Technical Report RT-MAC-2023-01

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Impacts of the COVID-19 pandemic on the bicycle sharing system in São Paulo

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Project developed with a research scholarship from the InterSCity Project

CNPq proc. 465446/2014-0

December 19, 2023

This research is part of the INCT of the Future Internet for Smart Cities funded by CNPq proc. 465446/2014-0, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001, FAPESP proc. 14/50937-1, and FAPESP proc. 15/24485-9.

Highlights

- The total number of bike-sharing trips in São Paulo decreased significantly after the onset of the COVID-19 pandemic.
- The average duration of bike-sharing trips rose substantially, mainly due to a higher proportion of trips exceeding 80 minutes in length.
- The patterns of trips on weekdays were more affected than those on weekends, with changes in the distribution of trip hours and a surge in circular trips.
- The proportion of weekend trips, in comparison to weekday trips, increased after the pandemic.

Contents

Introduction

The research project described in this report is part of the BikeScience research group, which emerged from a collaborative research project between INCT InterSCity and MIT Senseable City Lab. BikeScience is an open-source data science resource for analyzing bicycle mobility in urban environments. The study was developed in the second half of 2022 and updated at the beginning of the second half of 2023.

Through a partnership with Tembici, we gained access to company data from its bikeshare system in São Paulo. Thus, the first goal of the research is to process these data, so that they are available and easy to use for future research by the group. In addition, after processing the data, the proposal is to analyze the impact of the pandemic on the use of shared bicycles in the city of São Paulo.

Currently, Tembici is largely responsible for the bikeshare system in Latin America, which allows us to properly analyze the system by looking only at data from that company. We have data from the end of January 2018 to the end of July 2023. In this way, we will be able to analyze the short-term impact of the COVID-19 pandemic on this system.

The research code can be found in the bss-analysis repository. Tembici's raw data, being confidential, are not available in this repository. Thus, to be able to run the treatment and analysis, it is necessary to have external access to the data and insert them in a folder called `data/trips/original_data`, after cloning the repository. Details on implementing the steps and how to execute them are described in the form of documentation within the repository.

For data analysis and treatment, the Python language and its libraries for data processing and analysis were used. In addition, some modules previously built by the BikeScience project, present in the bike-science repository, were also applied.

The purpose of the data analysis is to answer some questions about the impact of the pandemic on the bike-sharing system. For this, we will use some questions to guide us during the analysis:

1. How did social isolation influence travel variables, such as the total number of trips taken, their average duration, distribution on days of the week, etc.?

2. Does the data suggest any changes in the behavior of users of the bike-sharing system in São Paulo during the pandemic?

Data treatment

The first stage of the research was data processing. A summary of the steps involved in this phase is described in the sections below. To facilitate future use, all data transformations were modularized, using the Object Oriented Programming paradigm, and each treatment and pre-processing step can be performed by running certain scripts present in the indicated repository. Instructions on what to run for each step are documented in the repository's `README`.

2.1 Initial processing

First, it was necessary to convert all the data to the `csv` format, since some were provided as a `.xlsx` file. It was also necessary to standardize the column names and the encoding format, in order to preserve the accents. Then, in addition to transformations in the date format, some columns were added to facilitate data analysis:

- Column with the age of the user for a given trip, calculated based on the information on the date of birth provided. However, this data was only collected from 2020 onwards, which makes it impossible to use it in the comparison between post- and pre-pandemic situations;
- Boolean column that indicates whether or not the trip was made on a weekend day;
- Boolean column that indicates whether or not the trip was made on a holiday.

2.2 Destination and origin stations

In the original data, for each trip, the names of the origin and destination stations were provided. A file listing the station names with their respective latitude and longitude coordinates was also provided. With this data, we could obtain the place of origin and destination of each trip, as well as estimate the distance covered in each one of them. However, some inconsistencies were found in the data. Station names did not have a standard format, varying between the following formats:

- ID - Station name
- ID - Station name - ID
- Station name - ID

In addition, some stations present on the trips, due to writing errors, did not have an equivalent in the station file. For example, there was a station named "Largo de Batata" within a trip, instead of "Largo da Batata", as present in the station file. For these reasons, we chose to extract only the station ID, in order to be able to combine it with the stations file. In this way, we were able to obtain the origin and destination coordinates of almost all trips.

2.3 Distance traveled in trips

The original data for individual trips does not contain the distance traveled on each trip. To obtain an estimate of this distance, we used the GraphHopper API, which, given the origin and destination coordinates and a mode of transportation, returns the distance between the two points, taking into account the likely route traveled. Using this tool, we calculated the distance between each set of existing stations in the Tembici system and thus obtained an estimate of the distance covered in each of the trips made.

2.4 Outliers removal

The data provided by Tembici starts in January 2018. However, for that first month, there is only data for two days, the 26th and 27th of January. As most of the analyses will be done by grouping the data by month, and January 2018 is not complete, we decided to remove the data for this month, so that it does not affect the comparison of certain variables in the data analysis.

Furthermore, some discrepant values of the "tripduration" variable (which indicates the duration of a given trip) were removed. The analysis of this variable showed us that there were very long trips, which lasted between 10 and 100 days. Since these values could significantly impact the average duration of trips, it was decided to use only the duration of trips of up to 12 hours, turning this column into a null value for longer trips.

2.5 Data grouping

Data were organized by day, week, and month to make analysis simpler. In addition to calculating the daily average for the given period, we counted the number of trips that occurred on each day, week, or month.

Data analysis

After processing the data, an analysis was carried out with the aim of capturing the impact of the COVID-19 pandemic on the observed system. The main conclusions of the analysis are described in the sections below.

Restrictions in the State of São Paulo due to the COVID-19 pandemic began on March 24, 2020 [1]. Thus, taking into account the range of data we have, we will consider the period from February 1, 2018 to March 23, 2020 as before social isolation, and the period from March 24, 2020 to July 31, 2023 as after isolation.

3.1 Number of trips

First, let's analyze the impact of the pandemic on the number of trips made using Tembici's bikesharing system.

3.1.1 Entire period

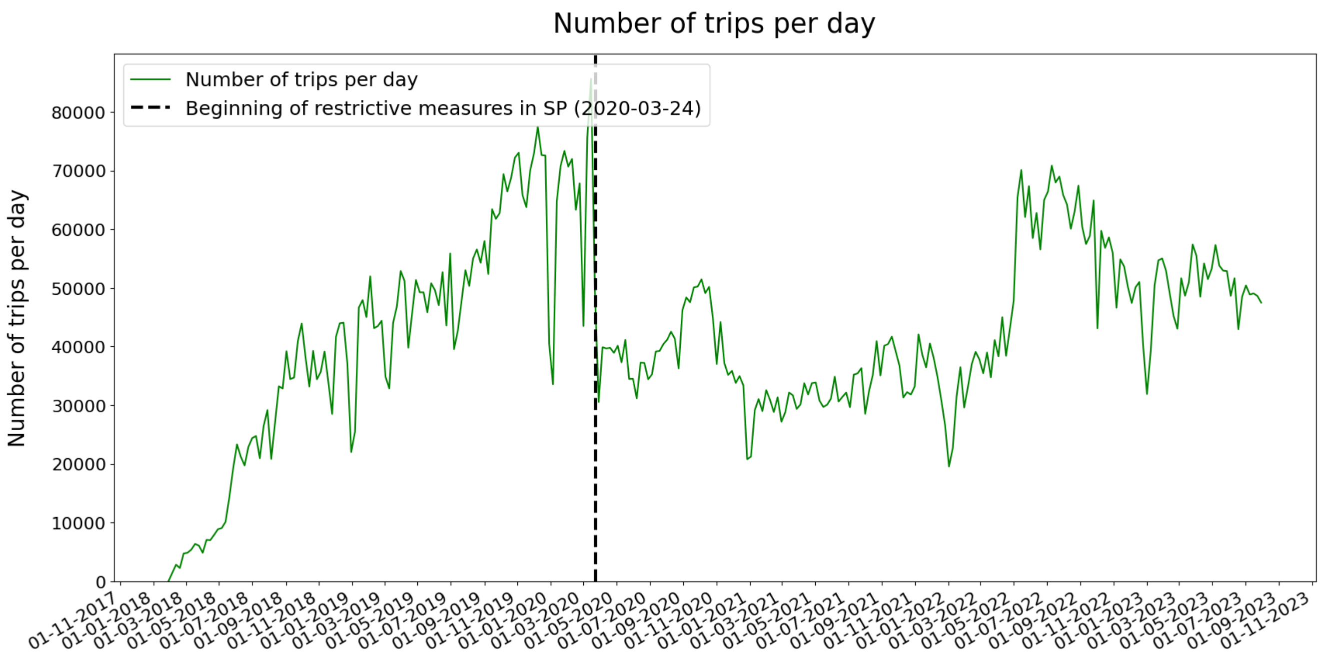

Figure 3.1: Evolution of the number of daily trips, grouped by week.

[1] Government of São Paulo determines statewide quarantine (in Portuguese).

Figure 3.1 shows the evolution of the number of daily trips made from February 2018 to July 2023. Trips were grouped by week, in order to reduce daily noise and enhance data visualization.

To analyze the chart, it is important to pay attention to the story behind the data provided by Tembici. The company started to scale in 2017, and in January 2018, they started collecting data about their travels. This explains the fact that the number of trips started at a very low level in February 2018 and grew above normal in the first months of that year, a behavior that was due not only to the increase in trips, but also to the expansion of data collection on pre-existing stations.

From the second half of 2018, however, growth stabilizes at a rate that lasts until the beginning of 2020. Such growth is due to the progressive expansion of the number of stations and users of the bike-sharing system. Thus, it can be seen that the trend before the pandemic was almost entirely growth in the number of trips, excluding seasonal fluctuations. As an example of this seasonality, it is interesting to note the following pattern: In the last weeks of each year and in the first week of the following year (the period that corresponds to the end-of-year festivities), the number of trips drops. Note that, in the graph in Figure 3.1, just before January of all years (2019, 2020, 2021, 2022, and 2023), there is a drop in the number of trips.

However, this growth trend was broken with the advent of the COVID-19 pandemic. On March 24, 2020, social isolation began in the State of São Paulo. In Figure 3.1, the drop in the number of trips in this period is visible. We can also observe that the amount of travel has not yet recovered from the decline it suffered in the pandemic, and the pattern of growth from before also seems not to have returned. Until April 2022, although we were able to observe moments of growth in the number of trips, as in the periods of the second half of 2020 and the beginning of 2021, the trend was to maintain the number of trips. In May 2022, however, there was a sudden increase in the number of trips, which then started to decline again. More details about this unexpected change are given in Section 4.

For the analysis of trends in the periods before and after the beginning of the COVID-19 pandemic, a linear regression was performed with data from both periods. The results can be seen in the graph in Figure 3.2. Taking into account this drop in the number of trips, for the purposes of comparing the behavior between the pre- and post-pandemic periods in the sections 3.3, 3.4 e 3.5, we will consider the percentage of trips with certain features. In this way, we will be able to better compare the impacts of COVID-19 without being influenced by the drop in the gross number of trips.

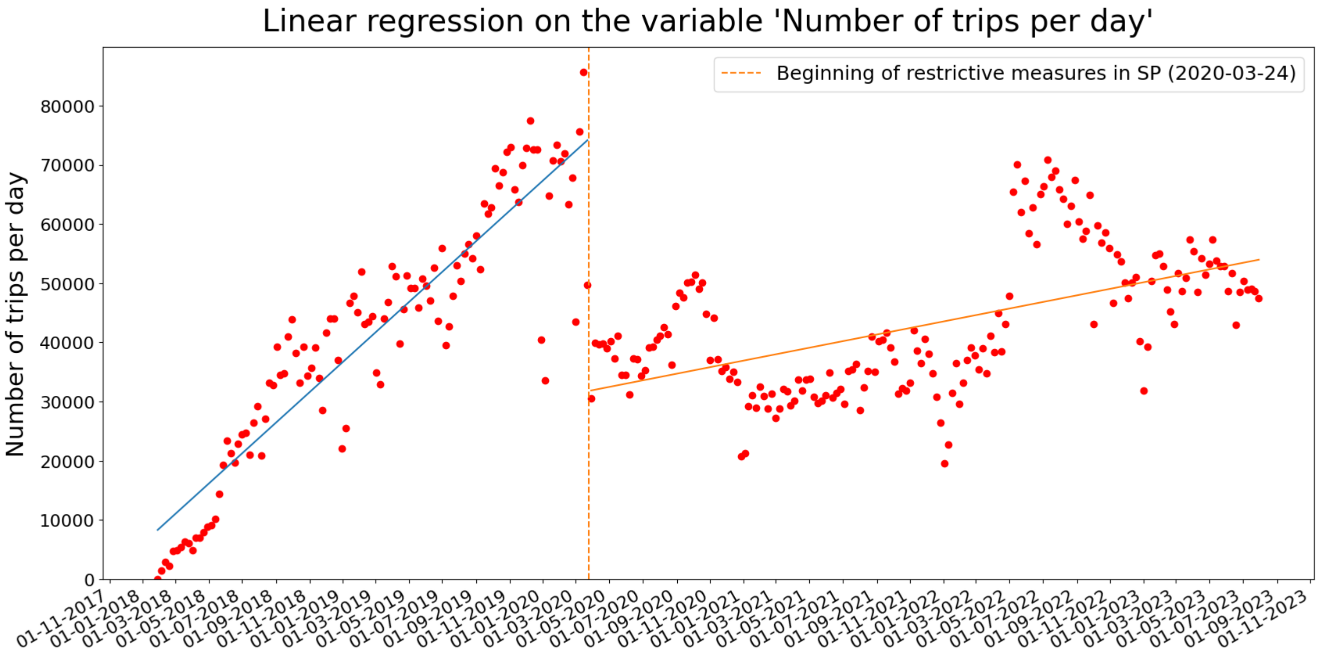

Figure 3.2: Linear regression for two periods of the variable: before and after the pandemic.

