A Framework for the proposal of Bus Rapid Transit in the Netherlands

Bachelor Thesis

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UNIVERSITY OF TWENTE.

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by

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Cover photo: **top:** (van der Heide, 2008), **bottom:** (Rio Prefeitura, 2023)

Preface

Before you lays my bachelor thesis, a framework for the proposal of bus rapid transit in the Netherlands, after three years of online and offline education it is time to close the chapter of my bachelor and continue a new chapter with my masters which will also be here at the UT. Finishing the thesis was not always easiest to do, with some motivational downs and writers blocks, but in the end it all worked out. In the 10 weeks that I worked on this thesis I've had fun exploring the world of public transport and reading about the current state and the future. I also had the pleasure to learn Python. I was not familiar with it at the beginning, but I'm glad I got the chance to learn the programme which will help me in further studies and maybe even once I get a job. I want to thank my UT supervisor Alejandro Tirachini for guiding me academically through the process. I want to thank the writing centre of the UT for helping me in the writing process and I want to thank Cees Bakker and Justin can Steijn for being my supervisors at Keypoint and sending reading material on the subject of BRT.

Daan de Wit
11 July 2023

Abstract

With an increasing population, travel demand also increases. It is impossible to keep widening roads and facilitate car travel. Therefore, alternatives are necessary. One alternative is increasing public transport coverage, frequency or capacity. Bus Rapid Transit (BRT) is a relatively unknown form of public transport in the Netherlands., BRT could be the key to offer high-quality public transit whilst still being relatively affordable. BRT is a bus-based system that uses median aligned busways to increase reliability and travel speed, making it comparable to trams/metros whilst retaining the flexibility and lower cost of buses.

In the Netherlands, it is not yet known between which places a BRT system could be implemented. The goal of this research is to set up a framework that determines where a Bus Rapid Transit system can be implemented in the Netherlands, with the required data. To determine the best corridors, two different approaches where used: one using a gravity model, and the second using an exponential decay function. The gravity model uses population quantity and a cost factor, whilst the exponential decay function uses job opportunities and a cost factor to establish the corridor rankings. To better rank the results, different criteria are used to assist in ranking the origin-destination pairs. For example, current travel time by train and the presence of a metro or tram on the link. The proposed approach automatizes the search of the most promising Origin-Destination (OD) pairs for BRT, as it uses data from all of the municipalities in the Netherlands. Once the top-ranked OD pairs are determined, a more detailed analysis of each case is performed, this requires a more fine-grained information gathering about each particular case including the acquisition of local knowledge.

From this framework four routes resulted: Zoetermeer-Rotterdam, ‘s Gravenhage-Westland, Ridderkerk-Rotterdam, Veldhoven-Eindhoven and Utrecht-Vijfheerenlanden. The required data to operate the model, are the population count per municipality, the number of jobs available per municipality and the coordinates of the centre of each municipality. Using APIs and these coordinates, the travel time by car and public transport as well as the distance between them was determined.

The four alternatives determined where manually analysed to see if there was already a good bus connection present. This was done because the model did not include bus travel times. Between Rotterdam and Zoetermeer there is already a quick bus connection present and research was conducted on the feasibility of an BRT system here, however, this was deemed impractical. Two routes were further worked out due to time constraints: ‘s Gravenhage-Westland and Ridderkerk-Rotterdam. The Eindhoven-Veldhoven and Utrecht-Vijfheerenlanden route were not explored further. The role that BRT can play in Transit Oriented Development and potential solutions to tackle the first and last-mile problem are briefly described.

For ‘s Gravenhage towards Westland the rough outline of the route is as follows and was determined by efficiently connecting the cities while also linking attractive places and transport hubs. The route, shown in Figure 1, will start at Den Haag Centraal and follow the Erasmusweg to Poeldijk. The route will then split into one route from ‘s Gravenzande towards Hoek van Holland and the other branch from Naaldwijk to Maassluis, both branches will connect to the metro network of Rotterdam. It is estimated that the travel time on this BRT line from Naaldwijk or ‘s Gravenzande towards Den Haag Centraal will be shortened by 8 and 19 minutes respectively, using public transit.

The route from Ridderkerk to Rotterdam, shown in Figure 2, will start at the carpool place Ridderkerk Oudelande and continue through Ridderkerk following the Rotterdamseweg. It will enter the A16 and exit the motorway at the first exit on the other side of the Meuse. The route will traverse the Maasboulevard and continue its way past Oostplein towards the central station. Compared with current public transit times, this route can save up to 19 minutes.

