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Aline Fileti Marcon

Using a multimodal database to assess the effect of the North-South line on the use of bicycle as a feeder mode to urban public transit in Amsterdam

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Orientador: Prof. Fernando Seabra, PhD.
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O presente trabalho em nível de mestrado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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Certificamos que esta é a **versão original e final** do trabalho de conclusão que foi julgado adequado para obtenção do título de Mestre em Engenharia de Transportes e Gestão Territorial.

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To all those who fight for a sustainable world.

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Even before starting the Master's programme, I knew I wanted to do part of it abroad, in order to get into a different culture and into new people's life. What I did not expect though, was realising this dream during a pandemic that affected the whole world in just a couple of weeks. I had just arrived in the Netherlands... like... I spent one month attending to classes at TU Delft, and suddenly everything just got closed!

– But is this "covid thing" that bad? It will probably be done in a week or two, right?

That was me in March 2020, however, after a couple of days, no one knew for sure what was going on in the world and how much we should really worry about everything. People started fearing the next day, and at that moment I started seeing foreign people leaving the country as soon as they could in order to be with their families. I thought about leaving Europe too, and I was more like coming back home when I met this group of people living the same situation as mine. In some way, they made me feel safe and I wanted to stay in Delft with them. This decision was the best I could have taken. For about three months I shared my life with people who are pure lights and who made me see a different version of life and of myself. They made me feel free, and that was the moment when I was finally able to learn how to live and enjoy the present time. You are always on my thoughts and heart Marco Pugliese, Guglielmo, Antonio, Aya, Francisca, Matteo, Marco Dreoni, Riccardo and all our Delft family. Love you. *Per ora viviamo.*

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Sometimes we are put under harsh situations which require us to find a way to get through it, even though we do not understand why that is happening. But the fact is that we just need to know that what belongs to us always find a way to come to us, and it comes in the best possible way, we just need to believe it. The Master's period reinforced inside me that living in the moment together with people I love is the best key to happiness.

Thanks to all the ones who made me who I am today.

"Think of bicycles as rideable art
that can just about save the world."
(PETERSEN, Grant)

ABSTRACT

In recent years, more and more attention has been given to the urgency for sustainable cities. Population growth is causing cities to expand in a fast and uncontrolled way. We can observe that by the increasing number of traffic congestion in the big urban centres. This is proven to cause not only environmental problems, but also healthy issues in the population. Private cars are still the most used transport mode worldwide, because, mainly in the emerging countries, there is no other competitive transport mode. Even in developed countries, where public transport normally meets population's necessity, there is the first and last mile problem, which does not always allow us to consider this system as a competitive alternative to the use of private vehicles. Within this context, bicycle and public transport combination has been found as a competitive alternative to the use of private cars, since it facilitates the transport door-to-door. In this research, we conducted some analyses regarding the bicycle transit combination in the Amsterdam region, focusing on how cyclists' behaviour regarding their choice of how to access the public transport system by bicycle changed due to this big network change with the new metro line (the North-South Line (NSL) which crosses Amsterdam from South to North. From the analyses we could see an increase on the choice of accessing the metro, instead of the tram or bus. Besides, as an indication of transportation mode substitutability, the higher the trip duration of the other PT modes (bus and tram), the higher the likelihood of a user to choose metro. It is also worth mentioning that a dummy variable for the time after the NSL line was in operation was estimated with a positive and significant effect, which ratifies that this new metro infrastructure increased the odds of a bicycle user to opt to ride her bike to a PT station and commute to a metro service.

Keywords: Bicycle Transit. Public Transport. Urban transport.

RESUMO

Nos últimos anos, cada vez mais atenção tem sido dada à urgência por cidades sustentáveis. O crescimento populacional tem ocasionado o rápido e descontrolado crescimento dos centros urbanos. O aumento na dimensão e frequência dos congestionamentos nos grandes centros urbanos são um reflexo vivo desta expansão. Está provado que essa dilatação das cidades tem causado não apenas problemas ambientais, mas também problemas de saúde para a população (estresse e problemas respiratórios estão constantemente presentes). O automóvel particular ainda é o meio de transporte mais utilizado no mundo, visto que, principalmente nos países emergentes, não existe um meio de transporte competitivo. Mesmo em países desenvolvidos, onde o transporte público normalmente atende às necessidades da população, existe o problema do primeiro e último quilômetro, o que nem sempre nos permite considerar esse sistema como uma alternativa competitiva ao uso de veículos particulares. Nesse contexto, a combinação entre bicicleta e transporte público tem se mostrado uma alternativa que pode se equiparar ao uso do automóvel particular, uma vez que facilita o transporte porta-a-porta. Nesta pesquisa, realizamos algumas análises sobre a combinação entre bicicleta e transporte público na região de Amsterdã, Países Baixos, focando em como o comportamento dos ciclistas – em relação à escolha de como acessar o sistema de transporte público utilizando uma bicicleta – mudou, devido a uma grande mudança no sistema de transporte: a nova linha de metrô (NSL) que atravessa Amsterdã de sul a norte. Pelas análises pudemos verificar um aumento na escolha de acesso ao metrô, ao invés do bonde ou ônibus. Além disso, como indicação da substituibilidade do modo de transporte, quanto maior a duração da viagem dos outros modos de transporte público (ônibus e bonde), maior é a probabilidade de um utilizador escolher o metrô. Também vale a pena mencionar que uma variável *dummy* para o tempo após a linha NSL estar em operação foi estimada com um efeito positivo e significativo, o que ratifica que esta nova infraestrutura de metrô aumentou as chances de um usuário de bicicleta optar por ir de bicicleta até uma estação de transporte público e optar pelo uso de serviço de metrô.

Palavras-chave: Bicicleta e Transporte Público. Transporte Público. Transporte Urbano.

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

B Before North-South Line. 40, 52–54

BTM Bus, Tram or Metro. 15, 29, 38, 42, 44, 46–50, 54, 58, 65, 66, 72

ICT Information and Communications Technology. 37

LR Likelihood-Ratio. 67, 68

NSL North-South Line. 11, 13, 15, 17, 26, 28, 29, 40–44, 48–51, 53–55, 58, 62, 68, 69, 71, 72, 75, 77

PT public transport. 15, 21, 23–25, 27–35, 37–45, 47, 48, 50, 51, 53, 54, 57–60, 63, 65, 66, 71–73

RA Right after North-South Line. 40, 52, 53

SA Shortly after North-South Line. 40, 53

UK United Kingdom. 26

US United States. 24, 26, 71, 73

YA One year after North-South Line. 40, 52–54

CONTENTS

1 INTRODUCTION

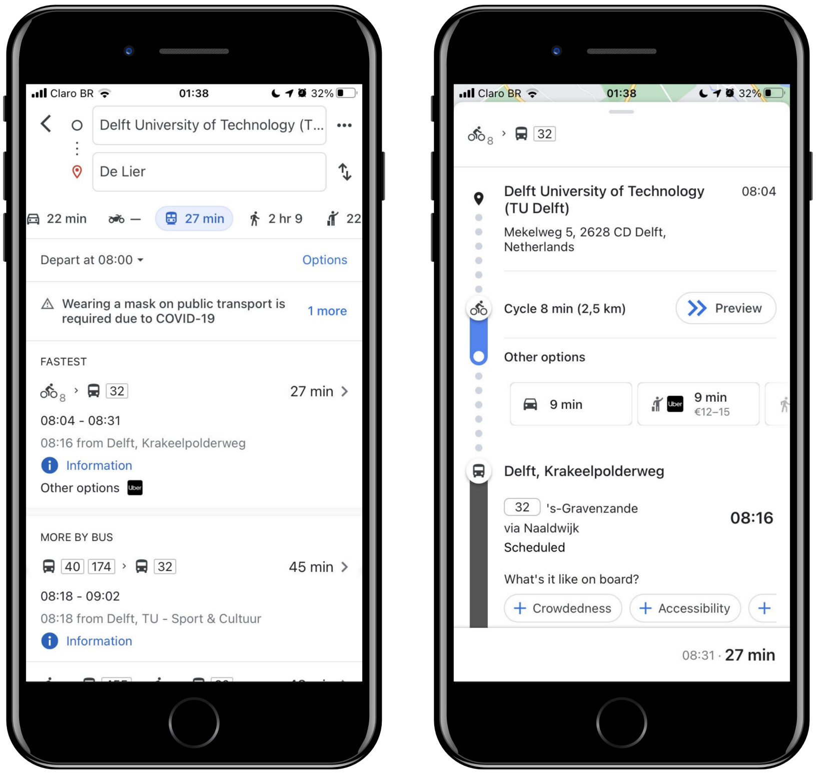
Cities around the world, especially the large ones, have been dealing with mobility related issues, such as traffic congestion and air pollution. The effects of air pollution are straightly felt in human health while poor performance of traffic systems causes, in addition to environmental problems, restriction to mobility and accessibility, hindering trade, efficiency and economic growth. Besides, traffic planning strategies face the burden of about 1.35 million people killed every year in road crashes; this is the main cause of death among people from 5 to 29 years old (DCE, 2021).). In order to solve these problems, governments face a fundamental dilemma: decreasing the number of private vehicles and, as a consequence, the advantages of time flexibility and door-to-door access, versus supporting the use of public transport (PT) and active transport means (e.g., walking and cycling) in order to implement a more sustainable urban space. Therefore, the challenge is to find a balance between building a less dependent car mobility urban space and matching the quality of accessibility provided by private motorised transport modes (BERTOLINI; LE CLERCQ, 2003; LUIU et al., 2018).

More recently, the combination between bicycle and public transport has been found out to be a powerful tool to mitigate the costs under this mobility dilemma (SHELAT et al., 2018). The integration between bicycle and PT can provide an increase of benefits, such as faster access to stations and route flexibility, as well as a reduction of costs (for both the PT provider and the traveller), which makes this combination highly competitive with respect to to private cars (MIL et al., 2018). In addition, bike and walk-friendly neighbourhoods are more likely to attract people to shop in the local commerce and also to interact with other people. Furthermore, Schneider (2005) argues for the need for some complementary measures to favour this combination, such as facilities to dock bicycles at stations and use the PT to reach the final destination. The author also points out the role of investments that improve bicycle paths and their integration with PT systems, so that users minimise their costs due to riding a bicycle in a bad weather, after dark, up hills and in localities that do not provide proper bicycle access – e.g. roads with tunnels, bridges and highways.

Technological innovation in electronic media has also played a significant role to improve the approachability of a bicycle-PT system. In mid 2019, Google (2019) announced a new feature in Google Maps™ which allows the user to plan their first and last mile to a PT system. When using the tool to simulate a route, if a user inserts their destination and chooses the option “transit”, the app automatically presents some options for the first and/or last mile, which are paired to a local PT. Figure 1 depicts a route simulation in Delft, the Netherlands, where it is possible to see the suggestion of using a bicycle as a feeder mode. In this simulation, the user is leaving from TU Delft and their final destination is the municipality of De Lier – a 15 km trip.

This simulation shows a route option that considers the use of bicycle as a feeder mode to the PT as the fastest alternative involving transit for a given set conditions (Tuesday at 8:05 in the morning - February 2021). The traveller has to cycle for 2.5 km to get to a bus stop; from there they can continue the trip using a bus. Note that the second option given to the user is using bus only, but that would take almost 20 extra minutes compared to the fastest option. Further, observe that the

Figure 1 – Google Maps™ PT route simulation in the Netherlands



Source: created with Google Maps (2021).

route option of travelling using a car is only slightly faster than the one with the combination between bicycle and PT. Both options allow the user to arrive at the centre of De Lier (final destination), with only 5 minutes difference. We can infer, therefore, that given that PT companies provide an efficient and reliable service and the municipalities provide quality on the accesses to the PT infrastructure (stops and stations), it is feasible to create competitive alternatives solutions to cars. The challenge of improvements to the urban environment is not the only problem that a system combining bicycle and PT modes can address. According to the DCE (2021), 30 minutes of cycling per day is equivalent to the level of one week of physical activity, and it helps to avoid serious diseases such as depression, obesity, diabetes and others. Due to its social, environmental and economic benefits, which also include the efficient use of roadways capacity, the use of bicycle as a transport and/or feeder mode is getting more attention worldwide, such as in Europe, in North America (TSENKOVA; MAHALEK, 2014) and China (ZHAO; LI, 2017).

In the United States (US), more than 50% of people live in an area of less than 3.2/,km from the closest PT route (FHWA, 2016); which indicates the significant potential of travel routes that could be capture by an efficient bicycle-PT mode. In Canada, the investments in bicycle infrastructure in the largest cities, along with other public policies, have resulted in modest improvements in the patterns to act in favour of cycling and PT (TSENKOVA; MAHALEK, 2014).

In the Chinese capital, Beijing, the government has introduced policies to encourage cycling, e.g. bicycle-sharing programs and regulations on car use. Besides, significant amounts of investments have been directed to improve metro services (ZHAO; LI, 2017). Since 2007, about 100 km of new metro lines have been constructed annually; and in 2015, the daily number of trips by metro reached 10.73 million in working days, except for Friday, when this number normally has an addition of 1.5 million passengers (ZHAO; LI, 2017 apud Y. DU, 2015). By the end of 2020, the metro network in Beijing covers about 1,200 km and the average daily number of passengers reached 15 million (WU et al., 2020). However, despite the policies to motivate the use of bicycle and the numerous investment projects in PT infrastructure, there is still not much attention to the integration of these two modes in government policy. The empirical evidence confirms that lack of connectivity between bicycle and PT systems, since the use of bicycle as a transfer mode to a station remains infrequent in Chinese cities (ZHAO; LI, 2017). Although the integration of bicycle and transit allows the user to reach much longer distances, in addition to the other benefits already mentioned, this practice is not part of a regular policy in most developing countries, especially compared to some cities in developed countries (WANG; LIU, 2013), such as the Netherlands, where bicycles are used both as a standalone travel mode and as a commuting mode to PT (KAMPEN et al., 2020).

In large cities like Shanghai, Beijing, London and Amsterdam, there is a great number of residents living in the suburbs, where the metro stations are commonly sparse. This “first mile” between home and PT stations is a major factor influencing residents’ usage of metro, tram and bus (ZHAO; LI, 2017; ZHANG et al., 2019). Especially for this first and last mile context, the use of bicycle as a transfer mode could turn the time to get to a station more flexible and increase the distance (with respect to walk) to be complete between origin (home) and a connecting destination (PT). According to Rijsman et al. (2019), the average walking distance to a station is equal to 380 m, while for cycling is equal to 1,025 m. In other words, the use of a bicycle as a feeder mode to PT systems, besides of being helpful to the user, it could yield an expansion of stations catchment areas. The size of a station catchment area is an important parameter to plan stations infrastructure as well as their network timetable. Despite the importance, not much is currently known about the aspects that influence the size of a catchment area, especially when bicycles are considered a feeder mode (RIJSMAN et al., 2019). Thereby, the integration between bicycle and transit can be seen as a strategy to enlarge catchment areas of current stations and to improve network reliability. More broadly, a major consequence is the reduction of air pollution, due to a lower number of buses, cars and even stations in a given urban space.

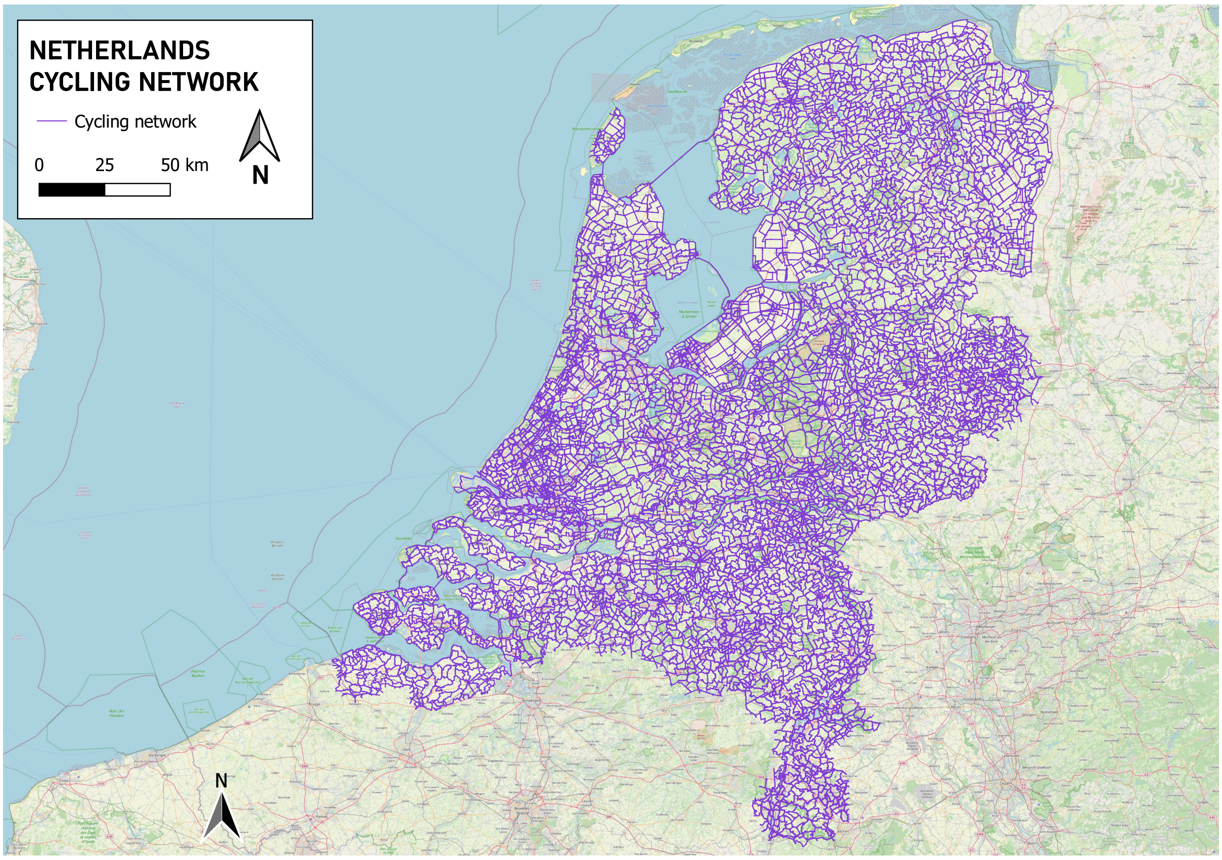
Several researches have been conducted to explore the integration between bicycle and trains; however, even in developed countries, not much has been done regarding the integration of bicycle and urban PT, as bus, ferry, lightrail, metro and tram systems. Therefore, the research problem of this study is related to identify the parameters that influence the use of bicycle as a feeder mode to access the PT systems. Regarding the feasibility of the research problem, we experience the use of an ultimate multimodal database known as Mobidot. Differently from unimodal databases, a multimodal one brings multi-variable information. In this case, Mobidot provides all relevant information concerning actual and alternative mode choices in the same database, dispensing the use of more than one data source. However, since this is a complete and new database, before applying to this research, it needs to be studied. Mobidot raw database includes a total of 16,463 records related to PT. This research also focuses on data about the Amsterdam region. Besides, all analyses here consider the new context of this region, which has been significantly affected by the operation of a new metro line, called the

NSL (officially metro line 52).

