_station_name
0	53279	2016-07-09 01:03:00	2016-07-09 01:15:00	714	Dundas St E / Regent Park Blvd	Danforth Ave / Ellerbeck St
1	53394	2016-07-09 02:15:00	2016-07-09 02:22:00	417	Riverdale Park North (Broadview Ave)	Dundas St E / Regent Park Blv
2	58314	2016-07-10 17:04:00	2016-07-10 17:36:00	1904	Dundas St E / Regent Park Blvd	Queen St W / Close Ave
3	60784	2016-07-11 01:45:00	2016-07-11 01:58:00	784	Union Station	Dundas St E / Regent Park Blv
8	102861	2016-07-20 13:12:00	2016-07-20 13:23:00	658	Dundas St E / Regent Park Blvd	Union Station

Analysis

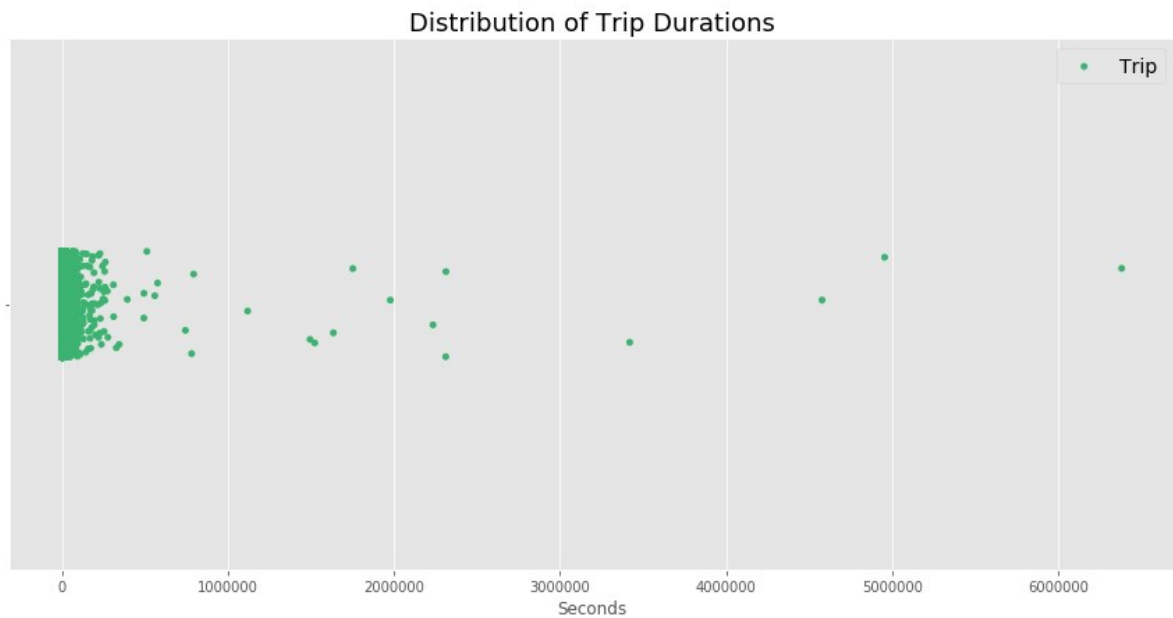
1. Measuring trip 'length'

We will consider two ways to measure trip length. First, we can measure the duration of the trip in seconds by using the information in `trip_duration_seconds` that came with the original dataset.

Secondly, we can measure the distance between the trip's start and end stations 'as the crow flies'. Of course, since bikes can't fly nor go through buildings, this trajectory will likely not represent the actual path a customer took. Because we don't have any tracking data, nor do we have a simple way to figure out the most probable shortest path the customer took, this method is the best available measurement of trip distance. It is very likely that a lot of users don't simply ride from station A to station B, but instead take detours and stop in different places inbetween, too. Despite these limitations, it still gives us some sort of idea on how long the trip was.

As mentioned previously, we have coordinates data for the bike stations, so we've used the [Haversine formula](https://en.wikipedia.org/wiki/Haversine_formula) (https://en.wikipedia.org/wiki/Haversine_formula) to compute the distance between the start and end stations in meters, and stored it in the column `trip_distance`.

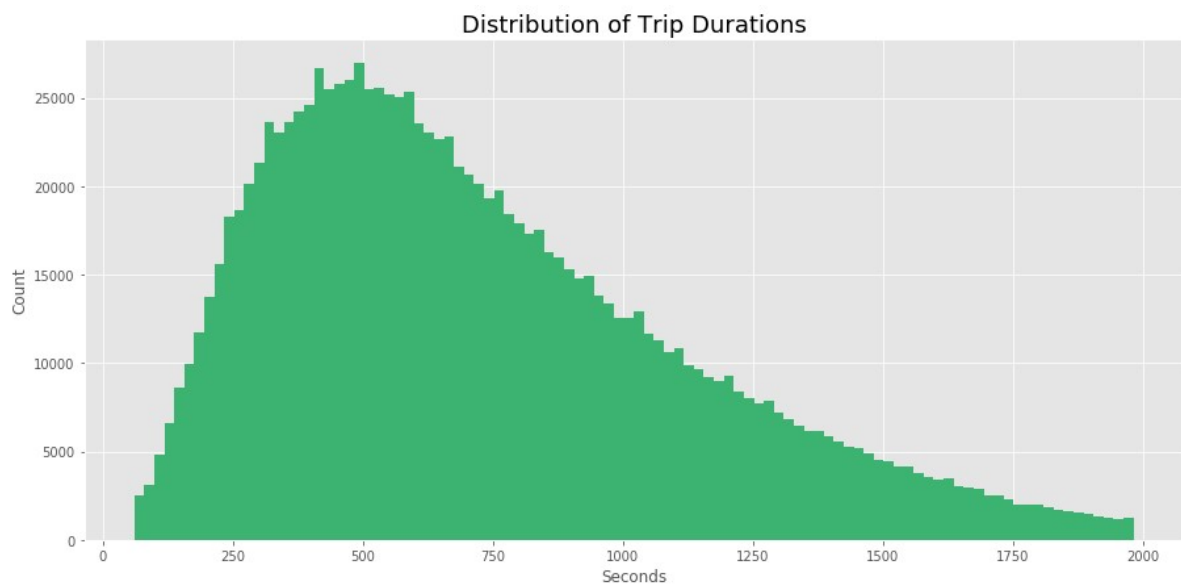
Let's now dive into the data and take a look at how these two measurements distribute. First, we will look at `trip_duration_seconds`. We will immediately realise that this distribution has some extreme outliers, which are clearly visible on this strip plot:



The longest trip recorded in this dataset is nearly 72 days long - that's over 2 months! Unless Forrest Gump gave up running and decided instead to pick up biking, it is safe to say that these outliers are invalid trips.

We will need to somehow deal with these outliers, but it is difficult to intuitively draw a hard line on how long a valid trip can be. Hence, we will use the commonly accepted definition that defines outliers as points that are at least 1.5 times the length of the inner-quartile range (IQR) away from either end of the IQR.

