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Exploring the Impact of COVID-19 on Tartu Smart Bike Usage

Bachelor Thesis (9 ECTS)

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Abstract:

The COVID-19 pandemic had a significant impact on our everyday life and one of the most visible effects was on the transportation sector. In Tartu, the fairly new bike-sharing system (BSS) Smart Bike provided an alternative mode of transportation during lockdowns and social distancing measures. However, little research has been done on how the pandemic affected the usage of these bikes. This thesis aims to fill that gap by analysing the public data of Tartu's BSS mainly during the 2020-2022 period to determine if and how the pandemic affected its usage patterns. The findings reveal changes in the nature of bike trips during lockdown periods characterised by longer trip durations, both in distance and time and lower distance coverage speeds, indicating that people used the bikes more for leisure and exercise. The study also highlights the potential of BSS data for developing more sustainable and effective infrastructure and transportation systems.

Keywords: Tartu Smart Bike, COVID-19, pandemic, bike-sharing systems, data analysis, active mobility

CERCS: P170 (Computer science, numerical analysis, systems, control)

COVID-19 mõju Tartu Smart Bike'i kasutusele

Lühikokkuvõte:

COVID-19 pandeemial oli oluline mõju meie igapäeva elule, märgatavalt oli ka mõjutatud transpordisektor. Tartus võrdlemisi uus rattaringlus süsteem Tartu Smart Bike pakkus alternatiivseid transpordi võimalusi pandeemia ja liikumispiirangute vältel. Siiski on vähe uuritud, kuidas pandeemia mõjutas nende rataste kasutamist. Antud uuringu eesmärk on täita see lünk, analüüsides Tartu Smart Bike süsteemi avalikke andmeid perioodil 2020 kuni 2022, et teha kindlaks kas ja kuidas on rattaringlus muutunud. Uurimustöö tulemused näitavad teostatud sõitude omaduste muutuseid liikumispiirangute vältel. Rattasõidud on muutunud pikemaks nii vahemaa kui ka aja arvelt, kuid keskmine sõidukiirus on vähenenud, mis võib viidata, et rattaid kasutati rohkem vaba aja veetmiseks ja treeninguteks. Uuring tõstatab esile ka võimaluse kasutada Tartu Smart Bike andmeid jätkusuutlikuma ja tõhusama infrastruktuuri ja transpordisüsteemi arendamiseks.

Võtmesõnad: Tartu Smart Bike, COVID-19, pandeemia, rattaringlussüsteemid, andmete analüüs, aktiivne liikuminean vaa

CERCS: P170 (Arvutiteadus, arvanalüüs, süsteemid, kontroll)

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Introduction

In the past years, COVID-19 has had a significant impact on our way of life around the world. Many aspects of our daily routine were disrupted or even put on halt. One of the most visible aspects of the pandemic was the effect it had on the transportation sector. People had to adapt to new rules and regulations, that restricted or did not allow them to travel the way they used to, which certainly changed some of the everyday patterns we usually saw.

In the city of Tartu, much like in other urban areas, there are various modes of transportation available, with one of the latest additions being Tartu city's bike network "Smart Bike". During the lockdown of 2020, with strict social distancing measures in place, bike-sharing systems became a potential alternative for commuting while offering a way for getting some fresh air and sun, or even to do some exercise. This trend was popular and even promoted by the government at the time. However, it is unclear to what extent the pandemic has affected the usage of these city bikes in Tartu since this kind of research has not yet been conducted.

Other main public transportation modes in Tartu, such as city buses, although good for effectively transporting large amounts of people, do not provide a lot of trustworthy data regarding the everyday commuting habits of passengers. Unlike in the Tartu BSS, where everyone, who uses the bikes, must be registered in order to unlock them, with buses it is mostly unclear who uses them since entering the bus does not necessarily force anyone to register their ride, although it is required. Therefore, in the end, it is unclear who might have used the bus and what was their trip like. This is just one link in the chain of problems regarding the data from buses. With bikes, the data is more consistent and therefore useful.

This thesis aims to investigate the impact of COVID-19 on the usage of the Tartu Smart Bike system. The investigation was conducted with the public data provided by Tartu city's bike rental system. The data consists of the information saved after every trip made with a bike. The practical part of this thesis will use Java as the main programming language for extracting the necessary information out of the given data and also for data visualization, which will help in providing a complete picture. The conclusions of this thesis will be based solely on the data provided by Tartu city's bike rental system.

This thesis aims to provide a better understanding of whether COVID-19 pandemic had an impact on the city's bike rental usage and patterns. Additionally, the study would possibly give us some insight into what motivated the people of Tartu to use these bikes in and out of the lockdown period. Are these bikes just a mode of transportation to get us from point A to point B, or do people use them for leisure, to experience the outdoors, or even to do exercise?

Additionally, some of the results of this thesis have been included in a research paper that has been accepted in SuMob (Appendix III).

The remainder of this thesis has the following structure: the first chapter will provide the necessary background information for the analysis. This includes the introduction to the world of bike-sharing systems, the COVID-19 pandemic and the impact it had on bike-sharing systems in other cities. The second chapter will go through the methodology and tools used to conduct the analysis. The third chapter will detail the data analysis and also contain the discussion part. The fourth and final chapter will be about future work which will be followed with a conclusion section and appendixes at the end.

1. Background

The following chapter provides the theoretical background necessary to analyse and compare the usage patterns of Tartu city bikes in and out of lockdown periods.

1.1. Bike-Sharing Systems

Bike-sharing systems (BSSs), also known by many other names, like free bikes, city bikes or public bicycle systems, all represent the same idea, which is a short-term bike rental service for public usage (1).

1.1.1. A brief history of BSS

In a report by Cooper (1) it is explained, that the original implementation of the concept of a publicly usable city bike was realized in 1964 in Amsterdam, Netherlands. More of an experiment and a political statement by an industrial designer and politician Luud Schimmelpennink and a radical youth group the Provos, than a service, was called *Witte Fiesten* or White Bikes. The network consisted of several hundred donated or lost bikes, that were painted white, for identification, and left on the street for anyone needing them. Because the bikes did not have any docking mechanism or even locks installed on them, people had little to no idea where the bikes could be found at any given time. This made the service notoriously unreliable, with bikes constantly being stolen or found floating in the city's canals. The project quickly failed, but the insights that were gathered helped develop the current BSS.

Cooper then describes (1), that the second generation of public city bikes came in 1996, in Copenhagen, Denmark. This time the bikes were specially made for the given service and had a web of stations, where the bicycles could be unlocked and later returned, which made finding them much easier. These bikes were relatively simple in design and usability, also durable and easily manufacturable and reparable. To counter theft, the bikes were equipped with an integrated coin-operated locking system, similar to those found on shopping carts.

The same report (1) also brought out, that the ongoing problem of theft and the lack of user accountability, as there was no way of knowing who was using these bikes, made way for the third generation of BSS, commonly known as *smart bikes*. The first large-scale *smart bike* network was installed in Lyon, France in 2005 by Vélo'v. The new BSS introduced new technologies like magnetic swipe cards, computerized terminals, and electronic locks, which were all intended to give the users more accountability and help keep track of missing or damaged bikes.

The report (1) also states that the fourth generation of public bike systems, which included cutting-edge technologies such as wireless data transfer and solar-powered and modular stations, changed the BSS landscape to the one known today. The users of these systems can download an app on their smartphones to access the bikes and track their carbon offsets, the amount of gasoline they have saved and the total amount of km they have travelled. This also introduced more accountability to the users, reducing theft and vandalism. The first such scheme was implemented in Montreal, Canada on May 12, 2009.

The next big step in BSS was the implementation of a dockless, or stationless, system, which is more affordable, reducing the cost and installation time by not needing to build any stations. As mentioned in an article by the Institute of Transportation and Development Policy (2) one of the earliest stationless BSSs such as Call-a-bike and Nextbike were established in Germany. Although cheaper, they relied heavily on government support and did not use the benefits of a smartphone app, which made them inconvenient and ultimately unpopular. The more modern dockless system was born in 2014 when five students from Peking University in Beijing founded a BSS called “ofo”, that provided transportation within the campus. In 2016, as the sharing economy, high-speed mobile networks and smartphones started to rise, this new approach to BSS exploded in China and expanded to other parts of the world.

1.1.2. Benefits of BSSs

As urbanization around the world is growing, people are in need of new and accessible ways of intracity transportation. The docking station system allows people to rent a bike and return it to another station, making the service ideal for short-distance travel (1).

In an article by Julio and Monzon (3) it is explained that installing a BSS in your city is also a good way to introduce more transport flexibility, giving the city's residents a new mode of transportation, which not only reduces road traffic and fuel consumption but also promotes a healthier lifestyle by helping to transition towards cycling in cities, where there is low cycling culture and infrastructure. With BSSs, the transition is also made smoother by bikes with electric assistance (pedelec bikes), which many newer BSSs have implemented.

One of the more long-term benefits of these BSSs is the data they provide. With each trip, the systems record information such as where the bike was taken, the duration of the trip (both in terms of distance and time) and the final station. This information is crucial for understanding the commuting patterns of citizens and the purpose of trips, explained in a report (4). And with enough research, this data can be used to not only improve the BSS but also to improve transportation infrastructure and the quality of life of the city's residents.

1.2. Bike-Sharing System in Tartu

Tartu's BBS, called Smart Bike, was introduced in Tartu, Estonia on the 8th of June 2019, when the city brought 750 bikes along with 69 docking stations, scattered around the city, for public use, as said in the Tartu city's official website (5). 500 of those bikes were pedelec bikes, which made the ride easier as well as more comfortable. The other 250 were regular manual bikes. The beneficial part of this system is the real-time communication between the system and the bikes, providing information about the bike's location, along with other data about recent trips, and allowing for quick response in case of any issues.

It is mentioned on Tartu city’s official website (5), that the project is funded by the European Regional Development Fund and the Horizon 2020 programme, which focuses on European research and innovation. To rent a bike, users must have a valid and activated Tartu public transportation ticket or purchase the bike share membership by creating a bike share account and connecting it to a credit card.

The idea of creating such an infrastructure was born back in 2014 when the Estonian Development Fund in cooperation with Tartu City Government commissioned a study aimed at presenting realistic guidelines and business cases for setting up BSSs in different Estonian cities (6).

According to Tartu BSS’s official website (7), today, more than 3 million journeys have been made with their bikes, covering more than 8.6 million kilometres. Due to high demand, the number of docking stations has also increased from 69 to 100 (8). Several studies have also been conducted to enhance the BSS experience, such as a master’s thesis by Helen Tera on the subject “Analytics and Decision Support for Public Bicycle Sharing in Tartu” (9).

1.3. COVID-19

This chapter provides the analysis of some important background information about the COVID-19 crisis and its relevancy in the case of this thesis.

1.3.1. COVID-19 and its brief history

Coronavirus 2019 (COVID-19) is a disease caused by the SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus-2) virus. The new coronavirus was first detected at the end of 2019 in China. As it is easily transmittable, it quickly spread to other parts of the world (10). On the 11th of March 2020 the World Health Organization (WHO) declared COVID-19 a pandemic (11).

From the 31st of December 2019 to the 30th of June 2020, there had been 10 273 001 confirmed cases of the virus, including 505 295 deaths (12). According to WHO the total number of globally confirmed cases has increased to 763 740 140, including 6 908 554 deaths (13).

As of the 5th of May 2023, COVID-19 has been declared as no longer a global health emergency by WHO (14).

1.3.2. COVID-19 in Estonia

A report titled "COVID-19 situation in Estonia, The first half of 2020" (15) states, that the first person in Estonia, infected with the disease, was identified on the 26th of February in 2020 and on the 12th of March, the government declared a state of emergency in the country, which was originally intended to last until May 1st. The period of the state of emergency, referred to as the 'first lockdown' period in this thesis, was meant to stop the possible spread of the virus.

The report (15) also states, that the lockdown brought some notable restrictions not seen in a long time. Visits to hospitals and nursing homes were prohibited and from the 16th of March all education centres, schools, colleges, universities, youth centres and hobby schools were closed and switched to distance learning, when possible. Entertainment centres like theatres, cinemas and museums were closed to the public and public events were cancelled (15).

From the 19th of March the testing was recommended only for those with symptoms (fever, dry cough, breathing difficulties) and who were either chronically ill, aged 80 and older, healthcare staff or other providers of vital services (Police, Rescue Board, Defence Forces, etc.), residents and staff of nursing homes and long term care facilities, or those with respiratory diseases, who were hospitalised or in need of hospital care (regardless of age). From April 8th, the testing expanded to those with upper respiratory tract infection symptoms (15).

On the 24th of April, the first lockdown was extended to last until May 17th, but at the same time, the restrictions were progressively dropped as early as May 2nd, allowing people to visit and organize events, that could be held outside maintaining the social distancing rules (15). On the 8th of May, the movement restriction was also lifted, allowing people to travel freely in the country (15).

In March 2021 the situation got worse, as Estonia became the country with the highest number of cases per million people (16). In response to that, the government reintroduced some of the lockdown rules. Education centres switched to distance learning and those, who could, were strongly recommended to work from home. In the context of this thesis, the Spring of 2021 is from onwards referred to as the ‘second lockdown’ period.

1.4. Effect of COVID-19 on the usage patterns of BSSs

The pandemic and the enforced lockdowns caused some significant changes in people’s mobility habits and lifestyles in general. There was a noticeable change in the short-term mobility patterns such as the choice of route, departure time and mode of transportation (17). The usage of BSS, which might have been the best option in the public transportation spectrum regarding social distancing rules, was also affected by the crisis. This chapter provides a brief overview of the studies, that were made to analyse these effects on the BSSs in cities around the world.