1.1 CONTEXT OF THE STUDY

Located in the Western Europe, the Netherlands is bordering Germany to the East and Belgium to the South. Most recent data show a population of about 17.4 million people in a space with 22.8 million bicycles (STATLINE, 2020; RIJKSOVERHEID, 2020a). In its 41,543 km^2, the Netherlands has a 35,000 km bicycle network of fast tracks – see Figure 2 –, which allows the Dutch residents to have more than 25% of their trips made by bicycle (RIJKSOVERHEID, 2020b). These data combined make bicycle indexes in the Netherlands to be about ten times higher than in countries like the US and the United Kingdom (UK) (PUCHER; BUEHLER, 2008).

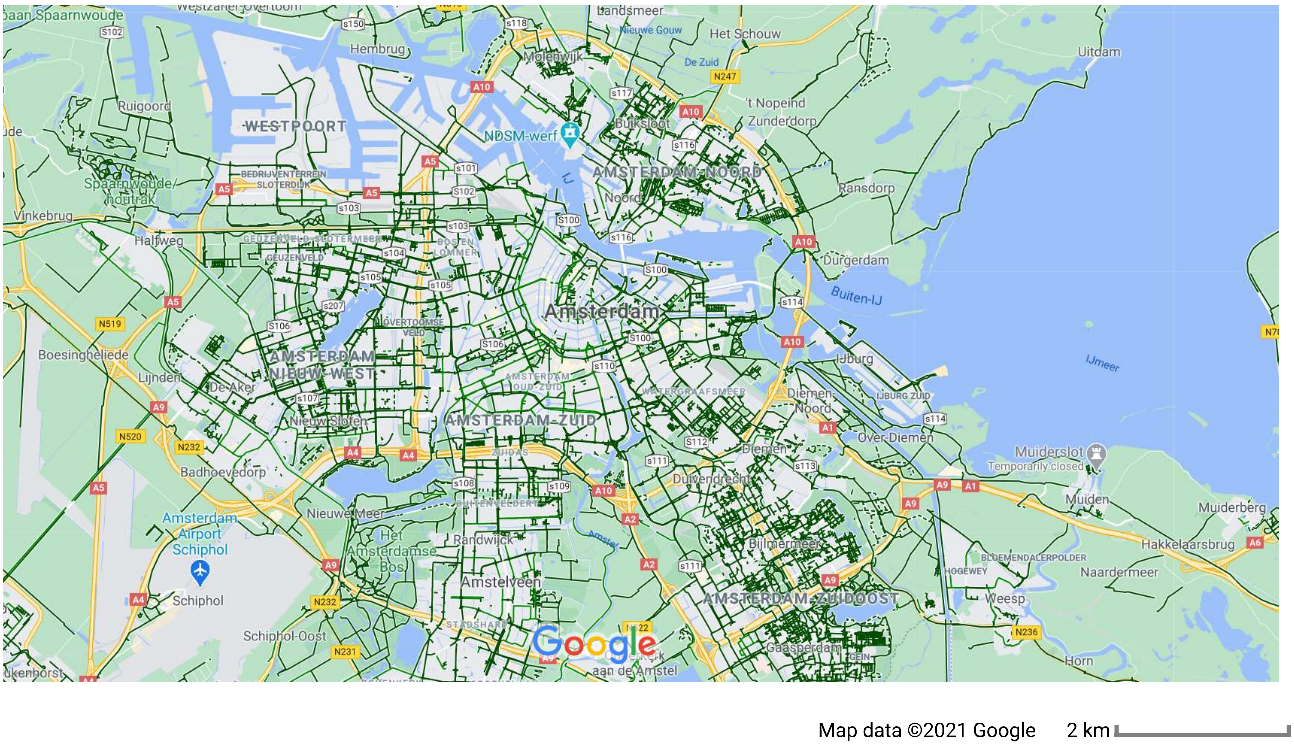
Figure 2 – Netherlands' cycling network



Source: Unknown.

Figure 3 presents the cycling network in Amsterdam municipality. It is noticeable that one can reach the whole city by bicycle, including the possibility of reaching Schiphol airport from North Amsterdam.

Figure 3 – Cycling network in Amsterdam region



Source: Google Maps (2021)

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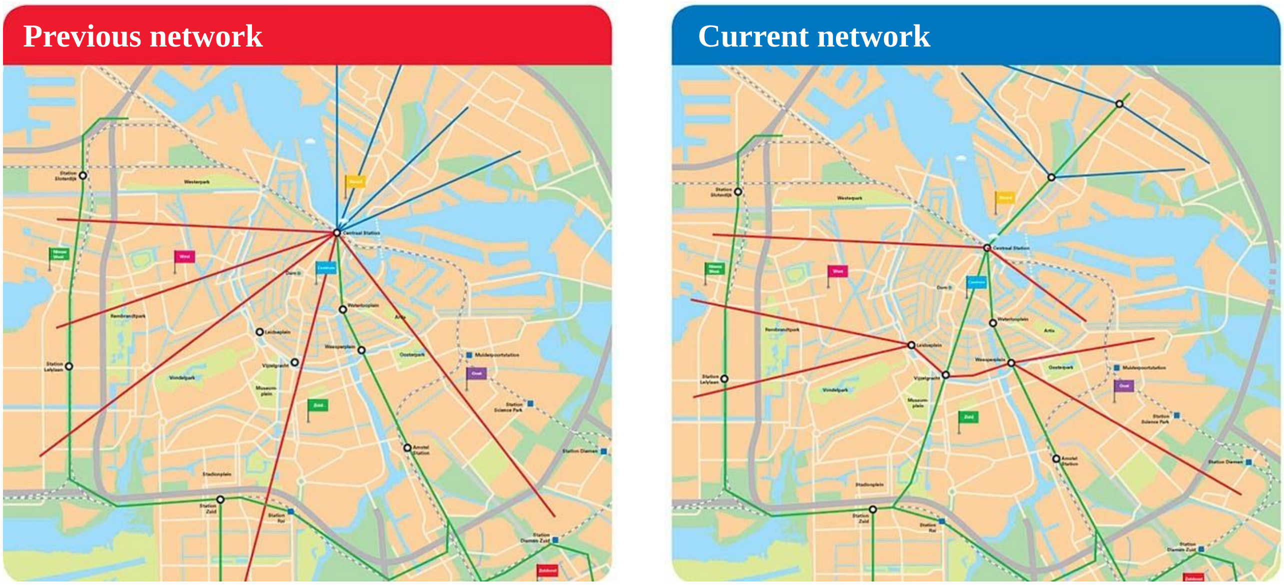
By the end of 2018, the government of the Netherlands announced an investment of 345 million euros in ultra-fast cycling routes and parking facilities for bicycles (RIJKSOVERHEID, 2018). It aims to raise in 20% the number of kilometres travelled by bicycle in the country in the next ten years (RIJKSOVERHEID, 2020b). According to the State Secretary for Infrastructure and Water Management, Ms. van Veldhoven, “bicycles are [the] secret weapon to combat traffic congestion in the Netherlands”.

According to a recent survey conducted by the DCE (2020), among the Dutch population, bicycles are the most appreciated mode of transport, surpassing even the car and the PT. However, cycling in the Netherlands has not always been as prospective as it is nowadays. Right after the World War II, the number of cars increased substantially and it became the main transport mode (DCE, 2018) in the country. Things started changing in the 1970s, when the number of traffic casualties – especially involving children – increased to a critical level, beyond the inflated oil prices due to the oil crisis faced by the whole world in that decade, which made the population call for change. Crucial and strong movements claimed for safer cities and safer cycling conditions; and due to the public pressure, urban planning policies started considering bicycles as part of mobility (DCE, 2018).

Additionally to that, in that same decade, the Netherlands became the first country in Europe with a national symmetric rail service. A symmetric timetable is mirrored in both directions, it means that a train meets its counterpart, which is travelling in the opposite direction, at a central point. In order to visualise it, imagine a train line $A - B - C$ where B is the middle point, so the vehicle leaving point A crosses the one leaving point C at the B point – it took both vehicles exactly the same time to arrive at the middle point. Thereafter, the Netherlands worked on significant improvements on its public transport, which made the country being seen as a logistic gateway to Europe (MINISTRY OF TRANSPORT, PUBLIC WORKS AND MANAGEMENT, 2010). A most recent development is the NSL, formally named Metro Line 52, built to connect the southern and northern parts of Amsterdam. It started being constructed in the year 2002 and was finished in mid-2018. Before the NSL, the access to Amsterdam North was relatively difficult, and this lack of accessibility was hampering the development of that region, but now, this line is contributing to the development of Amsterdam North as a living environment and economic area (MINISTRY OF TRANSPORT, PUBLIC WORKS AND MANAGEMENT, 2010).

As a result of the beginning of the NSL operation in July 2018, Amsterdam network went through a lot of changes (NOS, 2018). In this sense, Figure 4 depicts how the metro network looked like before the NSL and how it is structured nowadays.

Figure 4 – Amsterdam metro network before and after the North-South line



Source: OV Magazine (2016).

The image on the left shows the previous network, where the lines converge to Amsterdam Centraal (Amsterdam Central Station). The one on the right side shows the new metro network, already with the NSL in operation; here some lines are directed towards the NSL (green axis between Amsterdam Zuid (Amsterdam South Station) and Amsterdam Noord (Amsterdam North Station)) (SPIERENBURG, 2020). We can notice that the metro network went from a radial to a fish bone configuration. This restructuring in the metro network was also responsible for reducing the crowdedness in the central station by creating another hub stations. It also changed bus and tram networks and timetables and affected the way travellers use the PT. Especially those people living outside the city centre are likely to transfer more after the NSL; for example, before the NSL, a person who lived in the north part of Amsterdam, and was heading to Amsterdam Centraal would take a bus and reach the station directly. But after the NSL, this same person would need to take a bus and transfers to get to Amsterdam Centraal, increasing the number of transfers from 0 to 1 (SPIERENBURG, 2020).

Even though the NSL is located in the core of Amsterdam city, it influences the whole Amsterdam region, which is composed by the following 15 municipalities:

- Aalsmeer
- Amstelveen
- Amsterdam
- Beemster
- Diemen
- Edam-Volendam
- Haarlemmermeer
- Landsmeer
- Oostzaan
- Ouder-Amstel
- Purmerend
- Uithorn
- Waterland
- Wormerland
- Zaanstad

In view of that, the database used in this research – Mobidot – includes data from those 15 municipalities above. Mobidot database is a new multimodal database in the Dutch context and is detailed in chapter 3.

1.2 OBJECTIVES

This study deals with the conditions to improve the logistic integration between bicycles and PT modes. Such conditions are related to the user decision concerning their choice to cycle to a station, and to some infrastructure constraints - such as the distance of stations to the origin points and the impact of new arrangements in the PT network. The data scope we are dealing with includes travel combinations where users choose bicycle as a feeder mode to the PT. Therefore, the main objective of this study is to evaluate the use of a bicycle as a feeder mode to BTM in the context of bicycle and transit integration in the Amsterdam region. More specifically, the objectives of this research are the following:

1) to analyse the main characteristics of Mobidot database in terms of the use of bicycle as a feeder mode to the PT in the Amsterdam region;
2) to assess the main underlying determinants of cyclist behaviour when accessing BTM stations, mainly travel distances, waiting time and the impact of a new metro line (the NSL).

As for the specific objective (1), it is worth noticing that Mobidot is a new database with a significant potential role to find out more about bicycle users' behaviour. A diagnostic analysis of this database, exploring the main characteristics of bicycle riders in this sample and some inferences concerning future research topics, therefore, stands out as one of the goals of this study. In a following step, objective (2) stresses out an investigation of the cyclist behaviour concerning their decision of a PT mode. To accomplish that, a model is estimated to search for the main reasons that condition their decision to choose to use a bicycle to access the bus, tram or metro. The interest here is to identify the conditions which motivate – in parallel with the ones that demotivate – people to use bicycles as a feeder mode to each of these modes (BTM).

The aforementioned objectives aim to assess the hypothesis that a new investment on the PT system, such as the NSL, exerts impact on the bicycle users' decision making.

1.3 STRUCTURE OF THIS RESEARCH

In order to accomplish the research objectives, this study is organised as follows:

- chapter 2 presents a brief literature review regarding what has been done and studied so far in the track of transport modes, focusing on the bicycle and PT integration;
- chapter 3 details Mobidot database in terms of what kind of information it delivers and its structure; in the sequence, it presents all the descriptive analyses regarding this database, together with first conclusions about traveller's behaviour;
- chapter 4 describes the econometric modelling to analyse cyclists' choice among the three available PT modes, as well as the obtained results;
- lastly, chapter 5 presents the discussion about the results, the research limitations and future research suggestions.

2 LITERATURE REVIEW

This chapter is designed for a literature review regarding the PT characteristics and context, focusing on the bicycle and transit combination. Firstly, there is a brief introduction about the changes occurred in the scope of PT over the last decades. In the sequence, a succinct approach regarding the emergence and identification of the problem involving the world transport system and the environment, followed by the alternative transport modes which came to soften these environment issues.

2.1 THE LAST DECADES

Especially since the last decades, you surely have heard about biodiversity loss, landscape fragmentation, air and water pollution, ecosystem degradation, together with climate change – these conditions represent some of the world's environmental problems. Urbanisation, which can be defined as the "spatial expansion of the built environment that is densely packed by people and their socioeconomic activities" (WU, 2010), has commonly been considered as the responsible for all the previously mentioned environmental issues.

The world was largely agrarian in the 1700's, when less than 10% of the global population lived in urban spaces (BERRY, 2008). Shortly after, in the 17^{th} century, Amsterdam became the "warehouse" of the world, and the Republic of the Seven United Netherlands was the middle zone of negotiation, which caused this zone urbanisation level to grow more than 30%. Thus, the closer to Amsterdam, the greater the degree of environmental modification to uphold agricultural development. And this was the pattern worldwide: the further from the urban centre, the less the deforestation for ships' timbers and other components the new village configuration was requiring (BERRY, 2008). One of the reasons why the population started to establish in the urban centres was the facilities concentration, including those regarding the passenger and cargo transport. Naturally, from this period, the urban centres entered a non-stoppable expanding phase which is still evolving.

The World War I and II, together with other plagues waves, were responsible for a lot of changing in the urban areas and on the way people reestablished their lives in the urban centres. In the context of transport, right after the World War II, there was a significant increase on the global amount of cars – some even described the 20^{th} century as "the century of the car" (MILLER, 2020). However, despite the fact that cars deliver comfort, flexibility and distance reduction between families, friends, work... these advantages have come at the high expense of the environment, and society with great adverse social, environmental and public health impacts attributable to increasing car travel and usage (LUCAS, 2012; KHREIS et al., 2016; NIEUWENHUIJSEN et al., 2019). Besides the large occupation of the urban space – not only because of the cars themselves but also the infrastructure required to bear those vehicles –, the excessive number of cars causes visual and air pollution and other inconveniences such as the traffic jam.

2.2 THE PROBLEM STARTED TO BE NOTICED

Logically, since the first evidences of urbanisation, deforestation was already observed. Thereafter, urbanisation levels kept rising through the last decades and all the deforestation brought a lot of disastrous consequences to the planet.

As those environmental issues started to come up in the news, institutions and governments around the world started concerning about possible solutions to soften the damage caused by the urbanisation growth. Then, at some point in the 1980's, the popular term "sustainability" became the word of the year and the topic of an Era. Brundtland, former Norwegian Prime Minister at the time, has defined "sustainability" in her report "Our Common Future", launched in 1987, by saying that sustainability is "meeting the needs of the present generation without compromising the ability of future generations to meet their own" Brundtland et al. (1987). This report was a call for action and strengthened international cooperation in the direction of changing the current scenario.

Urbanisation evidently includes in its context a substantial aspect: the transport. The need on reducing the use of cars – which has increased in the period after the World War II – and shifting instead to active transport, such as bicycling and walking, is a growing awareness (RABL; DE NAZELLE, 2012) nowadays, and due that, governments worldwide have been willing to boost sustainable mode use, such as PT, cycling, walking and some types of shared transport. Almost three decades ago, Calthorpe (1993) first introduced the idea of the transit-oriented development as part of the new urban planning mechanism. This concept is characterised by "moderate and high-density housing along with complementary public uses, jobs, retail, and services in mixed-use development along the regional transit system". Ever since the introduction of transit-oriented development concept, there has been an increase in the demand for sustainable urban development, including the transport aspects of this (LEE et al., 2016).

2.3 ALTERNATIVE MODES AND BYCICLES

When people start choosing sustainable modes to replace car trips, they contribute to the emissions and congestion reductions, which also cause a positive impact on society's health (TON et al., 2020). As previously mentioned, due to be seen as a sustainable and environmentally sensitive transport, the PT calls researchers' attention, since it is an environmentally friendly alternative to cars, when cycling or walking are not the best option, such as when a person needs to reach a long distance. Besides the environmentally friendly condition, the PT is normally more economical for the population, compared to a private vehicle, and it benefits those people who do not have the access to a private car (KRYGSMAN et al., 2004).

Furthermore, when the municipality provides an efficient PT system, even those who have the access, or at least have the conditions to acquire a car, could choose to not put another private vehicle in circulation and use the PT instead. However, even when the provided PT is reliable, offers a wide timetable, a good infrastructure and it is affordable, it is not always considered as a fair alternative to the private vehicles, specially for those who live or work far from the city centres. This is due to their individual characteristics, as the fact that they do not provide door-to-door accessibility, although, the use of the bicycle in PT accesses and egresses can reduce the door-to-door travel time. As a feeder mode, the bicycle is considerably both faster than walking and more flexible than using the PT only. It suggests that the use of bicycle in the access to and/or egress from the PT helps to discontinue the 'travel time gap' between private vehicles and PT (KEIJER; RIETVELD, 2000; MARTENS, 2007).

The bicycle transit combination is a time-competitive alternative to private vehicle travel (MARTENS, 2007; TSENKOVA; MAHALEK, 2014). Existing evidence of this time competitiveness is the significant proportion of travellers replacing their car trips with bicycle transit in countries like Australia, for example (MARTIN; HOLLANDER, 2009). This alternative provides plenty of benefits not only in terms of affordability, health and environment, but also for recreation, access to jobs and other services (TSENKOVA; MAHALEK, 2014).