We can't say for sure that we aren't eliminating valid trips - there might be people who just decided to go on really long trips, but we have to draw a line somehow. Intuitively, we wouldn't expect anyone to use a bike for more than a short period of time, so under this assumption we won't remove many valid trips, which in return will not skew any of our later analyses. We can now take a look at how trip duration distributes:

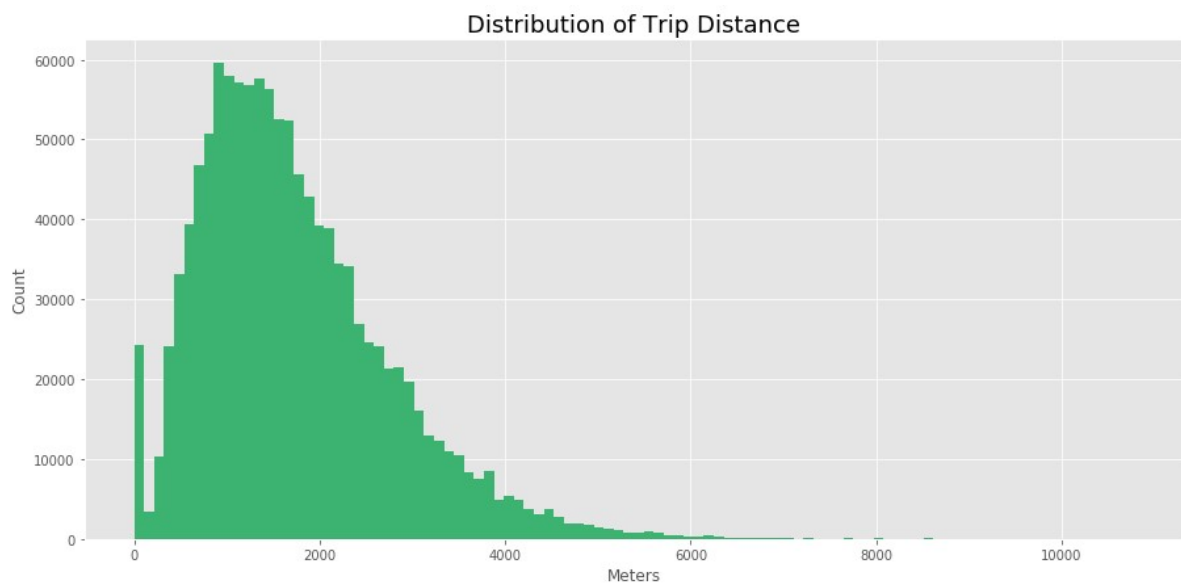


Out [29] :

	Trip Duration (seconds)
count	1187934.0
mean	728.6
std	398.1
min	60.0
25%	423.0
50%	650.0
75%	969.0
max	1982.0

After all of our data cleaning we are left with just under 1.2 million trips. We can clearly see how our changes have cut the distribution at 60 seconds, and at 1982 seconds - that is 33 minutes, which is where from onwards we consider trips to be outliers. The average trip duration is 728 seconds or just over 12 minutes. The distribution is unimodal with a mode at around 500 seconds or 8 minutes, and is right-skewed.

Now, let's take a look at `trip_distance`:

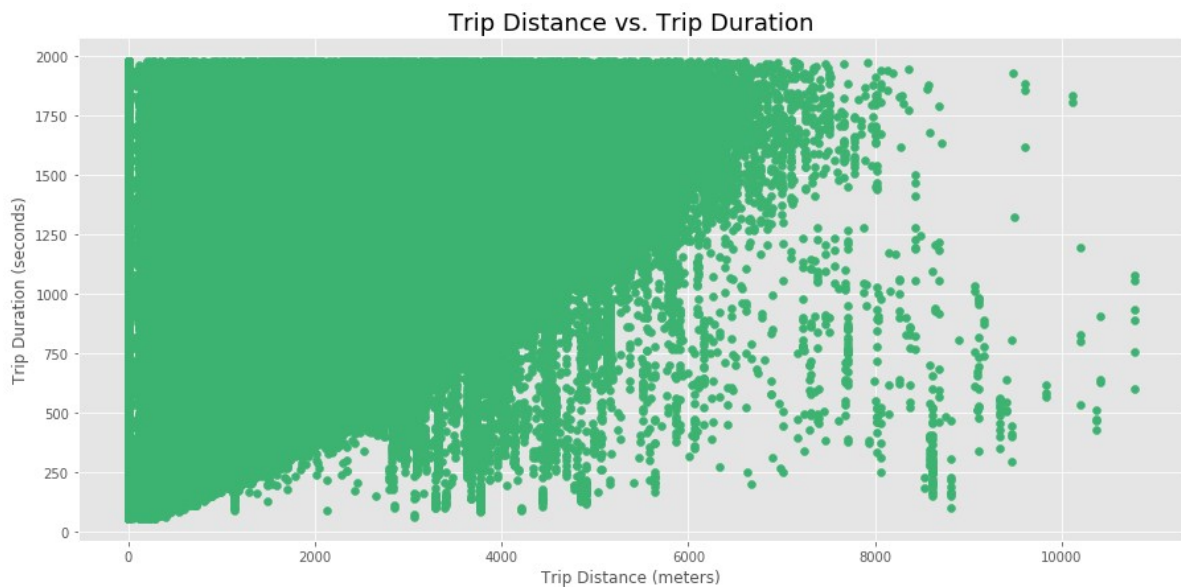


Out [31]:

	Trip Distance (meters)
count	1187934.0
mean	1728.3
std	1030.8
min	0.0
25%	977.9
50%	1540.2
75%	2286.7
max	10773.6

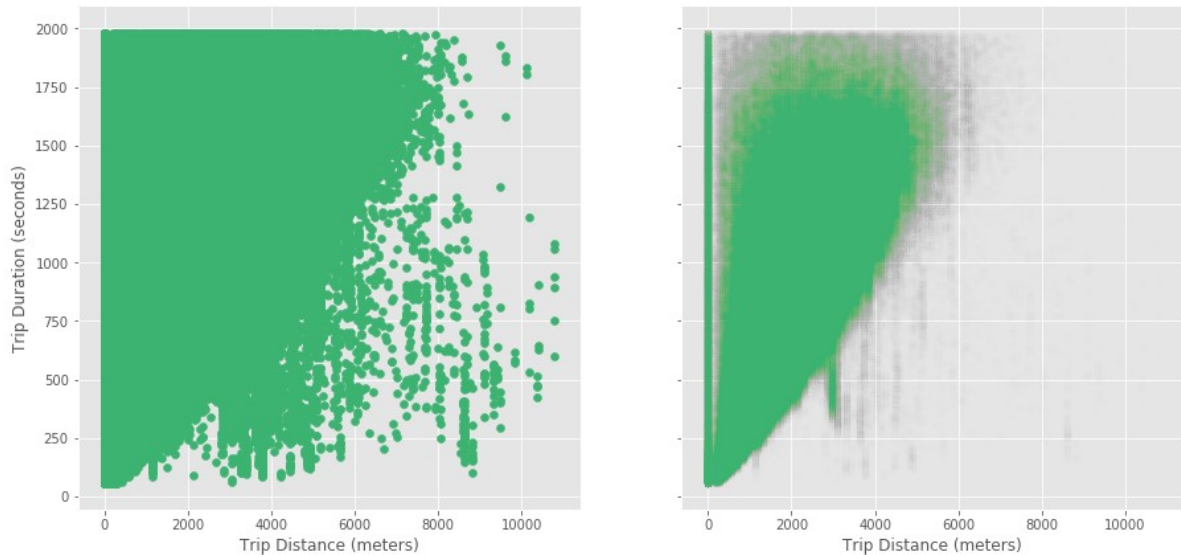
In terms of shape, we can immediately see that this distribution is similar to trip duration's distribution - it is also unimodal and right-skewed. Another interesting thing to notice is the outsticking high bin on the very left - this represents the trips which started and ended at the same station. As suggested earlier, we can now fairly safely say that there are valid round trips starting and beginning at the same station as we've done our best to remove any invalid entries. Similarly, it is interesting to see how the longest trip has been at least 10.7 kilometers long (recall that this is only the straight line distance).

We can look at the relationship between our two measurements of trip length. As one would expect, it takes a longer amount of time to cover a longer distance. However, as has been mentioned on numerous occasions already, there are many things we can't see from just the start and end stations - were there any stops or detours inbetween, or did the rider take the optimal path.



Boy, what a mess, but an interesting one! To get a better idea of what's going on, let's pair this graph with the exact same one, but let's make every dot partially transparent to better visualize the clustering.