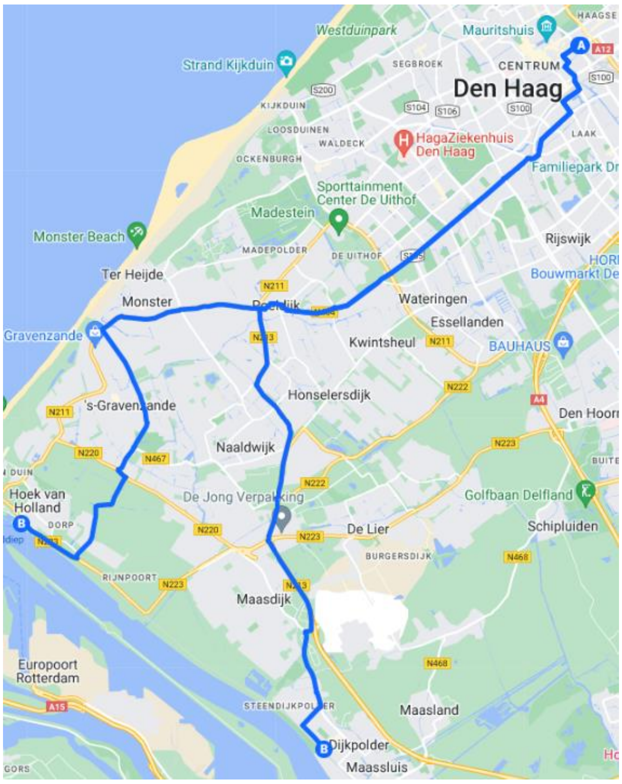

Figure 1: Proposed route between Westland and 's Gravenhage

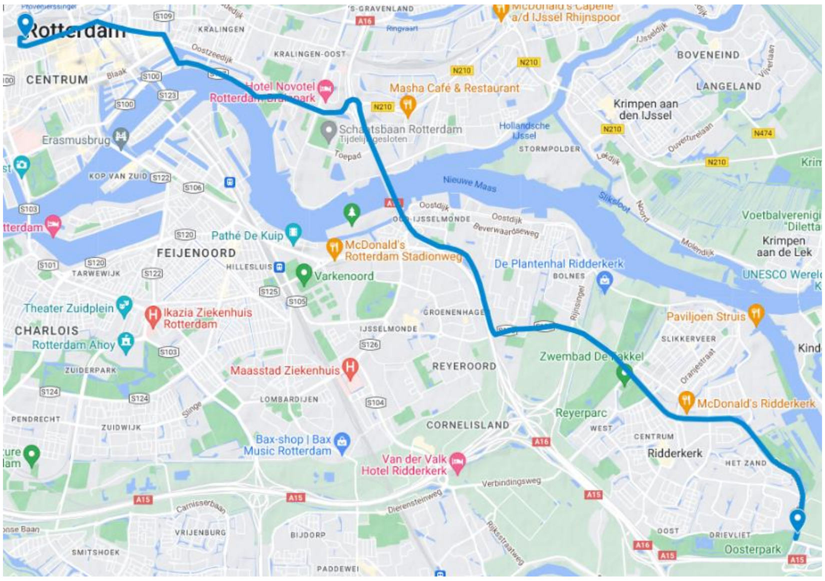

Figure 2: Proposed route Between Ridderkerk and Rotterdam

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List of abbreviations

- BRT Bus Rapid Transit
- CBS Centraal Bureau Statistiek
- ITDP Institute for Transportation & Development Policy
- KIM Kennisinstituut voor Mobiliteitsbeleid
- LRT Light rail transit
- OD pair Origin-Destination pair
- OSM Open Street Map
- OSRM Open Source Routing Machine
- PT public transit
- P+R Park and ride
- ROW Right of Way
- TAD Transit adjacent development
- TOD Transit oriented development

1 Introduction

The population is increasing, and cities are becoming denser. All of these people need to travel to work, school or leisure activities. As a result transport modes and the existing transport infrastructure are becoming more crowded (NOS, 2022). In this context, it is widely acknowledged that encouraging the use of public transport is crucial. Currently, public transport modes in the Netherlands include rail-based systems and bus-based systems. An alternative that aims to combine the flexibility and relatively lower costs of buses together with the efficiency and reliability of rail-based public transport is Bus Rapid Transit (BRT).

Currently, there are very few BRT connections in the Netherlands, and it is not known where the demand exists between municipalities. Therefore, there is a need to identify the areas where demand might exist. This thesis aims to develop a methodology to systematically determine where a BRT system could be implemented, focusing on the case study of the Netherlands. Once the corridors with the highest potential are identified, the study will explore possible routes, required infrastructural changes, it will also briefly be described what the role of BRT can be in Transit Oriented Development and possible solutions to solve the first and last mile problem.

A model will be constructed to make a ranking of the different corridors. This model will consider various scenarios based on different function and associated costs. The functions used in the model include a gravity model and an exponential decay function. Whilst the cost used are the great-circle distance and the travel time by car between the municipalities. To better rank the corridors, different criteria will be implemented, such as the presence of public transit.

The thesis is structured as follows. First, an overview of what Bus Rapid Transit is, its characteristics and the current state of BRT in the Netherlands will be presented. Second, the research aim, scope and objective derived form a gap in knowledge will be discussed. Third, the methodology used in the study will be outlined. Fourth, the research results related to the research objectives will be shown. Finally, the findings will be concluded, discussed and further areas for research will be proposed.

2 Theoretical background

In this chapter, some theoretical background will be given on the definition of Bus Rapid Transit and its characteristics in order to be able to design a system later on in the report. Next, the current state of affairs in the Netherlands will be analysed, showing the need for this research.

2.1 What is Bus Rapid Transit?

As the Dutch government puts it, ”Bus Rapid Transit is a bus system that operates at high frequency and speed, combines reliable journey times with high corridor capacity, offers comfort, and is easily distinguishable from regular bus transport for passengers.” (KIM, 2020). The Institute for Transportation & Development Policy (ITDP) proposes five main characteristics to differentiate Bus Rapid Transit (BRT) from normal bus transit (2017).

1. **Busway alignment:** Have the busway in the centre of the road to avoid stopping and turning cars;
2. **Dedicated right of way:** Have bus only lanes to avoid the mixing of traffic and increase reliability;
3. **Off-board fare collection:** Minimize stopping time;
4. **Intersection treatments**: Give buses the right of way at intersections and reduce the amount of intersections where traffic can cross the bus lanes;
5. **Platform level boarding:** Increase accessibility and reduce stopping time.

In Figure 3, the BRT system of Quito in Ecuador can be seen. This illustrates the five main characteristics of BRT. It is important to mention that these characteristics define what an ideal BRT system is. Infrastructure needs to be tailormade for each specific case. Sometimes diverting from these characteristics is necessary.

Figure 3: characteristics of BRT (ITDP, 2017)

2.2 Bus Rapid Transit compared with rail bounded transit

It has been briefly described what the characteristics of a BRT system are. However, the discussion of why one would choose a BRT system instead of rail bounded high capacity systems, such as metro or tram, has not yet been addressed. This section will discus the advantages and disadvantages of both systems to understand their differences.

Firstly, one of the main advantages of choosing for BRT instead of the metro or tramways, is the capital investment. A bus system has a lower initial investment cost compared to railways (Levinson et al., 2002). Studies have shown that, on average, BRT is 2.6 times cheaper to implement than light rail transit (LRT) systems (US General Accounting Office, 2001). However, if a BRT system needs to be constructed in a heavily congested area, dedicated bus lanes are necessary, which can increases the costs. It should be noted that this would also be the case with LRT

Next, a BRT system offers more flexibility. If a station, a defective bus or a section of road needs refurbishment, buses can continue to run on an alternative route. This may involve being in a mixed traffic situation, but the whole system does not need to be shut down, as is the case with rail based systems (Levinson et al., 2002). Moreover, a BRT system can be quickly set up and can be easily built incrementally. This allows the system to start operating before it is fully constructed, only some right of ways are missing for example (US General Accounting Office, 2001). Whilst in rail based system this is not possible.

There are also some similarities between BRT and LRT systems. Both systems provide opportunity to developed transit oriented developments around the stations. Land-use and transportation are integrated with one and other to make sustainable transport modes convenient and desirable, and maximize the efficiency of transport stations by concentrating urban development around them (Ibraeva et al., 2020).

However, there are also some disadvantages in using BRT instead of LRT. To transport the same amount of people, a greater number of vehicles is needed (Hsu and Wu, 2008). The number of buses depends on the type chosen to run the line. If articulated buses are chosen, the difference in fleet size compared to LRT fleets will be less. Additionally, LRT vehicles can be coupled together to make a longer train, increasing capacity during peak hours. This is not possible with buses. However, buses can have a smaller headway than the one for trains or trams, which can increase the capacity again (Hsu and Wu, 2008).

There is also a psychological factor to consider. People tend to view rail-based services as superior, even when the bus and rail system have comparable characteristics (Scherer & Dziekan, 2012). This perception, known as the psychological rail factor, leads to higher attraction in terms of ridership of rail-based systems in contrast to bus based. Meaning that getting the public to embrace a bus based system could be more difficult.

Additionally, if diesel engines are used, (sound-)pollution for the immediate environment is heavier compared to LRT (Staiano, 2001), and more maintenance is required. However, if electric or hydrogen buses are used this difference diminishes. Buses also have a shorter life span compared to trams. All in all, the fleet size required to operate with the same capacity is greater, necessitating more chauffeurs and supporting personnel. This additional staff is one of the main reasons why a BRT system is more expensive to run. Personnel and other factors can make a BRT system upwards of 4 times as expensive to run as an LRT system (Rizelioğlu & Arslan, 2019). The extra staff can also become an operational problem seeing the staff shortages currently present in the Netherlands (FNV, 2022).