The use of bicycles as a transport mode attracts researcher's attention also because of its great flexibility, fair distance range and low cost maintenance (RABL; DE NAZELLE, 2012; WU et al., 2019). Usually there are two types of bicycle use: the first one is as a standalone mode, that is a direct transport mode, i.e. there is no combination with another mode of transport; while the second one is as a transfer to access other transport mode (ZHAO; LI, 2017), such as the PT. Trips have some specific characteristics when the bicycle is used as a transfer – or feeder – mode to the PT, because in these situations, the travel distance is normally shorter and the cycling is quite influenced by bicycle facilities at transit stops and stations, as well as by the PT reliability (ZHAO; LI, 2017).

To summarise, on one hand we have the PT, which can reach great distances and be attractive due to its reliability, price and practicality, but despite that, the first and last miles can be an issue for some users, specially when they are away from the cities centres, where there is a major stops/stations concentration, since the PT does not offer door-to-door accessibility. On the other hand, we have the bicycle, which can not reach as long distances as the PT in a similar and comparable time, but it could supply the first and last miles needs. Regarding this, the combination of bicycle and the PT can provide a hybrid and distinct transport mode. Having the bicycle as a feeder mode can soften the rigidity of the PT and accommodate individual travel needed (KAGER et al., 2016).

The use of more sustainable transport mode, as the combination between the PT and bicycle, increases the accessibility and livability in urban areas. Due to its ability to achieve environmental, health and traffic benefits, cycling continues to increase in popularity and is gaining attention (KRIZEK; STONEBRAKER, 2011). As stated by Schneider (2005), there are several reasons why the integration between bicycle and transit has been increasing; in addition to all the reasons already mentioned, there is also the fact that transit agencies have realised that bicycle services can extend transit services catchment areas and also provide greater mobility to the users at the beginning and at the end of their transit trips. The catchment areas can be enlarged due to the larger distance a cyclist wills to cycle (KAGER; HARMS, 2017), compared to walking. Transit operators normally consider a fixed 400 m buffer as catchment area, however, some different sizes have been observed in the PT stops (EL-GENEIDY et al., 2014). Therefore, the distance-decay function is a more instructional way to describe catchment area (GUTIÉRREZ et al., 2011), which is defined as a tool to measure the impedance to travel (IACONO et al., 2008).

According to Shelat et al. (2018), there are four groups of factors affecting the use of both bicycle and the PT combined: infrastructural facilities, policies, travel characteristics and user characteristics. Continuity on improvement of bicycle infrastructure is meaningful to keep increasing the use of bicycles; the lack of bicycle facilities could discourage some people from cycling (TSENKOVA; MAHALEK, 2014). Further, Pucher et al. (1999) state that adverse weather and climate, as well as topography and urban density affect utilitarian cycling. Some previous research already identified some barriers for tram and bicycle combination, as insufficient safe bicycle parking places (RIJSMAN et al., 2019). In this sense, Schneider (2005) suggests that by providing better routes for cyclists to rail stations, there is an increase in the use of bicycle facilities and – as a cause or consequence – Martens (2007) argues that train stations with better bicycle access lead to a higher bicycle usage. Brons et al. (2009) share this same thought and add that the improvement in the transit stops access can increase not only the use of bicycles, but also transit usage itself. Another characteristic that can encourage the use of bicycles as a transfer mode is the possibility of taking a bicycle inside the PT modes, such as in trains. This is possible in the Netherlands, where cycling is for everyone and for all trips purposes; Dutch women cycle as frequently as men and cycling is distributed across all income groups (PUCHER; BUEHLER, 2008).

Together with the waiting and transfer times, the access and the egress stages are the most fragile part of a multi-modal PT chain as the bicycle transit combination. Further, these stages contribute to the total travel inconvenience (BOVY; JANSEN, 1979), which means that they have a direct influence on whether someone chooses to use that PT mode or not. For example, as stated by Cervero (2001), an increase on the access and/or on the egress time and/or distance to a PT mode is associated with a decrease on the use of this mode. Moreover, accesses and egresses determine the catchment area of a PT stop/station Bovy et al. (1991) and Murray (2001). Added to this, accesses and egresses are normally sensitive to weather conditions such as rain, wind and sun, as well as to the distance. These aspects call attention to policies that can improve the conditions of access and egress stages.

Integrating bicycle and transit in an effective way requires a complete analysis of individuals' needs, the travel patterns, built environment characteristics (as bicycle facilities and infrastructure) and the strategies to integrate both bicycle and the PT. According to Krizek and Stonebraker (2011), the most common strategies include the following:

1) Bicycle **on** transit: the possibility of transporting the user's bicycle aboard (inside or outside) the PT vehicle;

2) Bicycle **to** transit: the possibility of parking the user's bicycle at a PT station or stop;

3) Two bicycles: the use of one bicycle to access and another one to egress the PT vehicle;

4) Bicycle sharing: use a shared bicycle to access and egress the PT.

2.4 BICYCLE AND INTEGRATION

The use of bicycle as transportation means faces cultural, physical (geographic and climate issues) and infrastructural constraints. In an early paper examining some large cities in the US and Canada, Pucher and Buehler (2009) found out that despite a growing demand for bike-transit integration in these large cities, there is a systematic lack of facilities in PT modes – such as bike racks on buses, and bike parking at rail stations – which has staggered the increase of the role of bicycle in the US.

Based on a survey conducted with 1,098 respondents of the Berlin area in 2016, Oostendorp and Gebhardt (2018) found that more people use and depend on intermodal combinations in everyday transport. Besides, the authors evaluate that behaviours depend drastically on spatial differences, since, for instance, combinations of bike and public transport are quite strong in urban neighbourhoods. At last, they argue that an effective urban transport system to be successful -– to attract more users and achieve high level of users' satisfactions -– it needs to address users' needs (including their diversity in terms of priorities) and, the most frequent requirement showed by the survey, to emphasise time efficiency.

The issue of bicycle sharing is also present as an incentive for the integration of bicycle and PT modes. Molinillo et al. (2020) examined the impact of bicycle sharing on the integration of bicycle and other PT modes in the urban region of Malaga, Spain. Based on a face-to-face survey (1,984 respondents), they found that the combination of a bicycle sharing system with public transit modes responded positively to place of residence, time to access the bicycle docking station and the age of the user. Also dealing with the relationship between bicycle sharing systems and PT modes, Cheng and Lin (2018) emphasise the effect of public bicycle sharing system to the increase of coverage of metro stations service that are connected or near bicycle sharing services. The authors argue that the combination of bicycle sharing systems and PT modes increases cost effectiveness and sustainability indexes of integrated metro stations.

For a specific large city, such as Beijing, trip distance is one of the most relevant aspect influencing cycling rates (ZHAO; LI, 2017). Distances of 5 km or less are feasible by bicycle, often faster than any other transport mode (TOLLEY, 1997). A shift towards the integration between bicycle and transit can reduce travel time and traffic congestion (TSENKOVA; MAHALEK, 2014). Zhao and Li (2017) investigated the determinants of cycling as a transfer mode in Beijing, focused on metro station areas. The study used a multilevel logistic model which includes independent variables such as individuals' trip features – e.g. distance, duration and mode – individuals' socioeconomic characteristics, public facilities in metro stations and PT services. They use the transfer mode for an individual's trip between a metro station and home (or a workplace) as the dependent variable. Most studies regarding the integration of bicycle and PT focus on developed countries and deal with multi-modal bicycle-train trips. Not much is known about the integration of bicycle and other modes, such as metro and bus, in developing countries, where decisions are conditioned by entirely different socioeconomic and trip conditions (SOUZA et al., 2017). Along with that, even in the developed countries, at a national level, PT and bicycle integration has been thoroughly studied; however, there is still a knowledge gap at the urban level (TON et al., 2020). Martens (2004) discusses the use of bike-and-ride in three European countries with widely distinct bicycle infrastructures and culture: the Netherlands, Germany and the UK. In this work, the most part of bike-and-ride users travels between 2 and 5 km to a PT station or stop, with longer access distances reported for faster modes of PT. The main travel reasons are work and education; the first dominates the faster modes and the second, the slower modes of PT. Martens (2004) also observes that car availability hardly influences the choice for a combined use of bicycle and train, but strongly affects the levels of bike-and-ride for slower modes of transport.

3 DATABASE AND DATA DESCRIPTIVE ANALYSIS

One of the most relevant aspect of this research is the database (Mobidot) we use to analyze the use of bicycle as an access mode to the PT. In this chapter, the Mobidot database is detailed in terms of its contents, the data collecting method and how to use it. We describe, next, the methodology we use to conduct Mobidot database descriptive analyses. That includes details regarding the database preparation and some data cleaning steps. Finally, the descriptive analyses consist of charts and tables that allow us to generate some statistics about the database content, trends and structural characteristics.

3.1 DETAILS OF THE DATABASE

Mobidot is an innovative Information and Communications Technology (ICT) service provider established in 2013, which uses users' smartphone data to measure and analyse their travel behaviour (MOBIDOT, 2020). The choice for using smartphones is done specially because when combined to geographic databases, these devices can provide users' motion and position. These information are then used by Mobidot to infer routes, the reason for travelling and mode of transport (SWI, 2015; MOBIDOT, 2020) of each trip made by each user. This multimodal database differs from the unimodal ones on the amount of information it contains per record (per row), which allows many types of research using data from just one database instead of collecting information from two or more data sets. Since this is a modern way to construct a database, and Mobidot was recently composed, it is crucial to understand how it works and what its potential is.

Mobidot raw database is extensive and contains a large amount of data regarding people's daily itineraries. For this study, we have selected the parcel of Mobidot raw database which includes a total of 16,463 records involving transit – it means that trips taken by any standalone transport mode (no connection with the PT) are not included to this number. All the records hold at least one access mode to the PT, followed by one mode of PT (bus, boat, ferry, lightrail, metro, tram or train), and an egress mode from the PT. These records are divided according to five categories and adopt the following structures:

1) bicycle + transit: 2,032 records;

   These records can assume the following structure:

   i) bicycle + PT + car or walk or none;

   ii) car or walk or none + PT + bicycle;

   iii) bicycle + PT + bicycle.

2) car + transit: 2,329 records;

   These records can assume the following structure:

   i) car + PT + bicycle or walk or none;

ii) bicycle or walk or none + PT + car;

iii) car + PT + car.

3) walk + transit: 5,486 records;

These records can assume the following structure:

i) walk + PT + bicycle or car or none;

ii) bicycle or walk or none + PT + walk;

iii) walk + PT + walk.

4) bicycle + train only: 1,358 records;

These records can assume the following structure:

i) bicycle + train + car or walk or none;

ii) car or walk or none + train + bicycle;

iii) bicycle + train + bicycle.

5) transit only: 5,258 records.

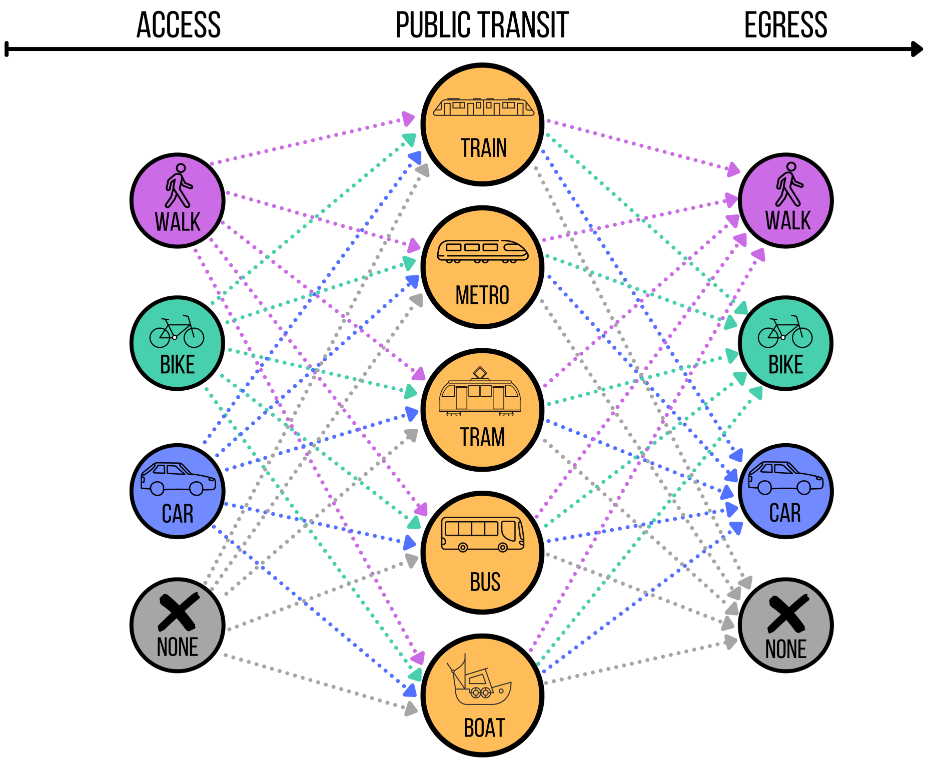
These records assume the following structure:

i) neglected walk + PT + neglected walk.

For the purpose of this research, we utilise the records from category 1 only (bicycle + transit), which relates the combination of bicycle and other PT modalities, such as BTM; it corresponds to about 12% of the total number of Mobidot records including transit (2,032 out of 16,463 records).

Regarding the bicycle aspects, as stated by Zhao and Li (2017), there are normally two types of bicycle use: as transfer and as direct mode. The first one works as a transfer mode to access or leave another travel mode, while the second one works as a standalone mode (without the combination with another travel mode). Therefore, in this database, all the bicycle use is treated as a transfer mode. Having said that, Figure 5 details how the records from category 1 work in the Mobidot database.

Figure 5 – Mobidot database structure



Source: author's own elaboration.

From Figure 5, it is possible to see that a person can access the PT and egress from it in four different ways: by bicycle, by car, by walking or none. When this last option appears in the records, it means that the person simply hopped in or off the PT – it is, in fact, a negligible walk. It happens when that person is too close to a stop/station, for the cases where "none" is recorded as the access mode, and/or too close to their final destination for those cases where "none" appears as the egress mode. Therefore, all the records in the sample contain, obligatorily, at least one combination of an access mode, a PT mode and an egress mode. There are some records showing the use of more than one mode of PT; in other words, some records are structured as follows: access mode 1 - PT 1 - egress mode 1 (which is also the access mode 2) - PT 2 - egress mode 2. Still, as aforementioned, all the records involve the use of bicycle at some point, even if it does not occur at the first access or egress. Hence, for the purpose of this research, in all the records, we consider only the first access to the PT, since we aim to analyse the first mile problem. Note that, so far, we are still taking into consideration the records where we have the first egress mode as bicycle, although, after some preliminary analyses, we decided to focus on the first access part only (first mile). That procedure is well detailed in chapter 4. To summarise, at this moment we are considering all the records that follow the structure of category 1, as previously presented:

i) bicycle + PT + car or walk or none;

ii) car or walk or none + PT + bicycle;

iii) bicycle + PT + bicycle.

Table 1 provides a general view of the content of Mobidot database that we use in this study. Additional details and analyses are presented throughout the next sections.

Table 1 – Mobidot global variables view

Variable	Description
starting_time	Trip starting time.
ending_time	Trip ending time.
date	Trip date.
org_lat & org_lng	Origin latitude and longitude.
dest_lat & dest_lng	Destination latitude and longitude.
modalities	Transport modality used in each segment of the trip.
access_mode & egress_mode	Access or egress to/from PT. Four modes: none, bike, car and walk.
bicycle_distance	Total distance run by bicycle to access and/or leave PT.
car_distance	Total distance run by car to access and/or leave PT.
walk_distance	Total distance run by walk to access and/or leave PT.
transit_board_latlng	Point where the person have boarded on the PT.
transit_alight_latlng	Point where the person have alighted from the PT.

Source: author's own elaboration.

Mobidot considers periods of time between 2018 and 2019 – therefore, before and after the start of the NSL line. The first amount of records was collected between June and July 2018, in the beginning of the summer and holidays period. In July 22^{nd}, the NSL started operating and a new round of data collecting was conducted, lasting 100 days. Differently from the first one, the second round was divided into two periods: right after (first 40 days) and shortly after (last 60 days) the NSL. The purpose of splitting the data in two distinct periods was to evaluate travellers' behaviour right after the beginning of NSL operation, in order to understand how users dealt with the new transit arrangement. A third round of data collecting took place in June and July 2019, one year after the NSL opening, and the goal was to assess travellers' behaviour after one year using the PT with its new arrangement and considering exactly the same period of the year, so it is possible to evaluate what have changed, under the same conditions. Table 2 shows the details about these four periods of analyses. The records are arranged per user, one per row, while the information about each user is arranged in columns. These characteristics allows us to say it is a longitudinal data set.

Table 2 – Periods of analysis according to the available database

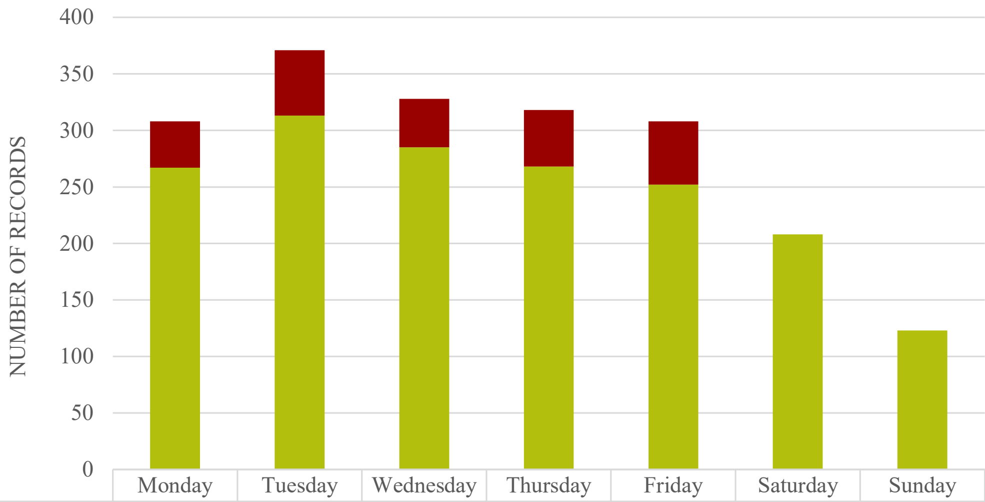
Period	From	To	Total	№of records	% of records	№of users
B the NSL[1]	01/06/2018	21/07/2018	50 days	619	32%	241
RA the NSL	22/07/2018	31/08/2018	40 days	192	10%	34
SA the NSL	01/09/2018	31/10/2018	60 days	598	30%	95
YA the NSL	01/06/2019	31/07/2019	60 days	555	28%	38

[1]North-South Line (*Noord-Zuidlijn*)
Source: author's own elaboration, based on Mobidot (2018,2019).

We can notice that the data is well distributed across the periods, except for the period right after the NSL, which has a shorter period of data collection, compared to the other three. Notice also that Mobidot database considers initially seven different PT modalities: boat, bus, ferry, metro, lightrail, train and tram. Two of these types were merged with other two modes due to their similarities and statistical representativeness: Boat+ Ferry = Boat and Tram + Lightrail = Tram (as previously depicted in Figure 5).