Authors in a similar study (18) analysed the effect that the COVID-19 pandemic had on the bike-sharing demand and hire time with evidence from London’s Santander Cycles BSS. The biggest advantage of this study is the amount of data available. Santander Cycles was launched in July 2010 and is one of the largest BSSs in Europe with over 11,000 rental bikes and over 10 years’ worth of data. The large amounts of data, that were available allowed the authors to estimate the expected bike usage patterns of 2020 if the pandemic had not occurred. The authors employed a Bayesian second-order random walk time-series model to predict the number of bike hires and hire time from March to December 2020 and compared these results with the actual data collected in the same period. The study shows, that, although there was a significant decline in the amount of BSS users in March and April of 2020 due to the pandemic, the demand for bikes rebounded in May of 2020 and remained in line with what was expected if the pandemic had not occurred, suggesting the resilience of Santander Cycles. Moreover, the data also revealed a substantial increase in bike hire time during April, May, and June 2020, which may have been due to a shift from public transit, as users were opting for longer bike trips.

The approach, used in the Santander Cycles study, cannot be applied in the current study, since Tartu BSS started operating in June 2019. However, the findings in this thesis are aligned with the results of the London report (18).

Another study investigating the short-term and long-term effects of COVID-19 on bicycle-sharing usage was performed in Budapest (19) using panel regression methods. The interesting part of this study is the separation of mobility and government restrictions as an affecting factor in the ridership, and also, as the study is made in 2022, the investigation is looking into the possible long-term benefits that the pandemic had on the BSS. The results indicate that both the mobility and government restrictions had a positive impact, bringing more people to use the BSS, particularly in residential areas and close to public parks. However, after the first wave of COVID-19 passed and the government started lifting the restrictions, the ridership declined. The study suggests that BSS was a valuable transportation mode during the pandemic, but a permanent increase in usage was not observed in Budapest despite a considerable price decrease in bicycle fares. Unsatisfactory experiences with the BSS, primarily due to heavy bike frames and solid rubber tires, may have contributed to this. The findings highlight the need to improve system characteristics that may undermine long-term ridership. However, the study also notes that these characteristics can be different for every BSS, hence local market research is required. These findings are relevant to this research, as it aims to investigate the impact of the pandemic on bike-sharing demand and usage patterns in Tartu.

The impact that the COVID-19 pandemic had on the behaviour of bike-sharing users was investigated in the example of Washington, D.C. (20). The study states that the popularity of the bike rental system has progressively grown compared to other modes of transport and how this demonstrates the high level of social adaptability of bike-sharing. Thus, this information provides more context for how the pandemic might have impacted Tartu's BSS (20).

In one study, the user behaviour of bike-sharing during COVID-19 was investigated in the context of environmental benefits (21). The study was conducted in Beijing, using big data techniques. The authors propose a novel method to accurately estimate trip distances and trajectories to calculate the environmental benefits of bike-sharing. They also use topological indicators from complex network theory to analyse the transformation of user behaviour patterns during the pandemic. The results show that the pandemic significantly impacted user behaviour and environmental benefits of bike-sharing in Beijing, such as reductions in energy consumption and emissions. Additionally, the article suggests that the pandemic lengthened the average duration of the bike-sharing trip, as well as showed that people were less likely to take bike-sharing to popular places (21).

Another study (22) analysed the impact of the COVID-19 pandemic on public transport usage and route choices. This work studied the travel behaviour of public transport users in Zürich, Switzerland, focusing on route choices and the recurrence of trips. The surveys were based on the GPS tracking of 48 users which was collected from spring 2019 and four months of 2020 (from 14 February to 13 July). Both the 2019 and the 2020 data were gathered from the same users. This allowed a precise comparison of travel behaviours before and during the pandemic. The authors used the Mixed Path Size Logit model to estimate the route choice criteria for public transport during the two periods. It was discovered that during the first wave of COVID-19, users had a different perception of the cost of transfers and railway travel time. In addition to that, the users did not use the same routes for recurrent trips.

Although the exact questions and methods in these described studies are not the same compared to the current thesis, the general argumentation can be applied to the data analysis.

2. Methodology

2.1. Data description

As brought up in previous chapters, what makes modern BSSs particularly useful, is how it collects information. After every trip made the system records from which station the bike was taken, which station the bike was brought to as well as additional information about the taken trip. The information includes unique identification codes, bike, and user information, start and end station details, trip length and duration, as well as information about the type of bike and subscription membership. This chapter describes the information the Tartu BSS can provide with each trip made and the significance it holds in the context of this thesis.

1) `Route_code` – A unique code for route distinction
2) `cyclenumber` – The serial number of the bike
3) `userID` – Bicycle users personal ID
4) `unlockedat` – The date the bike was unlocked
5) `unlockedattime` – The time of the bike was unlocked
6) `lockedat` – The date the bike was locked
7) `lockedattime` – The time the bike was locked
8) `startstationserialnumber` – The serial number of the start station
9) `startstationname` – The name of the start station
10) `endstationserialnumber` – The serial number of the end station
11) `endstationname` – The name of the end station
12) `length` – The length of the trip in kilometres
13) `DurationMinutes` – The length of the trip in minutes
14) `CycleType` – The type of bike (pedelec or manual)
15) `Membership` – The type of subscription membership
16) `dateofbirth` – The date of birth of the user
17) `PersonalIdCode` – First three digits of personal ID code

2.2. Technical approach

This chapter describes the tools and methods chosen to conduct the data analysis.

2.2.1. Java

The primary programming language used in this thesis is Java, mainly due to the author's familiarity with it and its suitability for the given context. Java, being a class-based, object-oriented programming language, can be helpful when dealing with a lot of objects comparing (in this case, bike trips). In the end, the choice of programming language may not have a significant impact. It is preferable to use a familiar tool that the author is comfortable with instead of investing time and effort in learning or mastering a new language, which may essentially achieve the same results.

2.2.2. XChart

The main data plotting (visualization) tool in this thesis is the XChart Charting Library for Java. It is a relatively simple tool for data visualization, providing many different features and chart types, which will help realize this investigation and provide proof for the conclusions (23).

2.2.3. FlowmapBlue

FlowmapBlue is a map software, that can be used to visualize traffic flows between two locations on a given map (24). This can include everything from buses, taxis, air travels, and in this case BBS usage. The map is also very interactive, even providing a timeline, if the uploaded data includes a time variable. This can be especially useful in this thesis.

The given software can be helpful for discovering interesting patterns of bike trips in the time period of interest. What makes this software even more useful is the fact, that the map of Tartu is already implemented, which means, that all that remains to be done, is collecting, and uploading the required data.

3. Research Questions and Data Analysis

This chapter focuses on the analysis of Tartu BSS data, mainly the 2020−2022 period of COVID-19. The research questions and hypothesises are based on the data. Also, some inspiration was taken from previous research done in other cities.

3.1. Remark

Since the Tartu BSS was launched in the middle of 2019, just six months before the virus, it is not feasible to use this period in the comparison as it lacks data before the crisis. Moreover, as a fairly new service, it attracted a lot of new short-term users, as Tartu BSS offered a 3-month free membership deal to users if they registered an account before the 8th of June and a 1-month free membership deal, when registering on the 9th - 30th of June (25). This had an enormous effect on bike usage (as seen in *Figure 1*) skyrocketing the initial number of trips to unusual heights. Taking this into account, data analysis for the most part will not be using the data from 2019.

3.2. Change in demand

The first topic, also the most obvious one, is the overall demand for the BSS from 2020-2022. Was there a significant rise in ridership during the two lockdown periods compared to the non-lockdown period in 2022? Was there a significant change in the number of users during the summer break?

Reading the reports from studies made in other cities for instance London and Washington D.C., it is reasonable to assume, that in the case of Tartu, it might be the same. People might have chosen the bike over a bus or a car to keep social distancing.

Figure 1. The number of trips over time with confirmed COVID-19 cases in Tartu County

As we can see from *Figure 1*Figure 1, there does not seem to be an overall change in the number of bike trips at the beginning of 2020. Notably, there is a relatively quick rise in the number of trips taken from April 2020 to May 2020 after the electric bikes were reinstalled. This rapid increase is also visible in the years, that follow, although the rise to the peak has not been that quick, and was divided into a three-to-four-month period, instead of the quick two months period seen in 2020. This can be COVID-19 related but could also be the reoccurring effect and can even be called the excitement period.

The blue graph line also shows an interesting pattern, that occurs in July or August every year. The demand slightly rises, and the next month begins to fall before the winter months, ending with the removal of electric bikes. This phenomenon is also recorded in 2020, but the descent has not been that rapid perhaps indicating, that after the lockdown, when schools were open, people were still keen on using bikes. But also, maybe because the excitement period, which started in 2019 with the launch of the BSS, was still ongoing.

Examining the amount of confirmed COVID-19 cases, it is hard to tell if it influenced the BBS demand overall. Using the most common linear correlation measuring tool, Pearson correlation coefficient (r), can provide an answer.

$$\mathbf{r} = \frac{\mathbf{n}(\sum \mathbf{xy}) - (\sum \mathbf{x})(\sum \mathbf{y})}{\sqrt{[\mathbf{n}\sum \mathbf{x}^2 - (\sum \mathbf{x})^2][\mathbf{n}\sum \mathbf{y}^2 - (\sum \mathbf{y})^2]}}$$

Equation 1. The Pearson Correlation Coefficient equation (26)

Using the equation in *Equation 1*, we can calculate the correlation between the virus cases and the number of trips taken. The first observed period is from the start of the pandemic in Estonia (the first confirmed case in March) to December 2020. The correlation in this period is -0.233. The second observation is done from January to December of 2021 to compare both lockdowns, which is -0.226. In the case of both periods of interest, the correlation stayed negative and weak. This indicates that the BSS stayed resilient under both lockdowns.

Another question that was worth looking into is the share of manual and pedelec bike usage. It is reasonable to hypothesise, that during the lockdown, especially the first lockdown, when the rules were stricter, manual bike usage would show an increase. This hypothesis is supported by the fact, that governments around the world were encouraging healthier and more active lifestyles, and since a lot of people could not go to work, school or the gym, the manual bike might have been an option for getting a workout done. As this assumption is based on the effect of both lockdowns, this thesis analyses the first six months of years 2020-2022.

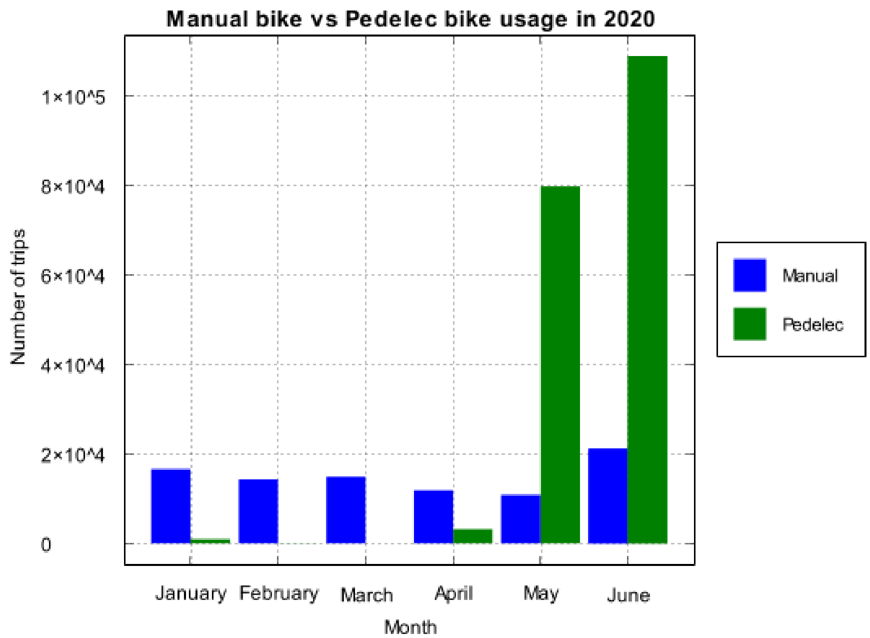

Figure 2. Manual bike vs. Pedelec bike usage in Jan-Jun 2020

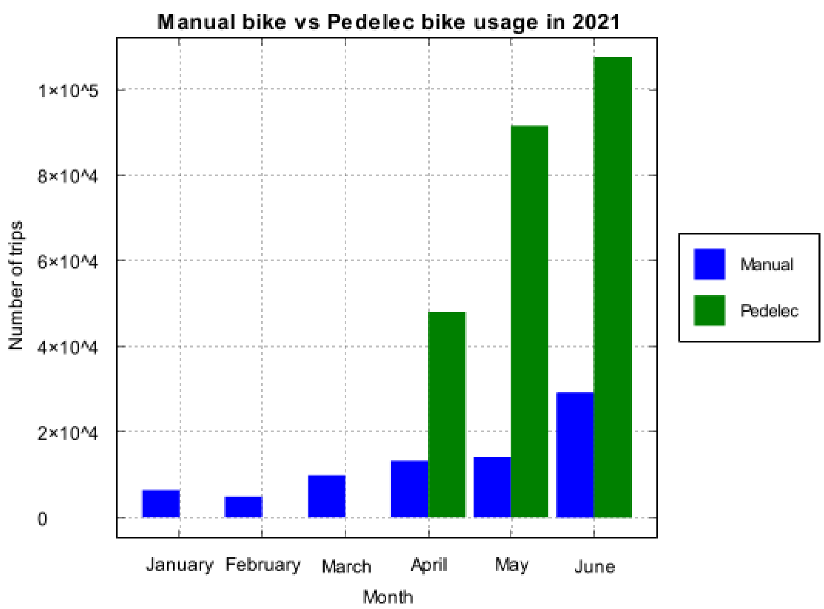

Figure 3. Manual bike vs. Pedelec bike usage in Jan-Jun 2021

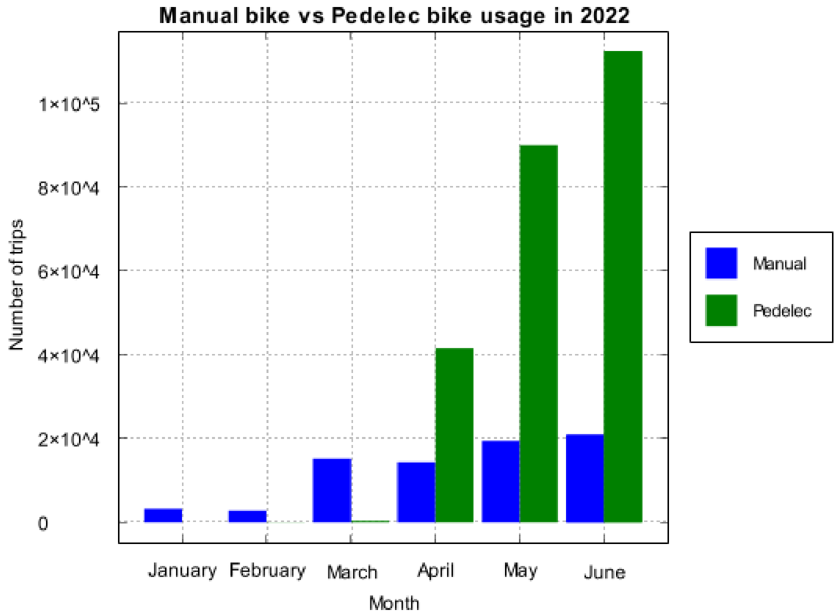

Figure 4. Manual bike vs. Pedelec bike usage in Jan-Jun 2022

The data from the observed time period (*Figure 2 - Figure 4*), clearly indicate, that there has not been a significant increase in manual bike usage. The manual bike ridership was consistently up for the whole six months in 2020, but again, it can be caused by the excitement period. The only time we see any rise in the percentage of trips made with manual bikes is in June of 2021.