Trip Distance vs. Trip Duration

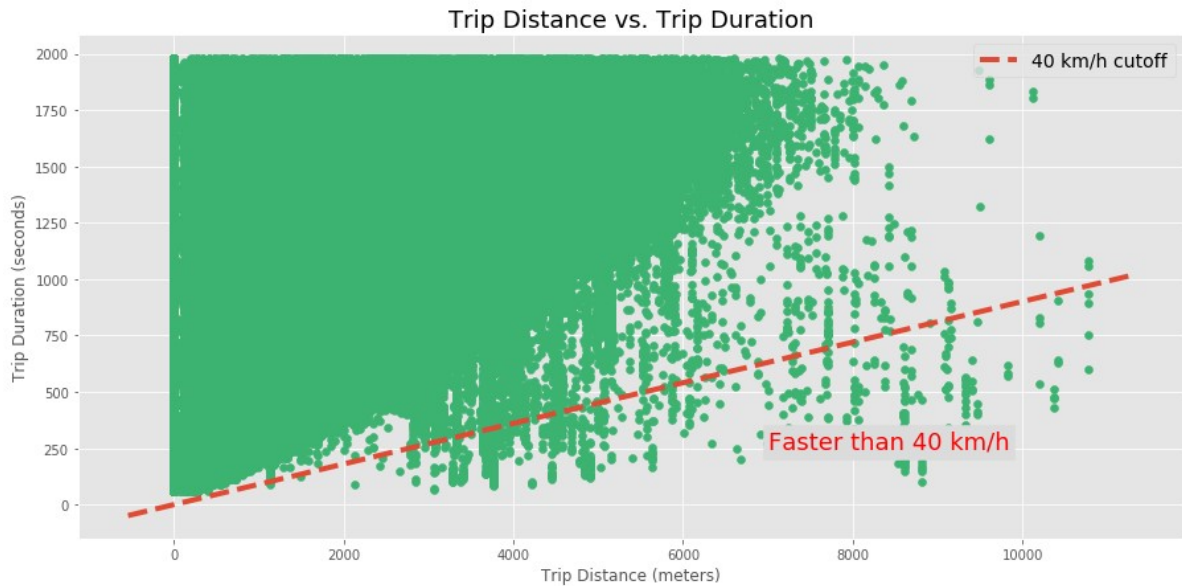


We can see how the data has, as expected, a lot of variance, but still we can notice a sort of exponential relationship between trip distance and duration, which matches intuition: on longer trips people become tired and so can't cycle as fast and may have to take breaks or slow down. We can again notice the trips starting and ending at the same station and see that people go on trips of very various durations of such type.

There's a very interesting outsticking cluster of trips around the 3000 meter - 500 second mark. Perhaps this is the effect of a popular route between two stations: users travel between these two stations often and with the same average time, causing it to appear on this visualization. We will have to investigate this further.

Once again we realise that there are anomalies in the data: notice some of the outliers in the bottom right corner. Some of these trips show as having completed around 10 000 meters in 500 seconds, that amounts to an average speed of 72 km/h - that is absolutely inhumane. The fastest recorded cycling speed in an upright position is 82 km/h (https://en.wikipedia.org/wiki/Bicycle_performance#Typical_speeds) and that is only over a distance of 200 meters, while the fastest Tour de France time set by Lance Armstrong was achieved with an average speed of 41 km/h (<https://www.cyclingweekly.com/news/racing/tour-de-france/fast-tour-de-france-useless-stats-429620>), and well, he had some extra help to achieve that, too.

Again, we would like to eliminate these outliers, but drawing a hard line is difficult to do. We can't use the 'IQR trick' on trip speed this time because, as previously explained, there are many reasons why the distance travelled may not represent the true value, and so trip speed is affected too. So, we are going to choose a fixed value based on the examples provided previously: we will remove any trips with an average speed over 40 km/h. While it is entirely possible that someone was in that much of a hurry, we are dealing with city bike data, and so it's reasonable to expect such trips to be invalid. When we graph our cutoff line, we see that we aren't removing any trips in the main cluster of the data:



Let's also investigate the outsticking small cluster of outliers that we noticed on the transparent scatterplot. Let's restrict ourselves to trips that had a distance between 2000 and 4000 meters, and a duration between 250 and 600 seconds, roughly outlining the range of the cluster. Then, let's see which stations are most popular for trips matching this criteria.

In total, there are 16690 trips matching this criteria.

```
Out[36]: 161 Bleecker St (South of Wellesley)    2622.0
         York St / Queens Quay W                1413.0
         Union Station                          1179.0
         dtype: float64
```

Above are shown the 3 most visited stations matching our criteria. Namely, these are the top 3 stations where such trips were started or ended at, with the corresponding trip count values also visible. Together, trips starting or ending at these 3 stations make up about a third of all trips matching our criteria.

First, let's compute the distances between these stations:

```
Out[37]:
```

	161 Bleecker St (South of Wellesley)	York St / Queens Quay W	Union Station
161 Bleecker St (South of Wellesley)	0	2959	2363
York St / Queens Quay W	2959	0	609
Union Station	2363	609	0

Above is shown a matrix of the distances in meters between all of our 3 stations. There are two station pairs that match our criterion: **York St / Queens Quay W - 161 Bleecker St (South of Wellesley)** and **Union Station - 161 Bleecker St (South of Wellesley)**.

For these two pairs of stations, let's look at all trips that were completed between these pairs, and compute statistics about the duration of such trips:

Out [38] :

	Trips between 161 Bleecker St and York St / Queens Quay W
count	1542.0
mean	621.0
std	339.0
min	281.0
25%	429.0
50%	486.0
75%	630.0
max	1978.0

Out [39] :

	Trips between 161 Bleecker St and Union Station
count	139.0
mean	951.0
std	339.0
min	472.0
25%	697.0
50%	839.0
75%	1100.0
max	1929.0

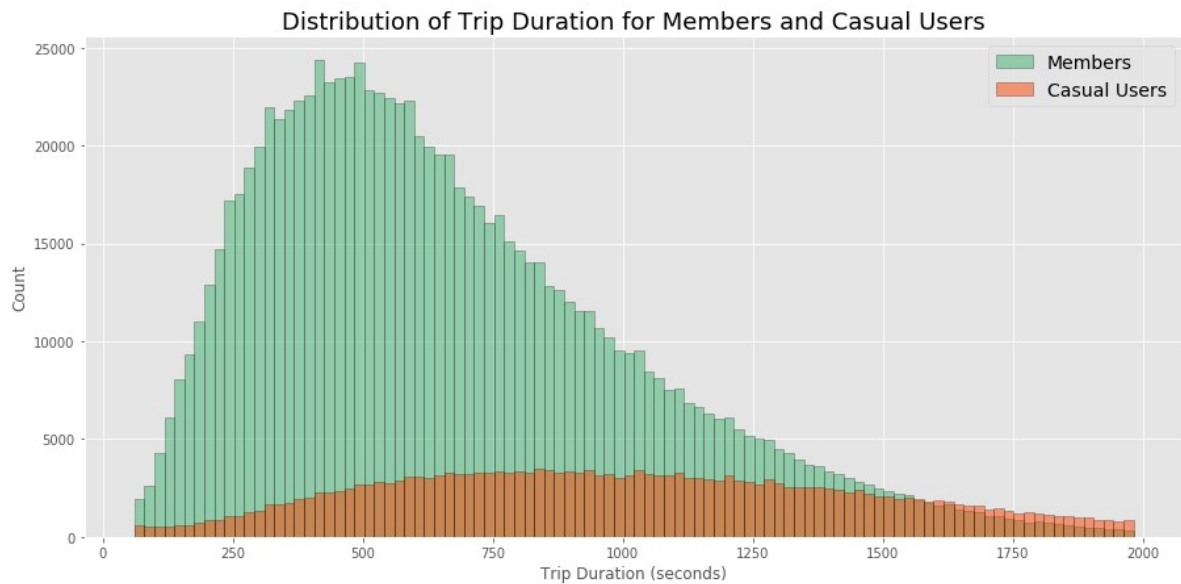
It appears that a popular route between 161 Bleecker St. and York St. / Queens Quay W seems to be the main culprit behind the curious outsticking cluster of trips: nearly 3/4 such trips have a duration in the range of 250 to 600 seconds. There are some few trips between 161 Bleecker St. and Union Station that contribute to the cluster, but most trips between this pair of stations are longer than 600 seconds in duration.