2.3 Comparable BRT systems in the world

In the world there are already many BRT systems present. These systems can be analysed to see whether the characteristics of these systems and the environment in which they are located, have similar characteristics as is present in the Netherlands. This way, it can be determined what kind of system is preferred for the Dutch corridors. Some examples follow.

2.3.1 Nantes busway, France

In Nantes, France, there are is a lines that can be considered BRT, this is ligne 4. Ligne 4 connects the city centre of Nantes with the porte de Vertou with de Foch-Cathédrale. Together both busways have a ridership of 25.000 passengers per day (BRT_Data, 2011). Ligne 4 rides buses every 2-3 minutes and has a total length of 7 km (BRT_Data, 2011). The buses have priority at intersections and ride on separated busways. The tickets are paid in advance at the stops or online, but they are checked in the buses themselves. Nantes itself has a population of around 300.000 people, making it comparable to some cities in the Netherlands (BRT_Data, 2011). The city chose for BRT instead of an extra tramway of which there already have three lines. This is due to the fact that tramways where deemed to be too expensive (Urban Transport Magazine, 2019). In Figure 4, the Nantes busway can be seen.

Figure 4: the Nantes BRT (Urban Transport Magazine, 2019)

2.3.2 Cambridgeshire guided busway, England

This busway connects the cities of Cambridge, Huntingdon and ST. Ives and a branch till Peterborough in the county of Cambridgeshire. Compared to most of the busways, this one is guided, meaning the busses are kept on there track with guiding wheels and with a guiding section of 21.5 km is considered the longest in the world (BBC, 2011). Part of the track is built upon the old railway embankments. The busway along the corridor has multiple faces, the busses are mixed with the normal traffic in Huntingdon. Separated busways in both directions and a separated bi-directional busway are all used in this corridor. There are four lines on this corridor with all slightly different branches. In contrary to major BRT systems, the fare collection of this BRT happens on the busses itself. The frequency of the busses ranges between 3 till 6 busses per hour per direction and there are about 12.000 riders per day (BRT_Data, 2015). A picture of the guided busway can be seen in Figure 5.

Figure 5: Cambridgeshire guided busway (Horgan, 2020)

2.3.3 Brisbane busway, Australia

The BRT network in Brisbane has a length of 27 km, a daily ridership of 356.800 passengers per day. At the busiest point in the day 294 busses cross a single point in an hour time (Currie & Delbosc, 2014). The fare needs to be paid beforehand and in the busses the tickets need to be scanned. The same busses that are used for the normal network are also used on the BRT network and they drive on bus only lanes. Most of the stations along the line have pedestrian bridges except for some stations located farther away from the city centre, see Figure 6 for an example of a pedestrian bridge station in Brisbane. Most of the network is above or on ground level. However, in the city centre there are bus only tunnels with stations. This makes the network resemble a rail based system even closer. (Currie & Delbosc, 2014).

Figure 6: Langlands park BRT station Brisbane ('Busways in Brisbane', 2022)

2.3.4 What could work in the Netherlands

The three systems described can be differentiated from each other. The Nantes busway has a relatively small ridership, with less than 50.000 riders per day. The same applies to the Cambridgeshire guided busway. The main difference is that the Camebridgeshire busway connects multiple cities together. Which does not mean that the service provided by the busways is inferior compared to busways within cities. The cities of Nantes and Cambridge can also be compared in size to most Dutch cities, making their busways suitable examples for designing a system in the Netherlands.

In contrast, the Busway in Brisbane has a much higher capacity and ridership, with over 300.000 riders per day. This means that most of the facilities are designed to accommodate the higher ridership and more frequent bus services. These features often aim to enhance passenger waiting times and passenger flows, such as pedestrian bridges at stations. For smaller lines, it may not be worthwhile to invest in building larger stations. Therefore, directly copying from the Brisbane busway may not be feasible, as its capacity exceeds what is expected for a system in the Netherlands. This difference can also be observed when comparing city sizes, where Amsterdam, the largest city in the Nerhalnds, is three times smaller than Brisbane.

To summarise, the Nantes and Cambridgeshire busways serve as a good example for designing a BRT system in the Netherlands. This is due to the relatively low ridership and comparable city sizes. The Brisbane busway can provide insights into the strengths of larger capacity services, but its ridership and population exceed what can be expected in the Netherlands.

2.4 Current state of BRT in the Netherlands

Currently, in the Netherlands, there are three lines that could be classified as BRT systems. The first one is the zuidtangent, also known as R-Net line 397 and 346, which connects Nieuw Vennep and Haarlem with Amsterdam (R-net, 2023). Figure 7, shows a section of this line where 8 buses per hour drive in both directions on a separated bus lane, during peak hours. The second is in Almere, where the entire city wide bus network can be considered BRT. since the bus lines ride in peak hours between 12 and 8 times per hour and the system is separated from other forms of traffic. Almere has a total of 8 BRT lines (AllGo, 2023). Additionally, line 28 in Utrecht can be considered as BRT. It connects the station Vleuten through Utrecht Central to the science park and operates 6 busses per hour per direction on separated bus lanes for most of the day. (U OV, 2023).

Figure 7: Zuidtangent in Amsterdam (van der Heide, 2008)

For all of these examples, it can be noted that there are no actual stations but the stops are more, as the name suggests, stops. Next to this the fare collection happens the same as for the normal busses in the Netherlands. Thus with an OV-chipcard or payment by card. Based upon these examples, it could be said that there is no full fledge BRT line in the Netherlands. However, lighter versions are present which align more with the normal Dutch us network. This means that for the normal everyday traveller the systems are more recognizable as bus services.

Especially within larger cities, BRT can be a solution to provide high-capacity bus services where there is no space for railway tracks or where the investment is deemed to be too expensive. Additionally, in the Netherlands, as demonstrated by the corridor between Haarlem/Nieuw Vennep and Amsterdam, BRT can be used to connect cities due to country's density. This is the plan for the Breda-Gorinchem-Utrecht corridor, as there is no direct railway line present between these cities, and the investment to build one is deemed not viable. BRT could provide a solution for the passenger movement between these cities (Rijksoverheid, 2022a). The Dutch government has also written a manifest for the implementation of BRT, with four categories: urban plus, urban region, urban rural area and interurban (Rijksoverheid, 2022b).

2.5 Problem statement

The previous discussion provides insights into the purpose BRT and how it differs from other public transit systems. However, there is currently no generalised method for determining the most suitable location of a BRT system. Therefore, this thesis project aims it will be worked out how to automate a ranking for determining the most promising locations to implement a BRT system for the case of the Netherlands.

This will be done by first working out what the possible origin destination pairs (OD pairs) are in the Netherlands. Once these OD pairs are established, criteria will be determined on how to rank them. For example, these could be travel time, distance and availability of alternative modes. With the criteria and OD pairs, the automation that determines the ranking can be built. After this is done, the most promised routes will be analysed in detail. Seeing if there enough space to develop such a high frequency service, what could be a possible route could be, how the last and first mile problem can be tackled and if the system can be used for developments farther away from the city centre.