Smartphone's applications make possible to follow door-to-door, daily travel behavior for a specific individual. In this context, regarding the data collection tool, all records were based on information obtained from users' smartphones through a mobile app called Sesamo. Data was collected, using this app, 24 hours per day, every day during the period of analysis. One first procedure of the analysis is to remove all outliers and inconsistent information from the database. The result is a modified database containing 1,964 records, collected from 408 different users. Figure 6 depicts these records distribution per days of the week.

Figure 6 – Collecting data days



	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Peak-hour (7-9h and 16-18h)	41	58	43	50	56	0	0
Off-peak-hour	267	313	285	268	252	208	123

Source: author's own elaboration, based on Mobidot (2018,2019).

In this figure, besides the number of records per day, we can also notice the different times the data was recorded: peak-hours (morning peak: from 7h to 9h and afternoon peak: from 16h to 18h) and off-peak-hours during the week-days. It is also worth noticing that Sesamo app can automatically register door-to-door multimodal travel behaviour and that users are authorised to correct trip data when necessary (MOBIDOT, 2020).

3.2 DATA PREPARATION

As for data preparation, we deal with a data cleaning process to implement a descriptive analysis. In order to accomplish the objective of describing the main characteristics of the Mobidot database, the first step is to study and understand the database structure and available information, focusing on the aspects related to the use of bicycle as a feeder mode to BTM. In this step, the tasks can be described as follow:

1) Understanding what is inside the database: identifying the variables and all the information.
2) Data cleaning: identifying and disregarding the information which are dispensable to this research (e.g. outlier and inconsistent data).
3) Descriptive analyses: visualising the remaining data.

In thi task, it is possible to visualise the first evidences regarding the bicycle use behaviour before and after the beginning of the NSL operation. To assess the impact of NSL on the use of bicycle as an access mode in Amsterdam, some other tasks are conducted:

4) Checking the PT network of Amsterdam region, before and after the NSL.
5) Checking the boarding and alighting points, before and after the NSL.
6) Identifying bicycle facilities around the NSL stations.
7) Studying the similarities and differences of the bicycle accesses made to the BTM.

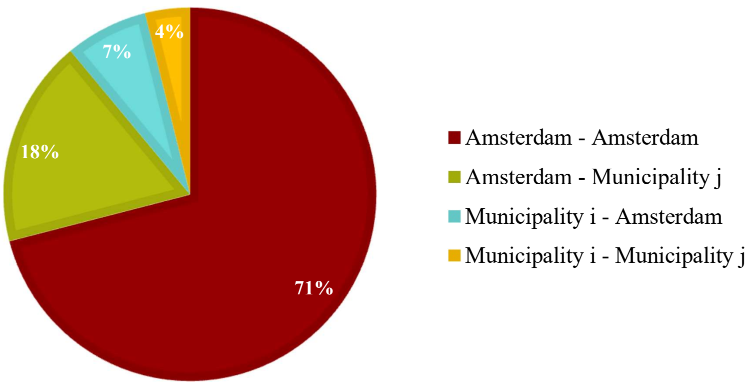
3.3 A DESCRIPTIVE ANALYSIS OF THE MOBIDOT DATABASE

Before starting to work with the Mobidot database, it needs to be clean it in order to disregard outliers and all the information that is not relevant to this research. As previously mentioned, this bicycle-transit section of the overall Mobidot database had initially a total of 2,032 records.

The first step of the cleaning process eliminated all the records registered outside the Netherlands, which resulted in a new total of 1,964 records (with reference to 409 different users). Based on these 1,964 records, a descriptive analysis is conducted, in order to understand the structure of the Mobidot database. Figure 13, at the end of this section, presents a summary with all the steps adopted to clean the database. The following charts depict the descriptive analyses that actually leads to other cleaning steps. The disregarded information refers to data that is not consistent with the main objective of this research; that is, to focus on the access by bicycle to the BTM stations in the Amsterdam region. Figure 7 depicts, in a simple way, the origin and destination of all the trips, according to the following four classifications:

- Amsterdam - Amsterdam: trips with origin and destination in Amsterdam;
- Amsterdam - Municipality *j*: trips with origin in Amsterdam and destination outside Amsterdam;
- Municipality *i* - Amsterdam: trips with origin outside Amsterdam and destination in Amsterdam.
- Municipality *i* - Municipality *j*: trips with origin and destination outside Amsterdam;

Figure 7 – Trips origin and destination



Source: author's own elaboration, based on Mobidot (2018,2019).

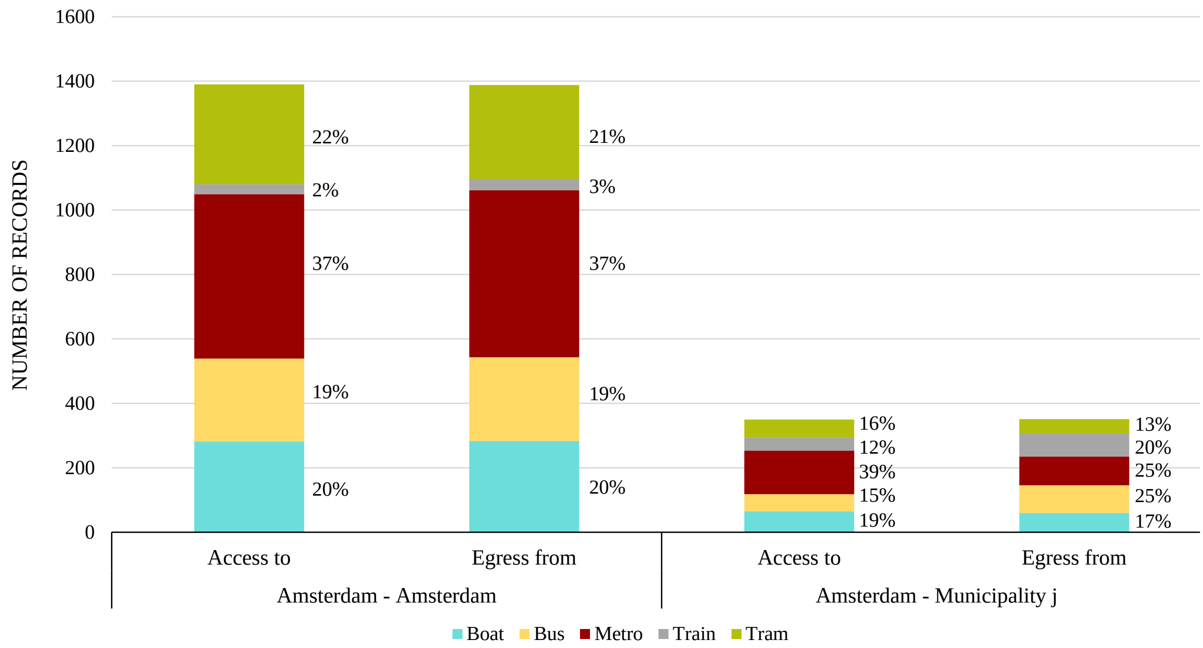
It is worth emphasising that Figure 7 is based on all the 1,964 records we obtained after the primary cleaning steps; that is, this figure includes records from the periods before and after the beginning of the NSL operation and records where accesses are made not only by bicycle but also by car and on foot. Besides, this set of records also contains the Mobidot pattern of five transportation modes: boat, bus, metro, train and tram.

Notice that 71% of all trips have their origin and destination within the Amsterdam region, and an additional 18% with Amsterdam region as their trip origin. Considering that this research focuses on the access to PT in the Amsterdam region, the records entirely taken outside the Amsterdam region (slice "Municipality *i* - Municipality *j*"), as well as those which have their origin in another municipality (slice "Municipality *i* - Amsterdam"), are disregarded. Therefore, our analysis is carried on considering only the remaining 89% of the database where the trip origin is in the Amsterdam region.

Next, Figure 8 stratifies the 1,747[1] records which represents 89% of all records presented in Figure 7.

[1] In fact, before building this figure, we still needed to disregard 7 records after they were identified as having the access to the as "unknown" and 8 records that were identified as having the egress mode as "unknown". It means that Figure 8 is built based on the remaining 1,740 records for the access part and 1,739 records for the egress part, and not 1,747.

Figure 8 – Access to and egress from each PT mode, with trip origin in Amsterdam region



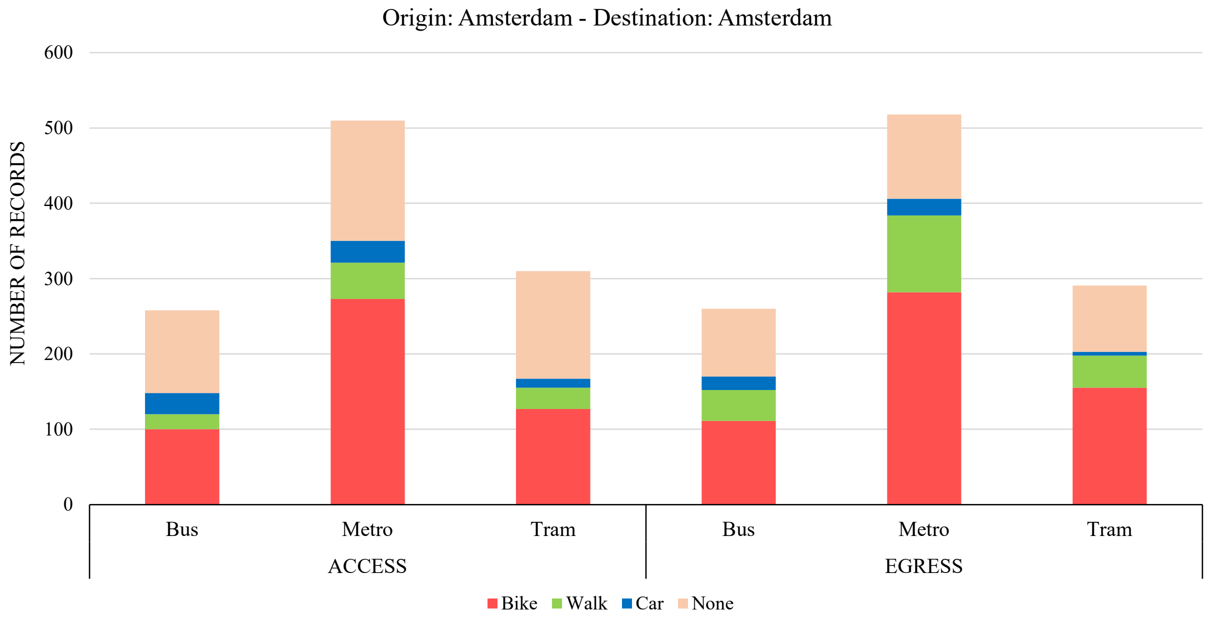
Source: author's own elaboration, based on Mobidot (2018,2019).

Taking into account only the access parts of our database, we are able to see that 37% of all the trip accesses with origin and destination in the Amsterdam region are to the metro, 22% to the tram and 19% to bus. Considering these trips with origin in the Amsterdam region and destination in another municipality, 39% of the accesses are to metro , while 16% to tram and 15% to bus.

Note that there is an increase of the number of accesses to train and, mainly, egresses from train, when the trips have their destination outside the Amsterdam area. It is more common to use the train to intercity trips. We can notice that for trips entirely within the Amsterdam region, 3% of the egresses are from trains; this percentage rises to 20% in trips with destination outside of this area. At this point, we can also observe that in both cases, the majority of accesses are to metro, followed by to tram. It is worth remembering that this information can be biased due to the data set we are using since it considers only the records that have at least one of segment by bicycle.

This research focuses on urban transportation modes only, since one of the main objectives is to analyse the impact of the new metro line (NSL). Therefore, our sample is simplified to consider the following commuting modes: bus, tram and metro. Then, Figure 9 depicts the access/egress modes to BTM used in trips with their origin and destination in the Amsterdam region.

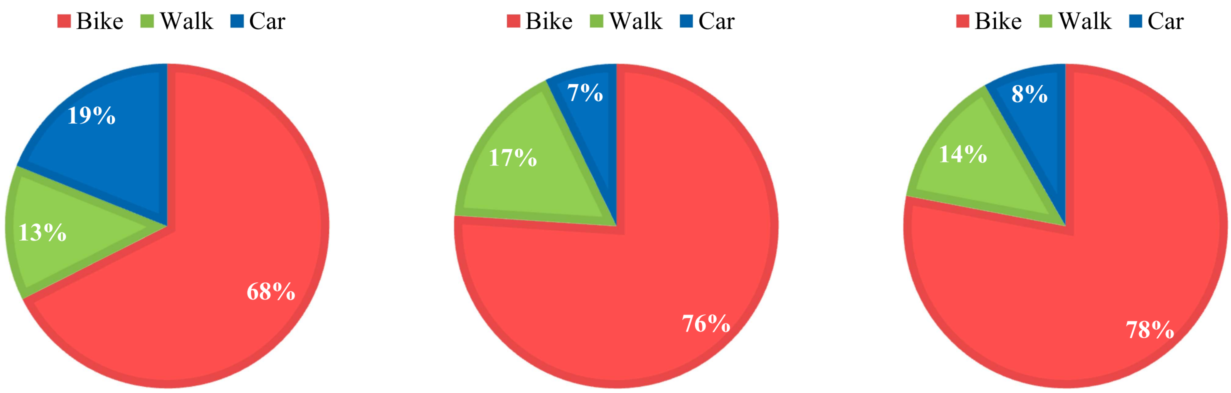
Figure 9 – Access and egress modes in trips with origin and destination in Amsterdam



Source: author's own elaboration, based on Mobidot (2018,2019).

In reality, "None" stands for a negligible walk; however, we can not merge both modes "None" and "Walk", because different from "Walk", "None" means that the user does not need to choose the access mode to reach the PT, since they were very close to a stop or station. For this reason, Figure 10 presents the mode of access to bus (Figure 10(a)), tram (Figure 10(b)) and metro (Figure 10(c)), in trips with origin and destination in the Amsterdam region, disregarding the mode of access "None".

Figure 10 – Accesses made to the bus, tram and metro in trips with origin and destination in Amsterdam region, stratified by each mode



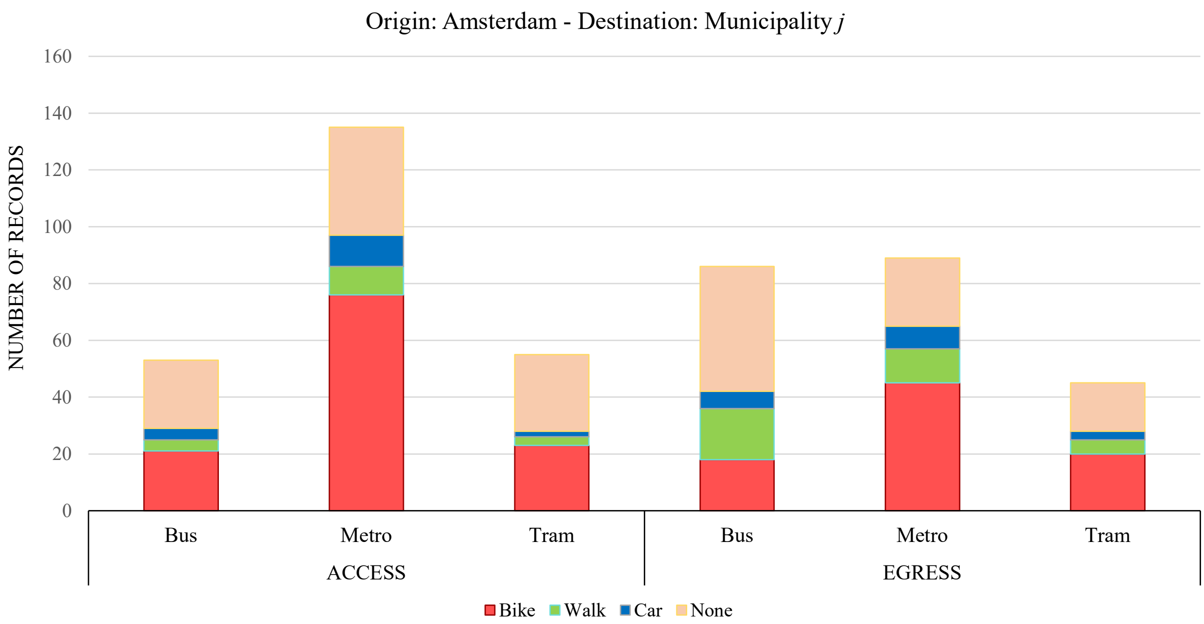
(a) Access to the bus (b) Access to the tram (c) Access to the metro

Source: author's own elaboration, based on Mobidot (2018,2019).

We can notice that to the three PT modes, most part of the accesses are by bicycle within the

Amsterdam region. Similar to Figure 9, Figure 11 depicts the occurrence of the same access modes to BTM, but now, for trips with their origin in the Amsterdam region and destination in another municipality.

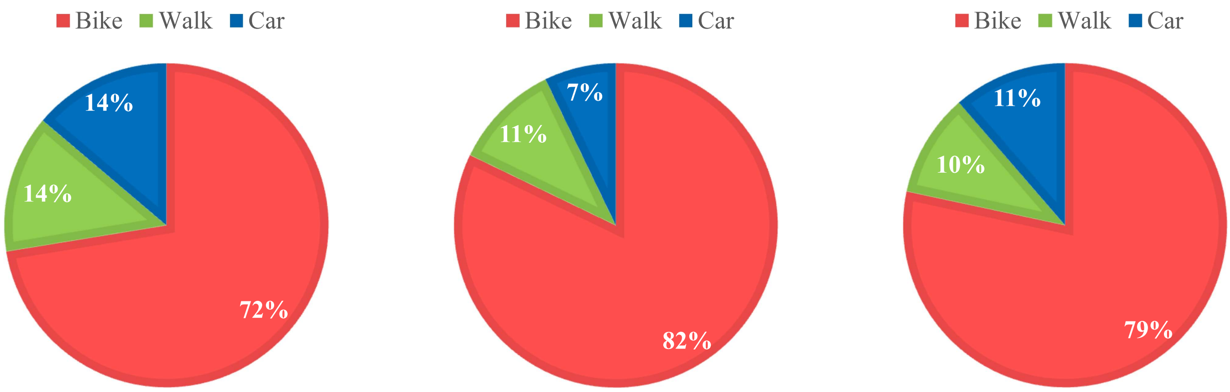
Figure 11 – Access and egress modes in trips with origin in Amsterdam and destination in another municipality



Source: author's own elaboration, based on Mobidot (2018,2019).

Figure 12 presents the mode of access to bus (Figure 12(a)), tram (Figure 12(b)) and metro (Figure 12(c)), for trips with their origin in the Amsterdam region and destination outside that region. Analogously to Figure 10, the mode of access "None" was disregarded.