If we take another look at the transparent scatterplot where we first discovered this cluster of trips, we can see that trips in that cluster had a faster average speed than most trips. The next natural thing to ask is "Why is this so?", however it is a difficult question to answer with the data we have available. Perhaps the route between these two stations has great infrastructure or little traffic, or perhaps this is a very popular commute route, so people don't have time to waste when biking from work to home or the other way around.

Keep in mind, though, that our original (but roughly defined) query into the data gave us nearly 17 000 trips that were between 2000 and 4000 meters in distance, and 250 and 600 seconds in duration. This range captures a fair bit more than that small cluster, but it is still possible that this popular route we discovered, with just 1 500 trips recorded, is not the only reason behind it existing.

2. Casual user vs. member behaviour

We will compare how both of our trip length definitions differ when looking at either casual users or members. By casual users we mean customers who purchased a temporary pass to use a bike, rather than purchasing a long-term membership. First, let's consider trip duration, stored in `trip_duration_seconds`.



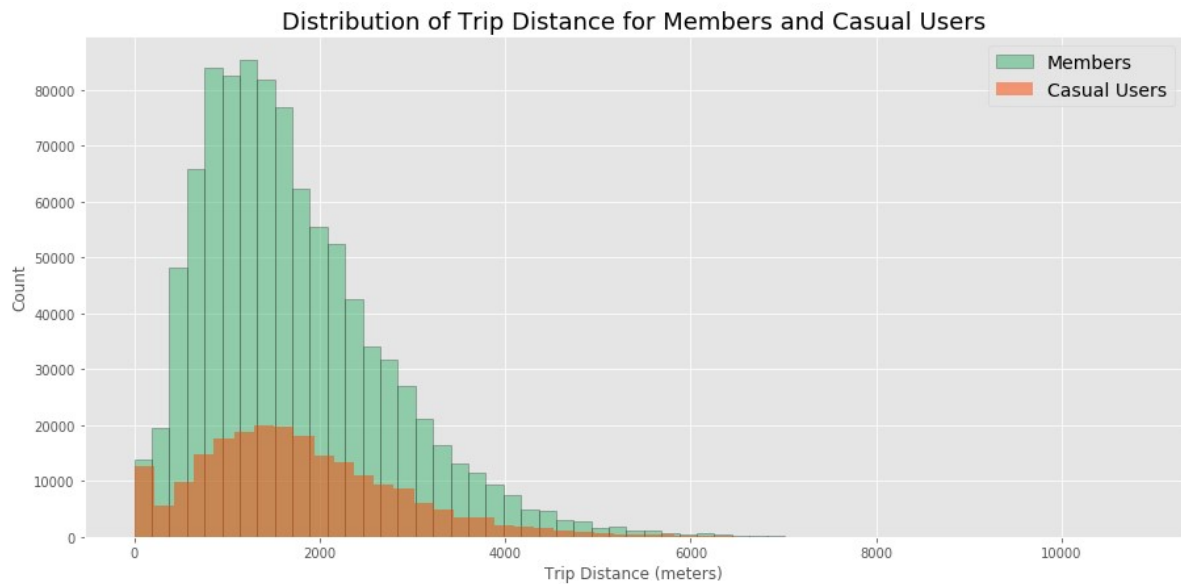
Out [41] :

	Members	Casual users
count	966135.0	221092.0
mean	666.0	1003.4
std	358.4	443.7
min	60.0	60.0
25%	395.0	658.0
50%	596.0	980.0
75%	874.0	1335.0
max	1982.0	1982.0

The first obvious observation is that the vast majority of trips are made by members. Thus, as would make sense, the shape of the distribution for members looks to be identical to the overall distribution of trip duration that we saw earlier. However, the distribution for non-members is completely different.

The distribution for casual users is fairly symmetrical, with a mean of 1003 seconds or 17 minutes, 50% more than the mean for members. We can notice how very long trips are more common among casual users, which is surprising considering we have more than 4 times the data for members.

Similarly, let's take a look at trip distance:



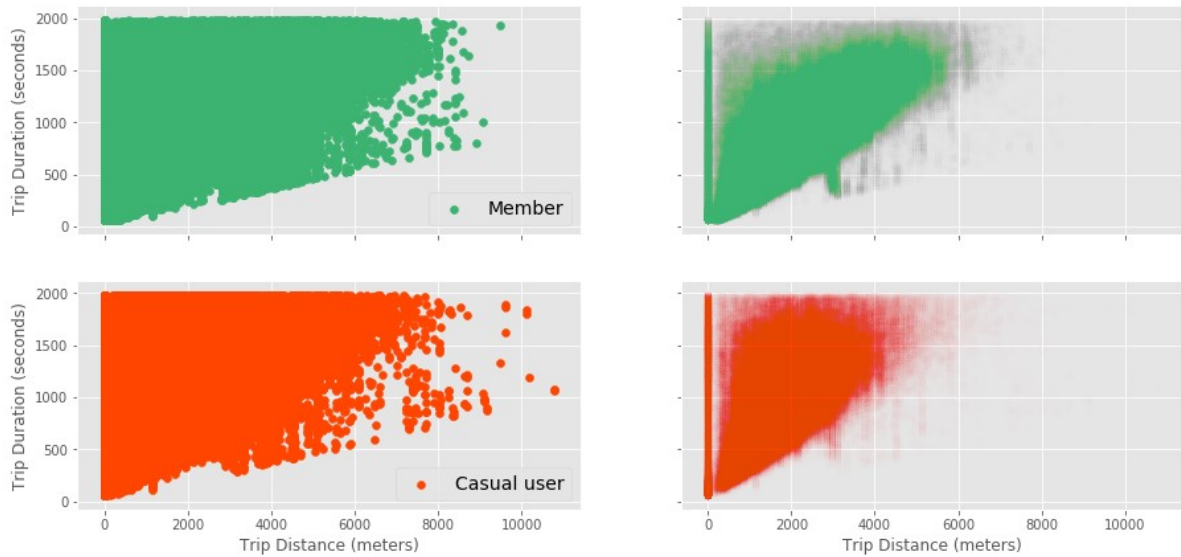
Out [43] :

	Members	Casual users
count	966135.0	221092.0
mean	1714.4	1777.0
std	1010.3	1090.0
min	0.0	0.0
25%	974.5	1014.7
50%	1520.4	1635.4
75%	2260.0	2394.8
max	9477.0	10773.6

This time we can see that the distributions for members and casual users have a very similar shape, and resemble the shape of the overall distribution for trip distance. Interestingly enough, casual users nearly match members in the number of trips that start and end at the same stop despite there being over 4 times fewer trips recorded by casual users.