3 Research dimensions

3.1 Research aim

The aim of this research is to develop a systematic approach for determining suitable locations for implementing bus rapid transit (BRT) within a traffic system. Once the potential routes for BRT implementation are identified, the focus will shift towards designing the system, evaluating the required investments and determining the system's role within the transit network. Additionally, the research will explore possible solutions for addressing the first and last mile problem and assess the possibility of urban development around BRT stations.

The first part of the research aim will be addressed by designing a model that allows for a systematic comparison of Origin-Destination pairs (OD pairs) based on different criteria. This analysis will generate a list of the most suitable OD pairs, and further attention will be given to the two most suitable corridors. These corridors will be studied by analysing a potential route and conducting a literature study.

3.2 Research Scope

The scope of the research is the whole of the Netherlands. It will be determined between which municipality BRT can be implemented. Transportation within cities or between single cities falls outside of the scope. This aligns with the Dutch government's BRT manifest, exploring inter-urban connections, connecting different cities or municipalities (Rijksoverheid, 2022b).

Once the OD pairs are determined, The two highest ranked routes will be worked out. This involves establishing a general route, estimating potential travel time savings and presenting a generalised cost. The existing infrastructure along the route will also be analysed. Lastly, a section will be dedicated to discussing the role BRT can play in urban development and how the first and last mile problem might be tackled. This section is aimed to be a preliminary study on the implementation of BRT, including an indication on which key elements that need to be considered.

3.3 Research objectives

From the information provided in previous chapters, a main research objective and sub questions to reach the objective can be formulated. The main objectives can be stated as follows:

1. **To develop a framework to determine where Bus Rapid Transit systems can be implemented in the Netherlands, including required data**
2. **To determine the main characteristics and infrastructure elements on each route, for the most promising case studies**

To reach the main objectives, multiple sub-questions can be formulated. These questions will support answering the main objective. The sub questions are divided into two different categories. The first is about determining the location and the second category is more about the implementation.

1.1 How can Origin-Destination pairs be determined?
1.2 Which criteria can be used in order to determine which OD-pair is the most suitable?
1.3 Which Origin-Destination pairs are the most suitable?

The next questions are about determining what these routes could look like.

2.1 What could be a possible route for BRT?
2.2 What does the current infrastructure look like along this route and are changes needed along this route?
2.3 What role can the BRT system play in the regional mobility and urban developments?

4 Research methodology

In this chapter the research methodology used will be described. This entails looking at which steps to take, how to rank the origin-destination pairs and which criteria can best be used to rank the origin-destination pairs

4.1 Steps used

To achieve the main objectives, several sub-questions need to be addressed. Various steps will be undertaken to determine the most suitable route for a BRT system. A model will be constructed to generate OD pairs between each municipality, after which criteria can be used to rank the OD pairs. The two most suitable OD pairs will be selected, and routes for these corridors will be determined. The analysis will include time savings, an estimation of costs and assessing current infrastructure. Consequently the role of BRT in urban development and strategies to overcome the first and last mile problem will be briefly discussed. The step by step overview is outlined below.

1. Generate OD pairs and determine their respective demand;
2. Identify relevant criteria to analyse the OD pairs;
3. Rank the OD pairs in accordance with the criteria;
4. Pick the two highest ranked OD pairs;
5. Determine the route for one of the OD pairs;
6. Asses the necessary changes to the current infrastructure, estimate the associate costs and the travel time;
7. Analyse the role the system can play in regional mobility and urban development;
8. Repeat step 5,6 and 7 for the second corridor;
9. Provide a conclusion providing the two most suitable corridors, costs, travel time and potential routing.

In Figure 8 the method can be seen worked out clearly to see what the interaction is and what the workflow will be.

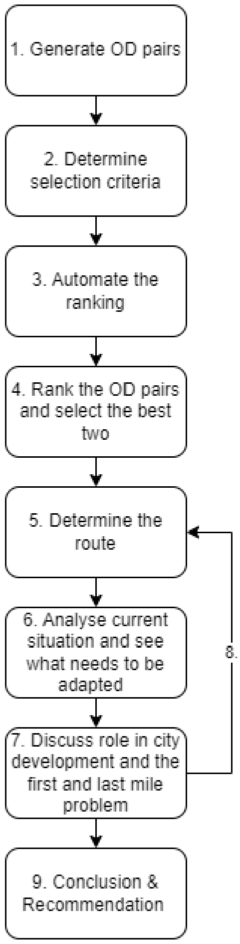

Figure 8: research method in a flowchart

4.2 Determining the Origin-Destination pairs

Origin-Destination pairs (OD pairs) can be defined at various levels of detail, such as street-to-street, city-to-city or county-to-county. For this research, OD pairs will be defined between different municipalities in the Netherlands. As of January 1st, 2023, there are 342 municipalities in the country (Ministerie van Algemene Zaken, 2023). However, since the data for 2023 is not yet available, the research will use the 344 municipalities that were present in 2022 (CBS, 2023).

Each of the 344 municipalities has travel demand to the others, resulting in 118.336 OD pairs between them. These pairs can be organized in matrix form, with the rows representing the origin and the columns the destination. The matrix can display the potential traffic demand between each pair of municipalities.

Determining the traffic movements can approached in different ways, depending on the specific needs. One approach is to use the four-step model, which involves trips are generated, distributed and the modal spilt and route choice are determined (Metropolitan Washington Council of Governments, n.d.). This is one of the earliest models that link land use and behaviour to transportation planning (McNally, 2000)

For individual roads, on-location counts of traffic can be conducted. Alternatively surveys can be conducted to gather data on daily travel patterns from a diverse range of individuals. However, obtaining sufficient data through surveys can be challenging. Another approach is the use of a gravity mode, which estimates a potential demand between two population centres. In this research, only a gravity model will be used as it provides sufficient level of detail for an initial study. Whilst the gravity model is also part of one of the steps in the four step model, in this case not all four steps need to be performed in order to get a level of detail that is sufficient.

As the name suggest, the gravity model operates similar to the Newtonian definition of gravity. Which states that all objects tug a force on nearby objects, the greater the mass the greater the tug is. Increasing the distance decreases this tug. In traffic systems, this concept can be applied by considering that larger populations generate greater travel demand, whilst distance can play a role in influencing travel potential between cities.

Equation 1 illustrates the gravity used in this research. The equation calculates the travel demand (T_{ij}) between point i and j, where M represents the population of i and j, and $f(D_{ij})$ represent the cost term. This term can be interpreted as a resistance to travel. In this research, cost will be defined as the great-circle distance and the travel time by car between two municipalities, the great-circle distance is the distance as the crow flies. The γ parameter, is set to two (Hong and Jung, 2016), influences the weight of the cost function. A higher γ value gives more weight to the cost factor, favouring shorter distances or travel times. Conversely as γ decrease, population sizes play a more significant role. The scaling factor G, set to 1 for this research, can be adjusted to more closely represent real life. Since the results will be ranked, scaling them will not impact the outcome.

$$T_{ij} = GM_iM_jf\left(D_{ij}\right) = G\frac{M_iM_j}{D_{ij}^{\gamma}} \qquad \text{(Hong and Jung, 2016) (1)}$$

For this research the population data was gotten from CBS (2023), the coordinates gathered using Open Street Map (OSM), the car travel time using the Open Source Routing Machine (OSRM) API and the distances are calculated using Geopy, which determines the great-circle distance between any two locations. All the municipalities in the Netherlands can be seen in Figure 9 with their geographic centre shown.