3.1.2 Correlation with pandemic phases

The graph in Figure 3.3 shows the number of daily trips after the start of the pandemic, along with the evolution of the phases of the São Paulo Plan, promoted by the state government in order to regulate the resumption of economic activities in the state after the isolation. We want to analyze whether there is a correlation between changes in the number of trips and the implementation date of these phases. Due to the abnormal behavior observed around May 2022 (discussed in Section 4), the phase graph was shown with the period up to April 2022.

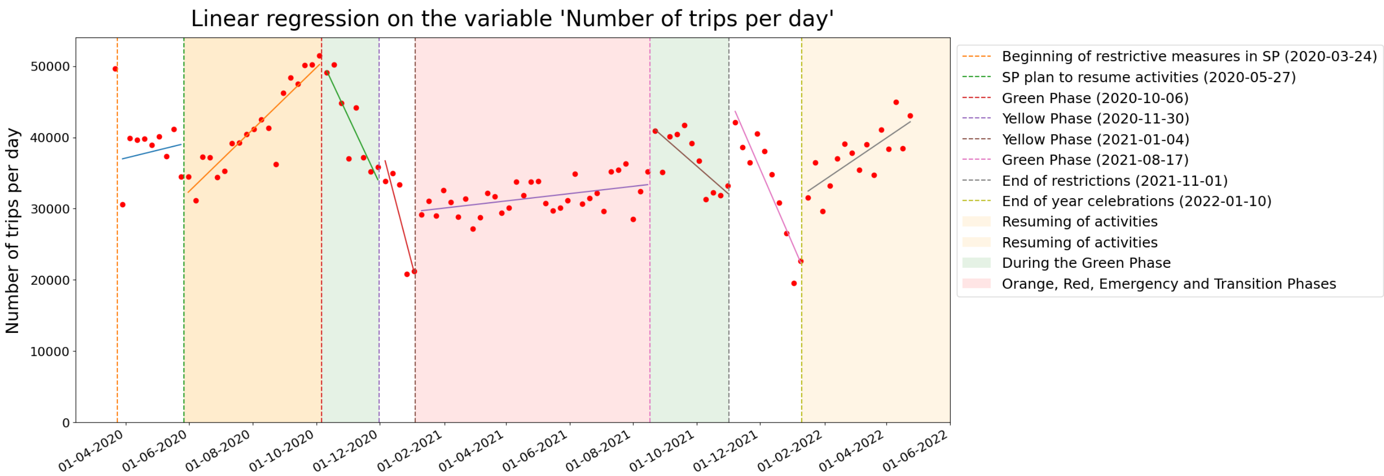

Figure 3.3: Linear regression in the intervals between the phases of the pandemic.

The graphs seem to demonstrate a correlation between the onset of certain phases and a shift in the behavior of the number of trips. This was particularly evident following the establishment of the Green Phase on October 6, 2020, when the upward trend in the number of trips was reversed and replaced with a downward trend that persisted until the start of the following year, after the establishment of the Yellow Phase on January 4, 2021. The fall in this period was also intensified at the end of the year due to the seasonality factor explained in the section 3.1.1. Additionally, we can see a similar declining trend following the introduction of the Green Phase on August 17, 2021.

A number of phase transitions occurred between January 4, 2021, and August 17, 2021, shifting between the Orange, Red, Emergencial, and Transition phases. The alternation between these phases did not seem to have much impact on the number of trips, which followed a similar pattern throughout the period, with a slight upward trend. The fact that the Green Phase has a greater impact on travel behavior can be explained because of its more appealing name, which conveys the idea of greater liberation and behavior change. For citizens, the distinction between an Orange and Yellow phase is not as strong as that between Yellow and Green, for example.

Finally, the return of many to in-person labor may have contributed to the decline that followed the Green Phase, which may have persuaded some individuals to give up the habit of riding a bicycle they had developed during the isolation period. In addition, the return to the in-person regime may have resulted in a drop in food delivery orders and trips made for this purpose.

3.2 Trip duration

Another variable that deserves attention in data analysis is the duration of trips. The graph in Figure 3.4 shows the average duration of trips, in minutes, for each month. It is observed that this average increased significantly after the pandemic. In addition, we can identify five main moments in the behavior of this variable. We separated these periods and fitted a linear pattern to each of them. This adjustment is shown in Figure 3.5.

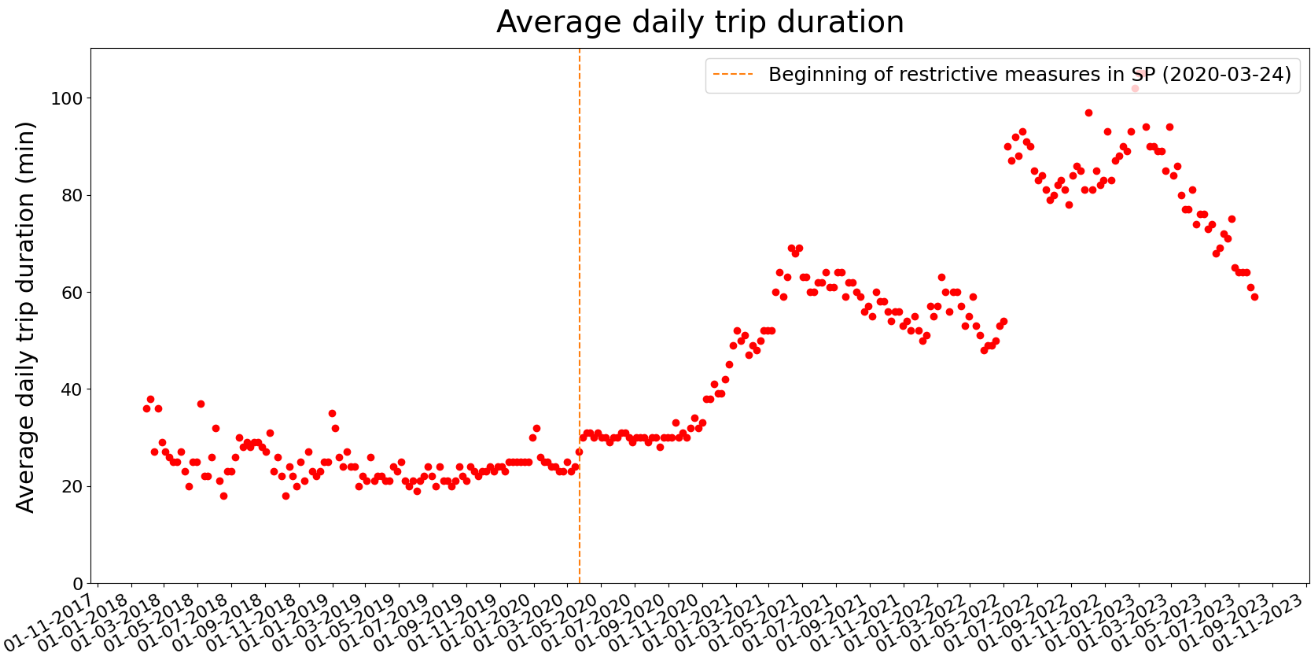

Figure 3.4: Evolution of the average daily duration of trips, grouped by week.

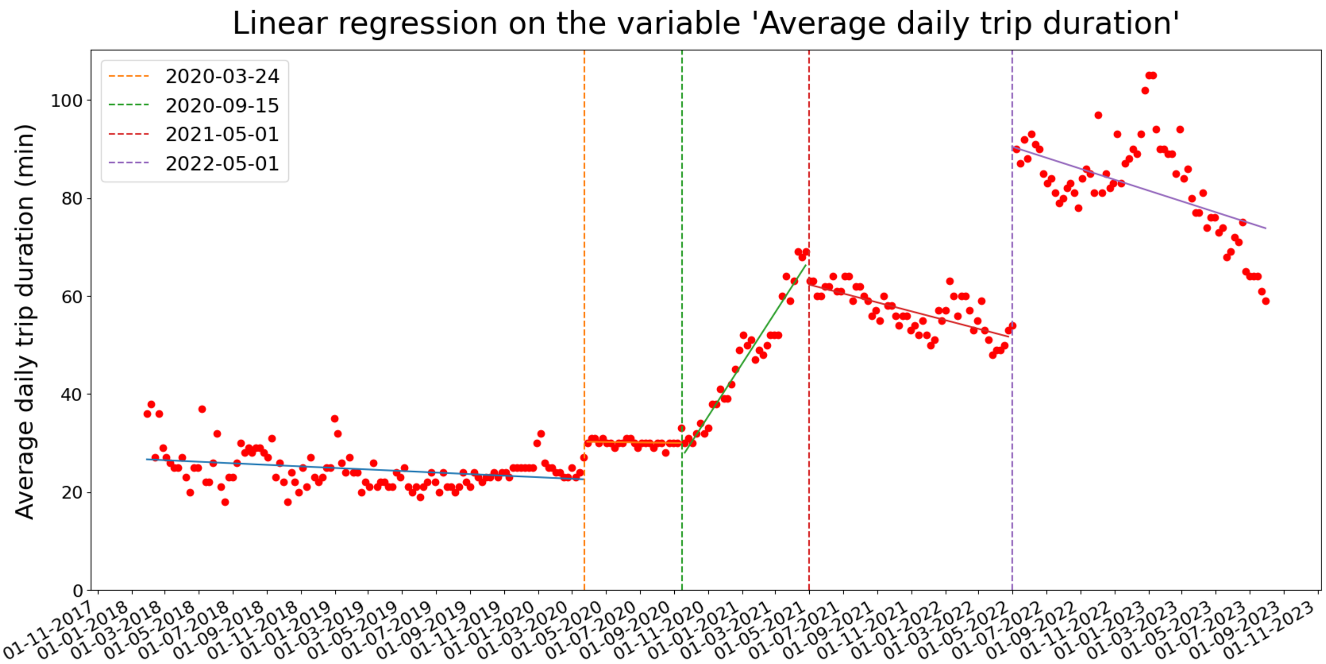

Figure 3.5: Linear regression on average daily trip duration, for five periods.

Before the pandemic, there was a pattern of maintenance in the average duration of trips, with a slight downward trend. With the beginning of isolation in São Paulo, at the end of March

2020, there is a slight upward shift in this average, but the pre-pandemic trend remains. However, around mid-September 2020, the average duration starts to increase with a high coefficient, reaching its peak around May 2021. After this period, the average returns to a downward trend.

We can explain this behavior as follows: The isolation caused by the pandemic resulted in an increase in delivery services. The use of shared bikes is common for delivery drivers, who tend to take longer trips than average, as they make multiple deliveries. However, it can be seen that, although there was an increase in the trip duration average soon after isolation, the true change in the pattern did not occur immediately. It took place just in the middle of the month of September. This is because Tembici, realizing that the demand for professional use of bicycles had grown with the pandemic, created its "Professional Plan" [2], which allows the user to rent a bicycle twice a day, for 4 hours in each loan. Before this plan, the payment for the use of the bicycle was made exclusively by time of use, with no distinction of payment per minute conditioned to the duration of the trip. In this way, the use of shared bicycles for long-term trips was more rare. Therefore, the Professional Plan proves to be very interesting for those who use bicycles for work. The plan was launched precisely in September 2020, which explains the high increase in the average duration of trips after this plan.

Therefore, the pandemic led the company to create this plan, which led to an increase in the average duration of trips. However, in May 2021, this average started to decline again. The reversal in this pattern of increase can be explained mainly by two factors: First, there was probably a saturation of the Professional Plan, which would explain the interruption in the growth of the average duration of trips. Second, there seems to be a correlation between the behavior of this variable and the number of deaths and cases of COVID-19. Around May 2021, there was a peak in deaths and cases, which coincided with the peak in travel duration. In Figure 3.6, it is possible to observe the evolution of the average duration of trips together with the number of cases and deaths from COVID-19. Note that, around May to June 2021, both the number of cases and the number of deaths declined again, along with the average duration of trips. Since the growth in average travel time was caused by the pandemic, it is natural that there will be a decline with a certain normalization of the situation. This correlation can also be observed around March 2022, when both the average duration and the number of cases and deaths peak and then fall again.

In May 2022, however, there is a sudden increase in the duration of trips, which then assumes a downward trend again until the end of the analyzed period (July 2023). A more detailed analysis of this surge can be found in Section 4.

It is not possible, given the range of data available, to evaluate the consequences of the pandemic on the duration of trips in the long term. However, it is likely that it will maintain a downward trend for a few months and then settle at a level above the pre-pandemic period, since delivery services are a trend that will probably settle at levels higher than the pre-pandemic and Tembici's Professional Plan remains active.