Because the distributions for members and casual users were so different for trip duration, but similar for trip distance, we would expect casual users to have slower trip speeds. Let's turn to the already familiar scatterplots we saw to investigate:

Trip Distance vs. Trip Duration

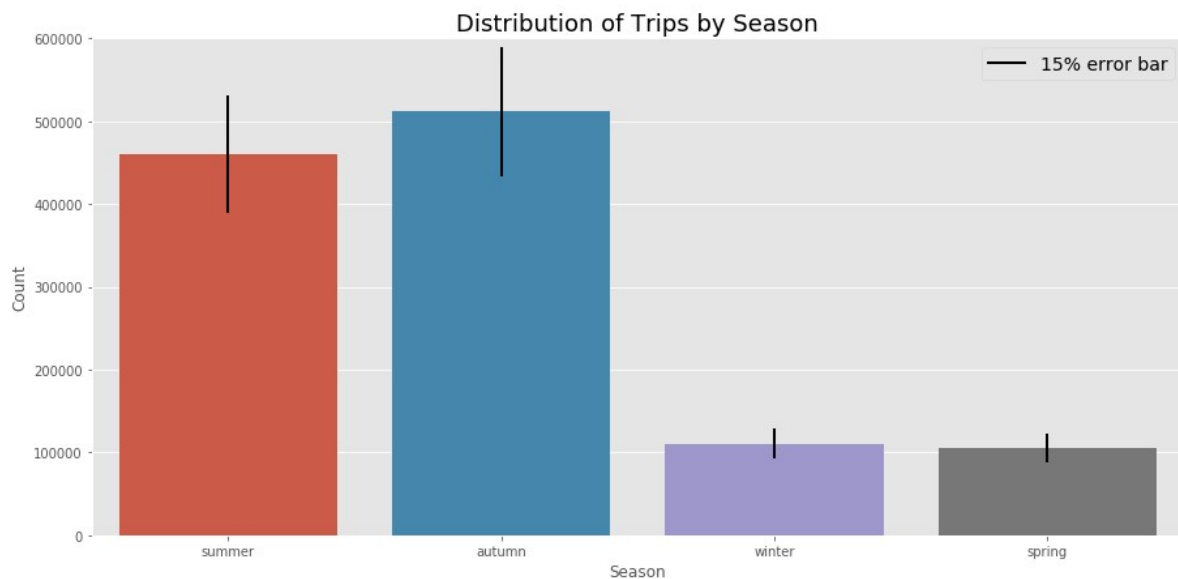


As hypothesized, casual users seem to have a lower average speed as the main cluster of points representing trips is more towards the top left corner of the graph - less distance covered in greater time. We can also notice how casual users have more extreme outliers compared to members: this is caused by long distance trips being more common among casual users, as we saw before. Again, we can see on both density graphs how there are trips starting and ending at the same time with very various durations.

3. Effects of the present season and weather conditions on trip length

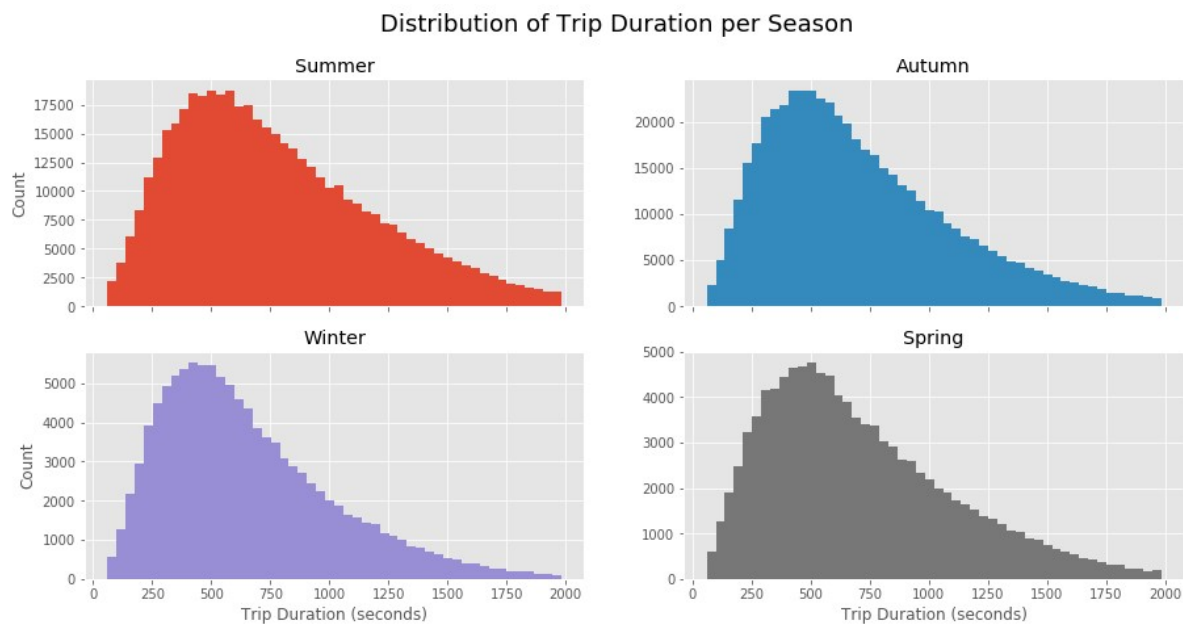
In this part we will analyze what sort of effect, if any, do the season and weather have on our two definitions of trip length. To start off, let's look at the effects season has.

Recall that we defined the season the trip took place in based on the trip's month, and stored it in the column `season`. During the data cleaning process we noticed how we removed a disproportionate amount of trips from winter and spring data, so let's first take a look at how our season data distributes:



We can see how the large majority of trips take place during summer and autumn months - this is clearly the case even when we try to account for the error we might have made previously when removing trips with missing trip distance data. We chose to display an error margin of 15% because this was the difference in the greatest and lowest proportions of values removed, for spring and autumn respectively.

Now, to take a look at how our two definitions of trip length are affected by the trip's season. First, trip duration:



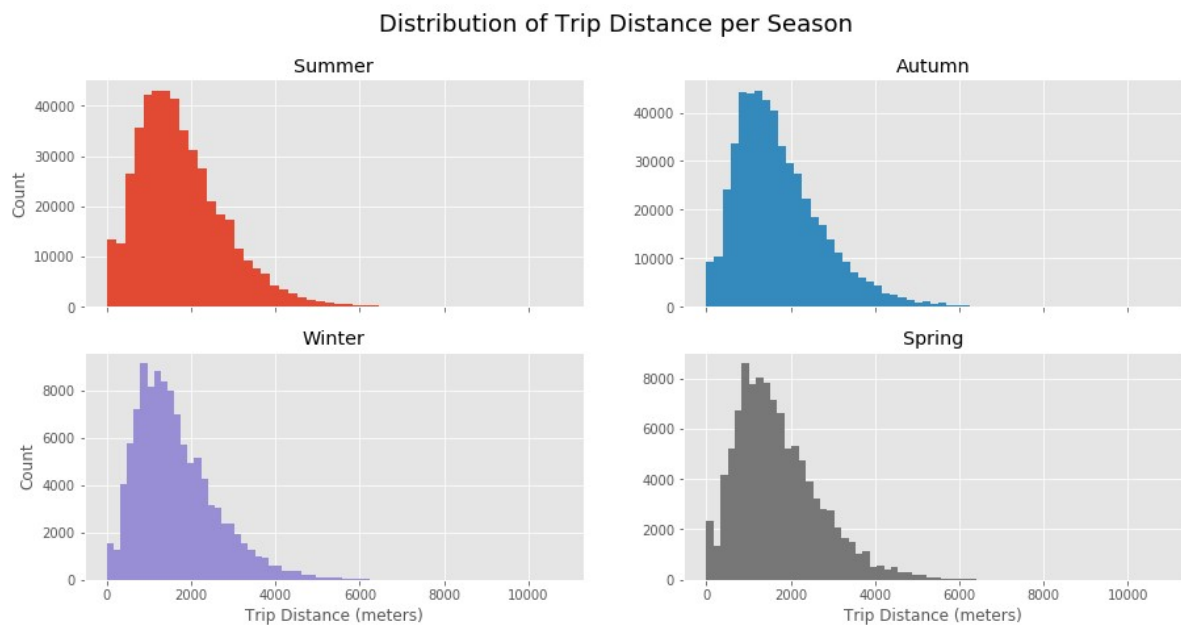
Out [47]:

	Summer	Autumn	Winter	Spring
count	460595.0	511534.0	110454.0	104644.0
mean	773.4	708.3	655.8	710.1
std	412.2	388.9	362.7	393.6
min	60.0	60.0	60.0	60.0
25%	453.0	412.0	382.0	409.0
50%	699.0	629.0	580.0	630.0
75%	1036.0	937.0	861.0	947.0
max	1982.0	1982.0	1982.0	1982.0

The shapes of the distribution for each season are nearly identical. Notice, though, that we are using a unique y-axis for each graph, while keeping the same x-axis throughout.