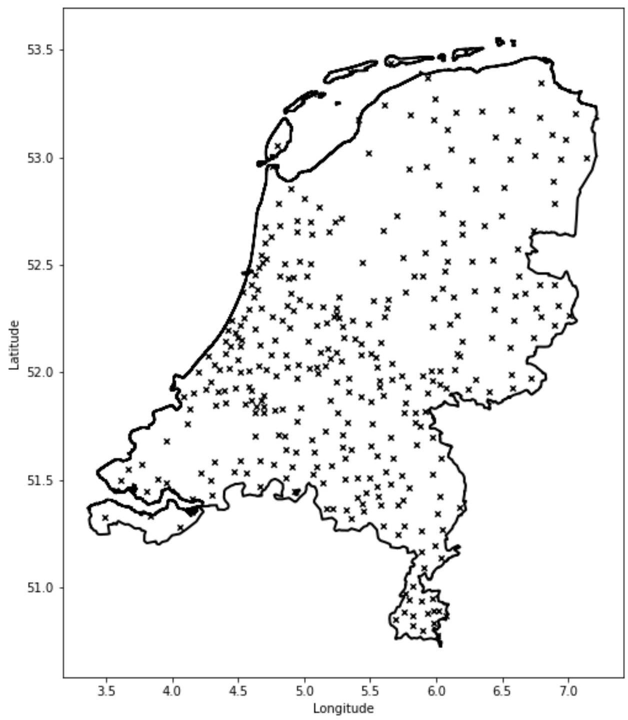

Figure 9: municipalities of the Netherlands displayed with their geographical centre, some waters such as the IJsselmeer and the Oosterschelde are missing

4.3 Which criteria can be used in order to determine which OD-pairs is the most suitable?

In order to determine which OD pair is the most suitable, the research will consider criteria beyond the potential demand calculated using the gravity model. This is necessary for several reasons, such as the existence of a public transit connection or a higher job count in a smaller city, which attracts more commuters. This is the case in Veldhoven which has 40.000 inhabitants but work for 30.000. Thus nine criteria will be proposed to create a more comprehensive ranking of the corridors.

The first criterion, which has already been discussed previously, is the use of the gravity model. The gravity model calculates a potential demand based on costs and populations size, providing a starting point upon which other criteria can be used to refine the ranking.

The second criterion is the current public transit travel time. Evaluating the travel time by PT alone may not provide significant insight. Therefore, comparing it with the travel time by car it can be determined if the current PT is quicker or not. If public transit is quicker than driving, it suggest a good existing connection, making a BRT system less necessary. However, if public transit travel time is longer, a BRT connection might be a viable option.

The Third criterion is the frequency of the existing public transit connection. Even if the connection is relatively quick, if it operates only once per hour and the demand is high, BRT could potentially be implemented.

The fourth criterion takes the existing Tram and metro network into account. Between some municipalities in the Netherlands there is already a connection available through tram or metro. This means there is already a high capacity service present, making it less viable to include a BRT system here.

Job opportunities will be considered as the fifth criterion. In the Netherlands, on average, 56% of people work in a municipality different from where they live (CBS, 2013). This means significant commuting happens across municipal borders, making a BRT line a potential solution to facilitate this movement.

The sixth criterion is related to study-related movement. Since higher education options are limited to specific locations, commuting is necessary for many individuals who cannot or do not wish to relocate to the city of study.

The seventh criterion focuses on congestion. If the corridor experiences heavy congestion and a high-capacity public transit alternative is available, it becomes easier for people to switch from cars to buses due to the time advantage gained. It has been said that Public transport does not drastically decrease the effect of congestion, since the spots on the road that are left behind by the people that switch to public transport will be filled in by other people that at first did not take the car (Stopher, 2004; Taylor, 2004). While public transport may not significantly reduce congestion overall, the goal here is to assess the potential for a public transit connection.

The eight criterion is daytrips, which attract a varying number of trips. The presence of a day trip destination such as: theme parks, zoos, beaches or shopping centres increases traffic demand. Although such traffic is often seasonal and time-dependent, it could still be a viable consideration, particularly when combined with another destination such as a smaller city.

The last possible criterion under consideration are airports. Airports have consistent travel demand throughout the year, attracting travellers from various locations. The presence of an airport can thus increase the travel demand towards a municipality.

From these criteria, a selection will be made to include in the model and why.

4.3.1 Which criteria will be used

To determine the most promising OD-pairs, a selection of criteria needs to be made for ranking purposes, considering time constraints and data availability, the criterion between which need to be chosen are:

- Gravity model
- Travel time PT compared with car
- Frequency of current PT
- Existing tram or metro
- Job availability
- Amount of students
- Day trips
- Congestion
- Airports

From the list above a selection is made for ranking purposes, considering time constraints and data availability. The chosen criteria are as follows:

1. The gravity model, this will be included to calculate a potential demand based on population sizes;
2. Travel time PT compared with car, the travel time by train will considered since data for buses is not available. This will be included to see whether or not there already is a quick connection;
3. Existing Tram or metro connection, to determine if there already exists a high capacity service;
4. Job availability, to obtain routes to municipalities where there are is a relatively high amount of jobs.

The following criteria will not be implemented due to various reasons:

- Frequency current PT, data was not obtainable;
- Amount of students, since obtaining data on the specific locations of higher education is challenging, the travel will closely resemble the one for job availability;
- Day trips, assessing the attraction of daytrips would require in-depth analysis, and the seasonal nature of such trips make it difficult to include it in the model;
- Airports, will primarily require a connection to their host municipality, and they mostly are already well connected;
- Congestion, obtaining congestions data automatically was not possible.

Overall the criteria selected will help rank the OD pairs and generate a ranking that will provide suitable corridors for BRT.

4.3.2 Implementing the criteria in the model

How the criteria will be implemented will now be discussed.

4.3.2.1 Gravity model

To implement the gravity model, three essential factors are required: population of municipality one, the population of municipality two and the distance or travel time between them. The population was obtained from CBS (2023). The car travel time was determined using OSRM and the cost factor includes the travel time by car gotten from OSRM and the great-circle distance gotten using geopy, this is a package in Python that can be used when working with geo-information, both the cost travel to and from the centroid of each municipality. The calculated values are entered into the OD matrix.

4.3.2.2 Travel time public transit compared with car

To implement this criterion, two things are required: the travel time by public transit and by car. To obtain the travel time by car between the municipalities, an API called OSRM is used. This API calculates the shortest travel path and determines the travel time using the imposed speed limits, which represent an off-peak travel time. For the travel time by train, the NS (Dutch railways) travel time API is used, with the option for driving, cycling or walking to the station enabled. This means that the total travel time obtained from the API includes traveling to and form the station. It should be noted that the NS API only provides travel time by train, thus places that are connected using metro, tram or bus such, as Den Bosch and Uden do not get an assigned value from this API. In the model implementation, if the travel time by public transit is quicker than the travel time by car, the assigned value in the OD matrix is set to zero.