[2] How Tembici became the survivor among the shared bicycles (in Portuguese).

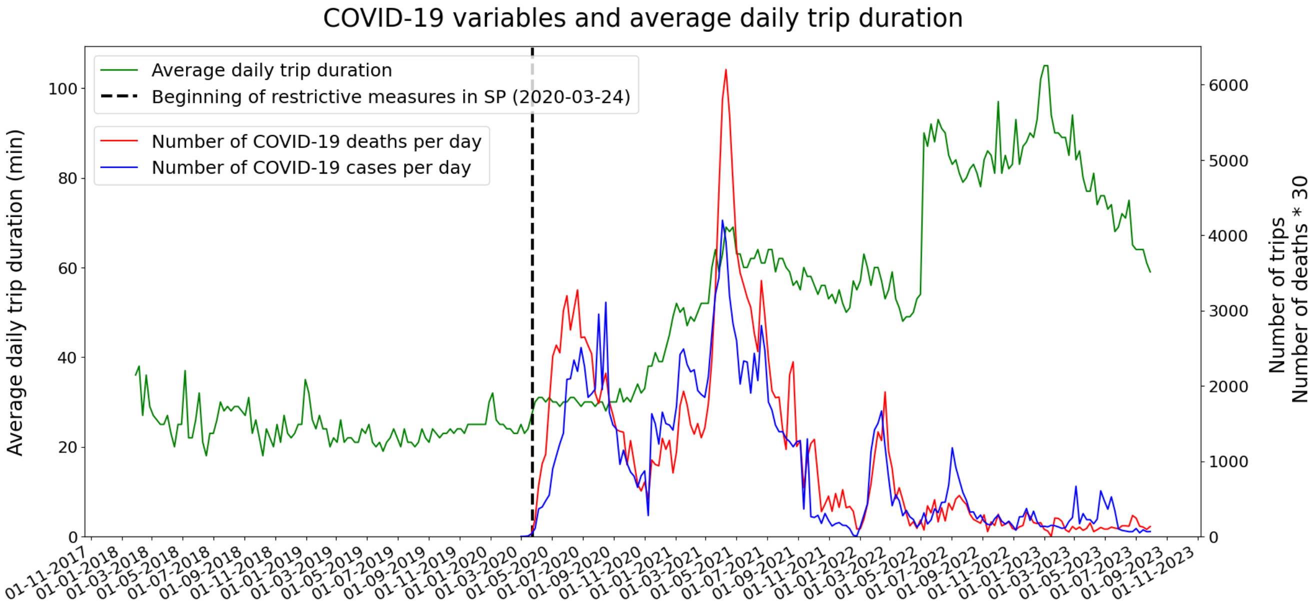

Figure 3.6: Average trip duration, along with the number of COVID-19 cases and deaths.

Thus, the reasons raised for the growth in the average length of trips would indicate that this increase was probably due more to certain trips that pulled the average up than to a behavioral change of the cyclist population as a whole towards longer trips.

This thesis is corroborated if we look at the distribution of trips by duration. Figure 3.7 shows the histogram of trip durations, in minutes, before the period of social isolation. Figure 3.8 shows this same distribution after the beginning of the restrictive measures.

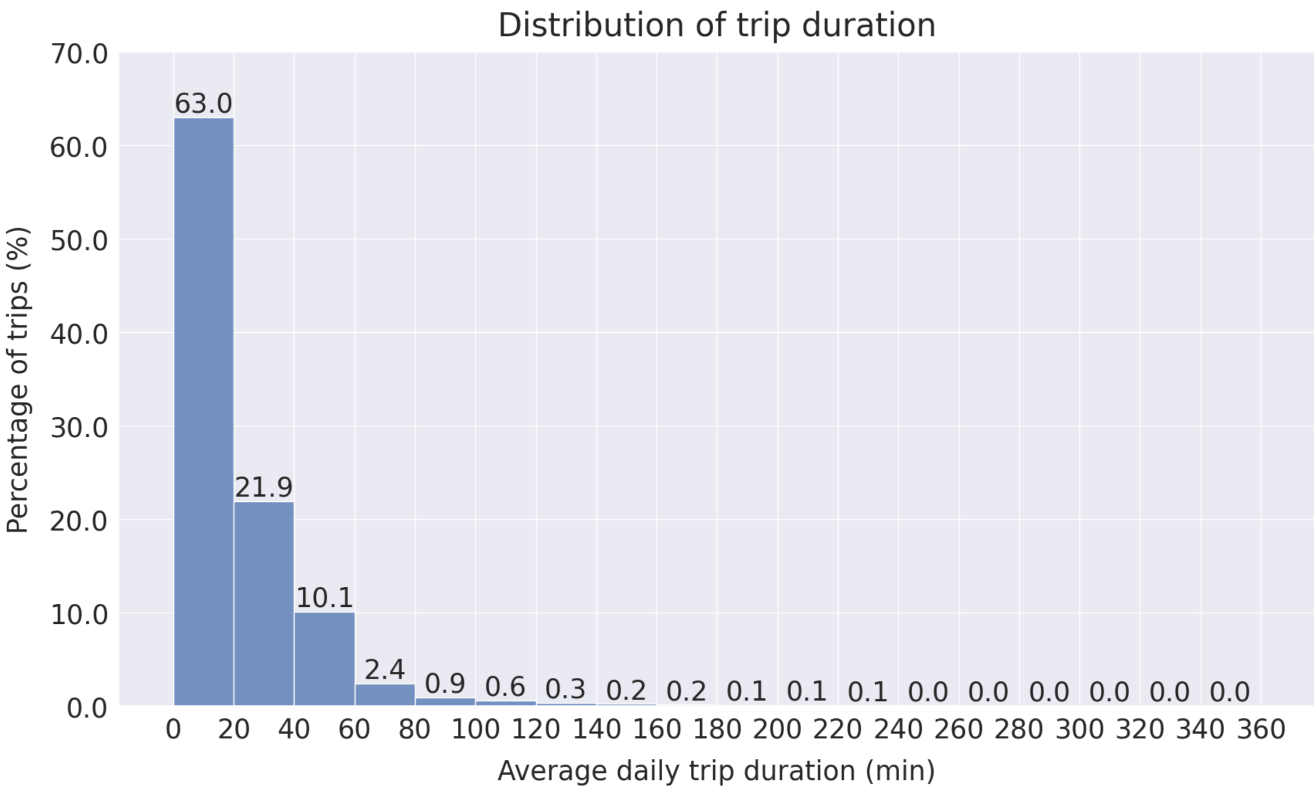

Figure 3.7: Distribution of duration of trips, before isolation (2018-02-01 to 2020-03-23).

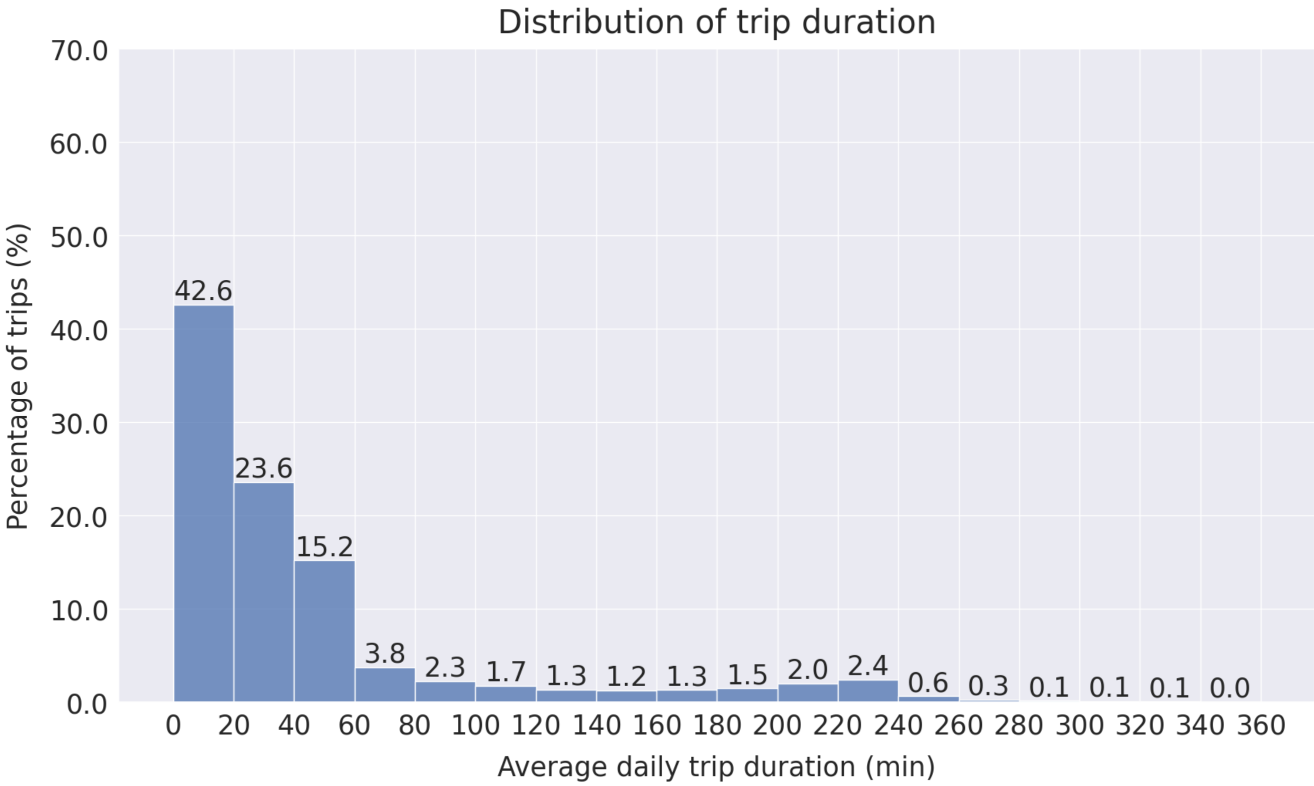

Figure 3.8: Distribution of duration of trips, after isolation (2020-03-24 to 2023-07-31).

By comparing the histograms, the shift to longer trips after the pandemic is noticeable. While before the pandemic, the percentage of trips longer than 80 minutes was 2.6%, the percentage after the lockdown rose to 14.8%. In addition, the percentage of trips lasting up to 20 minutes has dropped significantly, giving more space to trips longer than 40 minutes. Trips between 20 and 40 minutes remained at a similar percentage. Thus, we can conclude that the increase in the average observed after the pandemic was mainly due to longer trips, probably made mostly by people who use their bicycles for professional purposes and by people taking trips for leisure, which tend to last longer than routine trips. These two hypotheses will be revisited in Sections 3.4 and 3.5.

Finally, Figure 3.9 shows the evolution of the percentage of trips lasting more than 80 minutes over the months, from February 2018 to July 2023. A pattern somewhat similar to that seen in the average number of trips can be seen: From September 2020 on, the proportion begins to climb quickly, until it stabilizes around May 2021. This is yet another indication that these trips were largely responsible for increasing the average duration of trips after the start of the pandemic. Again, there is a sudden increase in May 2022. This increase in the number of long journeys (with journeys of over 80 minutes accounting for around 40% of the total) seems to have been the main driver of the large increase in the average duration of journeys from that month onwards, as observed in Figure 3.4. Due to this abnormal behavior, a comparison of the duration histograms was made separately for before and after May 2022. Such analysis can be seen in Section 4, in Figures 5 and 6.

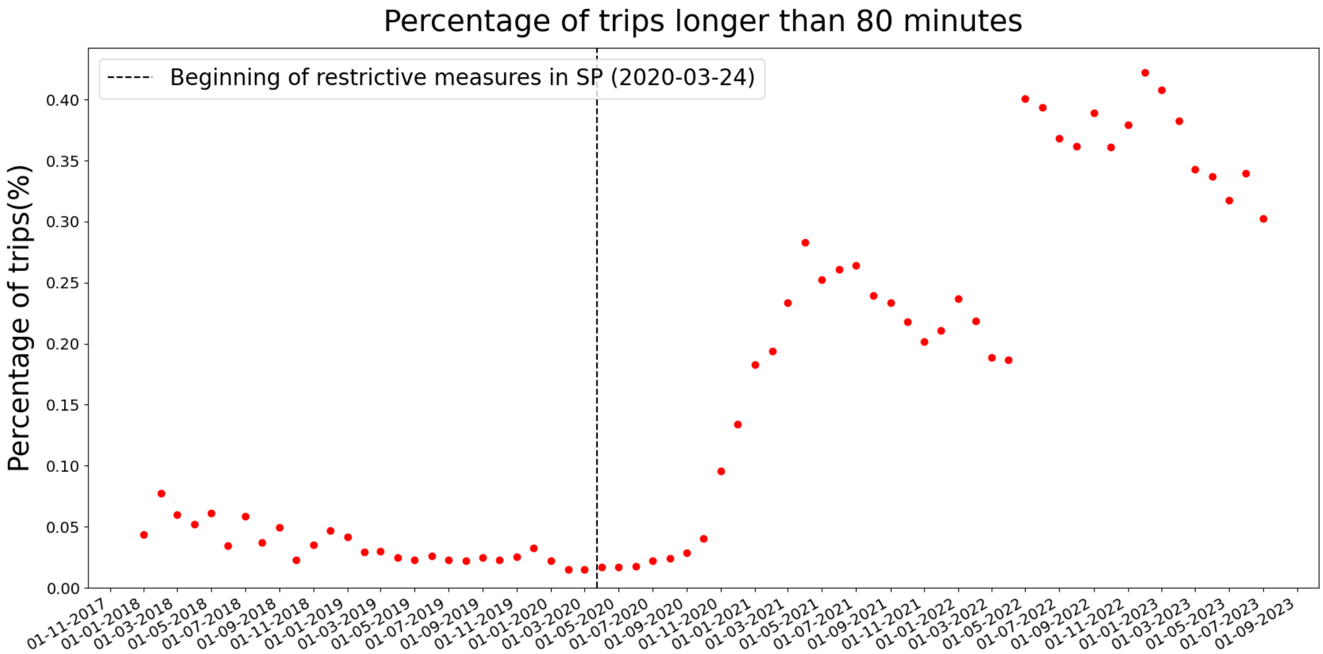

Figure 3.9: Evolution of the percentage of trips lasting longer than 80 minutes.