We can still see that the season does to some extent affect trip duration: the mean trip duration during winter is 656, or 11 minutes, while the mean for summer is 773 minutes, or 13 minutes. We cannot say for sure that this is a significant difference, it may just be caused by the specific data we happen to have. Recall also that we removed proportionately more values from winter and spring. If we had kept those records, we could potentially have more similar statistics across all seasons.

Let's also take a look at trip distance:



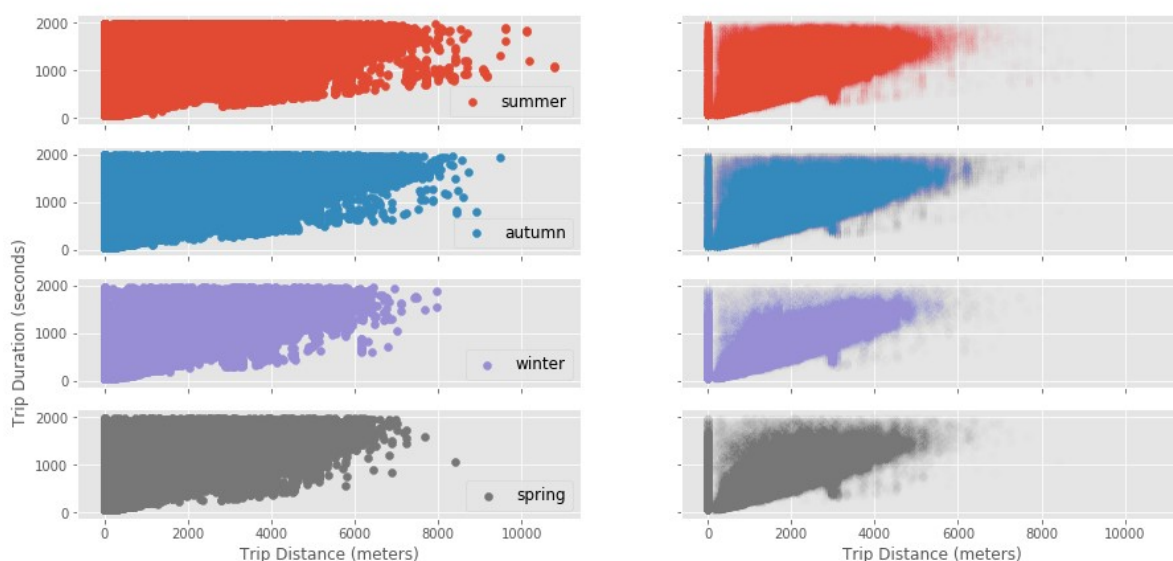
Out [49]:

	Summer	Autumn	Winter	Spring
count	460595.0	511534.0	110454.0	104644.0
mean	1750.3	1727.4	1640.7	1702.8
std	1038.6	1031.5	960.6	1003.2
min	0.0	0.0	0.0	0.0
25%	997.2	977.4	932.9	954.2
50%	1577.3	1527.2	1454.8	1524.9
75%	2318.5	2278.1	2159.6	2272.4
max	10773.6	9477.0	7979.8	8423.3

Again, we do not notice any significant differences between the distributions, but we can still see that trips are on average shorter during winter and spring compared to summer and autumn, though not by much. Looking at the 3rd quartile and maximum values, we can observe how very long trips are more frequent during summer and autumn months.

As has become tradition, we can take a peek at whether there's a difference in the average speed of trips across the seasons:

Trip Distance vs. Trip Duration per Season

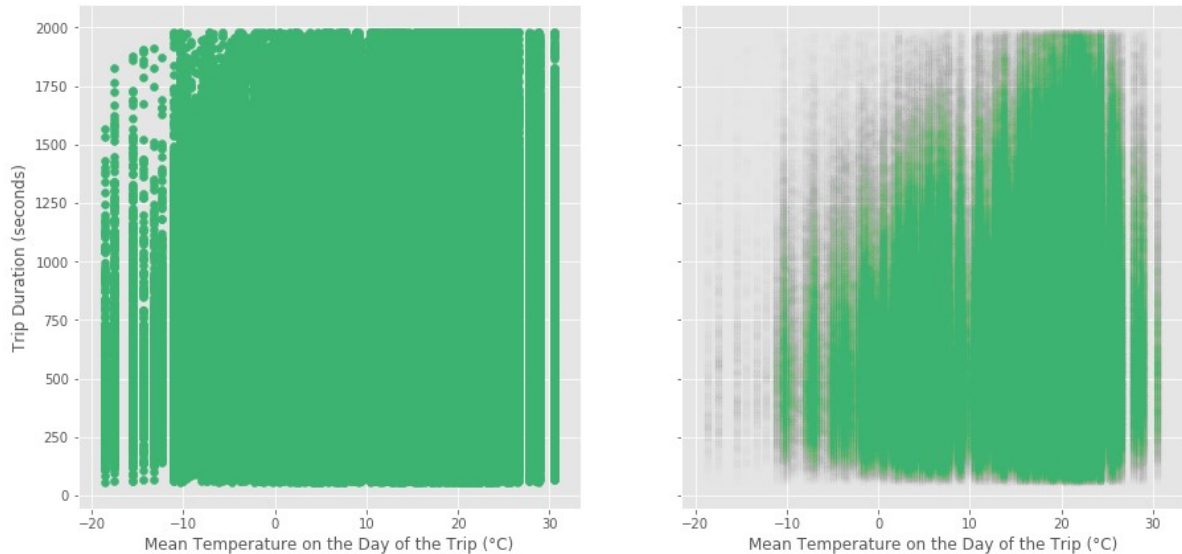


Since the distributions for trip duration and distance were very similar across all seasons, it is no surprise that their relationships are also similar. Still, we can once more notice how long distance trips are more common during summer and autumn. Trips starting and ending at the same station is a phenomenon that can be observed during all seasons.

In the scatterplots with transparent points we have adjusted the transparency of points to account for the differences in the number of observations per season: namely, we have made the points on the winter and spring plots 5 times more opaque as there are approximately 5 times fewer points on those plots compared to summer and autumn. So it might seem as if trips with very slow average speeds are less common during winter and spring. However, it is also possible that this is just an effect of how we decided to choose the transparency despite our best efforts to make it as fair as possible.

Now, let's dive into the weather data. Recall that we have columns `mean_temp`, representing the mean temperature in degrees Celcius of the day the trip took place, and `precipitation`, representing whether there was any precipitation on the day of the trip. First, let's look at how these two dimensions affect trip duration.