Figure 12 – Accesses made to the bus, tram and metro in trips with origin in Amsterdam region and destination outside of Amsterdam region, stratified by each mode



(a) Access to the bus (b) Access to the tram (c) Access to the metro

Source: author's own elaboration, based on Mobidot (2018,2019).

Based on Figure 9 and Figure 11, it is noticeable that bicycle is the most frequently used mode to access BTM stops/stations, as well as to egress from them. We should take into consideration that our database can be biased, mainly due to its characteristics of being dedicated to the bicycle mode analyses.

For the purpose of this research, and considering that we have bicycle as the main access mode used to BTM stations, from this point forward, the modes of access "Walk" and "Car" (from this point onwards) are also disregarded. Given that assumptions, the initial database is cleaned and ready to be analysed according to the objectives of this research. Figure 13 summarises all cleaning steps taken so far, and the next sections present the analyses regarding the use of bicycle as the access mode, cycling distances, as well as considerations related to other variables.

Figure 13 – Cleaning summary

SUMMARY

Data cleaning process:

0. Our starting database contains only records where PT and bicycle appears (a total of 2,032 records).
1. Removing from analysis those trips with origin and/or destination outside the Netherlands;
2. Removing from analysis those trips with origin outside Amsterdam region;
3. Removing from analysis all the records with accesses and/or egresses from trains and boats;
4. Removing from analysis all the egress information.
5. Removing from analysis the records in which the access is made by walking or car.

To start the analyses, cleaned data contains only the records with:

1. Trips with origin in Amsterdam region.
2. Accesses made by bicycle.
3. Accesses to the bus, tram and metro.

Starting database: 2,032 records and 424 different users.
Cleaned database: 620 records and 229 different users.

Important points about each step:

1. This research focuses on the records taken inside the Netherlands only. This is the reason why we disregard all the records with origin and/or destination outside of the country.

2. We are focusing on data recorded in Amsterdam region, specially regarding the accesses to PT stations. This is the reason we removed all records with origin outside this region. Since the focus is on the accesses, we do not mind if the destination is outside of Amsterdam region.

3. The attention here is directed to urban transportation only: bus, tram and metro systems.

4. We are considering the cyclist's behaviour only while accessing PT stations. The emphasis is to understand if the NSL changed the choice of the access mode.

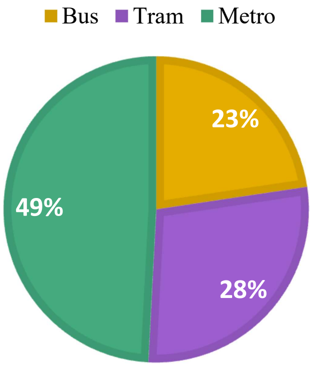
5. We previously mentioned that we are dealing with a database where there is at least one bicycle appearance in each record. That means that there are records where there is a different mode of access/egress: walk or car. Since we are dealing only with accesses by bicycle, we can disregard all the records where other access modes prevail.

3.3.1 Periods of analysis

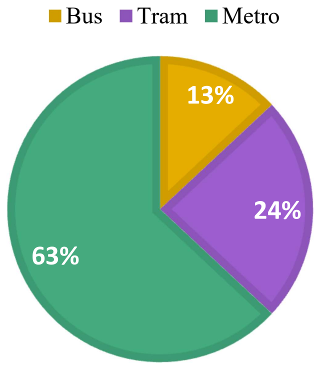
The data and results shown so far regard whole database, without distinguishing the trips that happened before or after the beginning of the NSL operation. In this section, we introduce the concept of these different periods (Table 2).

A first analysis is conducted to understand how people are using bicycles to access the PT system. Thereby, Figure 14 illustrates the use of bicycle to access BTM stops/stations and how that changes throughout the four periods.

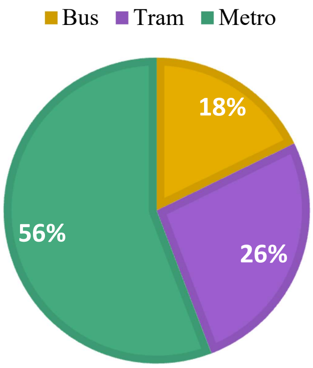
Figure 14 – Accesses made by bicycle to the bus, tram and metro, stratified by period



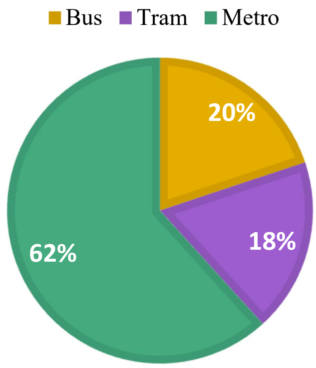
(a) Bicycle to the BTM before NSL



(b) Bicycle to the BTM right after NSL



(c) Bicycle to the BTM shortly after NSL



(d) Bicycle to the BTM one year after NSL

Source: author's own elaboration, based on Mobidot (2018,2019).

Figure 14(a) and Figure 14(d) are completely comparable, since they both consider the same period of the year (summer period in the Netherlands) with the interval of one year. Taking both figures into account, it is noticeable that there is an augment in the number of accesses by bicycle to metro, which shows the increase in the preference for accessing this mode instead of bus or tram.

We are now dealing with a total of 620 records and 229 different users. Out of this amount, 48 users had their trips before and after the NSL started operating (see Annex B). These 48 users generated a total of 240 records, compared to the 620 we are dealing with at this moment. Figure 15 depicts the mode of transport accessed by bicycle in these 240 records.

Figure 15 – Bicycle access to the BTM, considering only the records made by users who recorded their trips before and after the NSL

(a) Bicycle to BTM before the NSL (b) Bicycle to BTM after the NSL

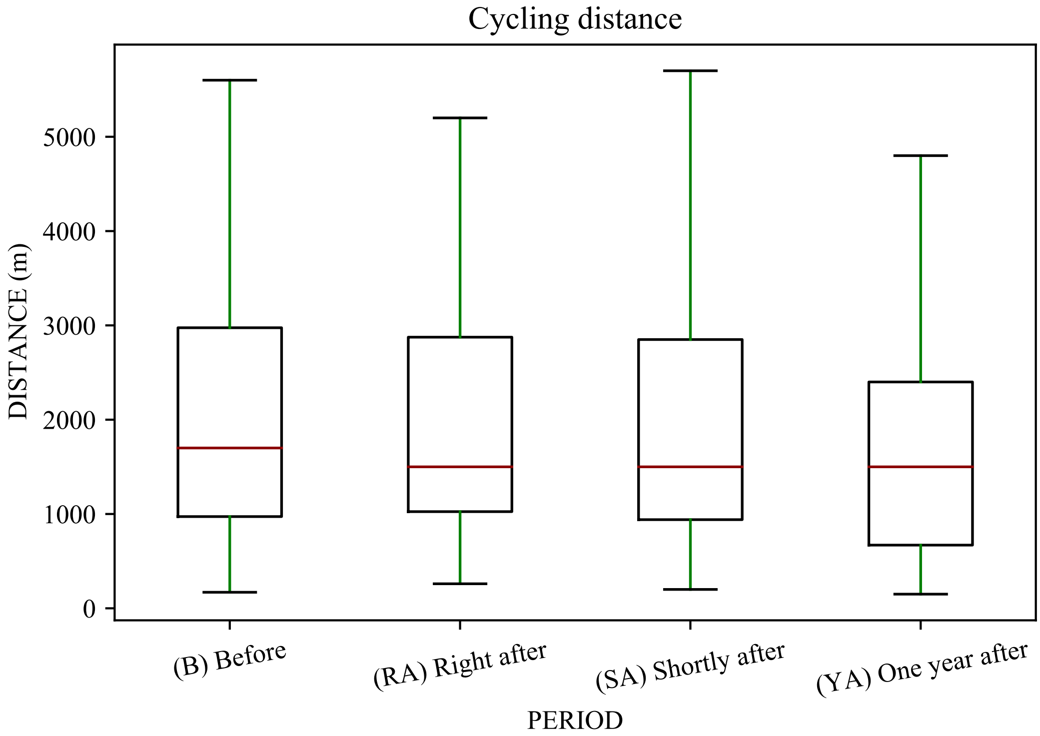
Source: author's own elaboration, based on Mobidot (2018,2019).

Similar to what we found in Figure 14, Figure 15 shows that there is an increase on the preference for the use of bicycle to access metro, compared to tram and bus. It is fair to assume that this higher number of users is a consequence of improvements to the PT network provided by the beginning of the NSL operation.

3.3.2 Bicycle as the access mode

The use of bicycle as a feeder mode to BTM stations should take into account the distance the user has to overcome to reach transit; that is, how far a person is willing to cycle. Even though we are not considering the egress part in this study, for the next analysis, it is relevant to mention that out of 620 records compatible with this research, 97 include a segment by bicycle – not only to access PT stations, but also to egress from them. Such emphasis is due to the fact that Mobidot database provides records only referring to the overall distance overcame by bicycle; it does not specify the distance to the access or the egress section. Therefore, in Figure 16, we disregarded the 97 records where bicycle is used both to access and egress PT stations. That procedure guarantees that the distance plotted refers only to users that are willing to access the BTM stations.

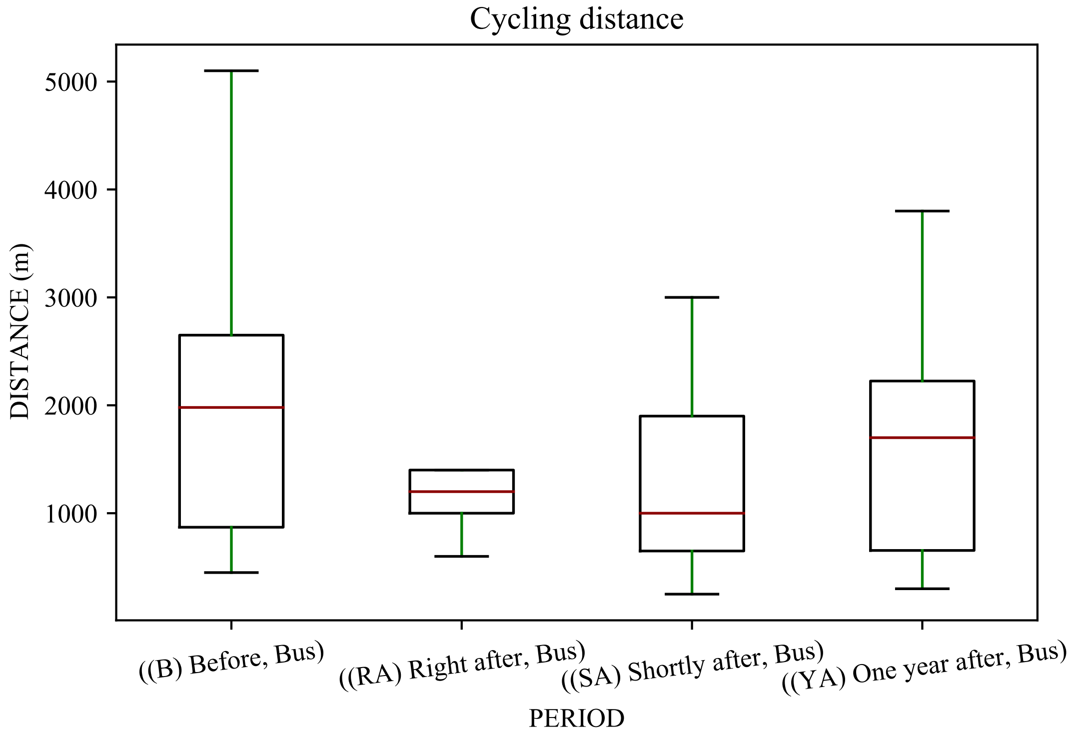
Figure 16 – Cycling distance per period (according to the NSL operation)



When examining the data (in a standard candlestick diagram), comparing the periods before and one year after the beginning of the NSL operation, we notice a decrease of the distance that the user cycle from/to PT stations. A possible explanation is that after the new metro line and the PT network rearrangement, some stations/stops can be accessed in a shorter distance compared to the period before the new arrangement. This hypothesis meets the evidence we reported in subsection 3.3.1, where we found an increase of the number of bicycle accesses to the metro system. In other words, we can infer that some people migrate to metro, and, as a consequence of the improved quality of the new metro line and of a higher accessibility in terms of a lower travel time (and distance) to cycle from/to the nearest station/stop.

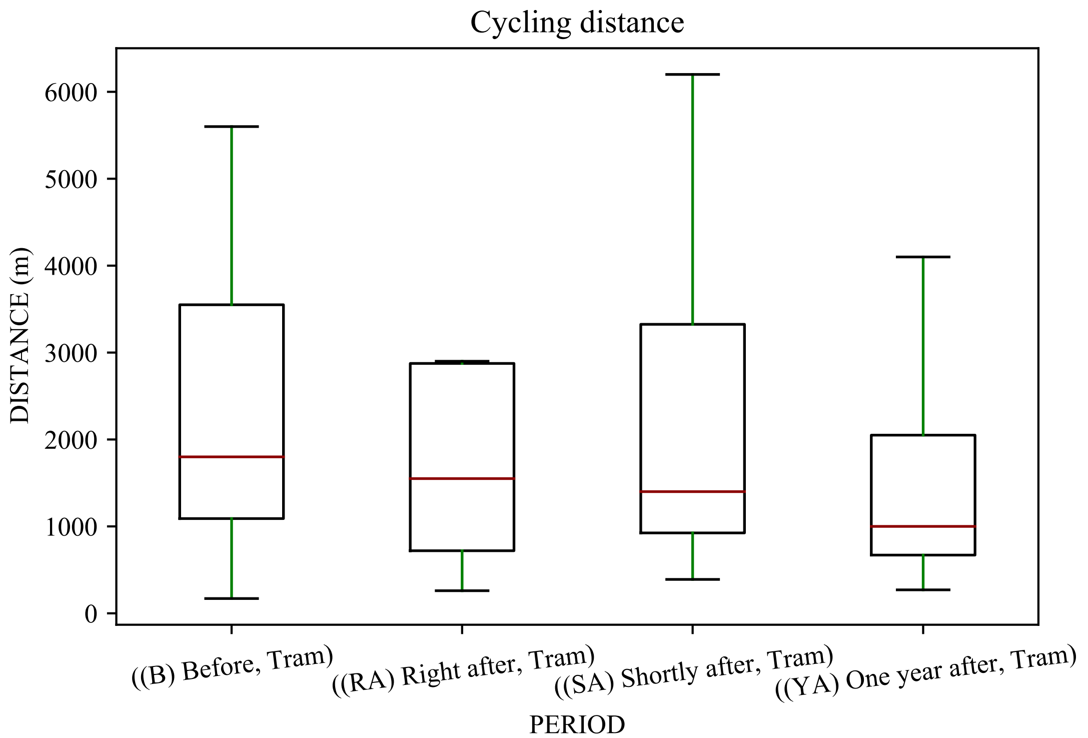
In Figures 17, 18 and 19 we show the results for travel distance for each PT mode and for each period of time.

Figure 17 – Bicycle distance to access the BUS, per period



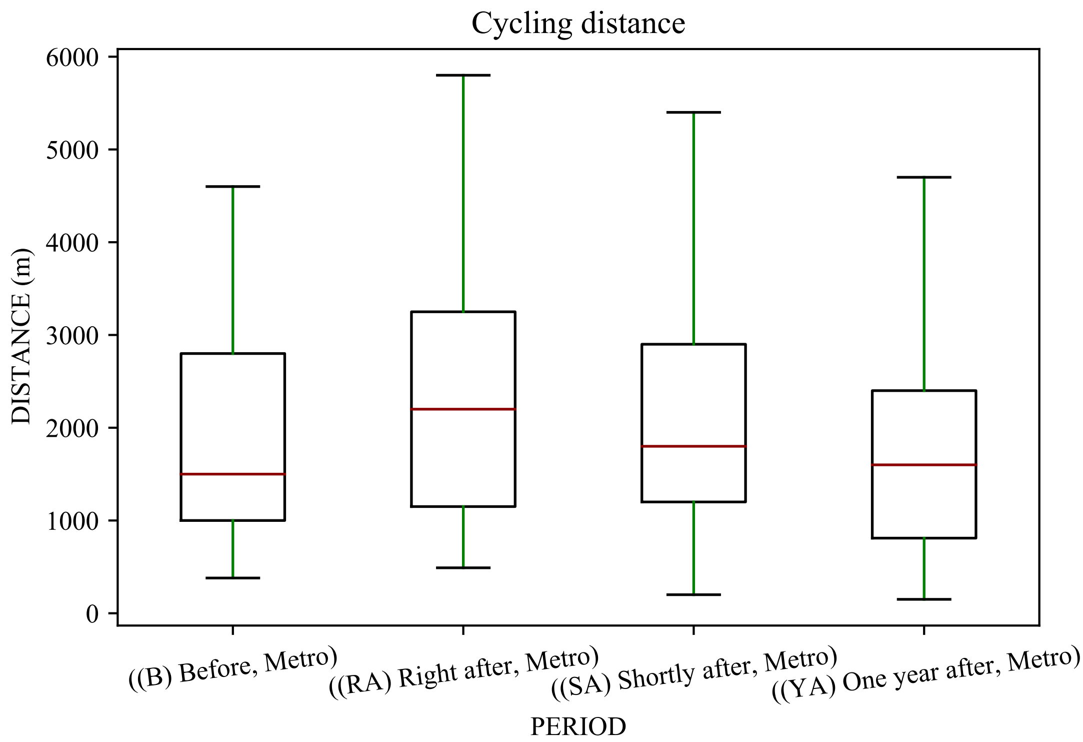
From Figure 17 we can notice a transitional moment during the RA period. However, when comparing the period B and YA, we do not notice a significant difference. One possible interpretation of this small reduction on the distance cycled to reach the bus stop/station is the increase on the preference for the metro, and as a consequence, people are cycling less to reach the bus.

Figure 18 – Bicycle distance to access the TRAM, per period



Similar to the bus user's behaviour, we can notice that there is also a decrease on the cycling distance to the tram stops. The interpretation is the same we got for the bus, that since people are boosting their preference for the metro, it is expected that they cycle less to reach the tram stop. One of the reasons for this preference is the connection between the stations Amsterdam Zuid and Amsterdam Noord, provided by the NSL, which allow people going from one of this stations to the other without any transfers.