3.3. Temporal changes

This chapter will study the temporal changes in Tartu BSS usage in the given period of 2020-2022. Temporal changes include daily usage patterns hourly, both on workdays and weekends.

The COVID-19 pandemic played a large part in the disruption of daily routines people previously had. Especially during lockdown periods, when people could not go to work or school. The hypothesis, therefore, is that as the lockdowns fell (in March 2020 and 2021) there was a significant decrease in the number of trips made during the common rush hours (especially in the morning rush hours). Once more, we cannot include 2019 in this investigation simply because by then the acceptable routine patterns had not been fully developed yet.

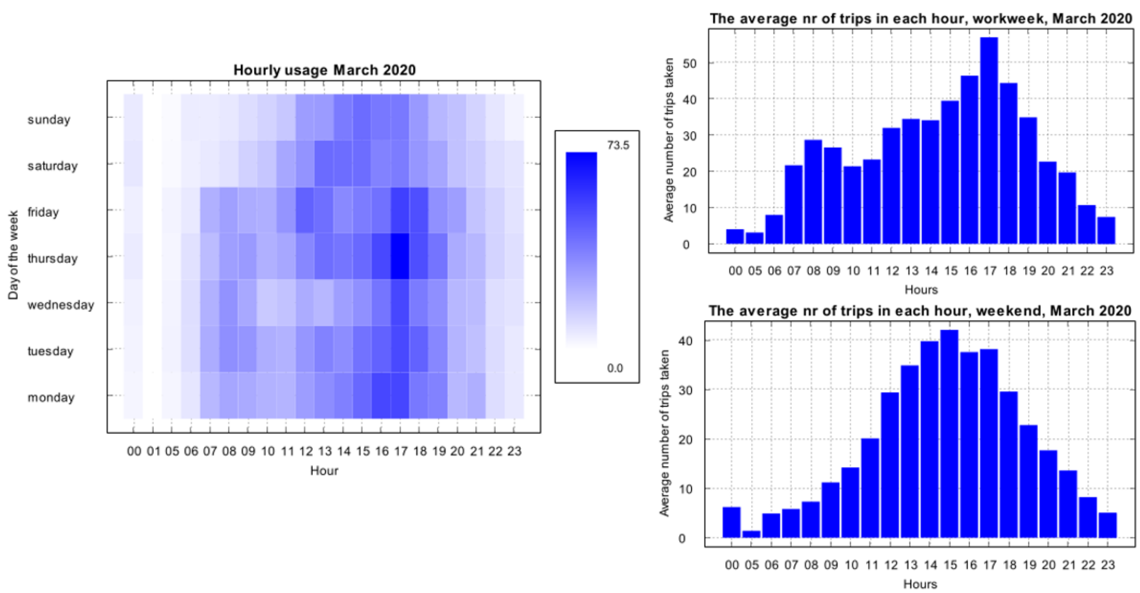

Figure 5. Average hourly usage March 2020

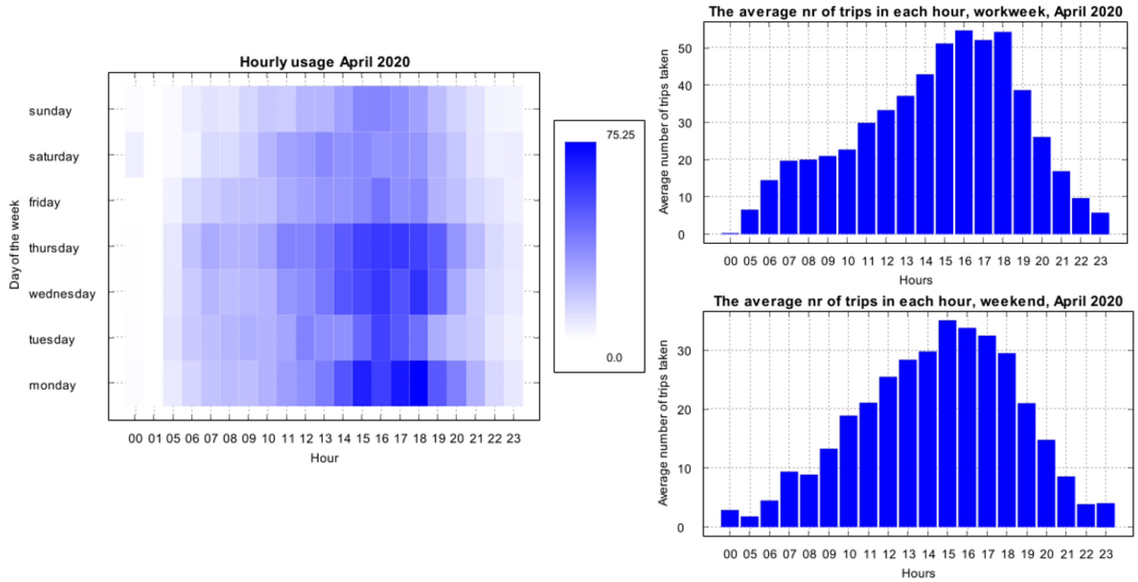

Figure 6. Average hourly usage April 2020

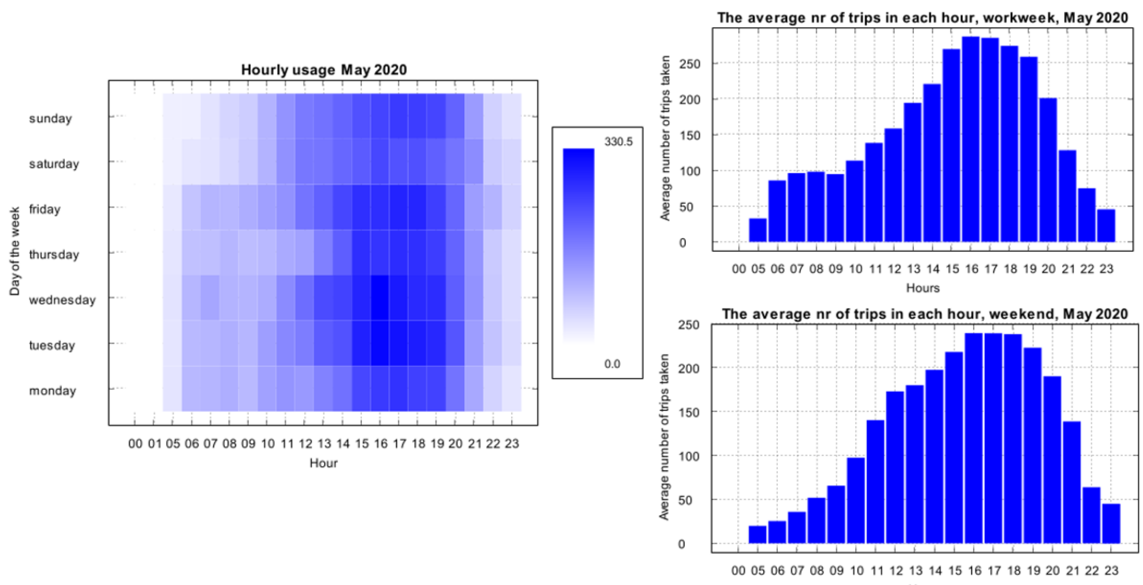

Figure 7. Average hourly usage May 2020

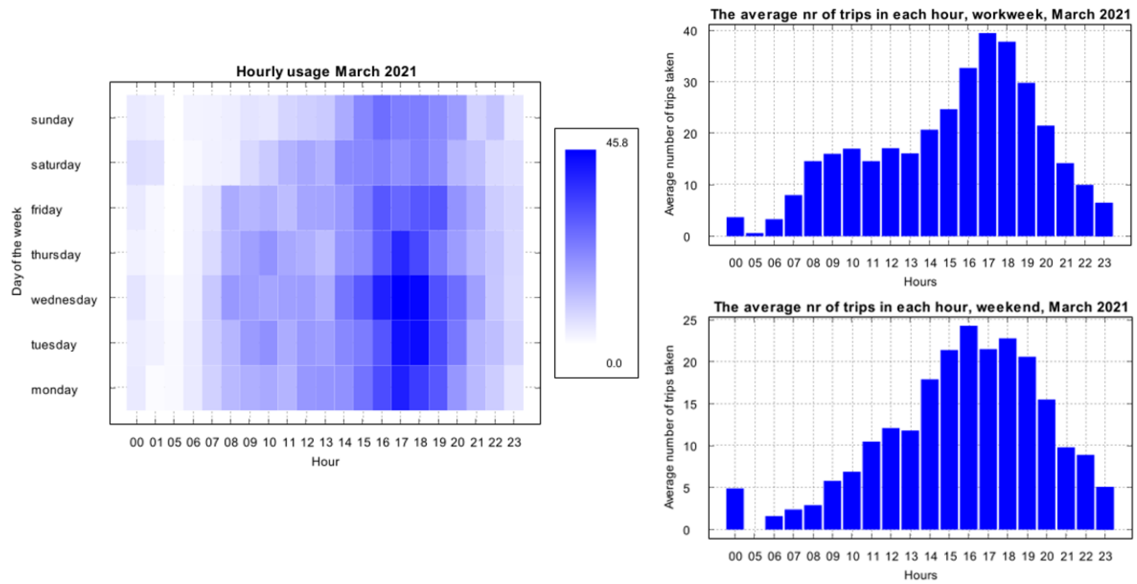

Figure 8. Average hourly usage March 2021

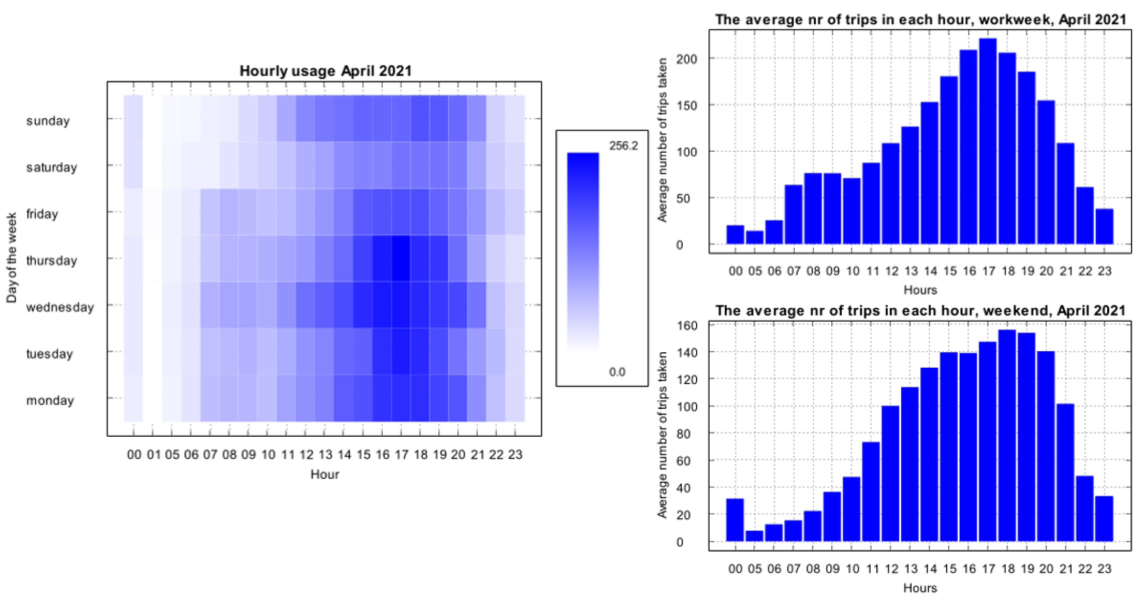

Figure 9. Average hourly usage April 2021

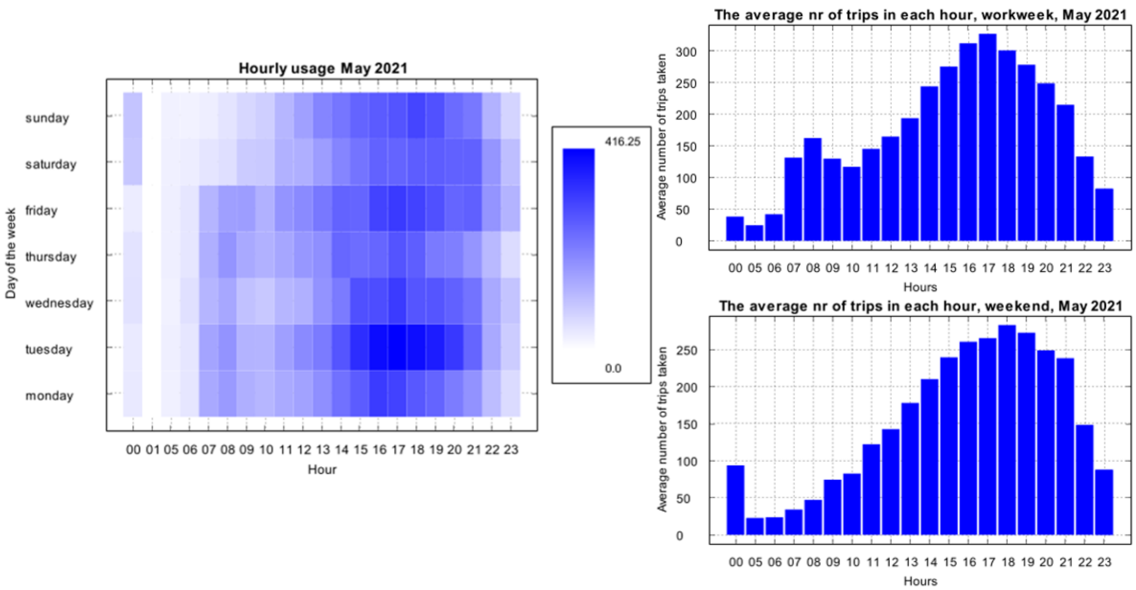

Figure 10. Average hourly usage May 2021

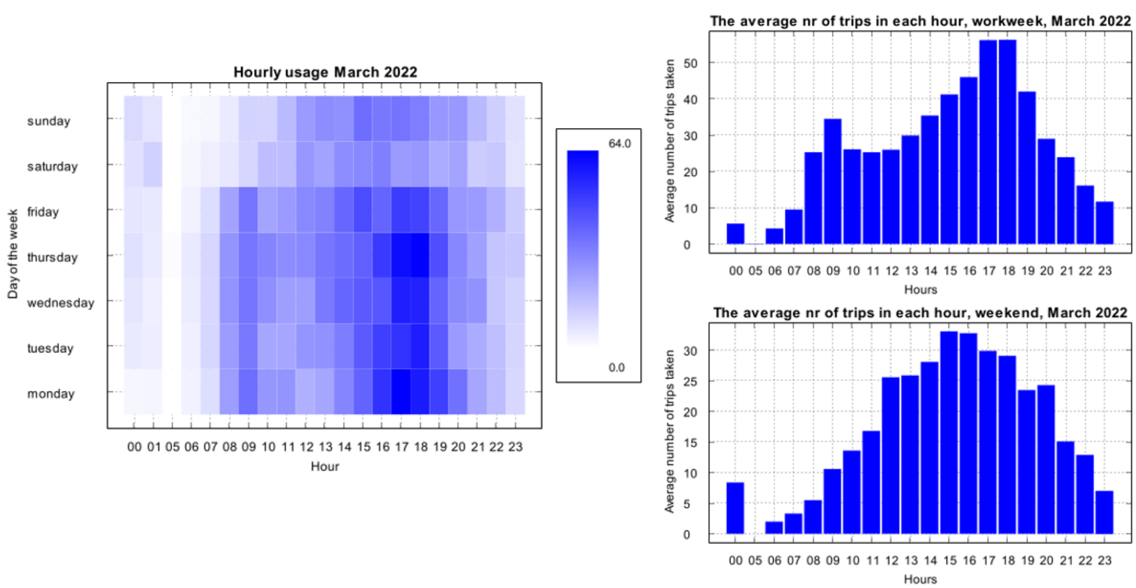

Figure 11. Average hourly usage March 2022

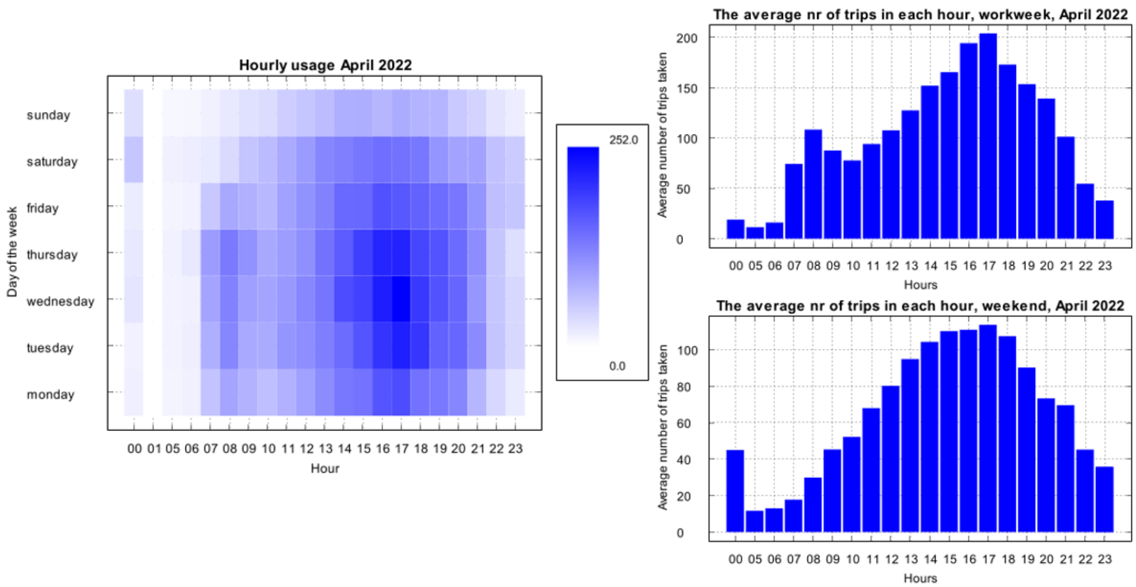

Figure 12. Average hourly usage April 2022

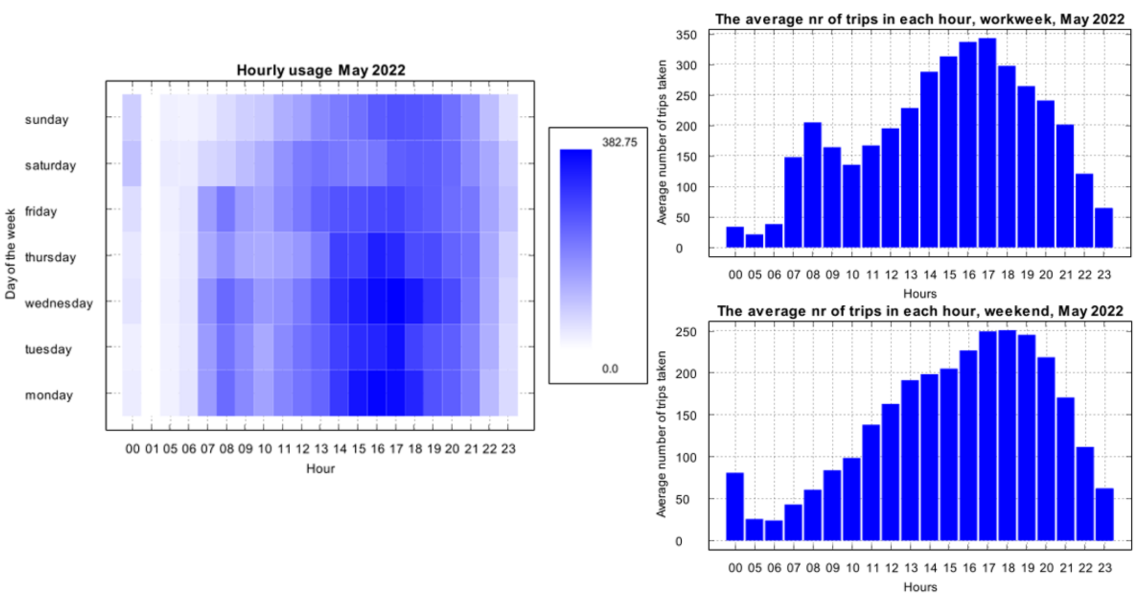

Figure 13. Average hourly usage May 2022

The first thing to note when analysing the visualizations from *Figure 5 - Figure 13* is the rush hours. Typically, they occur at 7 or 8 in the morning and 17 o'clock in the evening, as usually suspected, but they vary from day to day.

The best way to see the difference in the three inspected years is to look at the average number of trips in each hour chart. In April 2020, the spike, that usually appears in the mornings, indicating that people are going to school or work, is flattened out. Meaning that there was no longer a significant wave of people using the bikes at that time. A lot of users still had work and school activities but could mostly do them at home with no need to use the BSS. Later in the day, the rush hour peak is still visible and relatively in the same period as in the case of the two years, that follow.

Another aspect to compare is the late-hour rides on the weekend, till 1 o'clock in the morning. Both 2021 and 2022 saw this substantial spike in demand at that time, however, it is not reflected in the observed time period in 2020. This can be caused but the strict lockdown rules in 2020, which included the early closing of bars and clubs, as previously mentioned.

To get a better understanding of the numeric differences in the hourly usage between the three years, it is suitable to use Cosine Similarity (*Equation 2*). Cosine Similarity is a method for measuring the difference between two vectors. More specifically the difference in their directions. In this case, the vector is the list of average number of trips in each hour. The similarity between the two vectors is calculated by the angle between them (27).

$$similarity(A, B) = cos(\theta) = \frac{A \cdot B}{||A|| \, ||B||}$$