3.3 Trip time

For analysis purposes, we will consider the following time divisions:

- Morning: 6 a.m. – 8:59 a.m.
- Lunchtime: 11 a.m. – 1:59 p.m.
- Mid-afternoon: 2 p.m. – 4:59 p.m.
- Late afternoon: 5 p.m. – 6:59 p.m.

3.3.1 Morning

Figure 3.10 shows the evolution of the percentage of trips taken in the morning over the months, from February 2018 to July 2023. It can be seen that the number of trips at that time dropped sharply after the pandemic. Such a drop can be explained by the fact that, after the isolation of people in their homes, bicycle trips made to go to work or school, mostly carried out in the morning, were largely interrupted. This number gradually increased, stabilizing just below the pre-pandemic period in the first semester of 2022.

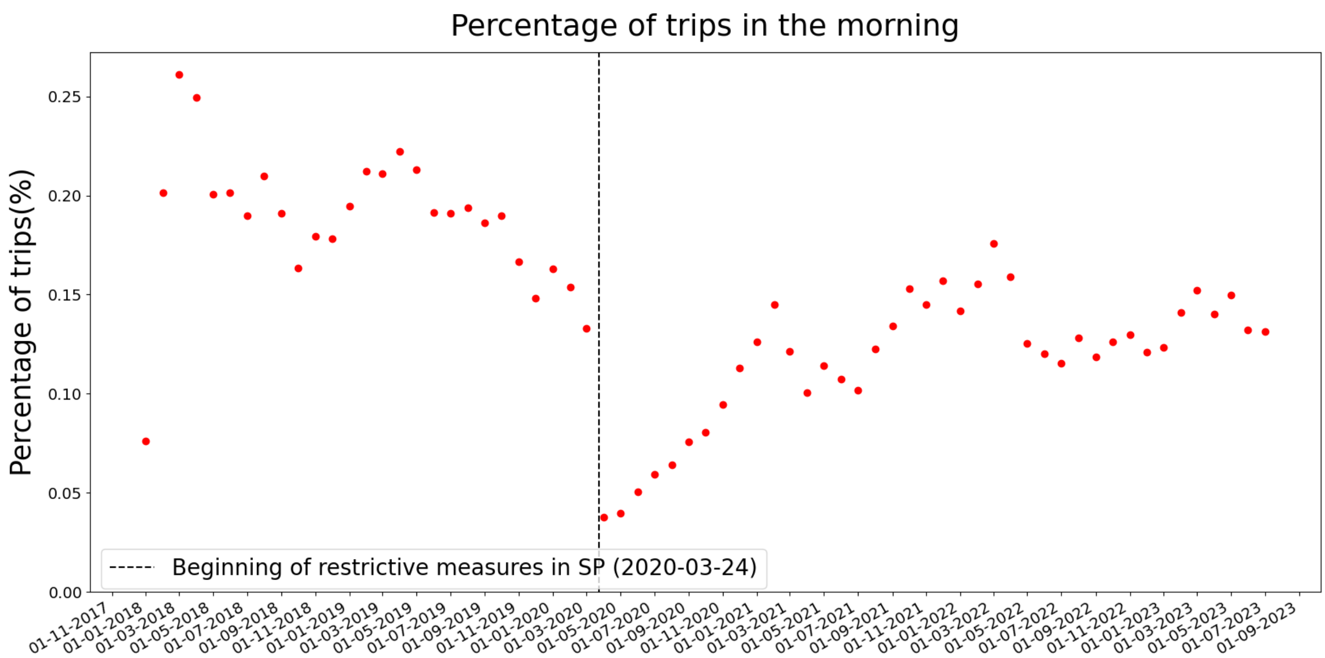

Figure 3.10: Evolution of the percentage of trips made between 6 a.m. and 9 a.m.

3.3.2 Lunchtime

Figure 3.11 shows the evolution of the percentage of trips made at lunchtime over the months, from February 2018 to July 2023. It is noted that the number of bicycle trips at this time jumped shortly after the isolation decree in São Paulo, remaining at a high level during the pandemic. On the other hand, if we look at these same percentages separately for trips that took place on weekdays and those made on weekends or holidays (Figures 3.12 and 3.13, respectively), we will see that this change in behavior was mainly driven by the change in the pattern of trips made on weekdays. Such behavior makes sense, since several people, now at home due to isolation, started using delivery services on weekdays for lunch. On holidays and weekends, however, the tendency is for the pre-pandemic state to persist: People who already ordered food before the pandemic tend to continue doing so, and the same goes for people who did not order.

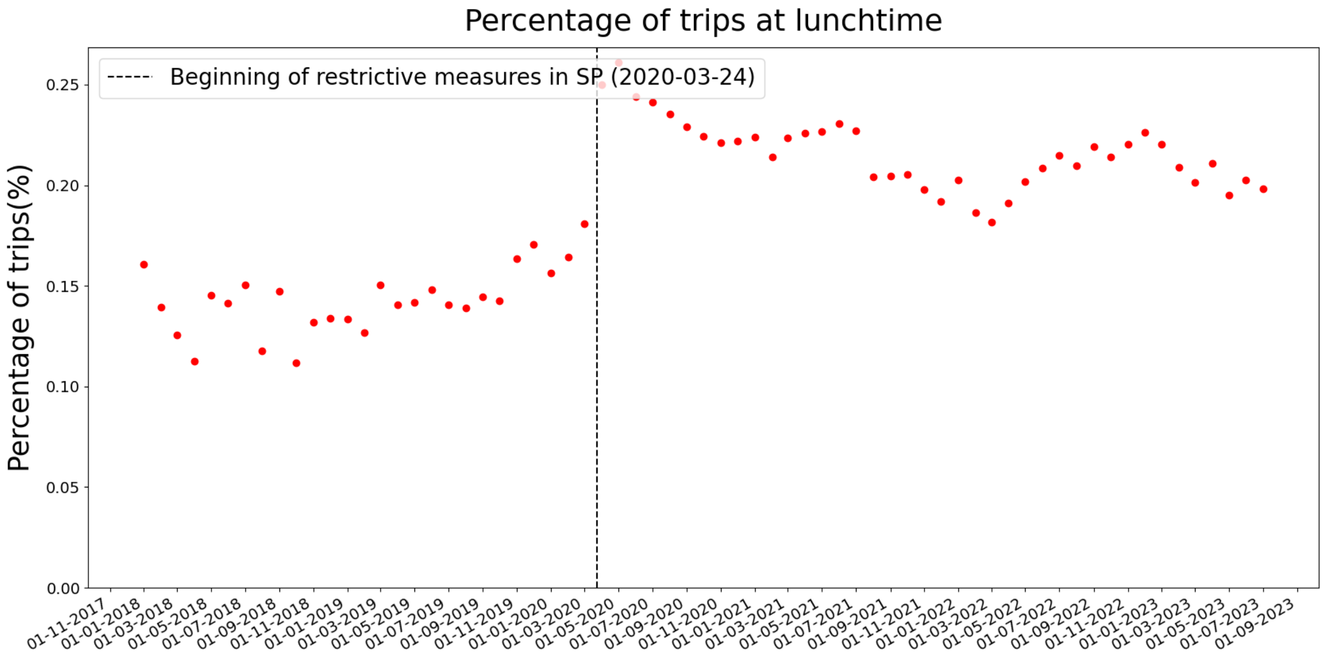

Figure 3.11: Evolution of the percentage of trips made between 11 a.m. and 1 p.m.

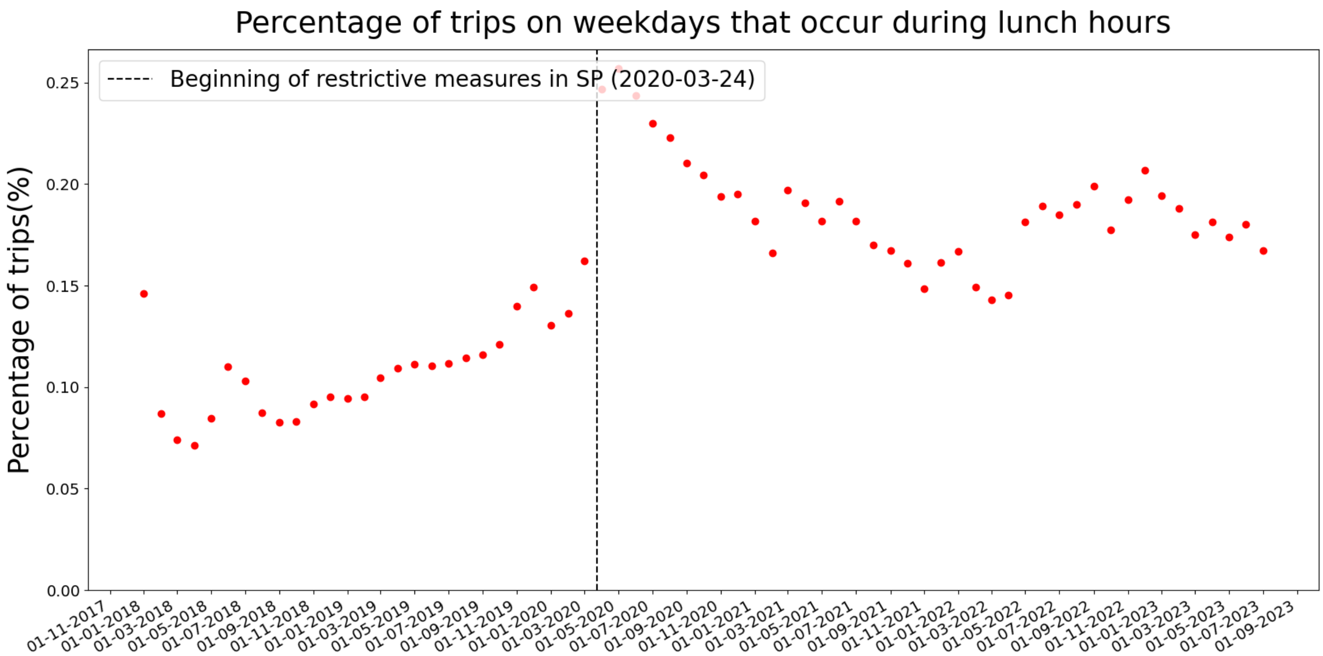

Figure 3.12: Evolution of the percentage of trips made during lunchtime within the set of trips made on working days.

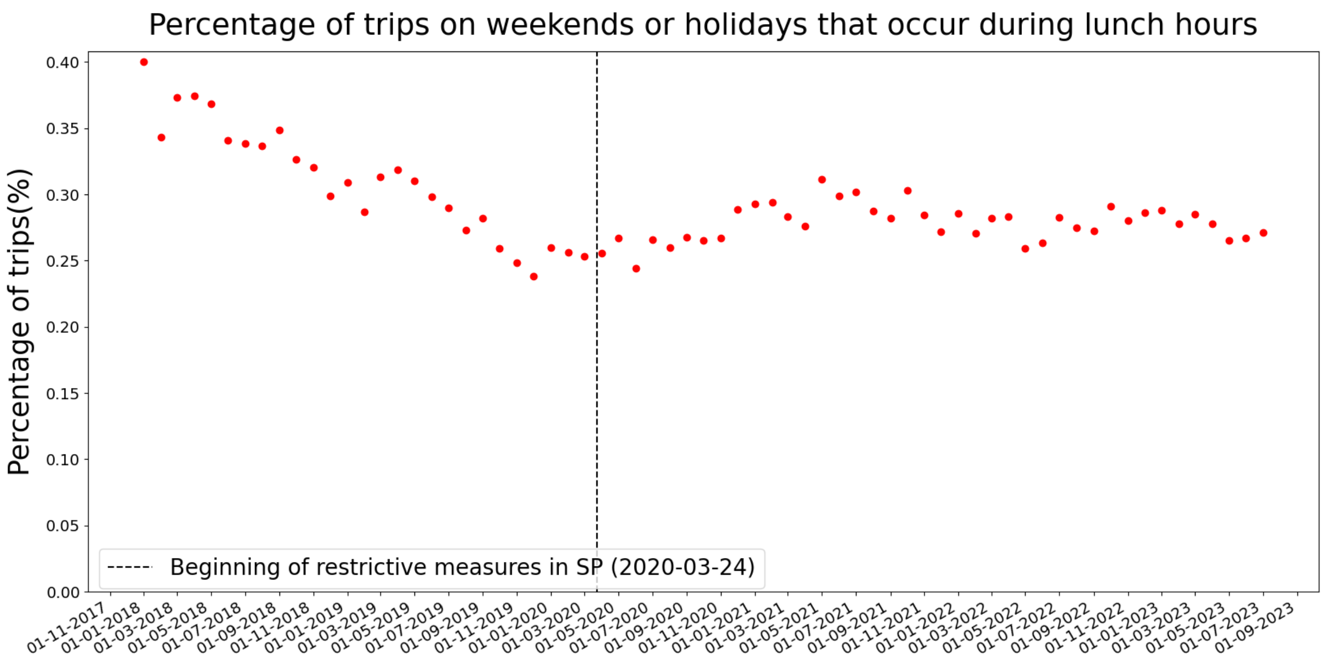

Figure 3.13: Evolution of the percentage of trips made during lunchtime within the set of trips made on weekends or holidays.