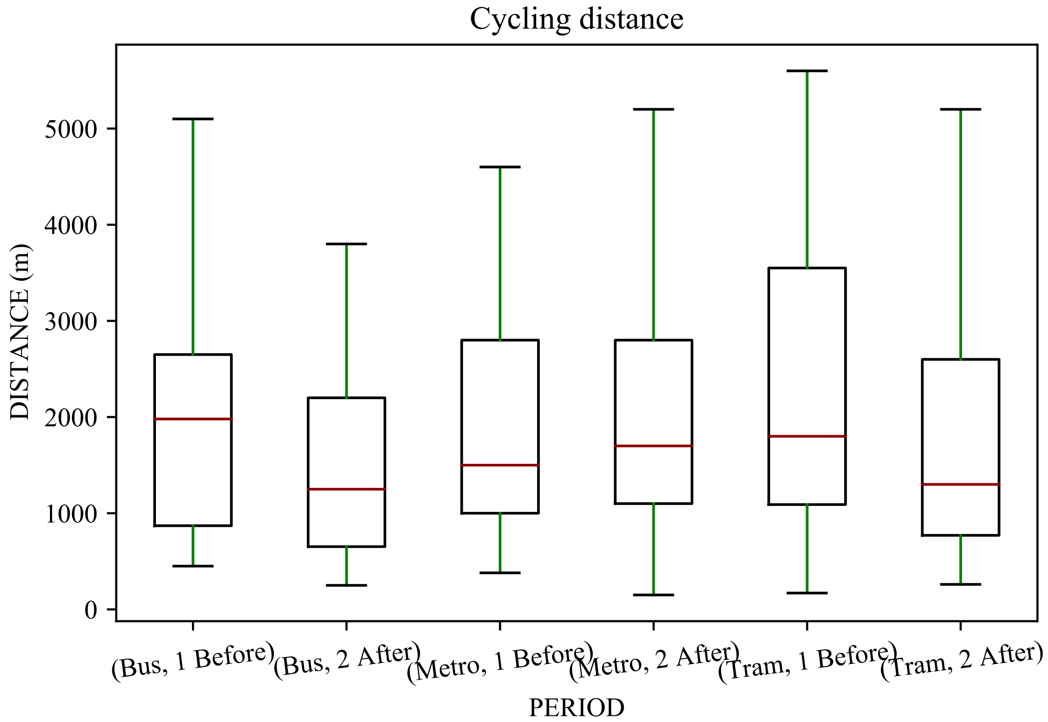
Figure 19 – Bicycle distance to access the METRO, per period



Following the same logic of interpretation, from Figure 19 we can see that there is an increase on the cycling distance to access the metro, when comparing the period B and the YA.

Figure 20 compiles the main information about the last four figures, to make it easier to visualise the cycling behaviour to each PT mode and considering the periods before (B) and after (RA + SA + YA) the NSL.

Figure 20 – Cycling distance to access the BTM, before and one year after the NSL



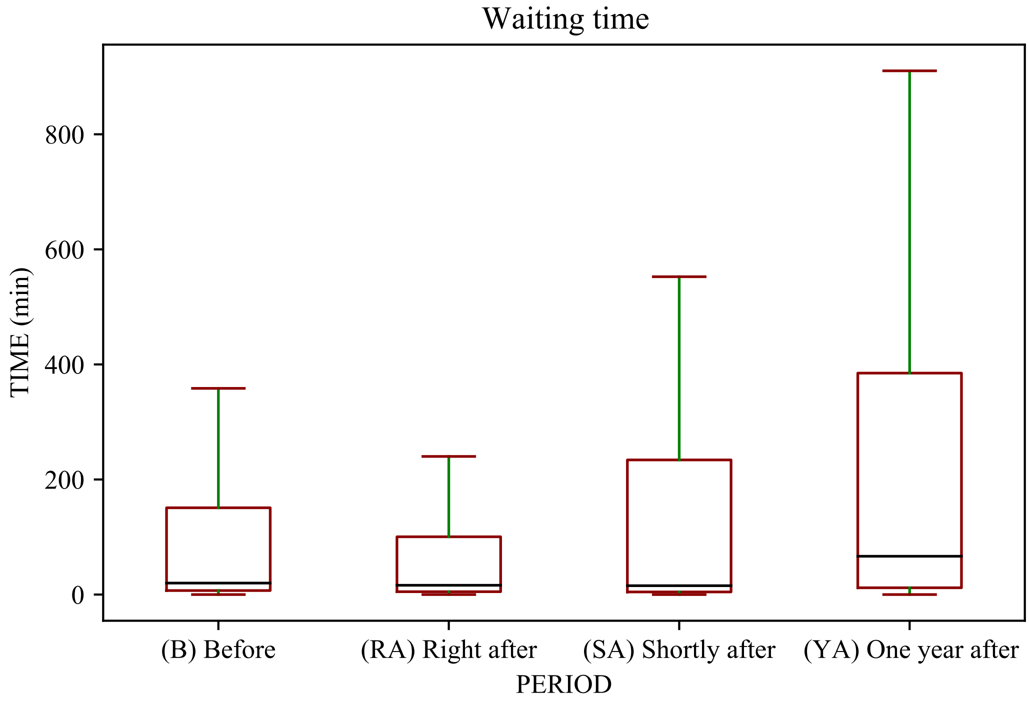
In this analysis we are comparing the periods before and after the beginning of the NSL, taking into account also the period of adaption, even though, we have the same conclusions from the period B and YA analysis we just did based on the previous figures.

3.3.3 Waiting time

Mobidot database also provides the total waiting time for each trip. The waiting time is defined as the time a person waits for her PT service after she arrives at a stop/station. This is an important variable to analyse since the time spent at the stop/station during a transfer directly impacts on the total travel time from origin to final destination. Especially in the context of an intermodal choice, the waiting time to change from one transportation mode to another is an indicator of connectivity of the whole transportation system.

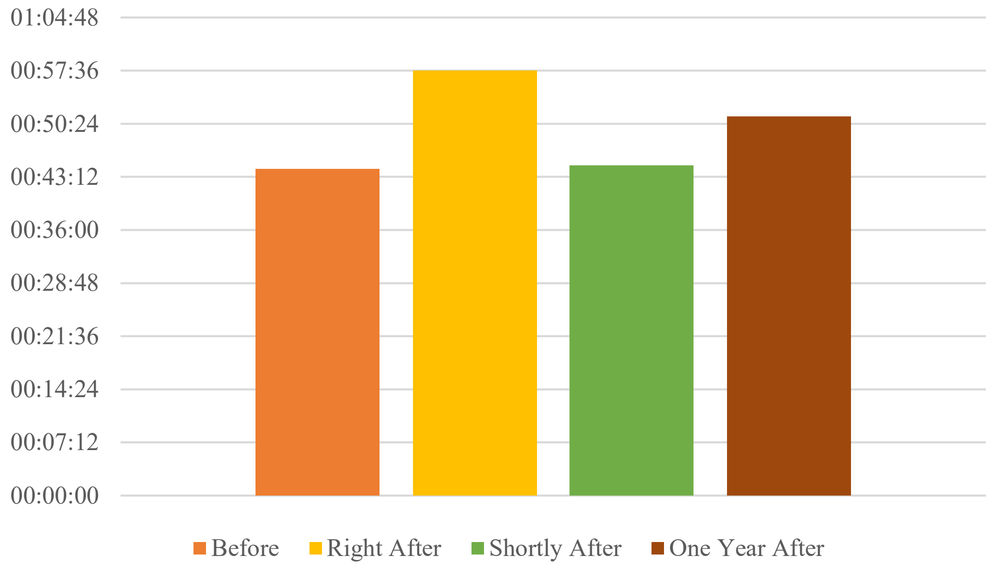
Since, in this study, the focus is on the first access stage of a trip, the waiting time in connections does not play a significant role. However, it can be useful to know how much time people wait at the stops/stations after reaching these PT by bicycle. Figure 21 shows that users experienced an increase of average and maximum waiting time shortly and, particularly, one year after the NSL implementation.

Figure 21 – Waiting time per period (according to the beginning of NSL operation)



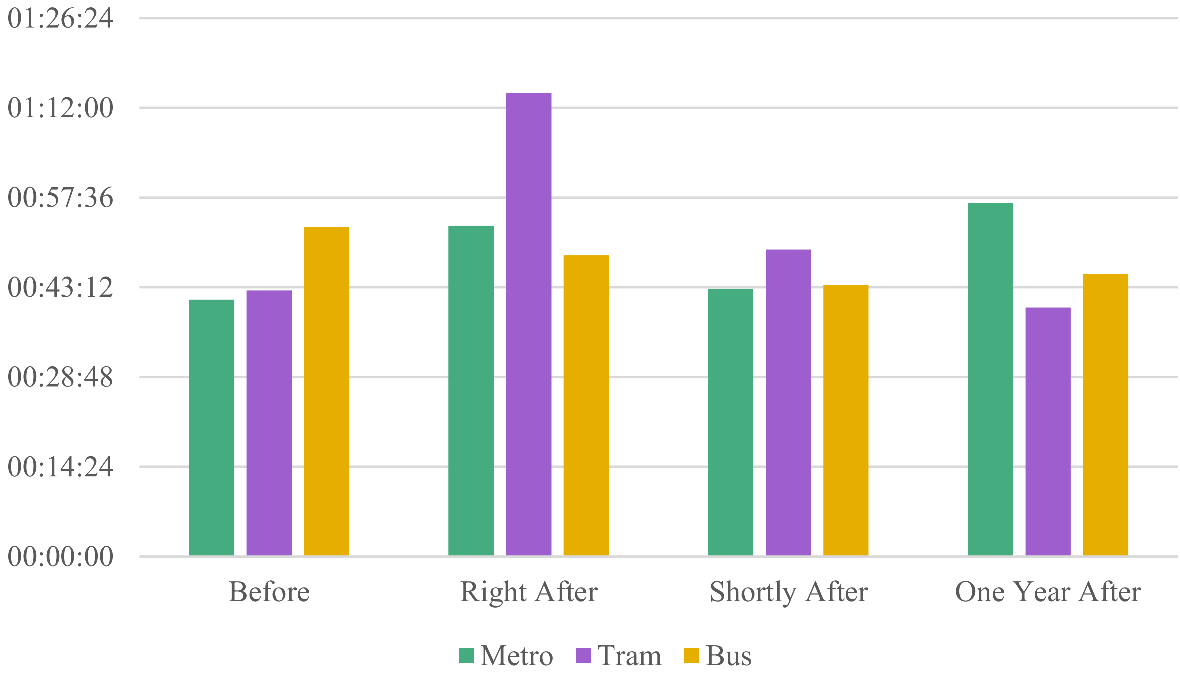
Notice that in Figure 21 we are considering the 620 records, since waiting time is associated to the access part only. It is worth noting that the significant increase of waiting time is accompanied by a non-significant decrease in total trip time, which makes the longer waiting period less bearable from the users standpoint. However, analyzing Figures 16 and 21, a potential reason to explain this behavior is the fact that bicycle users might be targeting closer stops/stations, where they do not mind waiting longer to catch their BTM mode. This is consistent with the fact that total trip time, before and after the NSL, did not significantly change, as we can see in Figure 22.

Figure 22 – Total trip duration comparative among the periods



Indeed, there is no much difference in total trip duration before and after the NSL, while users experienced an increase in waiting time and a reduction in the time they spent PTs. To make these results clearer, the next evidence shows trip duration for each PT mode. Our basic aim here is to identify if there is an increase on the trip duration when the user chooses metro.

Figure 23 – Total trip duration stratified per PT mode

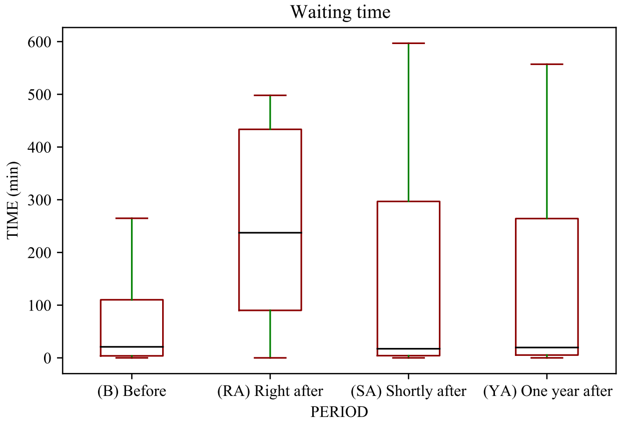


Based on Figure 23, we can notice that there is no clear trend for bus and tram. However, there is a significant increase of total trip duration for metro, mainly in a longer term (one year after). Total trip duration includes the time to access a station/stop, the waiting time, the time in the vehicle (PT) and the egress time.

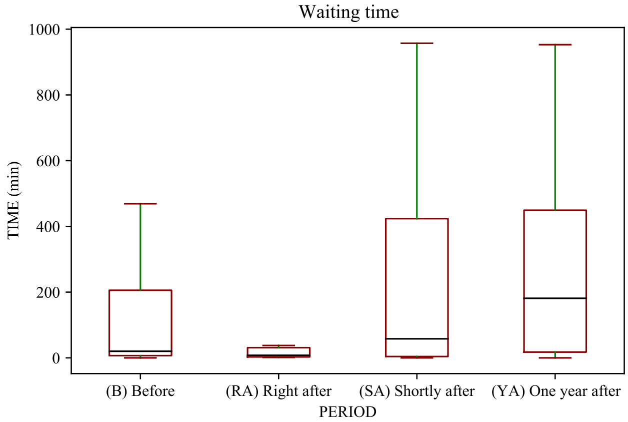
Figure 24 expresses the waiting time according to each PT mode and each period of time. Panels (a)-(c) show the results for each PT mode and panel (d) consolidates the results for the 3 PT modes (in only two periods: Before (B) and After (RA + SA + YA). The waiting time increases after the NSL for all PT, but that increase is larger for the cases of tram and metro. As previously mentioned, the relevance of analysing waiting time in this study is mainly due to oversee improvements needed in BTM stations/stops.

Figure 24 – Waiting time per period and per PT mode

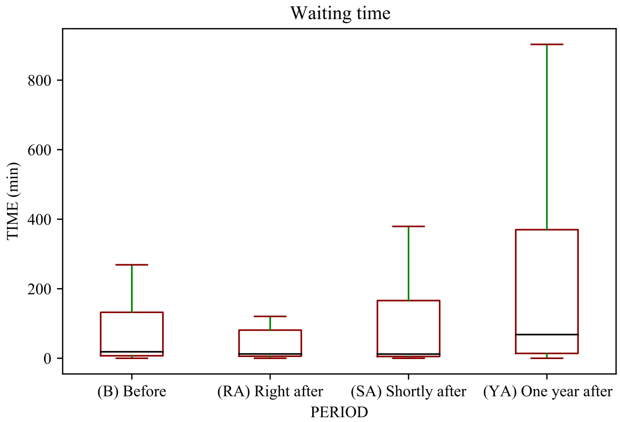
(a) Waiting time to access the BUS, per period



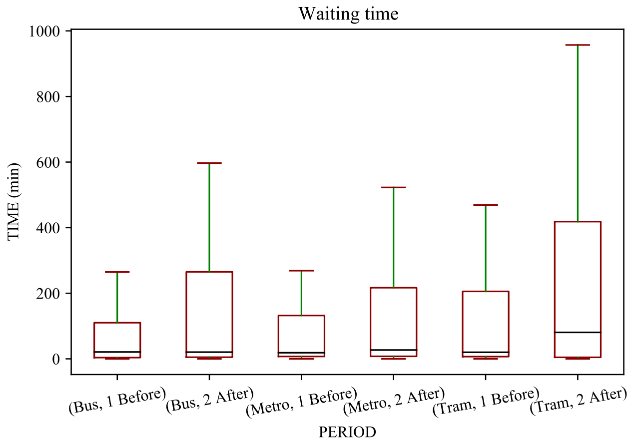
(b) Waiting time to access the TRAM, per period



(c) Waiting time to access the METRO, per period



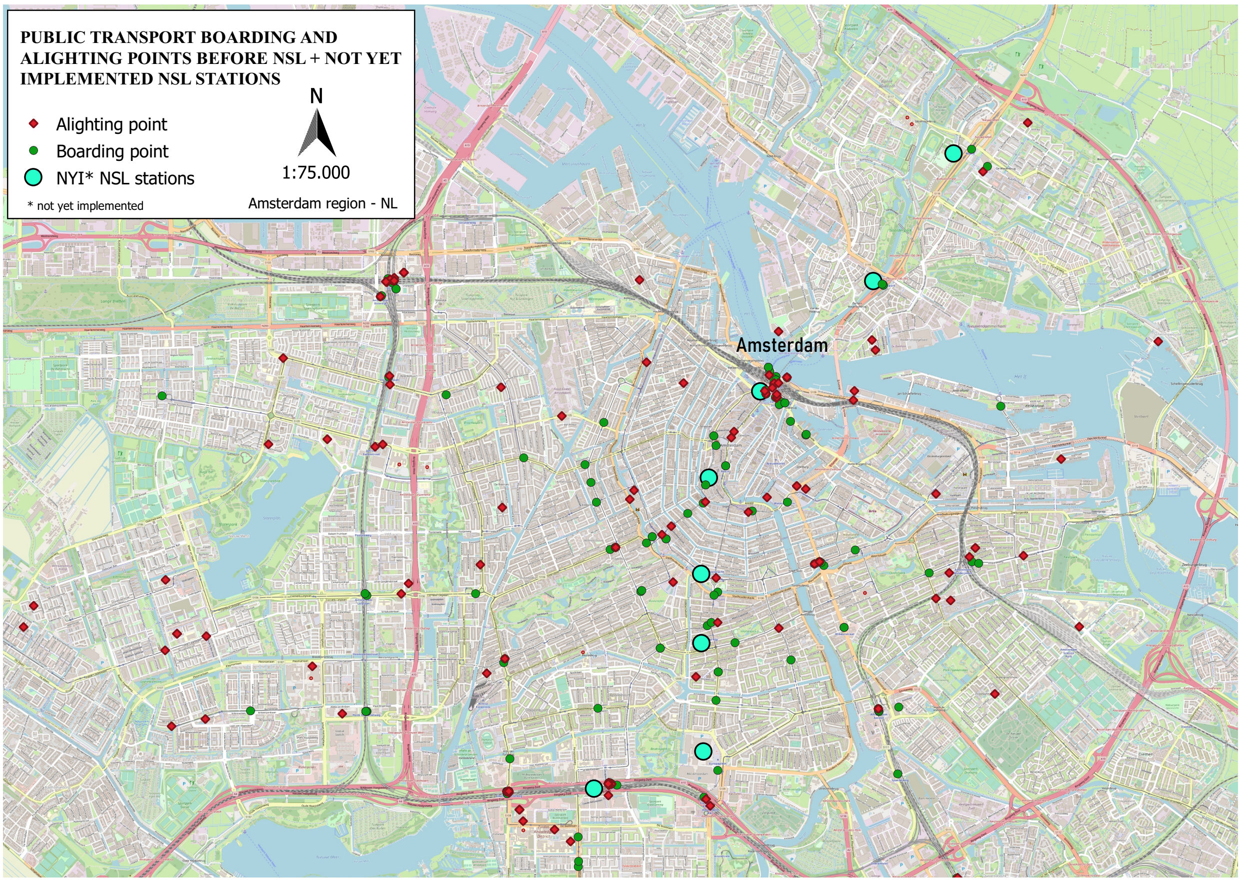
(d) Waiting time to the BTM, considering two periods only



3.3.4 Boarding and alighting locations

Figure 25 and Figure 26 depict the location of boarding and alighting points of users that choose to cycle to access BTM stops/stations, before and after the NSL, respectively. In this study, we are particularly interested in the boarding points during the user first mile. Although the density of boarding and alighting points is already high around the region of the NSL before its construction, such density increases significantly after the NSL, especially in Amsterdam North area. These maps are an alternative way to evaluate users' origin and destination locations. For instance, they provide the stops/stations that are most used and, then, allow one to check what of facilities are available in each case.