Equation 2. The Cosine Similarity equation (27)

	2020 vs 2021	2021 vs 2022	2020 vs 2022
January	0.978	0.964	0.968
February	0.962	0.954	0.957
March	0.954	0.979	0.969
April	0.959	0.972	0.957
May	0.977	0.980	0.979
June	0.976	0.992	0.976

Table 1. Cosine Similarity table

The Cosine Similarity can have a value between -1 and 1. If the two observed vectors have the same orientation, the value is 1, meaning that, the angle between them is 0 degrees. But if the value is -1, it means that the orientation between the two vectors is opposite, inversely 180 decrees (27).

Based on this calculation in *Table 1*, it is unclear whether there are any differences between the years. The problem with Cosine similarity is that it ignores the difference in magnitude between the two vectors (27). For further research it is reasonable to use the Euclidean distance equation (Equation 3. Euclidean distance between two vectors equation *Equation 3*) to measure the distance between the previous vectors, thus providing the idea of what was the difference in scale.

$$d(x,y) = \sqrt{(x1 - y1)^2 + (x2 - y2)^2 + \dots + (xn - yn)^2}$$

Equation 3. Euclidean distance between two vectors equation (28)

	2020 vs 2021	**2021 vs 2022**	**2020 vs 2022**
January	241.385	76.587	310.502
February	234.802	54.83	279.061
March	140.875	132.093	84.226
April	1096.327	347.658	966.378
May	555.614	475.559	576.029
June	654.994	384.484	637.94

Table 2. The Euclidean distance table

In general, the differences, seen in *Table 2*, in usage between the years are noticeable. Especially in the April – June periods. The biggest differences tend to be between 2020 and the rest of the years indicating that the hourly usage was significantly affected by the first lockdown. Comparing 2021 and 2022 shows, that the second lockdown did not alter the usage as much as the year before, though it was still noticeable, and herefore, providing support for the hypothesis made earlier.

3.4. Spatial changes

This chapter analyses the way the trips were made. More specifically the length, both in time and distance as well as the speed of the trips made.

Considering that most of the public places, such as schools and workplaces were closed, which eliminated the need to commute based on a busy schedule, it can be assumed that people were able to take their time while using the Tartu BSS. Meaning that the bike rides were longer both in distance and time, while also having slower average speed than in other years. This is used as a hypothesis.

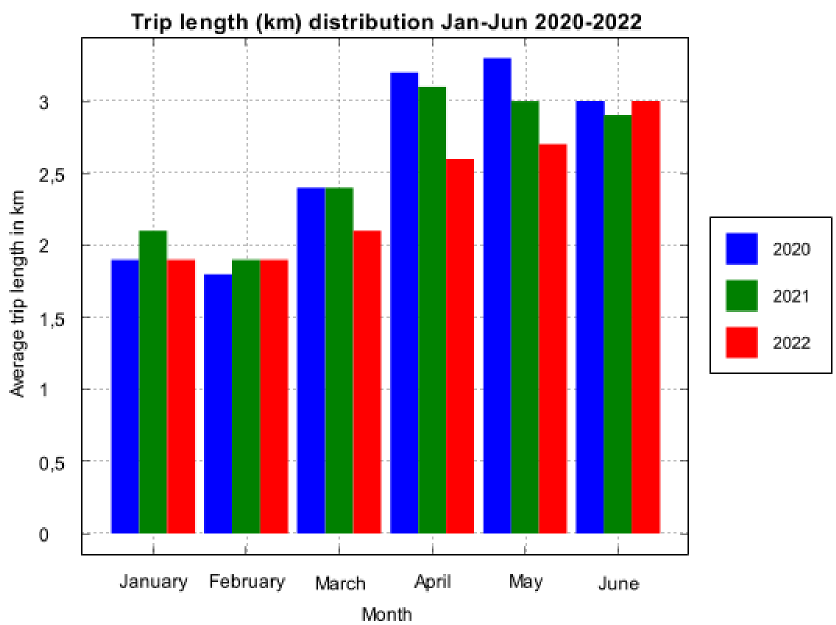

Figure 14. The average trip duration (in kilometres) distribution Jan-Jun 2020-2022

As seen in *Figure 14* the average trip length was longer compared to the other years during the lockdown period, which can support this hypothesis. Another notable fact is that between 2020 and 2021, there is a visible peak before the descent in the graph, in May and June. But in 2022 the length of the trips was steadily rising throughout the months. This can be an indication that after the lockdown restrictions were lifted in May and life started to return to normal, people preferred to socialise and walk, rather than ride a bike.