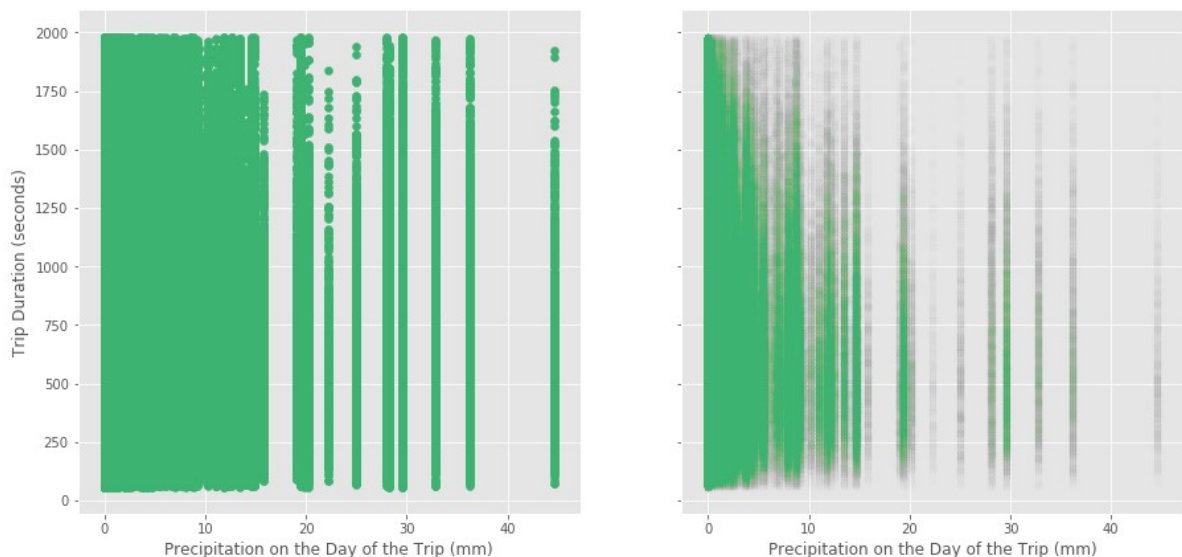
Mean Temperature on the Day of the Trip vs. Trip Duration



We can immediately notice how trips are much shorter during days with a very low mean temperature. As the daily mean temperature increases, so do trip durations, until around 25°C, where trip durations start dropping again.

Recall how when we plotted the countwise distribution of trips' daily mean temperature, we saw a distribution with two dominant modes: one centered around 5°C and the other around 20°C. The same bimodality can be noticed on the right graph: long duration trips become more frequent at around 5°C, but then drop until around 10°C only to rise again until 20°C. There are two possible explanations for this phenomenon: either it is just a cause of how the underlying data for trips' daily mean temperature distributes and hence makes those temperature ranges seem more dominant, or Bike Share users have both two 'favourite' temperature ranges to ride a bike, and also embark on longer journeys during such days.

Precipitation on the Day of the Trip vs. Trip Duration

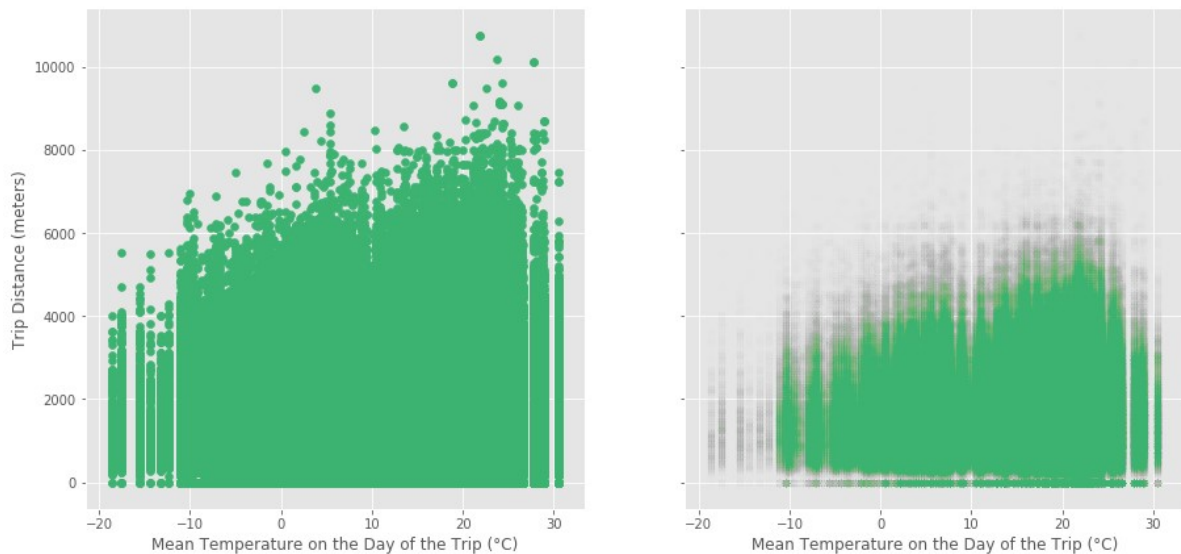


Just like for mean temperature we can observe how trips are much less frequent on days with precipitation. However, with mean temperature we could see how there were very few trips with long durations on days where there were overall few trips, but this is not the case for precipitation: there are still plenty of trips with long durations on days where there was lots of precipitation and not as many trips overall.

Hence, it seems like the day's mean temperature has a greater effect on trip duration than precipitation. Intuitively, it certainly makes sense: we are looking at weather data for an entire day - mean temperature is something that describes a summary of the day, but precipitation is a total value for the day. If it rains a lot on one day for a couple of hours, but the rest of the day is rain free, it may not have that much of an effect on ridership.

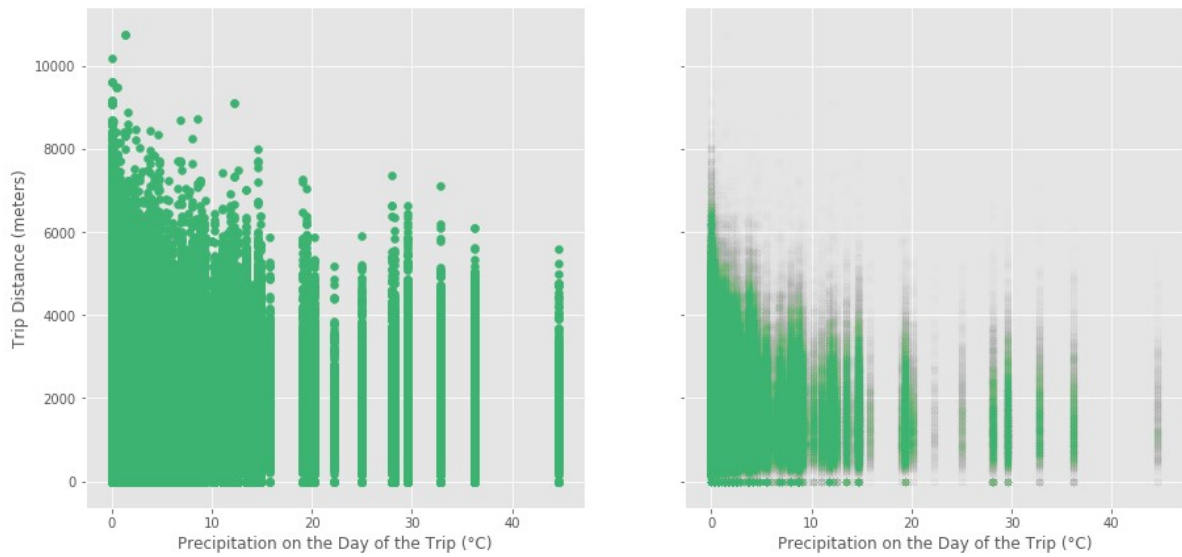
Now, a look at trip distance:

Mean Temperature on the Day of the Trip vs. Trip Distance



These results are similar to what we saw for trip duration: generally, trip distance and the trip's day mean temperature have a positive association. We can again notice the two modes centered around 5°C and 20°C, leaving us with the same two possible explanations as before. Because we observed this when looking at both trip distance and trip duration, it appears to be more likely that this phenomenon is caused by how trip frequency distributes depending on the trip's day mean temperature, rather than temperature or precipitation having a direct impact on duration and distance.