4.3.2.3 Existing Tram or metro

In the Netherlands, there are several locations where tram or metro systems are already in operation. In such cases, it is not advisable to build a BRT route along the same corridor, as there is already a high-capacity connection available. The information regarding the locations of these tram and metro lines is obtained manually by referencing the public transit networks of The Hague, Rotterdam, Amsterdam and Utrecht. OD pairs that are connected using tram or metro will be assigned a value of zero in the model.

4.3.2.4 Number of jobs

To incorporate the attractiveness of municipality based on job opportunities, the number of jobs in each municipality was obtained from the CBS. It is known that 56% of people in the Netherlands work outside their municipality of residence (CBS, 2013). On average the travel distance between work and home is 22.0 km (CBS, 2018) and the average travel time is 30 minutes (OECD, 2016), both averages include people only traveling within the municipality as well as people coming from outside the municipality. To model the job opportunities an exponential decay function was chosen, taking into account the distance and travel time between the municipalities. This function assigns a higher value to municipalities closer together reflecting a higher likelihood of people working nearby. In Equation 2 the exponential decay function can be seen. In this function the rate of decay is guided by the cost, which is either filled in by the great-circle distance or the travel time by car, and an α parameter. The resulting value multiplied with the number of commuters coming from outside of the municipality to obtain a value for ranking. In order to get a final score that can be ranked. This value will be filled into the OD matrix. It is important to note that this value cannot be added to the result of the gravity model. How this is approached with the criteria and ranking will be discussed more thoroughly in chapter 5.1.

$$jobs_{factor} = e^{-cost*\alpha} * Njobs * 0.56 \tag{2}$$

Parameter α determines the scaling and importance of the distance or travel time. This is necessary seeing that for the scale used every value would be too small to work with. The α parameter also determines the importance of the distance or travel time. A higher value for the α parameter weighs the cost factor more heavily. First, it will be looked at what the value of the α parameter should be in the formula where distance is the cost. This can be determined using different approaches. The first approach uses the average length of a BRT system in the world, which is 30.2 km (BRT Data, 2023). The second approach uses the average travel distance. Because the goal is to move people, travel distance is the approach to go with, seeing the length of other BRT systems should not be of influence. The average travel distance is 22 km towards work (CBS, 2018). In order to set a value for parameter α, the average commuting distance of 22km will be used. At the 22 km mark the value of the exponential function is 0.5, in this way, short distances get priority but the longer distances are not neglected, this is achieved at an value for the α parameters of 0.0315. The exponential curve is shown in Figure 10 from 0 till 100 km.

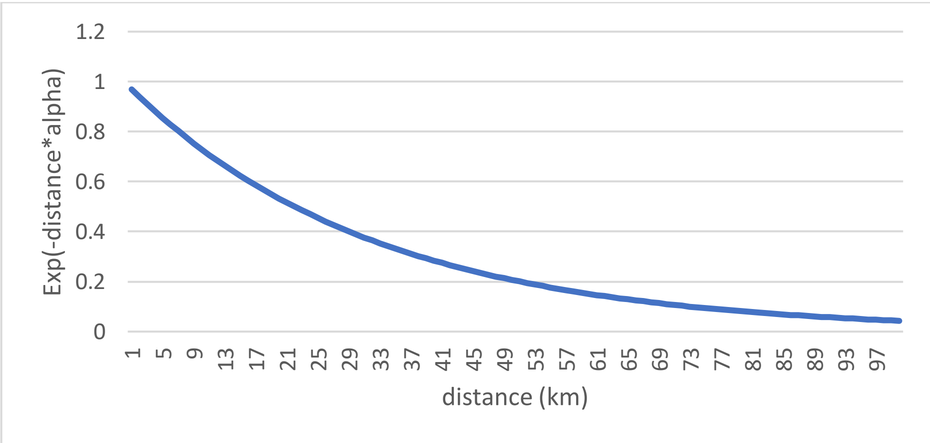

Figure 10: exponential decay over the distance with α=0.0315

A similar approach can be taken in determining the α parameter for when the cost is the travel time by car. To determine the alpha value the average travel time to work was used, which is 30 minutes (OECD, 2016). At the 30 minutes mark the outcome of the exponent should equal 0.5, to achieve this the α parameters should equal 0.0231. The decay is shown in Figure 11 from zero till 120 minutes.

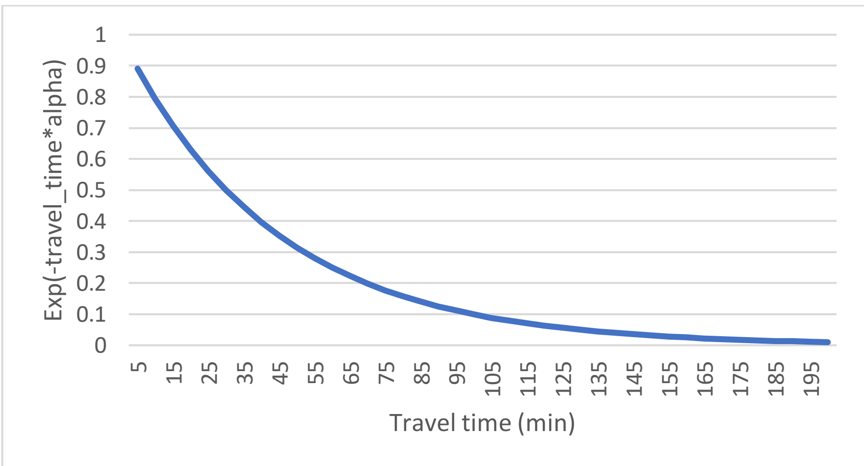

Figure 11: exponential decay with travel time using α=0.0231

5 Results

In this chapter the main results will be shown. This will be done according to the sub question that support the research objective.

5.1 Which Origin-Destination pairs are the most suitable?

To determine the most promising OD pair the criteria will be implemented into the model through four different scenarios. These scenarios aim to address the conflict that arises when wanting to combine the gravity model with the exponential decay function, as well as the different cost factors involved. By comparing the results from these scenarios, corridors that consistently appear as top performers can be further analysed for potential BRT implementation.

In all four scenarios, the existence of tram and/or metro connections and the comparison of the current public transit time with the car will be implemented. The first scenario will use the gravity model with the cost factor being the great-circle distance. The second scenario will also use the gravity model, but with the cost factor being the travel time by car.

The third and fourth scenario will use the exponential decay function based on job opportunities. In the third scenario, the cost will be the great-circle distance, while in the fourth scenario the cost is the travel time by car.

Each scenario will generate a ranking and the top 20 OD pairs from each scenario will be compared with each other. The pairs that consistently appear among the top 20 of the different scenarios will be selected for further analysis.