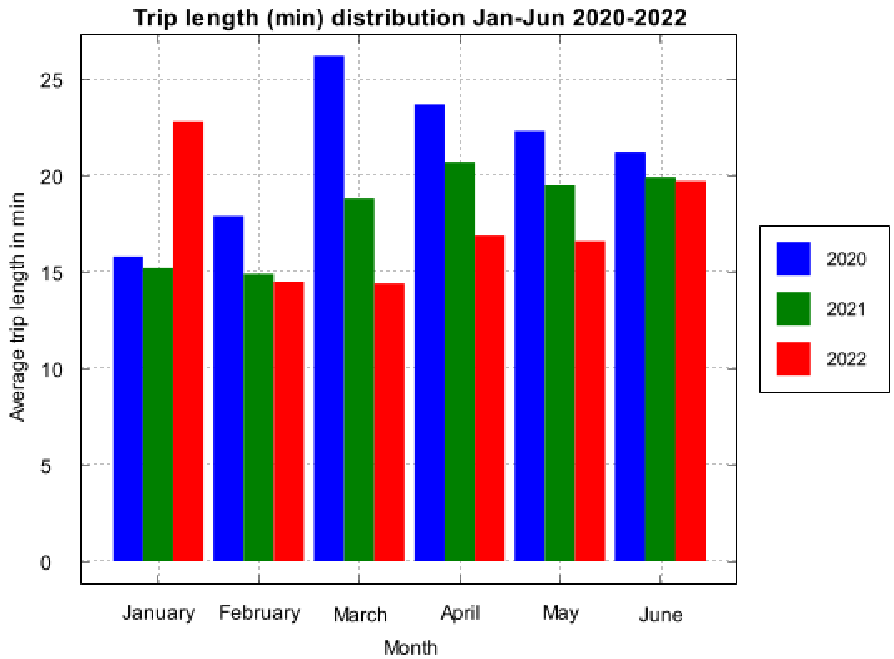

Figure 15. The average trip duration (in minutes) distribution Jan-Jun 2020-2022

In 2020, the average duration of the trips is also significantly longer (presented in *Figure 15)*, than the other years, which can further support the claim, that people, not being in a hurry, took more time riding the bikes. This theory can find more footing when looking at *Figure 19*, where the average speed of the trips was slower during the lockdown times, especially the first lockdown in 2020.

The only strange phenomenon, seen both in *Figure 15* and *Figure 19*, is the abnormally long duration and the noticeably slower speed of the average trip in January of 2022. One possible explanation for this could be found in the weather at that time.

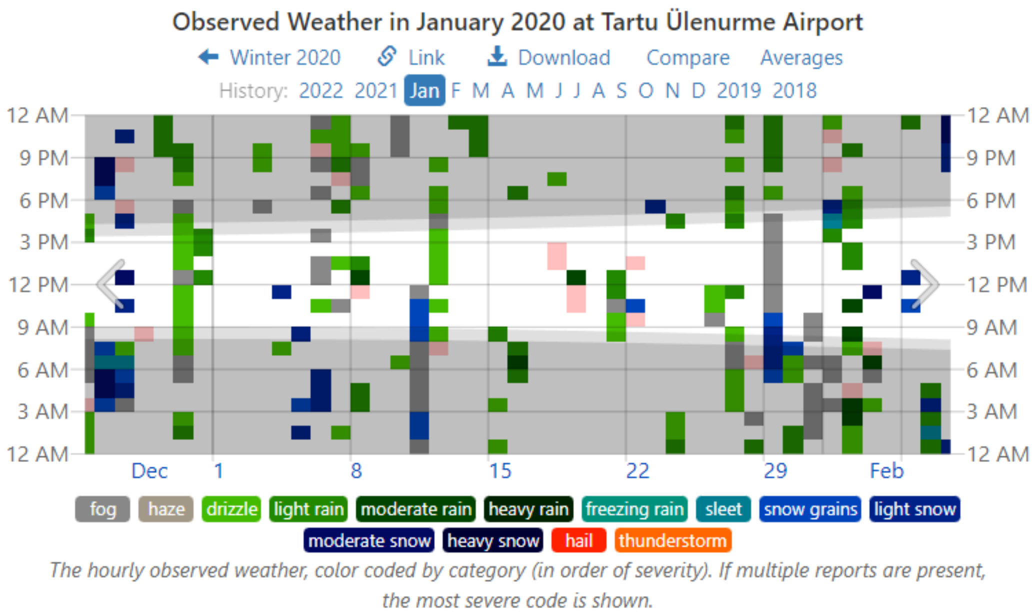

Figure 16. Observed weather in January 2020 at Tartu Ülenurme Airport (29).

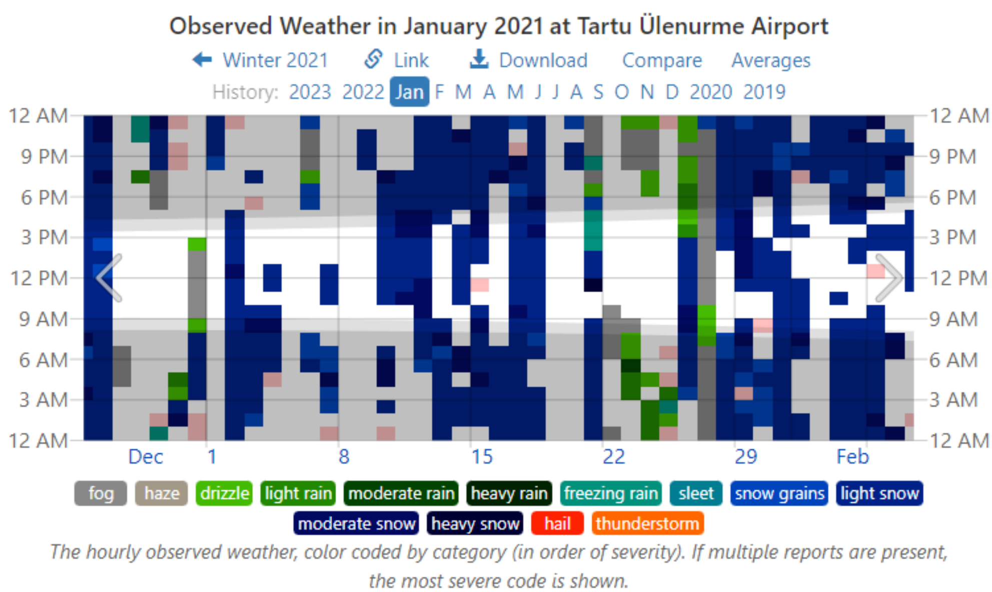

Figure 17. Observed Weather in January 2021 at Tartu Ülenurme Airport (30).

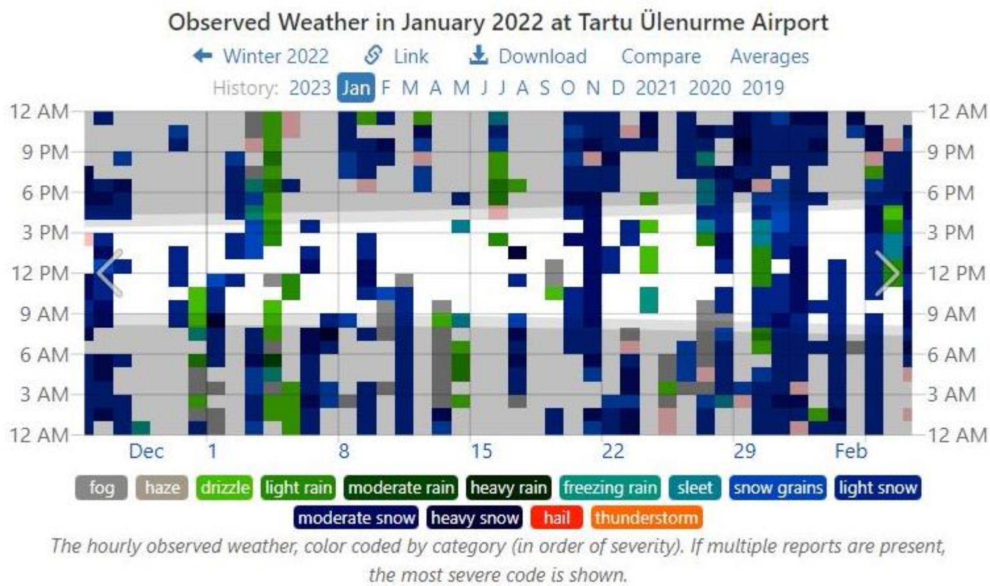

Figure 18. Observed Weather in January 2022 at Tartu Ülenurme Airport (31).

As seen in the weather reports (*Figure 16* - *Figure 18*), there was less precipitation in 2020, which is why it is impossible to conclude anything when comparing it to 2022. However, comparing the years that follow, it is still unclear, whether the snowfall or precipitation overall affected the trip duration and speed. On one hand, there was more snow in 2021, but, the precipitation was more frequent and diverse in the following year of 2022, which might have affected these trip factors, such as trip duration and speed, as people could not adapt to the everchanging weather. This is also evident for the daylight period. Therefore, it is difficult to claim that the weather was responsible for the observed results. It is also worth noting, that the overall usage in 2022 Jan – Feb (*Figure 1*) was record low. Meaning that there was less data, which can affect the outcome (small data problem (32)).

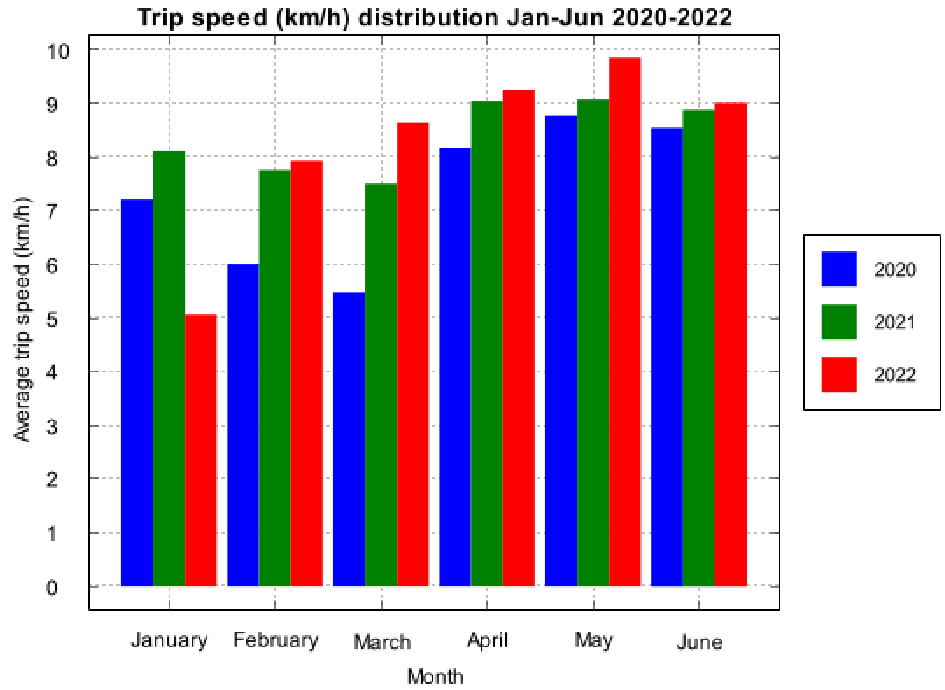

Figure 19. The average trip speed (in km/h) distribution Jan-Jun 2020-2022

From *Figure 19* it is clear, that the overall speed was lower during the lockdown periods. As the need for lockdown regulations began to fade over the years and life went back to normal, the average speed also rose. The interesting finding here is the relatively high trip speeds in January – March 2021 and from February 2022. In these periods, as seen in *Figure 1*, there were only manual bikes operating, which means, that the electric assist motors, although effective, may not influence the overall speed of the trips that much.

Based on these findings, a hypothesis, that people took more time for riding the bikes during the lockdown can be ruled plausible. The average length in kilometres and duration in minutes was longer and the average speed was lower, indicating just that.

Another hypothesis is that people were using the bikes more for making round trips (trips, that had the same start and finish stations). This supports the idea that during lockdowns bikes were used not only as a method of transportation for getting from point A to point B but also as a leisure time activity.

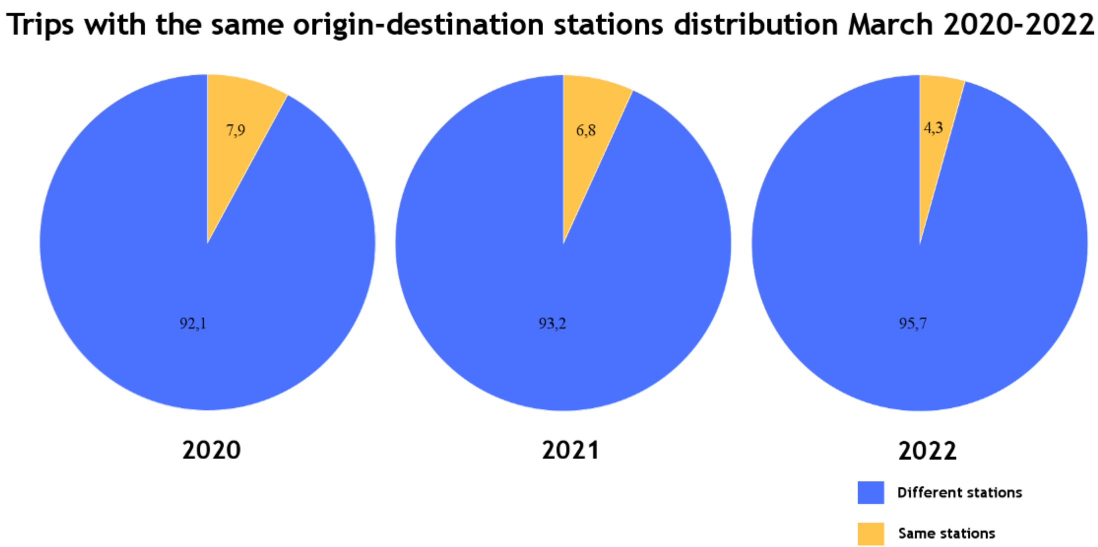

Figure 20. Trip with the same origin and destination station March 2020 vs 2021 vs 2022