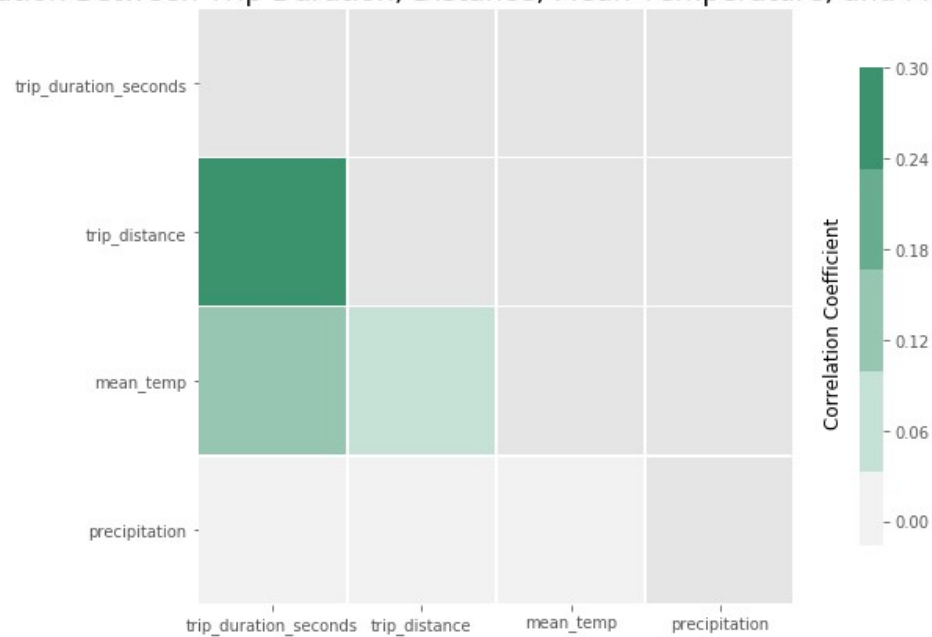
Precipitation on the Day of the Trip vs. Trip Distance



We can notice an immediate drop in trip distance when moving from days with no or extremely little precipitation to days with moderate amounts. When we were looking at how precipitation affects trip duration, we saw that trips with long durations were still common on days with lots of precipitation - this is not the case for trip distance: trips of all distances follow the overall tendency to decrease as precipitation increases.

In the above discussion we did not really give a definitive answer on whether mean temperature and precipitation had an effect on trip duration and distance. To give us a better idea of what's going on, let's compute the correlation coefficient between our columns of interest: `trip_duration_seconds`, `trip_distance`, `mean_temp`, and `precipitation`. We can display our results in this neat correlation matrix:

Correlation Between Trip Duration, Distance, Mean Temperature, and Precipitation



We can indeed see that there isn't much going on between our measurements of trip length and weather statistics. Mean temperature has a very weak positive correlation with trip duration and trip distance, while precipitation produces values very close to zero. This means that the tendencies we saw stem from how the number of trips distribute under mean temperature and precipitation, but these weather statistics have very little to no effect on our two definitions of trip length.

As a by-product of this visualization we can also see what we discussed in part 1. of this analysis - there is a positive association between trip duration and trip distance, but this value is also fairly low due to the great variance in the data.

Conclusion

In this report, we defined trip length in two ways: by its duration in seconds, and by the straight line distance between its start and stop stations.

The raw data came with many flaws, and it is possible that there are many more that were left unnoticed. We removed trips with absurd durations and average speeds, and also trips for which station name inconsistencies made it impossible to compute trip distance. In total, we reduced the dataset by around 40%, down to 1.2 million observations.

We noticed a positive association between our two definitions of trip length. Very roughly it seemed like the relationship is exponential, but the data has a huge amount of variance.

When looking at how Toronto Bike Share members compare to casual users using a temporary pass, it appeared as if casual users like to 'get their money's worth' by embarking on trips that had substantially longer durations. The same could not be said about trip distance, however: there did not appear to be any noticeable difference there. We also noticed that, to some extent, casual users frequently took more time to cover the same amount of distance as members, reinforcing the idea of casual users making sure to fully use what they paid for. The large majority of trips were completed by members.

There were nearly 5 times more trips completed during summer and autumn months compared to winter and spring. However, when looking at the distributions of our two definitions of trip length relative to the seasons, we did not notice too many differences. Still, one could notice how trips during summer both took more time and were longer in distance compared to winter, but these differences could be insignificant.

We scraped data from Canada's historical climate database for each day in the scope of this report: July 1st 2016 - December 31st 2017. We joined this data to our trip dataset, showing the mean temperature for the day each trip was started on, and the total precipitation on that day. Looking at how the mean temperature statistic distributed, we saw that there were two modes where trips were more frequent. When we looked at how temperature related to trip length and distance, we saw the similar bimodal phenomenon for both definitions, but as later analysis showed, this phenomenon was very likely caused by how the number of trips distributes relative to mean temperature, rather than mean temperature directly affecting trip length. Still, we saw that there was a very small, but still existent correlation between mean temperature and trip length. Similarly, for precipitation one could notice how trips became shorter in both duration and distance as precipitation increased, but there was no correlation between precipitation and our two definitions of trip length.

Limitations

Several compromises and generalizations had to be made during this report. We reduced the original Bike Share dataset by about 40%, the majority of which was caused by inconsistencies in bike station names. If we were to fix these issues, we could be more confident in our analysis as we would be using the entire data. As we saw, depending on which categories we looked at, we had sometimes disproportionately taken more data away from certain subgroups, which could have skewed our analysis.

We defined trip distance as the distance between the trip's start and end stations 'as the crow flies', which is a very simplified definition. We unfortunately don't have precise bike tracking data, and finding the actual shortest path between two stations is an incredibly complex task. Unless the stations happened to be on the same straight street, the distance we calculated would not represent the actual distance the cyclist covered. If we had the opportunity for a better measurement of distance, our analysis could be a lot more significant.

We noticed an interesting cluster of trips when visualizing the relationship between trip distance and trip duration and suggested that this is caused by a popular route between two stations. However, in the general and large region of the cluster's distance-duration range, the trips between these two stations accounted for around 10% of all trips in that region. Thus, it is possible that there are other reasons behind the cluster's existence, too.

There are many limitations to our meteorological data. Toronto is a very big city, and the weather in one part of the city is not always the same as in another. With weather data tied to specific parts of the city we could possibly achieve a lot more insight into our ridership data. Similarly, we could improve the precision on our temperature and precipitation statistics. They are an average and a total of the day, respectively - in other words, they are generalizations, summaries. Presumably, most trips happen during the daytime. If there happened to be a very cold or rainy night, but the following day is perfectly pleasant, it might not affect ridership numbers, but this would be interpreted differently in our analysis.

Throughout this report we mainly relied on visualizations and summary statistics to analyze the data, which on many occasions meant that we couldn't conclude if things were one way or the other. Many of these questions could be better answered by analysing them using a more complex methodology, suggestions for some of which are provided in the following extensions section.

Extensions

This section summarises some of the questions that were left open throughout the report, and tries to suggest potential ways of answering them.

Were we given tremendous amounts of computing power, one could come up with a solution to compute the shortest realistic path a cyclist could have taken to go from the start station to the end. This way we could compute an expected travel time, and compare it to the actual duration, which could provide many interesting insights. This could be achieved by using various Geographic Information Systems techniques.

We noticed an interesting cluster of trips when visualizing the relationship between trip distance and trip duration. These trips appeared to have a noticeably faster average speed than other trips, and we discovered that this is largely caused by a popular route between two stations. We could not answer, due to insufficient data, why Bike Share users were able to cover this distance so much quicker. This could be caused by there being substantially better infrastructure or less traffic between those two stations, or perhaps it is a popular commute route, so people don't have the time to wait around when biking from home to work or the other way around. Both of these proposals could be researched, or maybe there is something completely different going on. If we had a way to find out reasonable realistic paths between stations, and combined that with infrastructure, traffic, and commute data, we could possibly be able to come up with an explanation.

We saw how trip frequency distributed bimodally when looking at the mean temperature on the day of each trip. It could be very interesting to look into why this is - is this just a product of how temperature and people's trip frequency fall together, or do people actually have two ranges of temperatures during which they prefer to get on a bike. Should one research this, the first question to figure out would be whether this observation is possible because there are certain times in the year when ridership reaches its peak, and that's when the corresponding temperatures happen to occur. If that is not the case, this could be a very interesting discovery to further look into.