3.3.3 Mid-afternoon

Figure 3.14 shows the evolution of the percentage of trips made in the middle of the afternoon (between 3 p.m. and 5 p.m.) over the months, from February 2018 to July 2023. In the same way as with trips during the lunch period, the number of trips at this time jumped after the isolation. To gain insight into this pattern, we may, once again, compare the percentage changes between trips that occurred on weekdays and those that occurred on weekends and holidays. The Figures 3.15 and 3.16 show these separations.

From the analysis and comparison of these three figures, it is noticeable that trips on weekdays were again the main reason for pushing the number of trips in the middle of the afternoon upwards. This can be explained because, during isolation, most people stayed at home, either due to remote work or online classes. With this flexible arrangement, people are more likely to be able to rent bikes mid-afternoon on weekdays. On weekends or holidays, however, the pattern does not tend to change as much since people, in general, are not working during either period.

3.3.4 Late afternoon

Figure 3.17 shows the evolution of the percentage of trips taken in the late afternoon over the months, from February 2018 to July 2023. There was no significant change in the percentage of trips of this type after the advent of the pandemic. However, it is observed that the negative trend before the pandemic has been replaced by a slight positive slope. Therefore, the pandemic may have encouraged trips made by bicycle during this time of day.

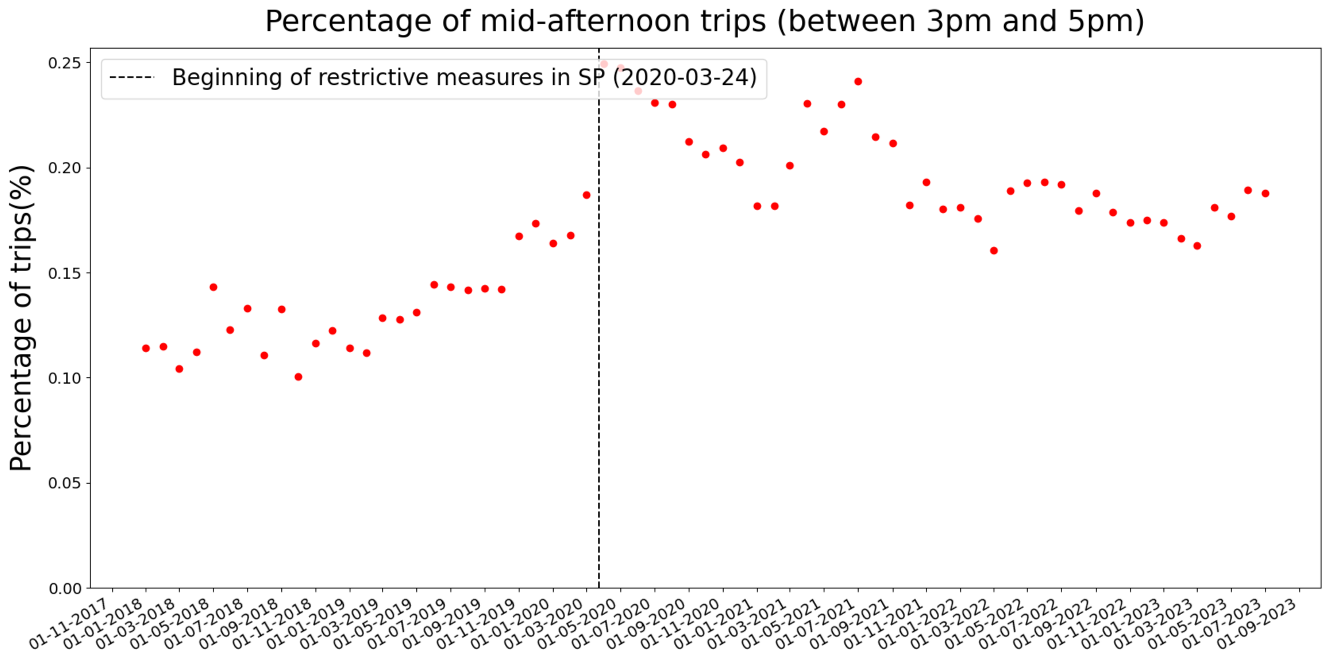

Figure 3.14: Evolution of the percentage of trips made between 3 p.m. and 5 p.m.

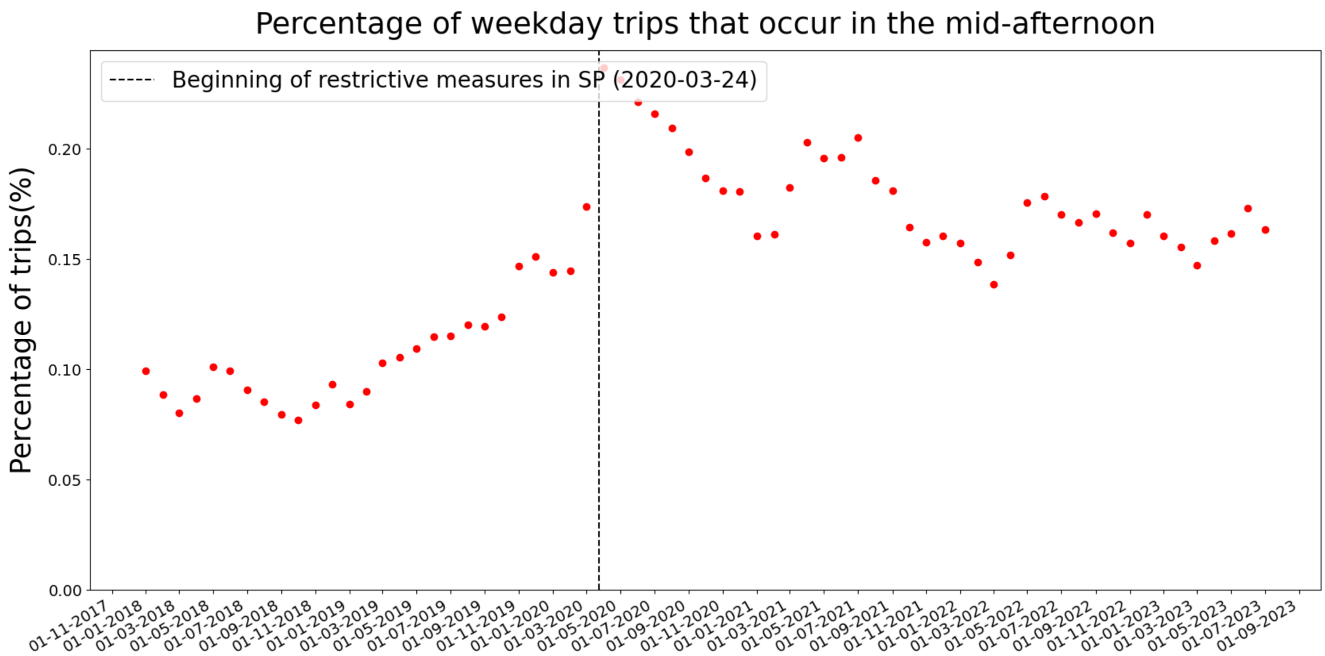

Figure 3.15: Evolution of the percentage of trips made in the middle of the afternoon within the set of trips made on weekdays.

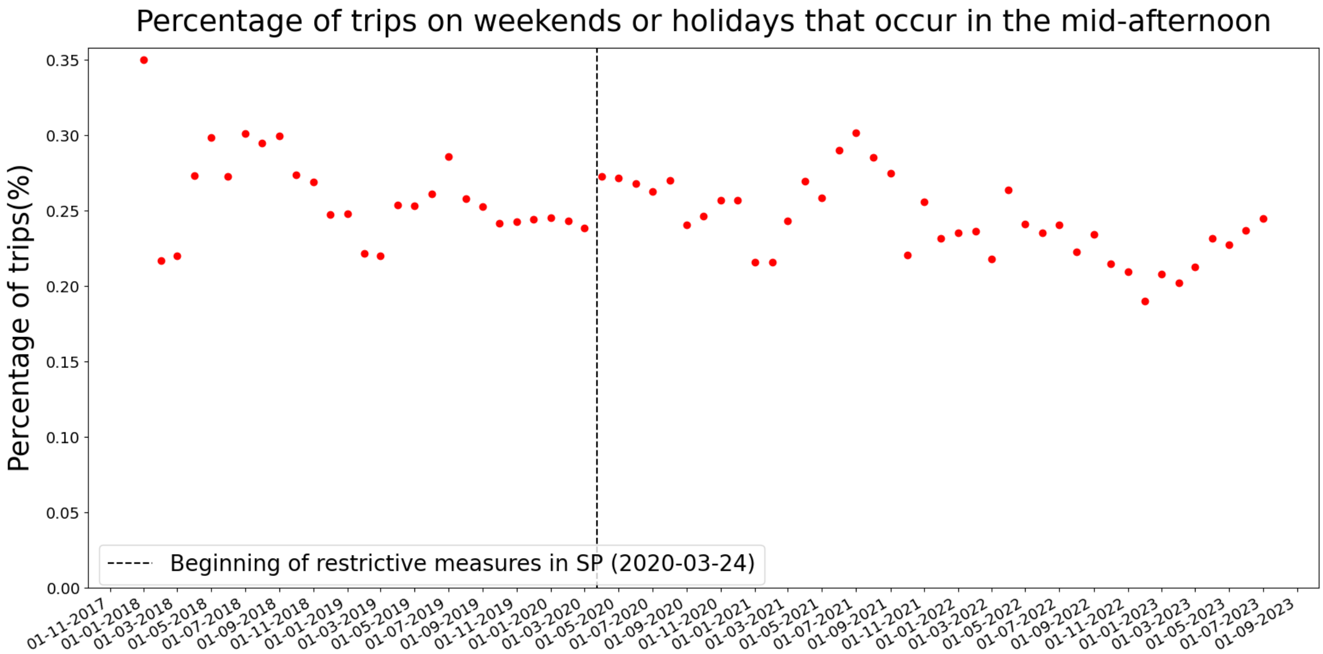

Figure 3.16: Evolution of the percentage of trips made in the middle of the afternoon within the set of trips made on weekends or holidays.

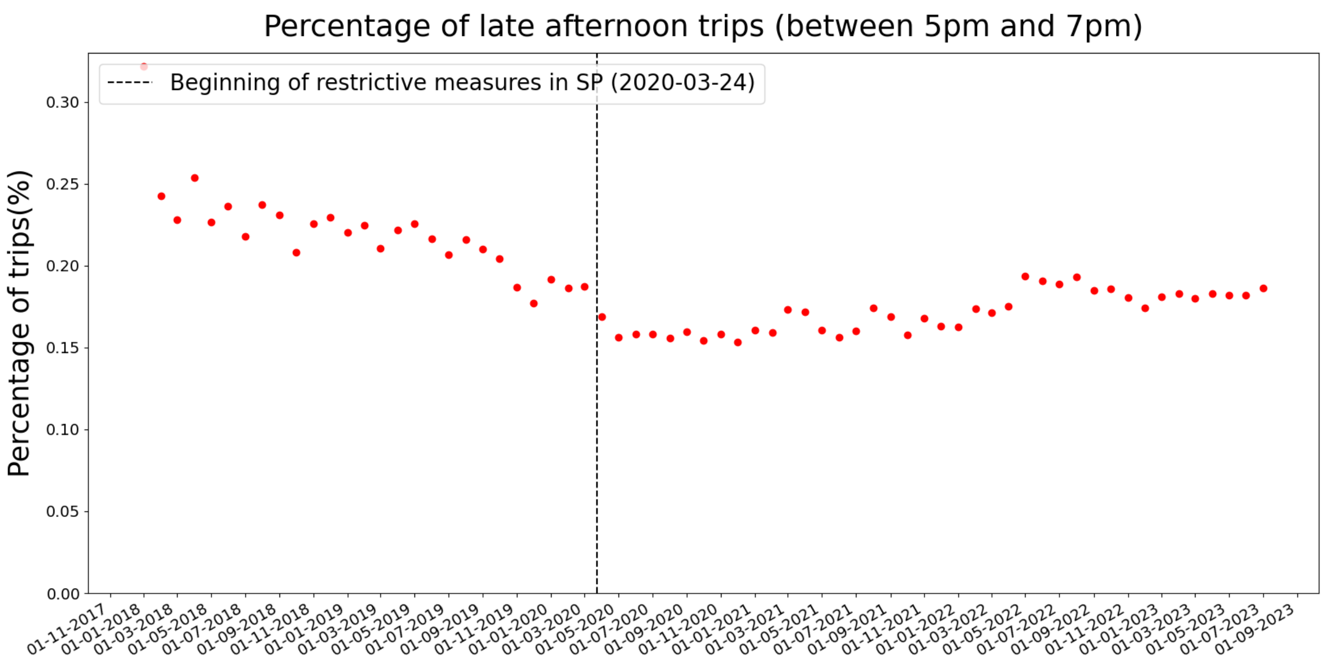

Figure 3.17: Evolution of the percentage of trips made between 5 p.m. and 7 p.m.