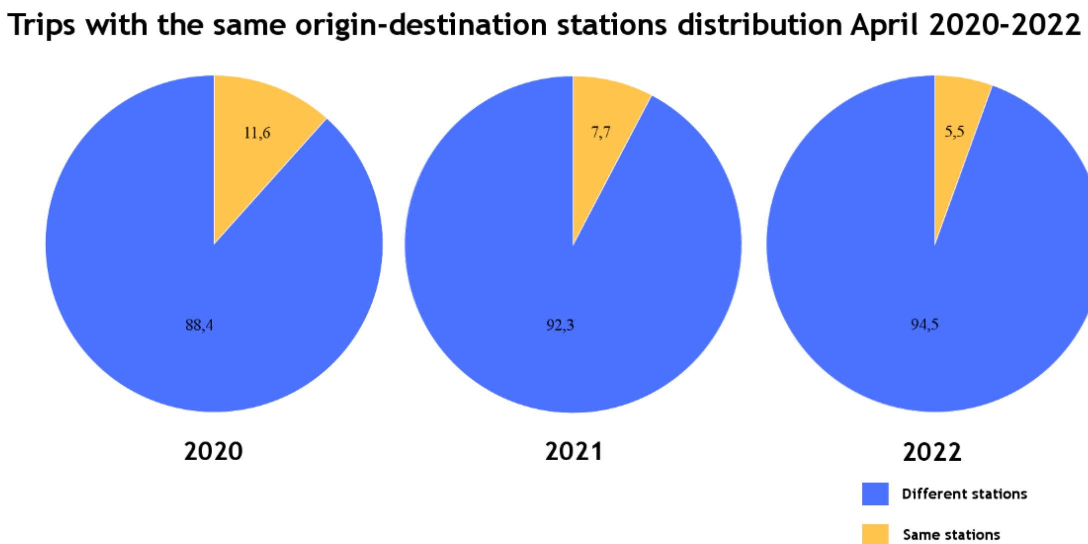

Figure 21. Trip with the same origin and destination station April 2020 vs 2021 vs 2022

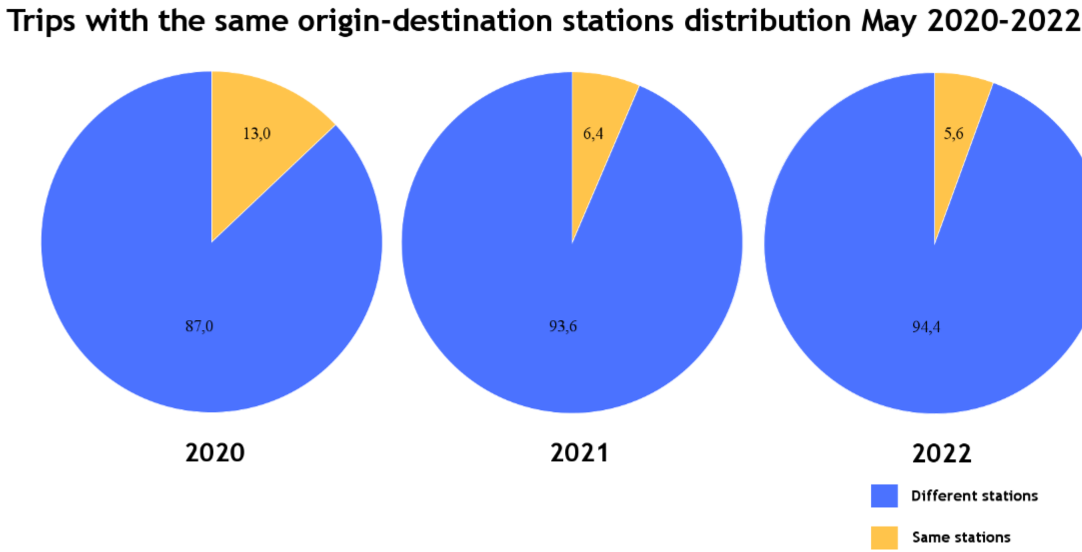

Figure 22. Trip with the same origin and destination station May 2020 vs 2021 vs 2022

When looking at *Figure 20 - Figure 22*, it is clear, that the COVID-19 lockdown period (especially in 2020) saw a larger percentage of round trips. This can be a basis for claiming, that during the lockdown periods the bike, for some people, had a different purpose, compared to non-lockdown times.

However, this tells only half of the story. To get a better understanding of where these bikes were taken and whether there were different areas of popularity based on the year, FlowmapBlue was used.

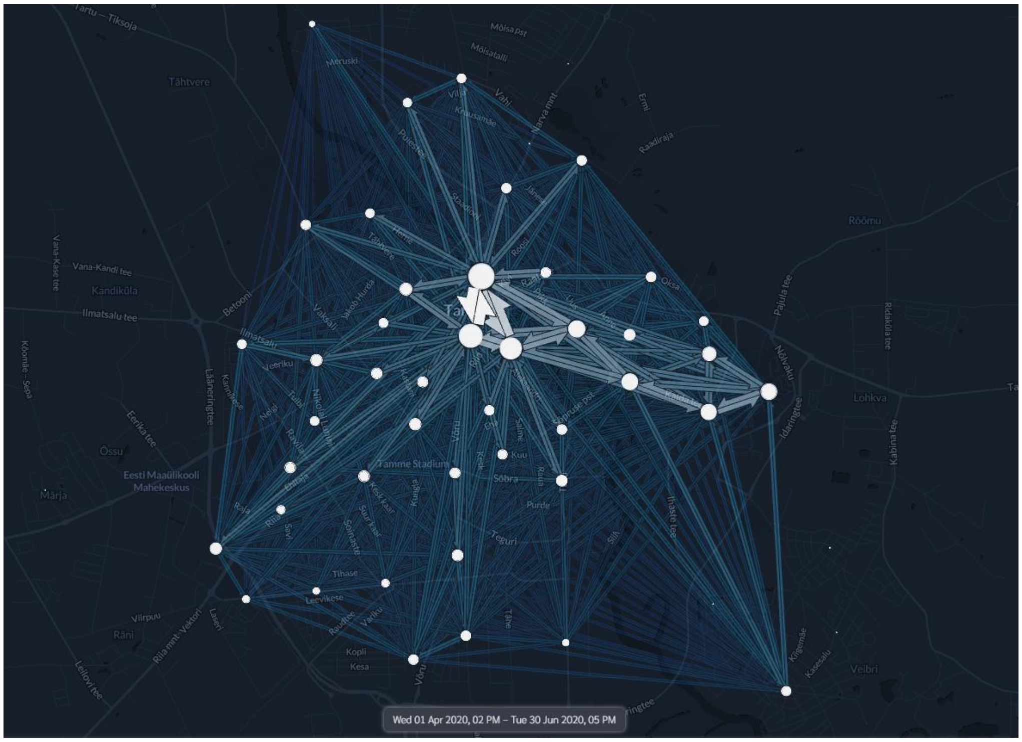

Figure 23. The trip distribution in April – June 2020, [*Map Link.*]()

Figure 24. The trip distribution in April – June 2021, [*Map Link.*]()

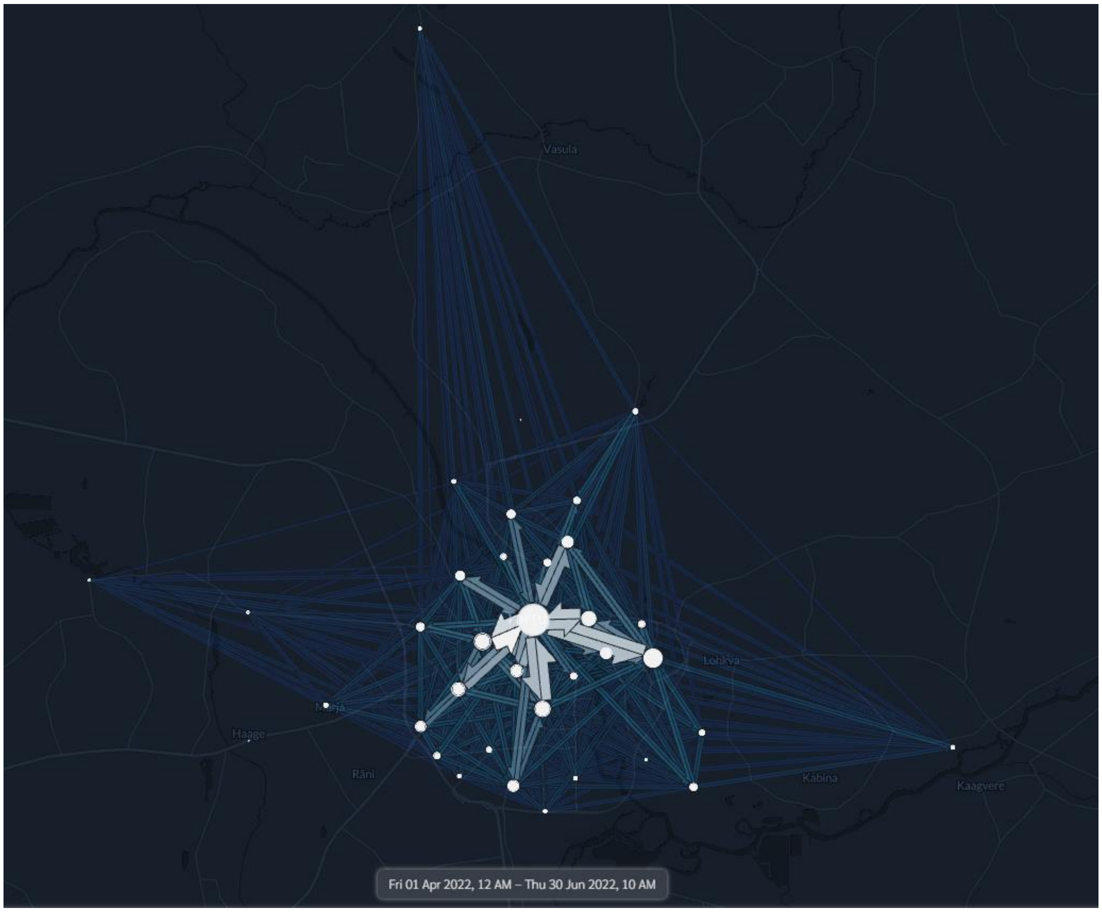

Figure 25. The trip distribution in April – June 2022, Map Link.

These visualizations *Figure 23* - *Figure 25* give a good understanding of the trajectories taken in the same periods over the three years. Both in 2021 and 2022 the main routes have developed. However, in 2020, the map is a lot more diverse. There are more highlighted stations, meaning that the bike usage was more spread out and not concentrated in the most popular docking stations. In addition, the main routes, seen in the following two years, are mostly not present in 2020.

To sum it all up, bike usage was very different in the first half of 2020 compared to 2021 and 2022. Users took more round trips and rode to places, where they normally would not go. The trip length, both in kilometres and minutes was longer in 2020 and also the overall speed of the trips was lower.

3.5. Demographic changes

Another interesting question is how the demographic of bike users is affected during lockdowns. The hypothesis is that, during the lockdown periods, the average age grew, as younger users, who typically used the bikes to go to school or workout classes, had to stay home. The other basis for this hypothesis was that the older users, who typically used a car to go grocery shopping, preferred the bike, which offered better social distancing and, maybe more importantly, was good for their health.

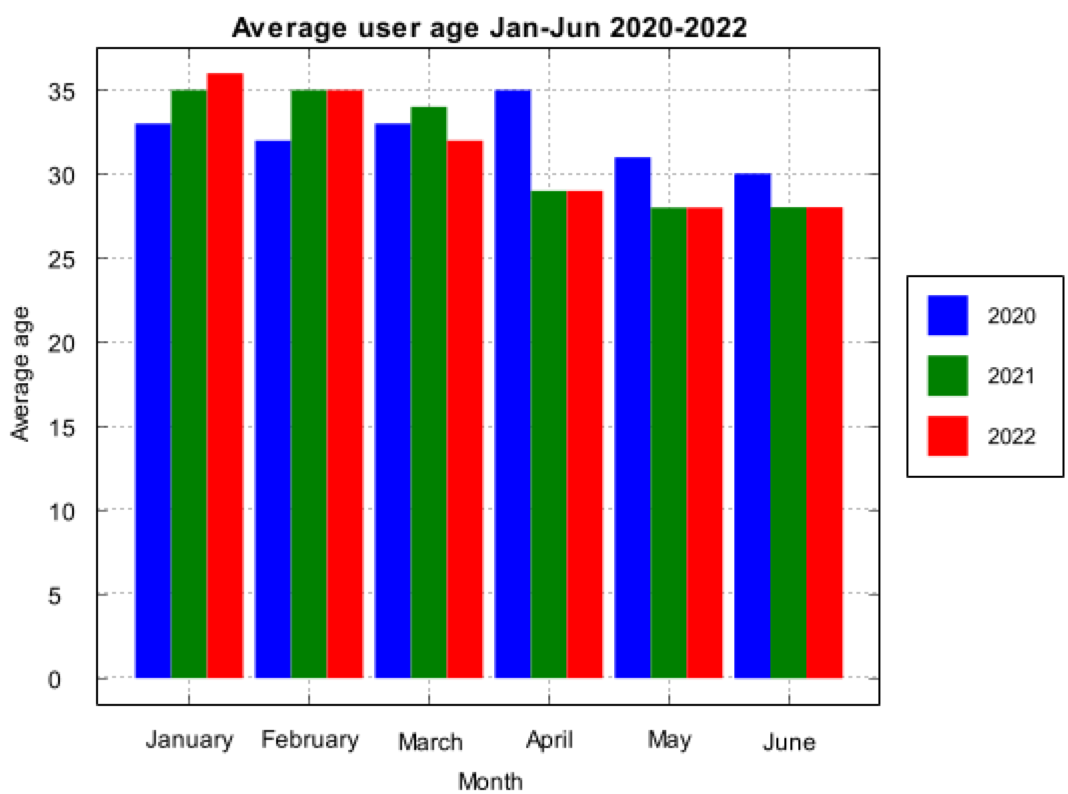

Figure 26. The average user age Jan-Jun 2020-2023

The findings from *Figure 26* point to the fact, that the average age was higher in the first COVID-19 lockdown period, from April, proving the hypothesis halfway. The remarkable thing, also worth noting, is that the 'pedelec season' usually starting in April (seen in *Figure 1*), brings a lot of users back to the service and drops the average age significantly down, as seen from 2021 and 2022 in *Figure 26*. This drop is featured in the 2020 data, but not in the scale compared to the following years.