In Figure 12 and Figure 13 the outcome of scenario 1 and 2 are presented, along with the written out OD pairs. It can quickly be seen that for both of the two scenarios most of the connections are concentrated in the Randstad region. This can be explained by the gravity models reliance on population as one of the main factors, and in the Randstad region being home to a significant amount of the population. Furthermore, most routes connect a major municipality with a surrounding smaller one.

There are both differences and similarities between both scenarios. The difference can be explained by the use of a different cost factor, namely the great-circle distance and travel time by car. Especially when there is a body of water in between them. Such as is the case with Papendrecht and Dordrecht. The great-circle distance goes straight over the water whilst the travel time by car needs to take a detour over a bridge or around the water, thereby increasing the travel time. This means that using the travel time by car gives a more realistic answer of the current situation, whilst the great-circle distance gives an more absolute answer to the question between which municipalities there is travel demand, based on an ideal situation. This ideal situation could be interested to look at when there is not a need to follow the current infrastructure.

Scenario 1 gravity model using great-circle distance as cost

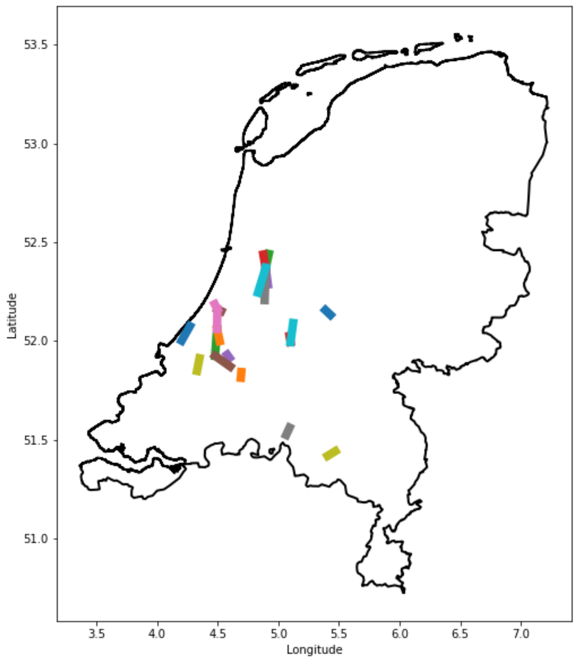

Figure 12: highest ranking BRT routes for scenario 1 OD pairs ranked from top to bot

Origin	Destination
's-Gravenhage	Westland
Dordrecht	Papendrecht
Rotterdam	Zoetermeer
Nieuwegein	Vijfheerenlanden
Capelle aan den IJssel	Krimpen aan den IJssel
Leiden	Leiderdorp
Leiden	Oegstgeest
Goirle	Tilburg
Eindhoven	Veldhoven
Utrecht	Vijfheerenlanden
Amersfoort	Leusden
Lansingerland	Zoetermeer
Amsterdam	Landsmeer
Amsterdam	Oostzaan
Amsterdam	Ouder-Amstel
Ridderkerk	Rotterdam
Leiden	Zoetermeer
Amsterdam	De Ronde Venen
Nissewaard	Vlaardingen
Amsterdam	Uithoorn

Scenario 2 gravity model using car travel time as cost

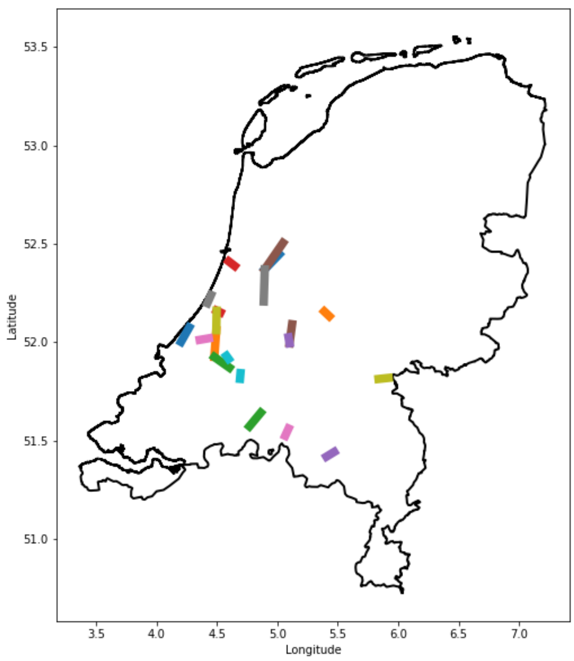

Figure 13: highest ranking BRT routes for scenario 2 ranked from top to bottom

Origin	Destination
's-Gravenhage	Westland
Rotterdam	Zoetermeer
Ridderkerk	Rotterdam
Amsterdam	Gooise Meren
Leiden	Leiderdorp
Eindhoven	Veldhoven
Utrecht	Vijfheerenlanden
Goirle	Tilburg
Katwijk	Noordwijk
Leiden	Zoetermeer
Capelle aan den IJssel	Krimpen aan den IJssel
Amsterdam	Waterland
Amersfoort	Leusden
Breda	Oosterhout
Bloemendaal	Haarlem
Nieuwegein	Vijfheerenlanden
Amsterdam	Edam-Volendam
Delft	Pijnacker-Nootdorp
Berg en Dal	Nijmegen
Dordrecht	Papendrecht

In Figure 14 and Figure 15 the results of Scenario 3 and 4 can be seen. One thing immediately stands out, which is the concentration around Amsterdam. Looking at the variables used, it is understandable seeing that Amsterdam has the highest amount of jobs and thus it will automatically rank higher.

Scenario 3 job function using great-circle distance as a cost

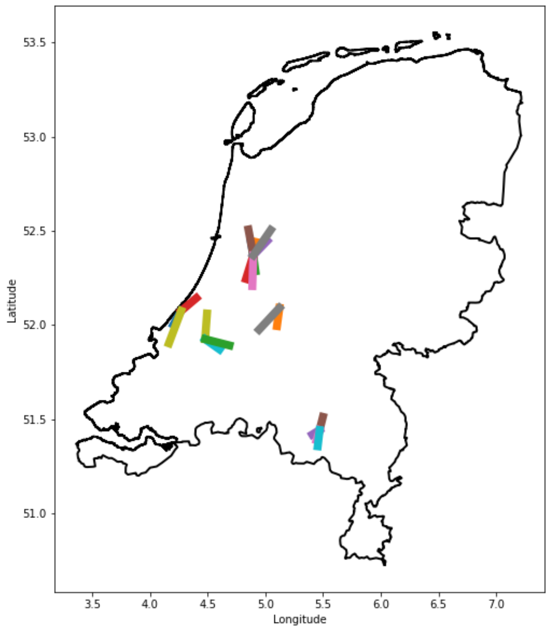

Figure 14: highest ranking BRT routes for scenario 3 ranked from top to bottom

Origin	Destination
Amsterdam	Oostzaan
Amsterdam	Landsmeer
Amsterdam	Ouder-Amstel
Amsterdam	Uithoorn
Amsterdam	Waterland
Amsterdam	Wormerland
Amsterdam	De Ronde Venen
Amsterdam	Edam-Volendam
Rotterdam	Zoetermeer
Ridderkerk	Rotterdam
's-Gravenhage	Westland
Utrecht	Vijfheerenlanden
Molenlanden	Rotterdam
's-Gravenhage	Wassenaar
Eindhoven	Veldhoven
Eindhoven	Son en Breugel
Eindhoven	Waalre
Lopik	Utrecht
Brielle	‘s-Gravenhage
Eindhoven	Valkenswaard