3.4 Circular trips

Trips that start and end at the same point are called circular trips. That is, the user rents a bicycle at a station and returns it a while later at that same station. There are usually two main reasons for circular trips:

1. Trips made for leisure: In this type of trip, it is common for the bicycle user to leave a place (home, for example), cycle, and then return to the same point.
2. Trips made by deliverers or other professionals who use bicycles for work. This user profile also tends to return to the starting point once their shift is over.

Comparing the proportion of circular trips before and after the pandemic reveals a striking rise after the outbreak. Prior to the isolation (from February 1, 2018 to March 23, 2020), the percentage for this type of trip was 10.2%. In the period from March 24, 2020 to April 30, 2022, this proportion rose to 18.1%. Figure 3.18, which shows the evolution of the percentages of circular trips in the set of total trips, shows us that there was in fact a jump in the proportion of this type of trip right after the isolation.

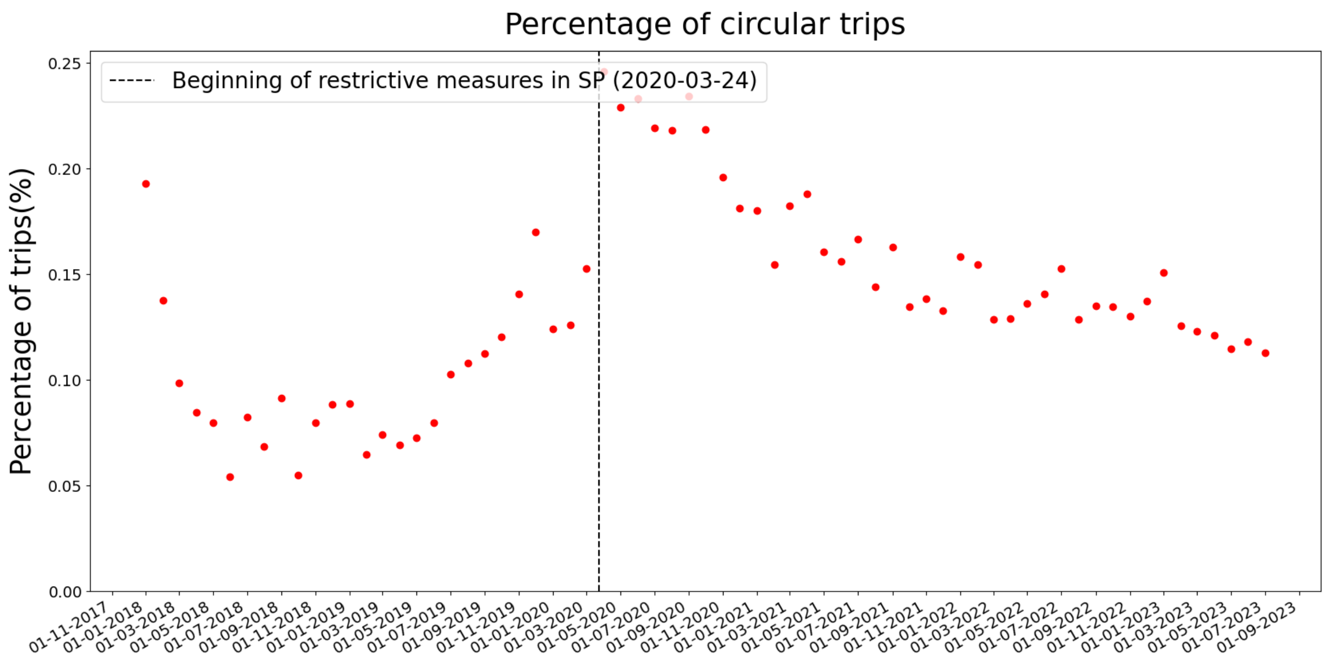

Figure 3.18: Evolution of the percentage of trips that start and end at the same station.

As done in previous sections, let's look at the percentage of circular trips that were made on weekdays versus trips made on weekends or holidays. Figures 3.19 and 3.20 show both evolutions. Table 3.1, in turn, shows the total proportions of both periods separately. Comparing the two periods, it can be seen that, similarly to what happened for other types of trips, trips made on weekdays were mainly responsible for the increase in circular trips after the isolation. This is probably due to the same factors mentioned above: increased delivery orders and greater demand for outdoor leisure activities during working days.

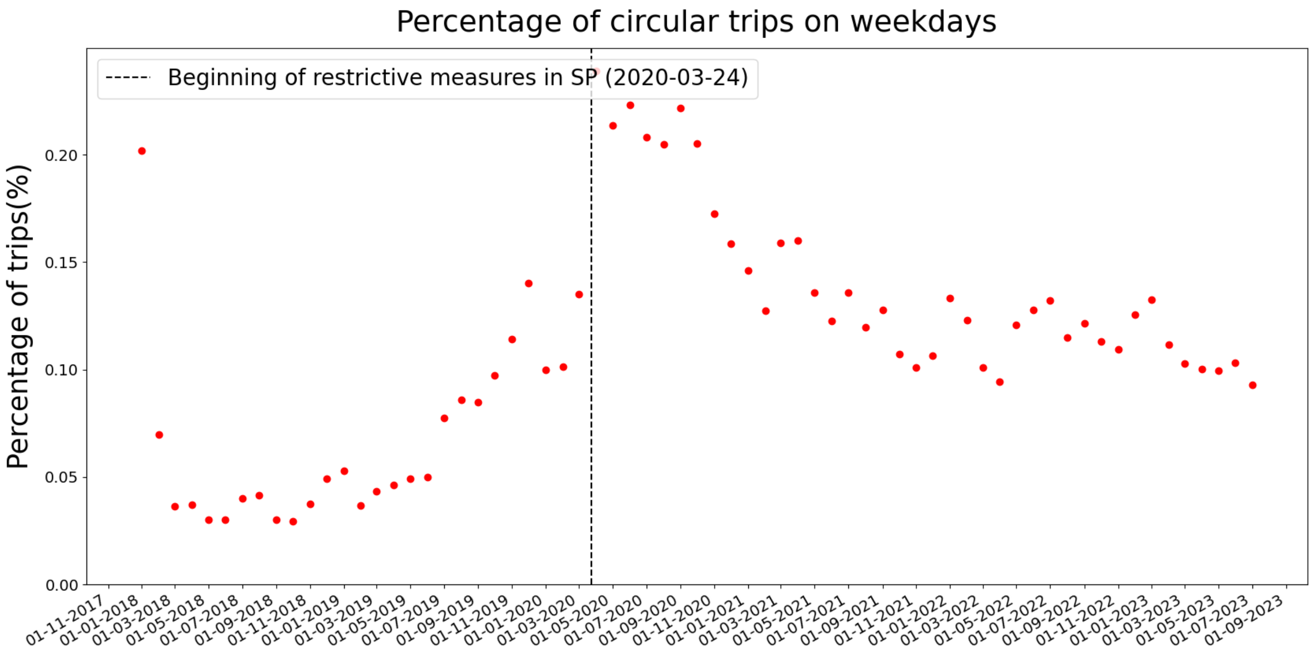

Figure 3.19: Evolution of the percentage of circular trips within the set of trips made on working days.

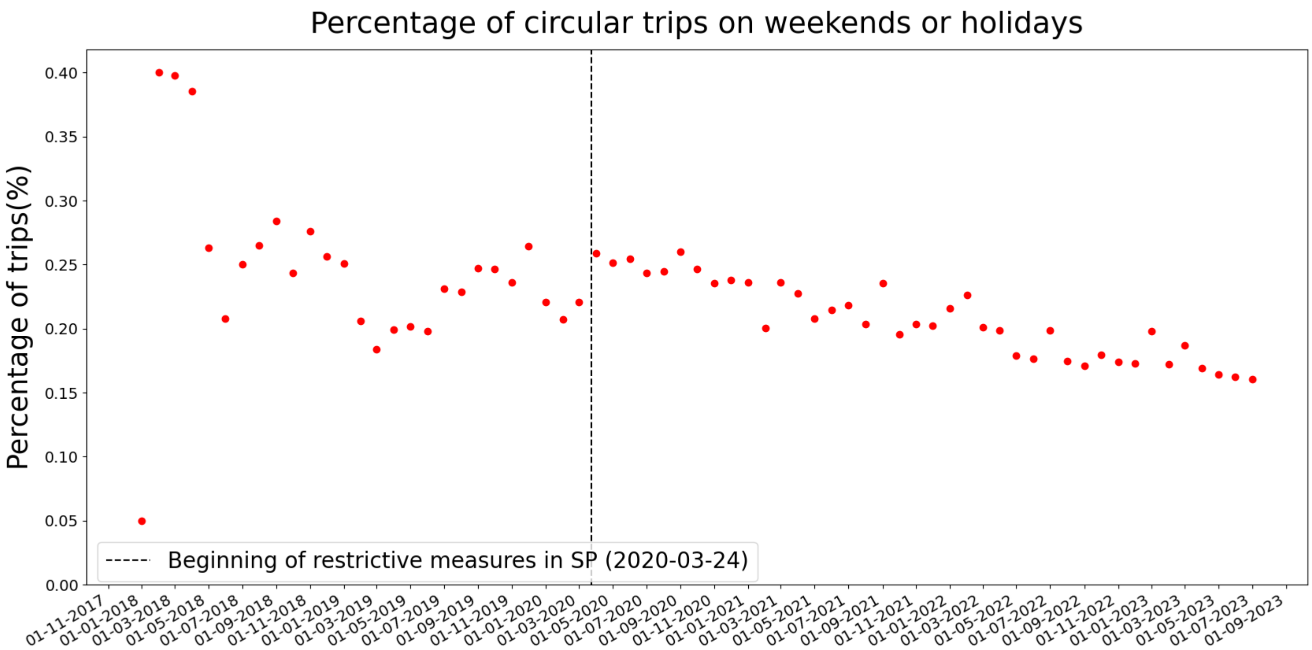

Figure 3.20: Evolution of the percentage of circular trips within the set of trips made on weekends or holidays.

Proportion of circular trips	Before lockdown	After lockdown
Among trips on weekends or holidays	0.23	0.23
Among trips on weekdays	0.07	0.16

Table 3.1: Proportion of circular trips before and after the lockdown.

3.5 Trips on weekends or holidays

From the previous sections, we can conclude that the behavior of trips (the time at which they are made, their duration, and the proportion of circular trips) has changed mainly in trips made on weekdays.

On the other hand, the number of trips made on weekends and holidays increased with the advent of the pandemic. Before the lockdown, the percentage of such trips was 17%. In the period following social restrictions, this proportion rose to 30.1%. One of the possible reasons for this is that, during the lockdown, leisure options decreased. Most people were isolated in their homes. Most establishments, especially those related to entertainment, were closed. As a result, the demand for cycling trips as a form of leisure, especially on weekends, tends to increase. If that wasn't enough, gyms and other facilities commonly used for physical exercise were also closed. Thus, cycling trips became a good alternative to staying active.

Furthermore, as we discussed in Section 3.2 (Trip duration), the percentage of trips made by deliverers grew. Since most deliveries are made at the weekend, it seems natural that this fact influenced the increase in trips on those days.

We may also track the evolution by month in the proportion of trips taken on weekends and holidays. Through this, it is clear that the increase in trips on weekends and holidays coincided with the advent of the COVID-19 pandemic. Figure 3.21 shows this progression.