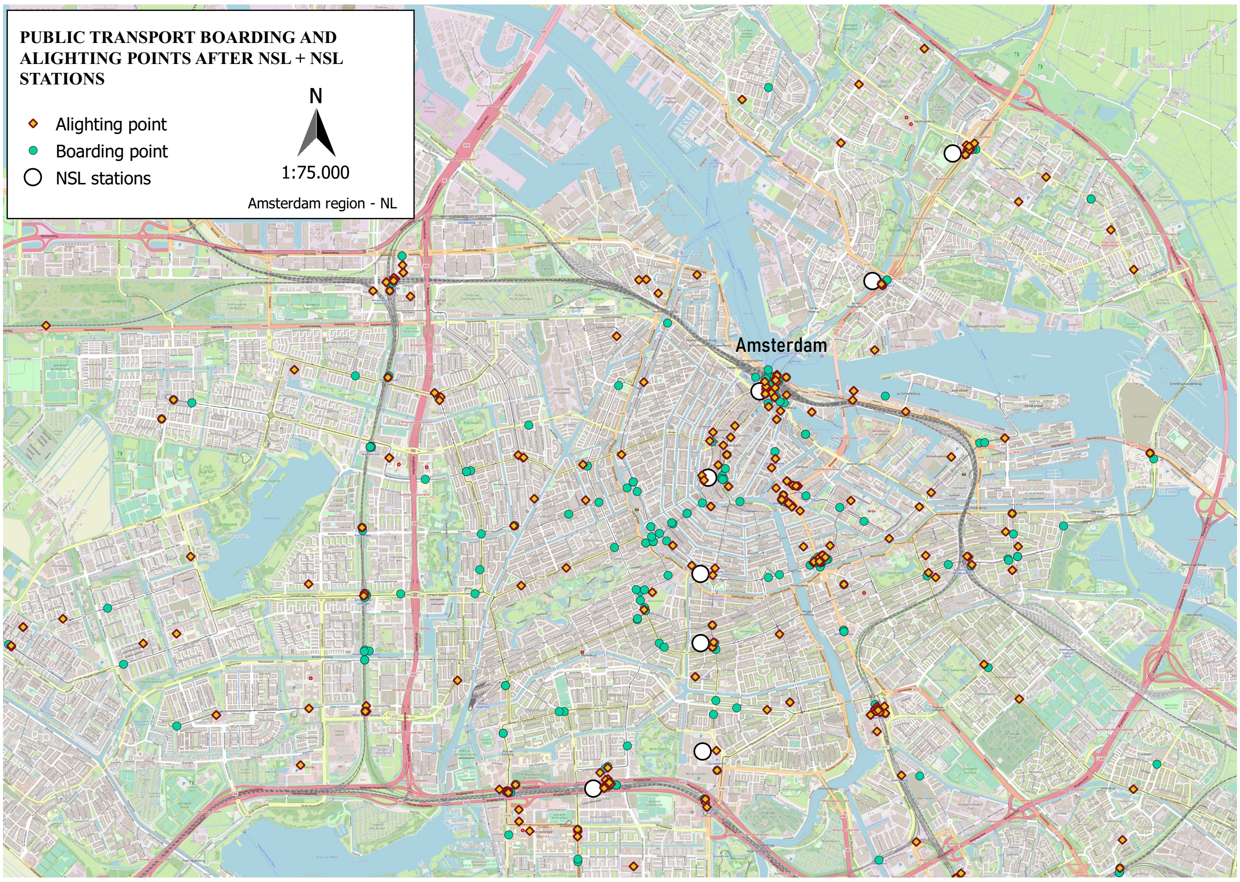
Figure 25 – PT boarding and alighting locations before North-South line



Source: author's own elaboration using QGIS (2020), based on Mobidot (2018,2019).

These maps are an interesting way to see users' origin and destination locations. They make room for a new analysis regarding the use of stops/stations. In other words, they allow to explore what are the stops/stations used the most and check what kind of facilities those ones provide.

Figure 26 – PT boarding and alighting locations after North-South line



Source: author's own elaboration using QGIS (2020), based on Mobidot (2018,2019).

4 ECONOMETRIC MODEL

In the previous chapter – **Database and Data Descriptive Analysis** –, we had some perspectives on the information and analysis based on Mobidot database. In this chapter, we deal with modelling the complementary modal choice of a public transportation user who leaves home by bicycle and needs to reach a farther destination. The chapter is divided into two sections. First, we specify the model, posing the modal choice problem, reviewing previous studies on bicycle choices and defining some main econometric issues involved in our model. Second, we present and evaluate our main results.

4.1 MODEL SPECIFICATION

Broadly speaking, the problem we have at hand is to model users' choice concerning three alternative transportation modes (bus, tram and metro) given that they chose a bicycle in the first mile of their journey. The problem of modal choice is well documented in the literature (BUEHLER, 2011; TYRINOPOULOS; ANTONIOU, 2013; ARBUÉS et al., 2016; CHARREIRE et al., 2021). More specifically, the challenge to examine the role of bicycle as a commute mode choice has been tackled mainly in the context of European countries, as Heinen et al. (2012) who have conducted an internet survey in four Dutch municipalities in order to investigate the related factors that influence the decision of cycling to work. Their results suggest that a positive attitude towards cycling, colleagues' expectations (that one is actually cycling to work), indoor parking lot for bicycles, access to dressing room facilities and occasional use of a bicycle during office hours increase the likelihood of choosing bicycle as a commute mode.

Furthermore, the use of bicycle as a feeder mode has been also studied in the mode choice context. La Paix et al. (2021) examined the effect of the perception of bicycle infrastructure on the choice of the bicycle as a feeder mode to access train stations in the Netherlands. They conclude that the impact of cost and time characteristics on access mode choice changes according to the infrastructure quality. The most critical observed factor which influences bicycle access choice to the train stations is the bicycle parking cost and the distance to the platform. Therefore, La Paix et al. (2021) reinforce the quality of bicycle infrastructure, the station connectivity and the attitude toward cycling as the main drivers of the decision to choose bicycle to access the station. In the present case, given the characteristics of the Mobidot database, we deal basically with explanatory variables that describe the transportation features of each mode, such as travel time, distance and waiting time (during mode connection). Since the main objective of this research is to understand the aspects that influence cyclists' commuting mode choice, the dependent variable is the probability of someone that uses bicycle as a feeder mode to each one of the BTM alternatives. Therefore, the model can be classified in the class of limited-dependent variable specification. More specifically, a logit model is applied in two two different assumptions. The first one is a multinomial model, where the dependent variable is a discrete scale (1, 2 and 3), which identifies each BTM (respectively, bus, tram and metro). In the second model type, we define a binary choice under the dependent variable: the cyclist is commuting either with metro (1) or not with metro (bus or tram; 0). The main purpose of this simpler binary approach is to confirm or reject the results obtained in the ternary model. In methodological terms, the multinomial logit is an extension of the traditional logit model from two attributes to n attributes.

The underlying model of a user's decision about her choice of a connecting mode from a PT station usually refers to a travel utility function where utility is associated with benefits such as gains in time, cost and comfort. The utility function allows us to analyse the individual behaviour before the set of alternatives they have, once it associates the product attributes to its utility (BEN-AKIVA; LERMAN, 2018). The theoretical model implicitly assumes the users (i) maximise utility in their selection (j). The typical utility function (U_{ij}), as pointed out by Liu et al. (2019), comprise two components: V_{ij} which is a systematic component and e_{ij} which is a random disturbance, expressed by Equation 4.1.

$$U_{ij} = V_{ij} + \epsilon_{ij} \tag{4.1}$$

The simplest way to express this utility function Is to assume it takes a linear form:

$$V_{ij} = x_{ij}\beta_{ij} + z_i\gamma_i \tag{4.2}$$

Where:

x_{ij} is the utility value of selection j;

z_i are the explanatory inputs which vary only with the traveler i;

γ_i are coefficients.

In order to connect this theoretical approach with our estimation procedure, we need to discuss the estimation methodology. Since we seek for a model that relates the probability of a user to choose each transportation mode with some characteristics of that choice (e.g., travel time and comfort), models of limited dependent variable are a natural option. A long discussion could be addressed to compare the pros and cons for parametric and non-parametric models. The reasons we do not go into that debate are the fact that results of parametric models are more intuitive and more applied in the context of transportation policy and the results allow us to evaluate the individual performance of each explanatory variable. Non-parametric models (e.g., neural networks) are successfully used, for instance, in the context of forecasts. Besides, the field of travel demand forecasting has been dominated by parametric approaches, as the logit models (LEE et al., 2018). The main aspects of a parametric approach is its capacity of dealing with stochastic noises and the possibility of accomplishing statistic hypothesis tests.

Considering the context of the study and objectives of this research, we can consider that our **null hypothesis** is that nothing has changed on the cyclists' choice on which transport mode to access by bicycle after the beginning of the NSL operation. Within models of limited dependent variables, we follow in this study the application of multinomial and binominal logit models, since we focus on the user decision concerning 3 alternatives (B, T or M) and also referring to 2 choices (M or non-M).

Formally, similar to the conventional logit model, the purpose in a multinomial context is to estimate the probability of occurrence of each attribute. In summary, the model can be expressed by the following Equation 4.3.

$$f(k,i) = a_0 + a_{1k}x_{1i} + a_{2k}x_{2i} + ... + a_{nk}x_{ni} \tag{4.3}$$

Where:

$f(k,i)$ is a linear function that predicts the probability of an observation i assuming the value k;

a_{nk} are regression coefficients; and

x_{ni} are a set of explanatory variables.

Based on this brief theoretical framework and estimation methodology, Table 3 presents the dependent and independent variables to be used in this model.

Table 3 – Variables to be used in the multinomial logit model

Variable	Description
$choice$	Dependent variable. It represents the cyclist's choice about which PT mode they are going to use. 1 - Bus 2 - Tram 3 - Metro
$tripduration\_BUS$ $tripduration\_TRAM$ $tripduration\_METRO$	Total trip duration in minutes (access to the PT + waiting itime + PT + egress from the PT)
$access\_bicycle\_distance\_BUS$ $access\_bicycle\_distance\_TRAM$ $access\_bicycle\_distance\_METRO$	Distance, in meters, made by bicycle to access the bus/tram/metro stop/station.
$period$ (dummy)	1 - Before 2 - Right After 3 - Shortly After 4 - One Year After
$dayoftheweek$ (dummy)	1 - weekday (from Monday to Friday) 0 - weekend (Saturday and Sunday)
$peakhour$ (dummy)	1 - peak-hour (from 6h to 9h and from 15h to 18h) 0 - off-peak-hour

Notice that we do not consider the variable "waiting time" in our model, since it is highly correlated with trip duration. Besides, our focus is on the first mile after the cyclist reaches the PT station and decides for Bus, Tram or Metro as a connecting mode to reach her final destination. The time she spends waiting for her connection is conditioned on many other aspects, such as her decision concerning the time she leaves home and the speed she rides her bicycle.

In order to know the variables dimensions we are dealing with, Table 4 presents each variable average and standard deviation.

Table 4 – Independent modelling variables details

Variable	Period ∗	Average	Standard Deviation (σ)
$trip\_duration\_BUS$	Before	35 min	15 min
	One year after	42 min	22 min
$trip\_duration\_TRAM$	Before	35 min	16 min
	One year after	42 min	24 min
$trip\_duration\_METRO$	Before	38 min	14 min
	One year after	41 min	17 min
$access\_bicycle\_distance\_BUS$	Before	1716 m	578 m
	One year after	1852 m	751 m
$access\_bicycle\_distance\_TRAM$	Before	1770 m	490 m
	One year after	1651 m	452 m
$access\_bicycle\_distance\_METRO$	Before	1728 m	504 m
	One year after	1716 m	601 m

∗ according to the NSL.

4.2 DATA SAMPLE ADJUSTMENTS

Given the previous explanation about modelling procedures, we aim, in this section, to make some data preparation in order to estimate the model. First, it is important to acknowledge that our data sample is a longitudinal data set (time series, cross-sectional data sample). In this case, the data sample is characterised by different amounts of records that are collected in distinct periods of time and not necessarily from the same data provider (we have different users/cyclists registering data in each period). Second, one way to comprehend the reason why someone chooses one option to another is by figuring out why one does not choose the other ones. Therefore, the main data sample adjustment is due to composing a database where both unobserved and observed records are taken into account. In other words, in addition to the original and actual data we retrieved from the Mobidot database, we also consider a number of unobserved records that are compatible with the information we obtain from the sampled data.

Thus, the proposal is integrating both unobserved and observed records. In other words, in addition to the original – and actual – data we got from the Mobidot database, we are considering also a number of unobserved records with compatible information, which will help in understanding the cyclists' behaviour. These are generated records and the way they are introduced to analyses is explained next, with Table 5.

It also means that the database used in this modelling step is slightly distinct from the one used in chapter 3, where we have worked on a descriptive analysis with actual data collected from regular users. In this chapter, however, the analyses are based in a compiled database, which is composed of the part of the Mobidot database we have been using so far, plus a set of generated records. These are records generated based on real timetables and present all the PT alternatives one had to access by bicycle at the specific day and time of each Mobidot record we have been considering. Hence, the generated dataset delivers the same information fields as the actual Mobidot data, so they express all the possibilities of choice that someone had when they decided to use their bicycle to access the PT system. Thus, besides the original record of an user “X”, the database we use from now on is a version which also has two other generated alternatives corresponding to the ones the user X could have chosen, but did not. To make it clearer, this new version’s structure is presented in the following Table 5.

Table 5 – Database new version’s structure

Record code	**Record**	**User ID**	(remaining data)	**Access mode**	**Access to (BTM)**
1	Actual	215340	...	Bicycle	Tram
2	Generated	215340	...	Bicycle	Bus
3	Generated	215340	...	Bicycle	Metro
1	Actual	215080	...	Bicycle	Metro
2	Generated	215080	...	Bicycle	Tram
3	Generated	215080	...	Bicycle	Bus

Source: author’s own elaboration.

As presented in Table 5, in real life (record we have from Mobidot database), the user “215340” used a bicycle to access the tram. Considering that, two generated (fictitious) records are included to this same user. The included records are generated based on real conditions and timetables – it means that they were, in fact, options that the user “215340” had at the same day and time they decided to choose the PT option recorded in the Mobidot database. Another way to say this is that, since this user chose to access the tram, fictitious records corresponding to the choice they could have had of using the bus and the metro, instead of the tram, are added to that user, so we are able to compare all the three alternatives they had in order to understand why they chose the tram instead of one of the other available modes.

Similarly, to the user “215080”, who, in real life, decided to use a bicycle to access the metro, two generated records containing the options tram and bus are added. To all the users in the Mobidot database we are considering in this research, two generated records are added to their registration. When there is no other possibility apart from the chosen one, we can understand it as being the reason to choose the only available option. Even though we have this in mind, for the following analyses, we consider only the records made by users who had the three options and had to decide between using the bus, tram or metro. It all leads us to the next section, where we present the results from the modelling.

As mentioned, the generated records were create from Google Maps™ tool. A whole dataset was generated, containing all the possibilities one had to go from the same point A to B presented in each record of Mobidot database. Since we generates all the possibilities, it included also alternatives out of the scope of this research, for example do the whole way from A to B by bus or by bicycle, or train only. That is why we needed to clean also this set of data before using it. After the cleaning process, we end up with the records where we had an access made by bicycle to a BTM vehicle. Only after this cleaning process we were able to merge both Mobidot and the generated data.

4.3 MODEL RESULTS

This section contains the modelling results from both the multinomial and binary logit models. We start with the multinomial logit and then use the binary results to verify the results convergence.

4.3.1 Multinomial Logit

As previously mentioned, our dependent variable $choice$ can assume three values: 1, 2 and 3. Each value corresponds to a transport mode option: bus, tram and metro, respectively. Thus, the higher the coefficient given in each result, the higher its association with the option metro (3). In this sense, Table 6 presents the first model results, containing all the variables presented in Table 3.

Table 6 – Model 1A: multinomial logit with all the variables

Dependent variable: choice				
Variable	**Coefficient**	**Probability**		**z-statistic**
$access\_bicycle\_distance\_BUS$	-0.169	0.7709		-0.291
$access\_bicycle\_distance\_TRAM$	0.645	0.3194		0.996
$access\_bicycle\_distance\_METRO$	2.289	0.0004	****	3.515
$trip\_duration\_BUS$	2.122	0.0461	**	1.994
$trip\_duration\_TRAM$	1.261	0.1668	*	1.382
$trip\_duration\_METRO$	-4.480	0.0000	****	-4.478
$period$	0.287	0.0688	**	1.820
$dayoftheweek$	0.003	0.9953		0.006
$peakhour$	0.016	0.9668		0.042

Pseudo R-squared: 0.144
Likelihood-Ratio (LR) statistic: 40.300
Sample: 351 records
Included observations: 142 after adjustments
Number of ordered indicator values: 3

**** = 1%, *** = 5%, ** = 10%, * = 20% of statistical significance.

In a first glance these results would lead us to understand that the higher the distance cycled until the PT station or stop, the higher the probability of someone taking the metro. Regarding the variable which represents the trip duration of each mode, the higher the trip duration, the higher the probability of taking a bus instead of a tram or metro. However, we must consider that some of these results are not statistically significant – as for the access by bicycle made to the bus and tram, the day of the week and the peak hour ($access\_bicycle\_distance\_BUS$, $access\_bicycle\_distance\_TRAM$, $dayoftheweek$ and $peakhour\_peak$). It means they are not relevant to determine whether someone chooses to cycle to a specific PT mode station or not. Therefore, a second model is tested after disregarding those non-significant variables from the analyses and it is presented in the following Table 7.

The second result, presented in Table 7, comes from a second version of Model 1A. Model 1B disregards the variables which were deemed as non-statistical significant in Model 1A.