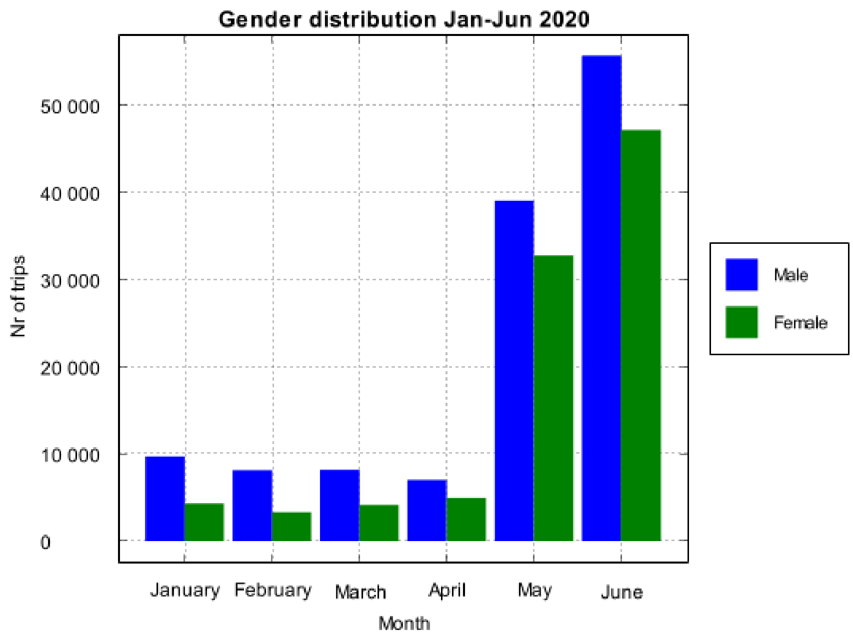

Figure 27. Gender distribution Jan-Jun 2020

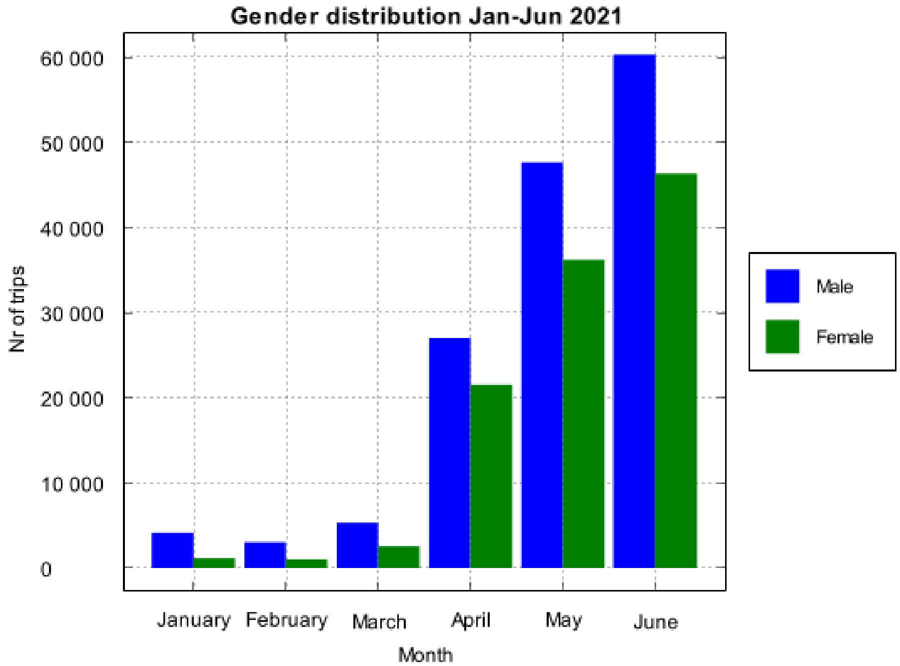

Figure 28. Gender distribution Jan-Jun 2021

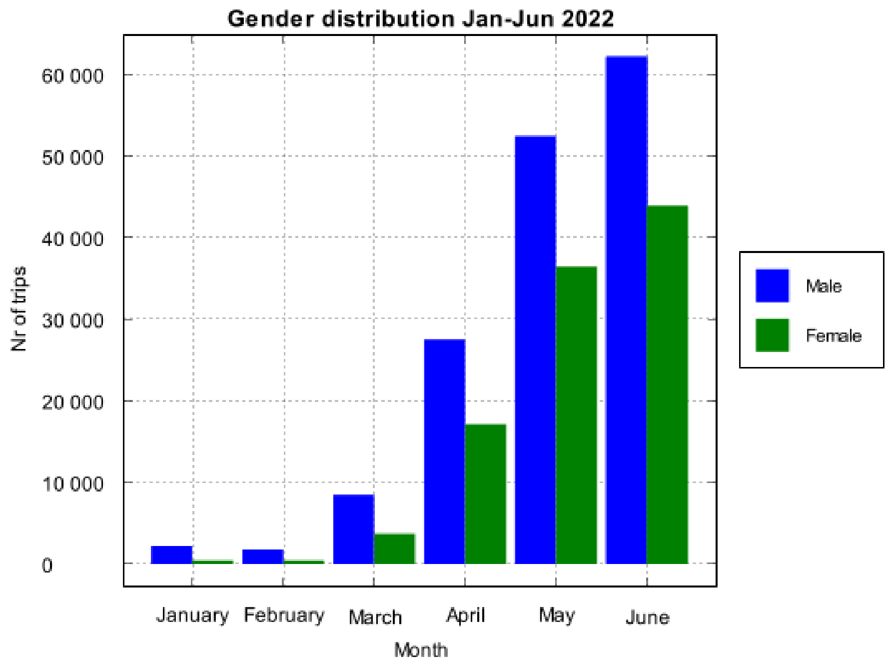

Figure 29. Gender distribution Jan-Jun 2022

Based on *Figure 27 - Figure 29*, the percentage of female users has fallen from about 45% in May and 42% in June of 2020 to 41% in May and 40% in June of 2022. A reason behind the drop in diversity might be that women, who are statistically more reliant on public transport, like city buses, might have switched from buses to bikes during the first lockdown period. This theory is also supported in a study, made in Lisbon, Portugal, which, in addition, suggested that women used the city's BSS as a tool for exercising during COVID-19 (33). This, regarding the fact, that gyms in Tartu were closed during the first lockdown in 2020, can be a basis for supporting the same idea in this case.

It is evident that the BSS demographic diversity of the ridership during the first COVID-19 lockdown was higher, both regarding age and gender.

4. Future work

The previous data analysis is just a glimpse into the world of BSS data. As previously mentioned, what makes these services so beneficial in the modern world, is the system itself on which the bikes collect data. This data can be used not only to improve and expand the overall service and its capabilities but also the quality of infrastructure in cities.

This data can be collected, analysed, and then used as a basis for proposing new innovative ideas for building and connecting more roads for dispersing ever-growing traffic jams, the problem most urban areas have. Before BSSs, this was not possible. In the case of Tartu, before BSS, public transport was limited just to city buses (Appendix II). It is possible that in the future the bus data is more precise and could be used to analyse it similarly to the given thesis.

Nowadays, as GPSs (Global Positioning System) have become more capable and precise, it is possible, even with the Tartu BSS, to track the exact movement of every bike during every trip allowing data scientists to make more sense of the trips and their nature. As the Tartu BSS is about to turn 5 in the summer of 2024, which means that regular usage patterns have started to form. This means that the data from now on is more predictable, and therefore, allows analysts to find irregularities and look for a way to solve them.

A possible way to use this data is to study the long-term impact of the pandemic on travel mode choices of citizens as well as changes is their commuting habits. To conduct such a thorough analysis, it should involve more than a single public transportation mode. For example, it can include shared scooters, shared vehicles and other public transportation modes, that gather usable data. These studies can assist city planners optimize the quality of life of citizens by helping to build better transportation infrastructure. Such stuides can also be used to make public transportation more available based on the emerging needs of citizens and their sustainability goals.

Conclusions

The purpose of this thesis was to analyse the data from Tartu BSS primarily during the 2020-2022 period. The research findings revealed a noticeable shift in the nature of bike trips, characterized by a longer duration in terms of time and distance, and a slower pace of distance coverage, particularly during the initial lockdown period in 2020, when the government enforced stricter regulations. Moreover, the lockdown resulted in a significant reduction in trips during the traditional rush hours, especially in the mornings, in both 2020 and 2021. The analysis also includes the study of the main routes, that were taken during the observed time period. What was found, was that during the first lockdown period, more trips were made to comparatively unpopular stations and at the same time the percentage of round trips was noticeably larger. Indicating that people used these bikes more for leisure and perhaps for exercise. The diversity of the users during lockdown periods was also observed. This was especially the case during the first lockdown, where the average user age was 35, compared to 28 in the following two observed years. The percentage of female users was also higher in the first lockdown period. Perhaps indicating that women, who usually preferred commuting by bus, converted to using bikes as an alternative for social distancing.

Conclusively the COVID-19 pandemic had a significant impact on the BSS usage patterns in Tartu during the observed period. The overall number of trips remained relatively the same, the pandemic resulted in noticeable changes in the duration, both in time and distance and the purpose of the trips. The findings indicate that the BSS played a notable role in providing the city’s residents with a safe and accessible mode of transportation during the crisis, helping maintain the social distancing rules. In addition, this thesis sheds light on the potential of the data that the BSSs around the world provide, which can be used for developing more effective and sustainable transportation systems. The research paper (Appendix III) submitted to SuMub can be considered to be the beginning of such a process.

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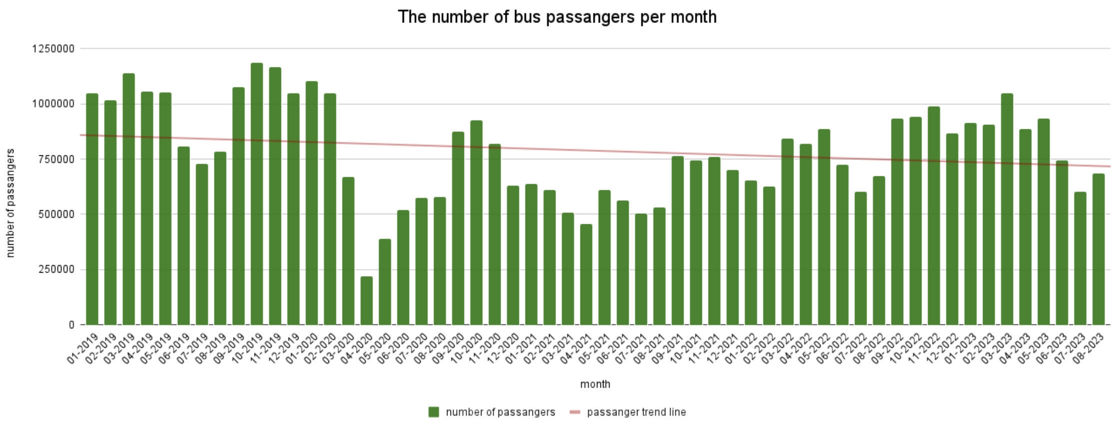
09/11/2023

II. The number of bus users by month



III. The paper accepted to SuMob

COVID-19, From Lockdown to Recovery: Exploring the Dynamics of Bike-Sharing and Public Transport in Tartu, Estonia

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ABSTRACT

The COVID-19 pandemic triggered a seismic shift in global commuting and travel habits, ushering in significant changes in transportation demand. These alterations in travel behavior have proven to be more than transient reactions to the immediate crisis, persisting beyond the pandemic's aftermath. Despite extensive research into contemporary travel pattern changes during and after the pandemic, our understanding of the short-term and long-term repercussions of COVID-19 on travel behavior remains limited.

This research investigates the enduring effects of pandemicinduced lockdowns on bike-sharing and public transport utilization in Tartu, Estonia, a city renowned for its northern climate, evolving cycling infrastructure, low traffic, compact urban layout, high car ownership rates, and walkability. Our empirical analysis reveals the bike-sharing system's rapid and adaptive response to changing circumstances, highlighting the system's ability to navigate crises effectively, contrasting sharply with the protracted recovery observed in public transport demand.

CCS CONCEPTS

• Applied computing → *Transportation*.

KEYWORDS

Bike-sharing systems, Public transport, COVID-19, Modal share, Travel behaviour

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1 INTRODUCTION

The COVID-19 pandemic has ushered in a sweeping transformation in various facets of our daily lives, compelling us to reevaluate routines, habits, and priorities. Among the areas most profoundly

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affected is the realm of transportation. Stringent regulations, heightened safety concerns, and evolving individual preferences have collectively prompted a thorough reassessment of travel behaviors on a global scale. This transformation has ignited widespread interest and scrutiny, offering profound insights into the future of urban mobility.

Various studies in the literature have explored the impacts of the COVID-19 pandemic on transportation and travel behaviors. Teixeira et al. highlight the resilience of BSSs compared to public transport and recommend expanding BSSs, improving cleaning, subsidizing trips for essential workers, and addressing equity [10].

Chen et al. emphasize the shift towards autonomous travel due to health concerns and the increased use of shared bicycle schemes as a sustainable and socially distanced alternative [2]. Kim et al. examine the impact in Seoul, reporting a decrease in public transit use and increased bike-sharing for longer trips, emphasizing the importance of bike-friendly infrastructure [6]. Teixeira et al. focus on Citi Bike's resilience compared to the subway during disruptions, advocating for bike-sharing promotion and cycling as sustainable alternatives [9]. Bi et al. study spatial-temporal changes in bike-sharing usage patterns and recommend enhanced cleaning, contingency plans, and cycling infrastructure to ease the strain on urban transport networks during outbreaks [1].

These studies indicate a significant shift in transportation behavior during the pandemic, with individuals reducing reliance on public transport, embracing telecommuting, and exploring alternative travel modes. These changes have become lasting habits, underscoring the need for informed decision-making in transportation infrastructure, urban planning, and sustainability. Ongoing research remains crucial, as the full extent of the pandemic's longterm transportation impacts continues to evolve [14].