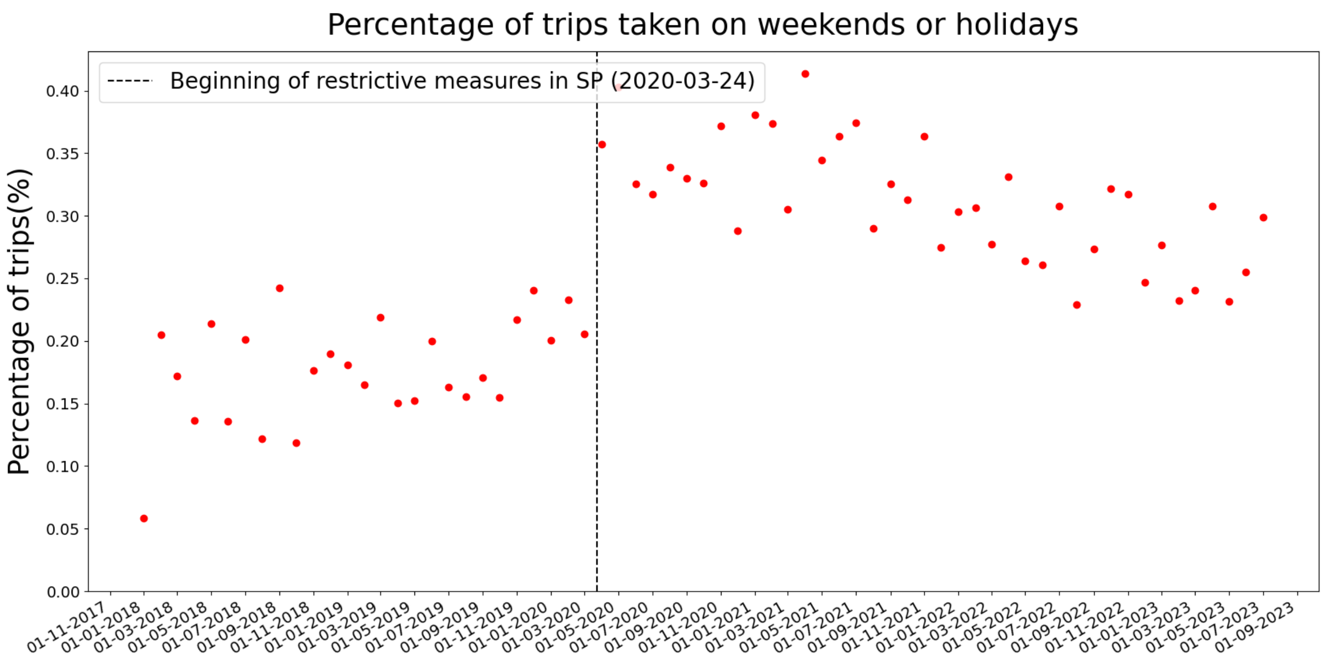

Figure 3.21: Evolution of the percentage of trips made on weekends or holidays.

Conclusion and Future Work

This study performed a data analysis to examine the effects of the COVID-19 pandemic on the bike-sharing system in the city of São Paulo, Brazil. The data source was Tembici, a leading bike-sharing company in Latin America, which provided data on the usage of its service from January 2018 to July 2023. The results revealed that the bike-sharing system experienced significant changes due to the pandemic.

First and foremost, we observed a substantial decrease in the total number of trips following the onset of the lockdown. This phenomenon mirrors the global trend, where restrictions and public health concerns associated with the pandemic have led to a decrease in commuting and outdoor activities, impacting the demand for bike-sharing services.

Furthermore, our analysis revealed a salient increase in the average duration of bike-sharing trips. This shift in trip duration resulted mainly from a higher proportion of trips exceeding 80 minutes in length. The rise was linked to the introduction of the "Professional Plan" by Tembici, which was created in response to the growing demand for bikes for work-related purposes.

We also found that the patterns of trips on weekdays were more affected than those on weekends. In particular, we detected alterations in the distribution of trip hours, with a surge in trips during the mid-afternoon and lunchtime hours and a decline in the morning. Moreover, there was a noteworthy increase in circular trips, especially on weekdays. On the other hand, the percentage of trips made on weekends increased after the pandemic. These changes could be attributed to various factors. Firstly, more people started to work from home, thus not needing to commute as much during traditional rush hours. Secondly, many may have switched to using bike-sharing systems for leisure activities such as exercise or sightseeing rather than just commuting to work.

Future work can target several directions. First, while our analysis has provided valuable insights, further investigations could incorporate statistical tests to rigorously validate our findings and uncover the statistical significance of observed trends. Additionally, it is worth noting that the data provided by Tembici did not include demographic information about users. Exploring the potential impact of the pandemic on the user profile, such as changes in the distribution of age, gender, or socioeconomic characteristics, would contribute to a more comprehensive understanding of the pandemic's repercussions on the bike-sharing system.

Appendix A: Behavior from May 2022

As shown in Figures 3.1 and 3.4, trips exhibited an unusual behavior subsequent to May 2022: both the number of trips and the average duration of trips increased very suddenly (with both values increasing by more than 50% within a short span of days).

Figure 1 depicts this daily variation in the total number of journeys taken. It can be seen that the number of daily trips increased sharply on May 1. To further show this increase, a linear regression was performed on the data for these two time periods.

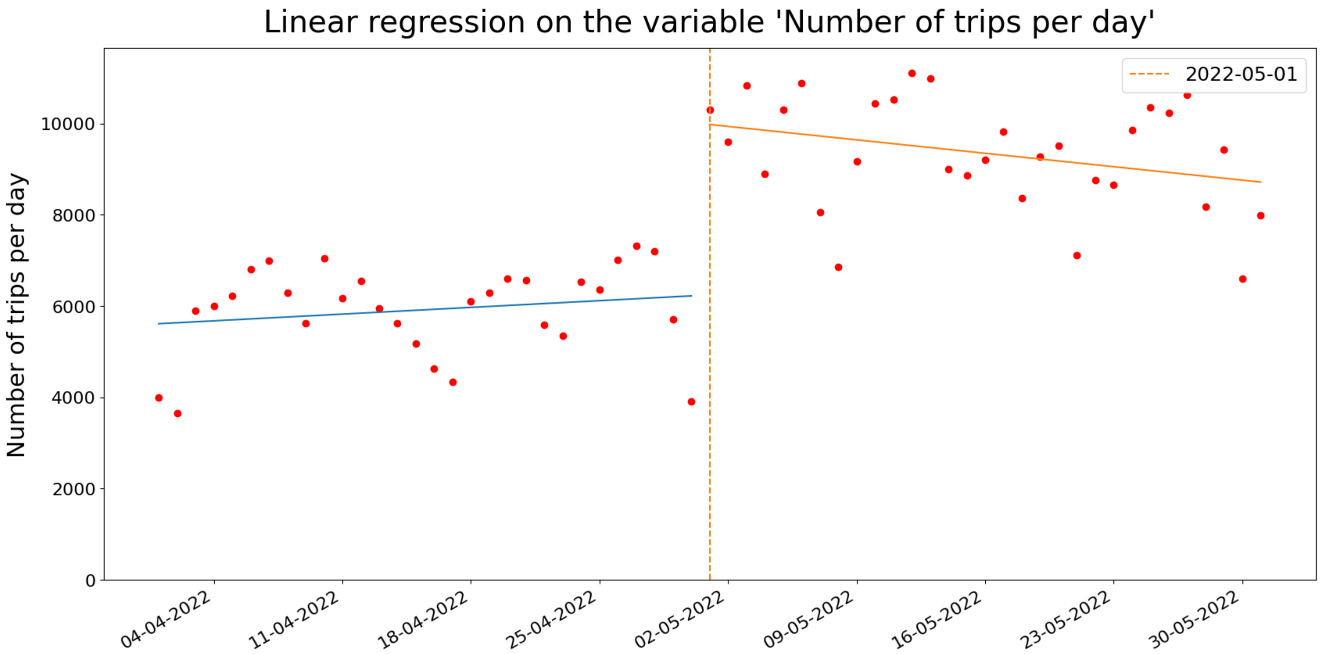

Figure 1: Evolution of the number of daily trips in April and May 2022 (2022-04-01 to 2022-05-31).

Figure 2 shows the average duration of trips per day for April and May 2022. By week, an intriguing seasonal pattern emerges: trips start the week with a lower average daily duration, and this value rises throughout the week. For example, April 4, 2022 is a Monday, and the graph shows that the duration of trips increases from that day onwards, decreasing again on April 11, 2022, the next Monday. This behavior can be explained by the increased demand for delivery services throughout the week, as this type of professional travel tends to take longer, as discussed in Section 3.2. At the beginning of May 2022, however, there was an increase in the average duration of trips. The seasonal behavior continues, but now with an upward shift.

Therefore, it is interesting to note that, for both variables (number and duration of trips), the increase was sudden at the beginning of May. This leads us to think that a change may have occurred regarding the data collection carried out by Tembici. Such a change does not appear to have been caused directly by variables of the COVID-19 pandemic, as there was no unusual event in early May 2022 that would immediately (overnight) impact trips made using shared bikes. In

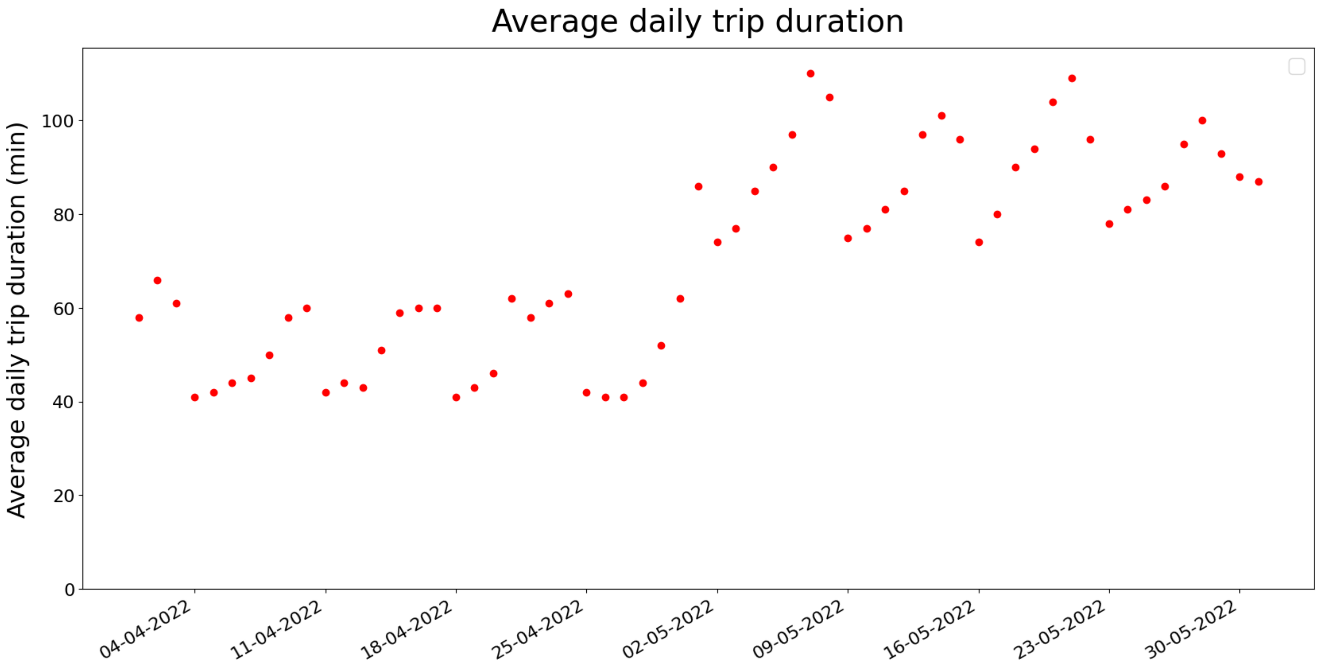

Figure 2: Evolution of the number of daily trips in April and May 2022 (2022-04-01 to 2022-05-31).

fact, we investigated this fact with Tembici, who reported that it was at this moment that the company introduced weekly plans for delivery drivers, and that the program had a great response. In a partnership with the delivery company iFood, the plans enable couriers to use the bike for 4 hours once or twice a day, without dynamic pricing [1], in a comparable way to the "Professional Plan" explained in Section 3.2. Despite this change, the previous sections demonstrated that the months from May 2022 onward follow trends similar to those identified for the post-pandemic period.

Furthermore, Figures 3 and 4 show the distribution of the number of trips in April and May 2022, respectively. By comparing these histograms, we were able to see that the increase in the average duration of trips between these months was mainly due to the increase in the percentage of long-term trips (over 2 hours). Special emphasis can be given to trips lasting just under 4 hours (240 minutes). In both histograms, the proportion of trips increases close to this value. This is consistent with the hours limit established by the delivery drivers' plans and the Professional Plan, reinforcing the likelihood of a correlation.

Finally, Figures 5 and 6 show the trip duration distributions separately for the period from the beginning of the pandemic until April 2022 and from May 2022 to July 2023, respectively. We can see that, even considering only the period up to April 2022 (Figure 5), the shift to longer trips after the pandemic is still clear (compared to Figure 3.7).