Table 7 – Model 1B: after Model 1A adjustments

Dependent variable: choice				
Variable	**Coefficient**	**Probability**		**z-statistic**
$access\_bicycle\_distance\_TRAM$	0.633	0.3201		0.994
$access\_bicycle\_distance\_METRO$	2.263	0.0004	****	3.523
$trip\_duration\_BUS$	2.120	0.0404	***	2.050
$trip\_duration\_TRAM$	1.229	0.1660	*	1.385
$trip\_duration\_METRO$	-4.473	0.0000	****	-4.502
$period$	0.286	0.0677	***	1.827
Pseudo R-squared: 0.144				
Likelihood-Ratio (LR) statistic: 40.214				
Sample: 351 records				
Included observations: 142 after adjustments				
Number of ordered indicator values: 3				

**** = 1%, *** = 5%, ** = 10%, * = 20% of statistical significance.

In Model 1B, we can already find better results compared to the previous model. Firstly, We now have a lower Likelihood-Ratio (LR) statistic info criterion, which means that Model 1B presents higher quality than the Model 1A – which implies that this second model better represents the reality. Even though, there is still room to improve the model, whereas there is this variable $access\_bicycle\_distance\_TRAM$ which is statistically non-significant in this second attempt. After running this second model, we found out the strong correlation between the variables $trip\_duration$ and the $access\_bicycle\_distance$, thus we tried to remove from analysis the variable $trip\_duration\_TRAM$ instead of the $access\_bicycle\_distance\_TRAM$, which was considered as statistically non-significant. Hence, we run a third attempt which is presented in Table 8.

Table 8 – Model 1C: the final model

Dependent variable: choice				
Variable	**Coefficient**	**Probability**		**z-statistic**
$access\_bicycle\_distance\_TRAM$	1.159	0.0474	***	1.983
$tripduration\_BUS$	2.608	0.0008	****	3.369
$tripduration\_METRO$	-3.199	0.0002	****	-3.734
$period$	0.318	0.0351	**	2.107
Pseudo R-squared: 0.085				
Likelihood-Ratio (LR) statistic: 23.885				
Sample: 351 records				
Included observations: 142 after adjustments				
Number of ordered indicator values: 3				

**** = 1%, *** = 5%, ** = 10%, * = 20% of statistical significance.

Model 1C delivers more reliable results than to the Model 1A and 1B. This is noticeable by the variables significance, as well as the LR. As previously mentioned, the dependent variable $choice$ ranges from 1 to 3, where 3 means the cyclist choice for the metro, and it indicate that the higher the coefficient, the higher is the probability of someone choosing the metro over one of the other two modes. From the final results presented in Table 8, we can observe that the lower the metro trip duration (which depends not only on the distance, but also on the vehicle speed and the number of stops it does), the higher is the probability of someone choosing to take the metro. Furthermore, the higher the bus trip duration, the higher is the chance of someone taking the metro as well.

Regarding the access distance to the station, the higher the distance someone needs to cycle, the higher is the probability of this person choosing the metro. We can understand that as a preference to cycle more and use the metro, which has been improved its quality. Finally, the variable period indicates that the probability of someone choosing to use the metro increased after the NSL opening.

In addition to the multinomial model, in the next section we conducted other two binary modelling in order to verify if the results converge even when using another method.

4.3.2 Binary Logit

The first model (Model 2A) assesses the relation between the tram and the metro only, while the second one deals with both bus and metro. The dependent variable is the same as in the multinomial logit models – $choice$ –, but instead of assuming the values 1, 2 or 3, in these binary models $choice = 1$ when the user chose to use the metro and $choice = 0$ when thy chose the alternative mode.

4.3.2.1 Binary Logit: Metro vs Tram

The following Table 9 presents the outputs we got from analysing the cyclists' choice considering that the available options are the metro and the tram only.

Table 9 – Model 2A: binary model where $choice = 1$ stands for Metro and $choice = 0$ stands for Tram

Dependent variable: choice

Variable	Coefficient	Probability		z-statistic
β_0	-13.3222	0.2924		-1.052
$access\_bicycle\_distance\_TRAM$	0.775	0.2416		1.171
$access\_bicycle\_distance\_METRO$	0.081	0.9016		0.124
$tripduration\_TRAM$	4.4356	0.0000	****	4.800
$tripduration\_METRO$	-4.182	0.0000	****	-4.148
$period$	0.446	0.0076	****	2.668
$dayoftheweek$	0.524	0.2652		1.114
$peakhour$	-0.278	0.5008		-0.673

LR statistic: 52.723
Sample: 168 records
Included observations: 168 after adjustments

**** = 1%, *** = 5%, ** = 10%, * = 20% of statistical significance.

From this first version of the binary model we note that the distance cycled to the stations, regardless if it is until the metro or bus stations, is not influencing the choice between the two modes of transport. The same is observed for the variables “day of the week” and “peak hour”. Due that, we run a second version of this binary model without those statistically non-significant variables, which is presented in the Table 10 below.

Table 10 – Model 2B: binary model where $choice = 1$ stands for Metro and $choice = 0$ stands for Tram

Dependent variable: choice				
Variable	**Coefficient**	**Probability**		**z-statistic**
β_0	-0.714	0.1785	*	-1.345
$tripduration\_TRAM$	4.498	0.0000	****	4.892
$tripduration\_METRO$	-4.214	0.0000	****	-4.252
$period$	0.448	0.0059	****	2.756
LR statistic: 49.796				
Sample: 168 records				
Included observations: 168 after adjustments				

**** = 1%, *** = 5%, ** = 10%, * = 20% of statistical significance.

In this last attempt (Model 2B), the variables presented themselves as statistically significant. The results achieved here converge with those analysed in subsection 4.3.1, once in the same way we have that the higher the trip duration, the higher is the probability of the user choosing another mode (in this case, the tram) instead of the metro. Additionally to that, the conclusions regarding the period are also that the chances of having an user choosing to cycle to the metro have increased after the NSL opening.

In order to complete the analyses, the last modelling part consider a binary logit model where the choices are either the metro or the bus.

4.3.2.2 Binary Logit: Metro vs Bus

In this section we have built another binary logit model. In this turn, we consider the two mode options metro and bus. Table 11 shows the first results.

Table 11 – Model 3A: binary model where $choice = 1$ stands for Metro and $choice = 0$ stands for Bus

Dependent variable: choice				
Variable	**Coefficient**	**Probability**		**z-statistic**
β_0	-18.683	0.1105	*	-1.596
$access\_bicycle\_distance\_BUS$	-0.662	0.2963		-1.044
$access\_bicycle\_distance\_METRO$	2.043	0.0024	****	3.040
$tripduration\_BUS$	2.486	0.0059	****	2.751
$tripduration\_METRO$	-3.204	0.0018	****	-3.127
$period$	0.008	0.9661		0.042
$dayoftheweek$	-0.356	0.5716		-0.565
$peakhour$	-0.054	0.9173		-0.104
Likelihood-Ratio (LR) statistic: 19.078				
Sample: 155 records				
Included observations: 155 after adjustments				

**** = 1%, *** = 5%, ** = 10%, * = 20% of statistical significance.

According to the obtained results from Model 3A, we notice that the period of analysis is not that important as it is to the other model results we got so far. However, this model may be enhanced, thus in Table 12 there is a second attempt of this last model.

Table 12 – Model 3B: binary model where $choice = 1$ stands for Metro and $choice = 0$ stands for Bus

Dependent variable: choice				
Variable	**Coefficient**	**Probability**		**z-statistic**
β_0	0.903	0.0011	****	3.275
$tripduration\_BUS$	1.955	0.0177	***	2.372
$tripduration\_METRO$	-2.425	0.0086	****	-2.629
Likelihood-Ratio (LR) statistic: 8.149				
Sample: 155 records				
Included observations: 155 after adjustments				

**** = 1%, *** = 5%, ** = 10%, * = 20% of statistical significance.

From Model 3B, we confirm the results presented in subsection 4.3.1 regarding the mode bus in which the lower the trip duration, the higher the probability of someone taking the metro. In the same way, the higher the trip duration, greater is the chance of someone using the bus instead the metro.

5 RESULTS DISCUSSION AND CONCLUSION

Based on the results of this study, we are able to conclude that there is, indeed, a change in the cyclists' preferences when accessing PT stops and stations by bicycle, comparing the periods before and after the NSL. Cycling to metro has become more preferable compared to the other two options: tram and bus, due to improvements of the PT network and, consequently, to reduction in travel times. From our model results, we found out that the variables that exert the largest influence over the choice of cycling to a metro station are those related to trip duration. Therefore, the lower the trip duration of metro, the higher the probability for metro to be the commuting mode at PT stations. Besides, as an indication of transportation mode substitutability, the higher the trip duration of the other PT modes (bus and tram), the higher the likelihood of a user to choose metro. It is also worth mentioning that a dummy variable for the time after the NSL line was in operation was estimated with a positive and significant effect, which ratifies that this new metro infrastructure increased the odds of a bicycle user to opt to ride her bike to a PT station and commute to a metro service.

In a transportation policy perspective, we are able to state that there is still a lack of competitive alternative transportation means to private vehicles in the context of developing and developed countries. Some choices have been stimulated by government policies and investment and have found positive response and performance in some countries and transport sectors. One of these cases of relatively success of alternative transportation modes is bicycle in the Netherlands. Urban planning in programs like Mobility as a Service (MaaS) have included walking and cycling as means to reach different destinations. In spite of being potentially more sustainable than private car, these means are effective for short trips, but not the best option to overcome longer distances.

In the present study, we discussed an alternative means that integrates PT systems and bicycle and provides a door-to-door solution, also effective to overcome longer distances. Although not original, this proposal could yield significant gains in traffic congestion, environmental conditions and travel time – besides some positive side effects on human health; but the main question is: are people willing to adhere to this idea? Besides all positive aspects mentioned here, there are also some problems when thinking about the use of bicycle as a integration mode, such as the weather (especially in too cold or too hot regions; rain could be a demotivating aspect too) and the lack of safety, both in terms of transit and public aspects. In the Netherlands, the bicycle infrastructure is efficient, as well as the public safety system. However, it does not happen in every other place in the world; in Brazil and other similar countries, for example, there is not bicycle path everywhere and depending on the city, it is not safe to ride a bicycle in the middle of the night, for example. The problem is not only visible in the underdeveloped countries, places as the US do not provide properly bicycle infrastructure either. As the main countries in the world, the main transport mode is still the private car.

This study focused on a bicycle-transit combination in a particular scenario and context: Amsterdam region, with a great change on the PT network after the implementation of the NSL line. It means we are studying a situation in a country where the bicycle infrastructure is efficient and it is safe, in all aspects, to ride a bicycle. It is always important to point out that this is an huge achievement based on the population desire for a better place to live; it took years to the Netherlands to become the transit reference they are today, so all the other countries could follow the same steps. This is one reason why this research is important: it can be replicated in other countries.

The main objective was to assess whether such improvement to the PT system would change cyclist behaviour (in terms of frequency and connecting mode) when accessing PT stations. This combination has been proven as an efficient concept, since bicycle meets the needs of the first and last mile context, while comfort and the possibility to reach longer distances are provided by the PT means. The bicycle-intermodal mode comes with several positive aspects for both sustainability and logistics conditions, including the capability of increasing stations' catchment areas.

As previously mentioned, one innovative feature and main contribution of this study is the access to Mobidot database, which provides survey data on users' choices on urban transportation means. This Dutch database was not completely explored by the time we started this research, that is why we needed to study and prepare it before building all the analyses presented in chapters 3 and 4. This study is an important contribution of this research. One of the preparation steps was selecting the information according to the interest of this research, it led us to work only with a small part of the database that deal with users that choose bicycle in their first mile to reach a PT stop/station. By analysing Mobidot data, we were able to verify an increase in the number of users cycling to the metro instead of to the bus and tram, after the NSL started operating.

The main hardship of this research was dealing with all the data. Since we were not sure about the content it kept, Mobidot demanded time to be studied and prepared. The generated data from Google Maps™also demanded time and data analysis skills to be introduced to the econometric model. As aforementioned, this was, indeed, the main contribution of this research.

In chapter 4 we have proposed a different approach, where we added some generated records to the initial part of Mobidot database we were using, in order to evaluate users' behaviour. For that, it was necessary to build a whole dataset from Google Maps™to get compatible alternative information to each record we had in Mobidot database. All this work was worth to investigate the reasons why one chooses to use their bicycle to access one PT mode to another, with this data we were able to run the econometric analyses.

In order to contribute to reduce the lack of information regarding the use of bicycle as a feeder mode to urban public transit systems (BTM), a second contribution is the identification of the determinants that motivate people to use bicycle as a feeder mode to BTM stops/stations and what can be improved in terms of infrastructure and public policies to increase the probability of someone choosing a bicycle as a feeder mode instead of other modes.

Notice that in this study, we did not consider socioeconomic variables – such as gender, income and reason to travel. For future studies regarding this topic, these variables could also help to understand people's motivation to cycle to a station/stop. Besides, an interesting research direction could be the exam of infrastructure conditions, not only in the sense of meeting the demand of users, but also planning ways to motivate people to cycle, mainly focusing on promoting station facilities.

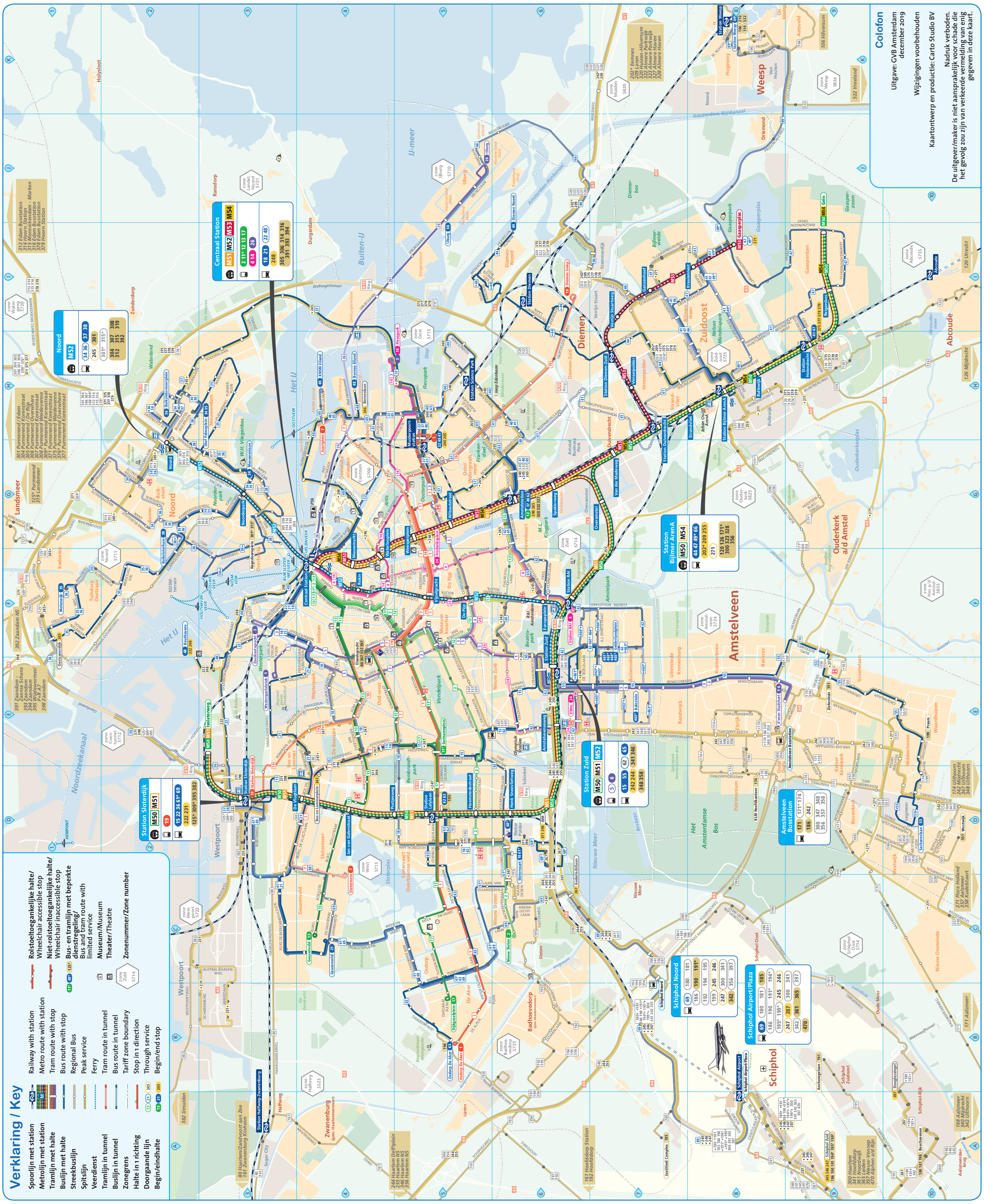
The world is urging for sustainable alternatives in most aspects of society's life, and the transport system is one of them. When thinking about the transport situation worldwide, we still see the car as the main transport mode in most of the countries, as in Brazil – an emerging country – and in the US – a developed country. It is known that the inordinate use of motorised private vehicles is one of the enormous causes for environmental damage, such as air and noise pollution together with the use of soil demanded to shelter all the vehicles and the infrastructure required. Even so, its use is extremely intense worldwide, especially due to the flexibility and comfort it provides when compared to other transport alternatives, such as the public one. Regarding the PT, there is an aggravation when referring to cities, or even whole countries, where the PT is precarious. In emerging countries like Brazil, even in metropolitan areas there is a clear preference for the use of the car, once the PT system does not commonly offer a reliable service – especially because of the scarcity of investments on rail transport systems. As we could drawn from this research results, the investments in a reliable PT timetable, as well as infrastructure motivate people on choosing to use sustainable transport alternatives more than the cars.

For future researches regarding this topic, some other variables could be introduced to the analyses, such as the economic ones. This would help to understand also what public policies could be developed to increase the preference for the use of PT to private vehicles. Another point is considering also the egress modes. It would lead to another analysis about how bike-sharing could help on the bicycle and PT combination. Since one would be able to use a public bicycle to access and egress from the PT vehicle. Even though, some people would rather using their own bicycle, and this would contribute for the possibility of improving the options of taking the bicycle inside the PT vehicles. This is already common in trains, for intercity displacement, and could start being a common option for urban transport as well.

A ANNEX: AMSTERDAM NETWORK MAP

Figure 27 depicts Amsterdam network containing all public transit routes. This map is from December 2019, after NSL started operating.

Figure 27 – Amsterdam public transit network



Source: GVB (2019).

B ANNEX: USER LIST

Table 13 presents a list with the users who recorded their trips before and after the NSL. This data is important to evaluate whether their modal choice has changed after the NSL operation or not.

Table 13 – Users ID with recorded trips before and after the NSL

213882	214766	215080	215576
214482	214770	215088	215678
214508	214774	215256	215682
214528	214784	215340	215732
214540	214817	215441	215736
214564	214832	215442	215818
214589	214833	215457	215827
214642	214892	215484	216138
214653	214926	215485	216212
214663	214941	215491	216319
214732	214968	215500	232521
214752	215076	215522	232566

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