Tartu, Estonia, like many cities, offers diverse transportation options, including the "Smart Bike" bike-sharing network. During the 2020 lockdowns and social distancing measures, Smart Bike became crucial for urban mobility, promoting outdoor enjoyment, fitness, and social distancing adherence. However, the extent of its pandemic influence remains uncertain due to limited research. Meanwhile, Tartu's public transportation system, mainly buses, faced challenges similar to global trends, with ridership dropping and recovery prospects in question.

This study examines COVID-19's effects on Tartu's Smart Bike system and public buses, analyzing transportation patterns during and after lockdowns. It emphasizes the adaptability of bike-sharing for emergency responses but also raises concerns about the slow recovery of public transport and the growing use of private vehicles, which could undermine sustainability efforts.

2 CASE STUDY AND DATA ACQUISITION

2.1 An Overview of Tartu City

Tartu is Estonia's second-largest city, with a population of approximately 100,000 inhabitants and an area of 38.8 square kilometers.

The modal share of the city of Tartu is calculated daily based on the data stream received from an Internet of Things (IoT) devices [1][4, 5, 7]. The share of cycling in daily commuting ranges between 10% and 5%, exhibiting season-dependent variations. Notably, city bikes contribute to approximately 20% to 30% of the overall bicycle traffic, although this proportion undergoes significant fluctuations across different seasons and weekdays [11].

Tartu, situated in a region with proximity to the northern latitudes, experiences a temperate continental climate that significantly influences cycling patterns within the city. These challenging winter weather conditions often deter cycling, leading to a reduction in bike usage.

In addition to the climatic challenges, Tartu's cycling landscape encounters another significant obstacle – the limited availability of designated bike lanes. Currently, a mere 30% of the total length of the city's roads are equipped with dedicated cycling lanes [11], with poor connectivity, impeding the seamless and safe integration of cycling into the urban transportation fabric.

Tartu boasts a dense and walkable urban landscape, a testament to its pedestrian-friendly design. Nevertheless, there has been a noticeable upward trajectory in car ownership and usage in recent years, ushering in newfound challenges related to traffic congestion and urban mobility management [8].

2.2 Tartu Smart Bike

Tartu Smart Bike Share, launched in June 2019, is a self-service BSS for short trips. It started with 750 bikes at 69 stations and has now grown to 100 stations. Most of the fleet has electric-assist motors, but they are temporarily removed in winter for safety. Initially, subscribers enjoyed three free months of membership in June, July, and August 2019, leading to increased user demand.

The salient facet contributing to the utility of contemporary BSSs resides in their comprehensive data collection mechanisms. After each trip, these systems record various information. In Tartu, this data includes bike details, user information, start and end station details, trip duration and length, bike type, and subscription membership. To protect user privacy, only the first three digits of the personal ID code are shared, indicating the subscriber's gender and birth year.

2.3 Public Transport in Tartu

Buses exclusively comprise the public transportation system within the municipality of Tartu. The city boasts a network of 15 distinct bus routes. In September 2015, Tartu introduced an Automated Fare Collection (AFC) system across its bus network, enabling passengers to use contactless chip-based ticketing. The AFC system

in Tartu records the bus stop ID, bus line, and the time stamp of ticket validation for each bus passenger.

2.4 COVID-19 in Estonia

In Estonia, the first COVID-19 case was confirmed on February 26, 2020, leading to a state of emergency declared on March 12. This initial lockdown aimed to curb the virus's spread, resulting in significant restrictions, including hospital and nursing home visitation prohibitions, the shift to distance learning in educational institutions starting March 16, and the closure of entertainment centers and event cancellations.

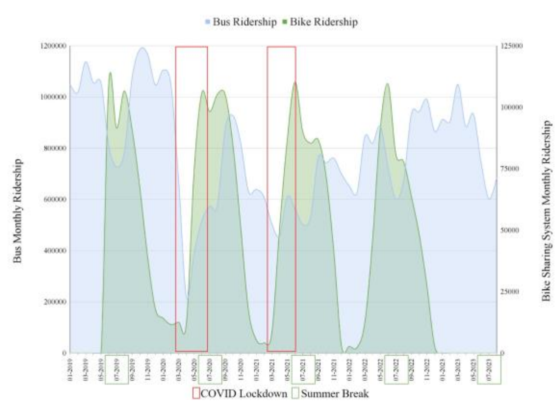
The first lockdown, originally set to conclude on May 1, extended until May 17, with gradual easing starting on May 2. During this phase, outdoor events were allowed with social distancing measures, and internal movement restrictions ended on May 8.

In March 2021, Estonia faced a resurgence in COVID-19 cases, ranking highest globally in cases per million people. Consequently, the government reintroduced certain lockdown measures for a second period, including a return to distance learning in educational institutions and strong recommendations for remote work where possible.

3 RESULTS

This section explores the various aspects of changes in BSS and public transport demand during and after the lockdowns.

3.1 Temporal Changes in BSS Demand



[1] https://its.cs.ut.ee/modsplit/

Figure 1: Monthly number of BSS and bus ridership in Tartu.

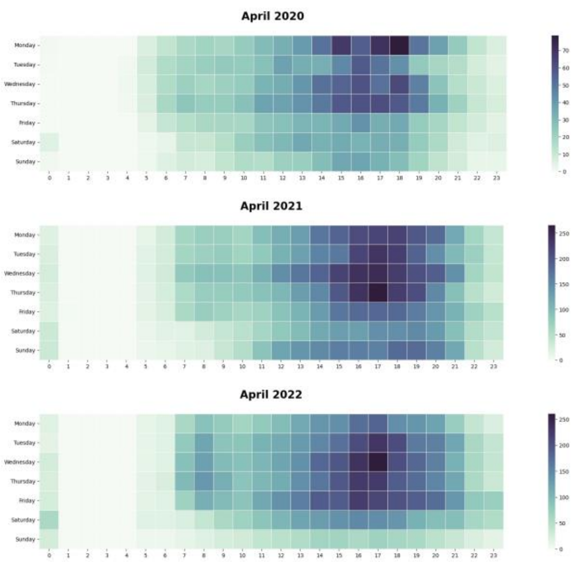
Fig. 1 provides a longitudinal illustration of the fluctuations in the volume of BSS trips and public transport ridership. As elucidated in Subsection 2.2, the inception of Tartu's BSS occurred in June 2019, resulting in an initial surge in trip numbers during the inaugural three months. This surge can be attributed to the heightened enthusiasm for testing the system out and the complimentary threemonth membership provided to all subscribers. Furthermore, it is discernible that demand experiences periodic declines coinciding with school summer breaks, and notably, the temporary withdrawal of electric bikes during the winter months leaves a noticeable mark on the trend.

The Pearson correlation coefficients computed for the relationship between the counts of confirmed COVID-19 cases and

and 2021, when restrictions were more stringent, the demand appeared more evenly distributed throughout the day, with relatively quieter weekend nights. In sharp contrast, April 2022 reveals a distinct surge in demand during peak hours and on weekdays, during postpandemic time.

3.2 Spatial Changes in BSS Demand

A thorough examination of the BSS data reveals a significant disparity in trip length and speed, corroborating earlier research findings. Specifically, during April and May 2020, the average trip length increased by over 30%, while the average trip speed concurrently declined by 18% when compared to a similar timeframe in 2022. This variance may be attributed to a shift in trip purposes, transitioning from home-work commuting to leisurely



the Figure 2: Hourly usage patterns of BSS in Tartu.

volumes of BSS trips in both 2020 and 2021 stand at -0.233 and -0.226, respectively. These values collectively signify a relatively weak negative linear correlation between these two variables. In simpler terms, the demand for BSS exhibits a limited adverse response to the virus's prevalence. This observation underscores the resilience of the system, which managed to withstand the challenges posed by the ongoing pandemic crisis.

Nevertheless, the temporal trip patterns of BSS exhibited notable variations throughout the COVID-related restrictions. To illustrate these fluctuations, Fig. 2 provides the hourly heatmaps of bike trip distributions on different hours of weekdays throughout the month of April for the years 2020, 2021, and 2022. In April 2020

This trend is particularly pronounced in April and May 2022, accounting for 11.6% and 13% of the total trip count, coinciding with the period of stricter lockdown measures. In contrast, during analogous months in 2020 and 2021, trips with similar ODs constituted a smaller share, representing 5.5% and 5.6% of total trips, signifying a greater prevalence of excursions in these periods.

Another noteworthy transformation involves the spatial distribution of trip flows. Post-pandemic analysis of OD trip distribution reveals a heightened concentration of trips in the central area of the city, aligning with the presence of workplaces, public institutions, and shopping centers (Fig. 3c). In contrast, Figs. 3a and 3b depict a more equitable dispersion of trips throughout the city, with noticeable clusters in densely populated residential areas.

3.3 Demographic Changes in BSS Users

Existing research has noted increased diversity among BSS users [1]. Our data analysis also confirms a significant rise in the average user age during the initial lockdown. However, the reintroduction of electric bikes, primarily in April, resulted in a surge of users and a subsequent decrease in the average age, notably observed in 2021 and 2022.

Regarding the gender gap, while it is narrower in Tartu compared

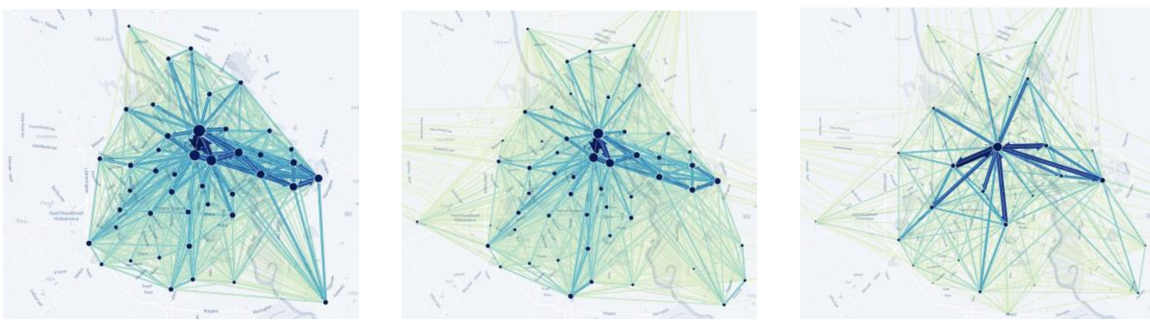
excursions.

Furthermore, a noticeable shift in the spatial patterns of bike trips is the rise in trips with similar Origins and Destinations (OD). to other regions, we observed an increase in the percentage of women using the BSS during lockdowns compared to the same period in 2022. Notably, the percentage of female users declined slightly from April, May, and June 2020 (41%, 45%, and 42%) to April, May, and June 2022 (38%, 41%, and 40%).

3.4 Changes in Public Transport Demand

While public transport plays a pivotal role as a sustainable transportation mode, the COVID-19 pandemic substantially disrupted public transport usage, primarily due to health concerns. This period witnessed a noticeable shift away from public transport toward alternative modes of transportation [3]. As we navigate the postpandemic landscape, it remains uncertain whether the impact of COVID-19 on public transport has fully receded. Given the challenges associated with altering travel behavior [13], further research in this domain is imperative [12].

In this study, we explored the ticket validation data of Tartu's public bus system, the sole public transportation mode in the city, spanning from the start of 2019 to August 2023. The monthly count of passengers is illustrated in Fig.1. Notably, the number of bus riders exhibits seasonal fluctuations, with lower ridership observed during the summer school break. As depicted in Fig. 1, the COVID19 outbreak had a profound impact on passenger numbers, with a pronounced decline, particularly during the lockdown periods, as overall commuting to workplaces and schools diminished. However, even after the easing of movement restrictions, while there was an increase in the number of trips, it did not rebound to pre-pandemic levels. While in April 2023, the World Health Organization declared an end to the COVID-19 pandemic as a public health emergency, in the months leading up to this declaration, health concerns had significantly subsided. Nonetheless, it appears that the modal shift among previous bus users persisted as a lasting change in travel behavior. During the first eight months of 2023, which can be considered post-pandemic, the number of bus trips in Tartu registered a 12% decline compared to the equivalent period in 2019, the prepandemic era.



(a) OD BSS flow in April and May 2020. (b) OD BSS flow in April and May 2021. (c) OD BSS flow in April and May 2022.

Figure 3: Mobility Flow patterns of bike trips during April and May, in three consecutive years.

4 CONCLUSION AND DISCUSSION

This study provides an exploratory investigation into the potential impact of the COVID-19 pandemic on transportation dynamics in Tartu, Estonia. Initial observations indicate pandemic-induced shifts in travel behavior affecting both bike-sharing and public bus systems. The bike-sharing system appears to exhibit a degree of resilience, with demand holding relatively steady during the crisis, potentially highlighting the value of diversified transportation alternatives.

The adaptability of bike-sharing is reinforced by increased user diversity and trip flexibility, promoting healthier habits and a sense of community. Conversely, public buses experience a substantial ridership decline with a challenging post-pandemic recovery.

The drop in public transport ridership, induced by the pandemic, is a prevalent concern, likely extending to other regions. Given the complexity of altering citizens' travel behaviors, this issue necessitates further exploration and heightened attention from urban planners and policymakers, as they strive to steer travel modes toward sustainability in the post-pandemic era.

Tartu being chosen as one of the EU mission's climate-neutral and smart cities by 2030 highlights its strong dedication to sustainable urban development, serving as an example for other European cities to follow by 2050. However, it is crucial to acknowledge that the findings of this study underscore the persistence of uncertainties concerning the long-term effects of the pandemic on public transport. Additionally, the upward trend in private vehicle usage poses a substantial challenge to the city's environmental aspirations. Achieving the milestones outlined in the action plan [8] demands renewed efforts and focused attention.

Future research should delve into the specific factors contributing to travel behavior differences between bike-sharing and public buses, while understanding the long-term effects and implications for urban mobility remains crucial. Transportation systems must continue to evolve to meet the changing needs and preferences of residents in a post-pandemic world, with this study serving as a primitive step in this understanding.

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