[1] https://ifood.tembici.com.br/

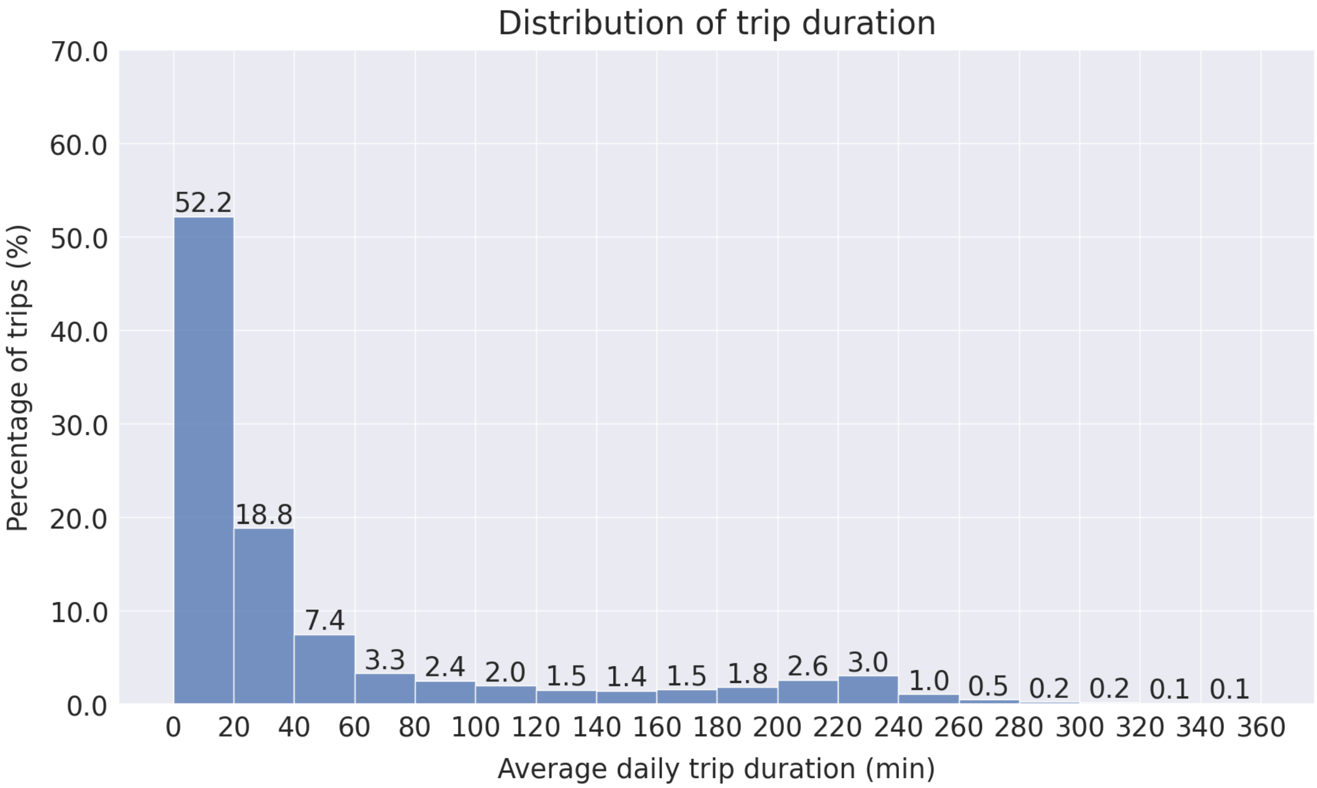

Figure 3: Distribution of trip duration in April 2022 (2022-04-01 to 2022-04-30).

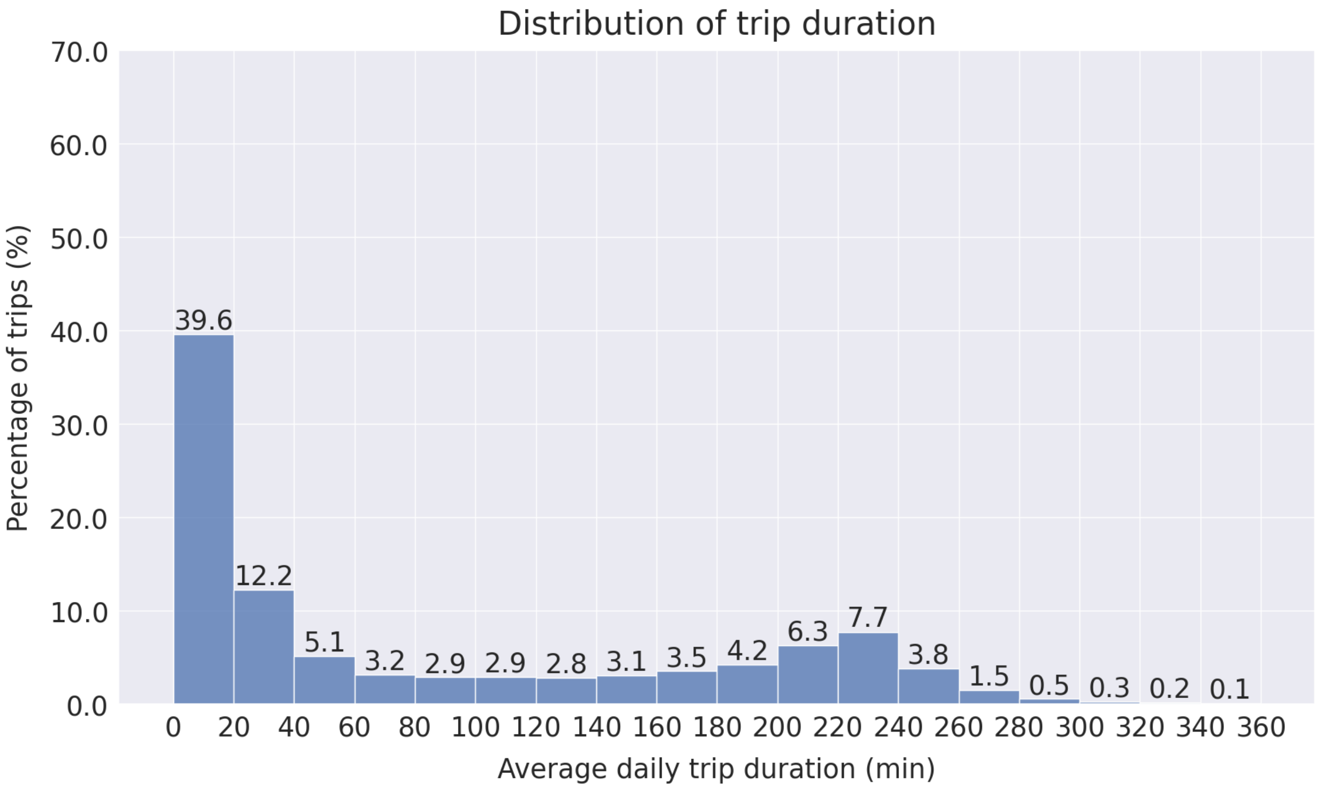

Figure 4: Distribution of trip duration in May 2022 (2020-05-01 to 2022-05-31).

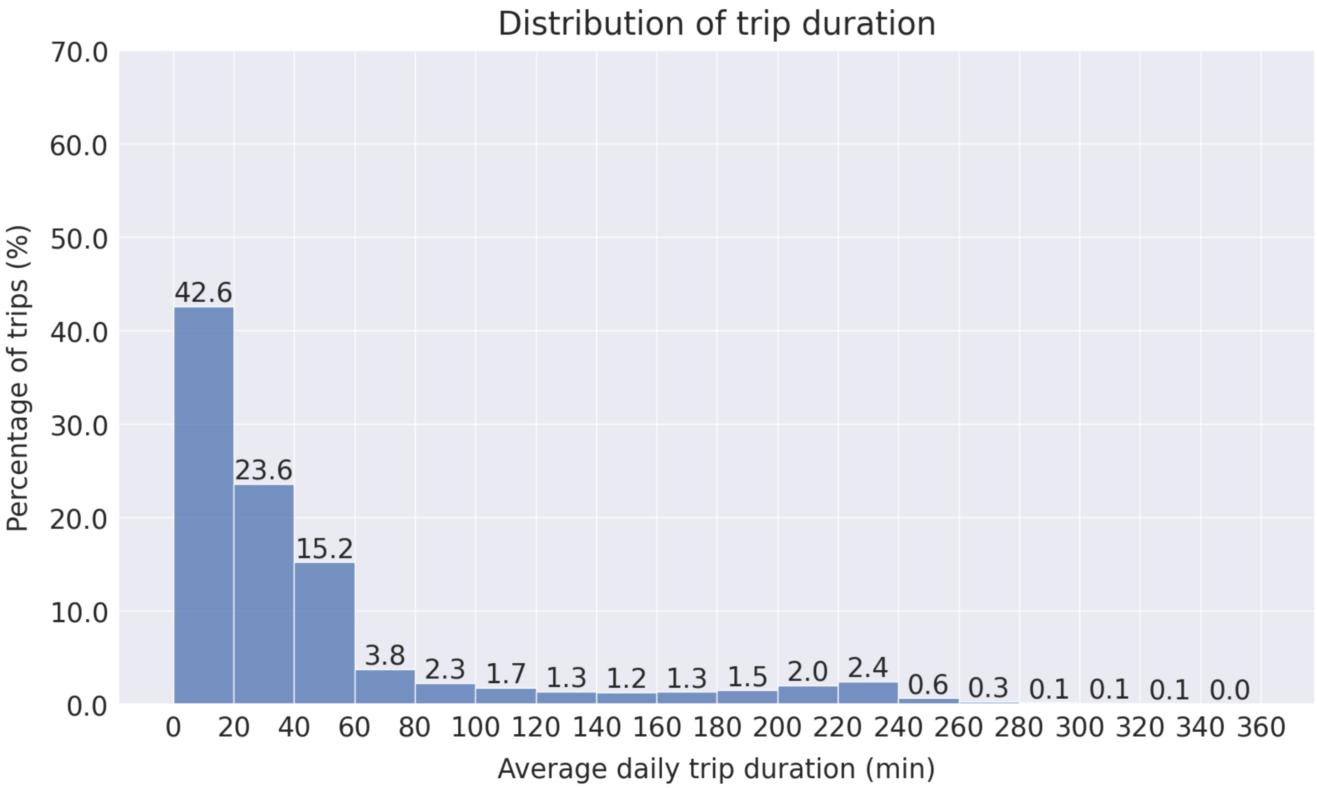

Figure 5: Distribution of duration of trips between the beginning of the pandemic and April 2022 (2020-03-24 to 2022-04-30).

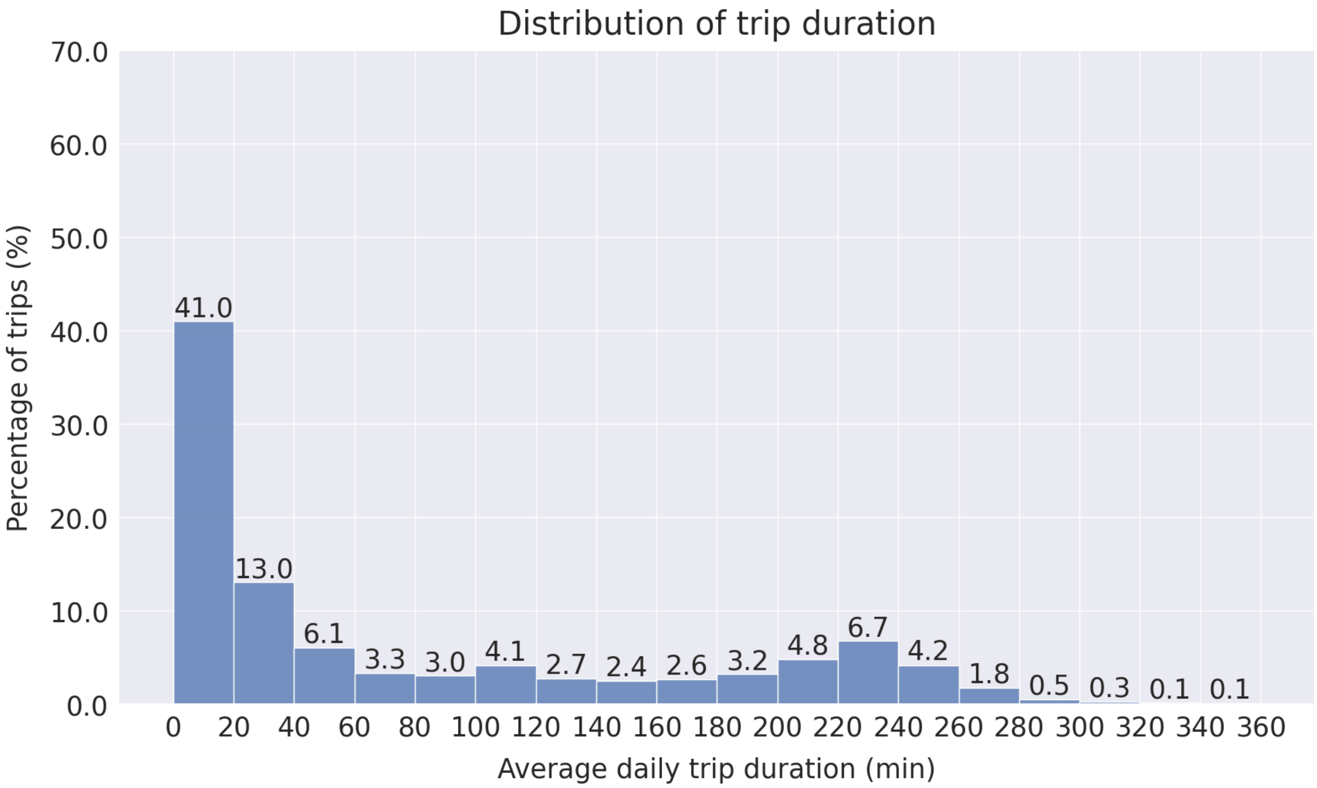

Figure 6: Distribution of duration of trips from May 2022 to the end of July 2023 (2020-05-01 to 2023-07-31).