Scenario 4 job function using car travel time as a cost

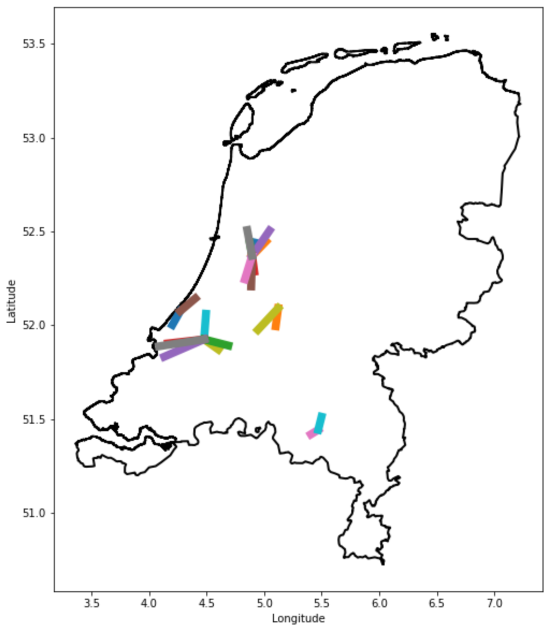

Figure 15: highest ranking BRT routes for scenario 4 ranked from top to bottom

Origin	Destination
Amsterdam	Landsmeer
Amsterdam	Waterland
Amsterdam	Oostzaan
Amsterdam	Ouder-Amstel
Amsterdam	Edam-Volendam
Amsterdam	De Ronde Venen
Amsterdam	Uithoorn
Amsterdam	Wormerland
Ridderkerk	Rotterdam
Rotterdam	Zoetermeer
's-Gravenhage	Westland
Utrecht	Vijfheerenlanden
Molenlanden	Rotterdam
Brielle	Rotterdam
Hellevoetsluis	Rotterdam
's-Gravenhage	Wassenaar
Eindhoven	Veldhoven
Rotterdam	Westvoorne
Lopik	Utrecht
Eindhoven	Son en Breugel

Each ranking from each scenario is different, however, there are multiple similarities. There are, for example, routes that show up in three or in all four of the analyses, indicating their high suitability. The following routes, ranked based on their scores in each analysis, consistently appears in all four scenarios, and can be seen in Figure 16.

- Rotterdam-Zoetermeer
- ‘s Gravenhage-Westland
- Ridderkerk-Rotterdam
- Eindhoven-Veldhoven
- Utrecht-Vijfheerenlanden

Figure 16 most suitable lines for BRT

One of the main differences between the analyses is that in using the exponential decay function a higher dependency around Amsterdam can be seen. This can be attributed to the fact that in Amsterdam the most amount of jobs are located, however, also the largest amount of people live here and thus it should also have appeared in the outcomes of scenario 1 and 2. The difference can possibly be explained by the fact that cost factor weighs more in the gravity model than in the exponential decay function.

Looking into existing bus connections is crucial before selecting which routes to work out further. This needs to be done, because the model does not take existing bus routes into account. For the case of Rotterdam-Zotermeer, there is already a bus connection present between Zoetermeer and Pijnacker where at Pijnacker a transfer is possible onto the metro system of Rotterdam. Although it is possible to extend the ZoRo busway and make a full fledge BRT system out of it, previous research on connecting Rotterdam and Zoetermeer concluded that upgrading the ZoRo busway to BRT and extending it into Rotterdam is infeasible (Metropoolregio Rotterdam Den Haag, 2022). This is due to practical limitations of fitting in a busway in this part of Rotterdam and integrating it in the normal traffic of Rotterdam would decrease the reliability of the system. Therefore, a route between Rotterdam and Zoetermeer will not be determined.

In the case of ‘s Gravenhage and Westland, there is currently no direct connection present between the two municipalities. Every connection between ‘s Gravenhage and Westland requires a transfer, either from a but to tram in the suburbs of Den Haag or bus to train in Delft or Rotterdam. This leads to longer travel times than necessary. Therefore implementing a BRT system could provide a solution to easily connect the two municipalities and improve the connectivity.

Regarding the Ridderkerk-Rotterdam corridor, there are already two connections between Ridderkerk and Rotterdam, one goes towards Zuidplein and the other goes towards Kralingse Zoom. At both these end stations there is a metro stop and place to transfer towards other buses. These connections do thus always require a transfer to reach the centre of Rotterdam. Alternatively from Ridderkerk it is also possible to catch the bus towards Zwijndrecht or Barendrecht and hop on a train towards Rotterdam. Implementing a BRT system on the corridor could provide a quicker and more direct connection towards the city of Rotterdam and with that to the rest of the country. There are challenges with implementing bus lanes in Rotterdam especially in the centre where there is a high concentration of tram lines.

Between Eindhoven and Veldhoven six different bus lines operate at this moment. These lines all have varying frequencies, with some running on half hour or hourly intervals and one line only operating in the morning rush hour. Some of these lines do not take a direct route towards Veldhoven, but take a detour towards Waalre or meander through the suburbs. While it may seem there are already enough connections, this may not be the case with the growing industries and a major hospital in Veldhoven. A quick reliable connection towards the centre of Eindhoven and with it the rest of the Netherlands ensures growth opportunities for businesses as well as the city itself.

Currently, between Utrecht and the municipality of Vijfheerenlanden, there is one bus that connects Vianen and Leerdam with Utrecht. This bus operates in a loop which switches direction in the afternoon. There are also two urban lines that connect vianen with Utrecht. The bus that connects Leerdam only stops a few times, it is therefore already a quick connection, the journey ends at Utrecht Central station. This line can be upgraded to a BRT line in order to upgrade the capacity on this line if deemed needed. The BRT connection between breda and Utrecht that is currently in first phase can also stop in Vijfheerenlanden to increase the connectivity of the region.

5.1.1 Sensitivity

Working with a models output it is important to see how sensitive the model is. In all models parameters carry a certain uncertainty, a sensitivity analysis gives insight in the robustness of the model, identifying sensitive parameters and can help determine critical values (Pannell, 1996). In short it can help in determining how uncertain the model is. For this model the value of alpha in the exponential decay function will be looked at as well as the γ parameter in the gravity model. For the sensitivity analysis it will be checked how the model behaves if the γ parameter is made larger and smaller. The same will be done for the alpha value. Next to this it will also be checked to see whether the results would be different if for populations the exponential function would be used and the gravity model for employment opportunities. The full results of the sensitivity analysis can be seen in Appendix A. sensitivity.

5.1.1.1 γ parameter

The γ parameter should influence the weight that the cost factor has on the outcome in the gravity model. To check this the model was ran both for scenario 1 and 2 with different γ parameters. Meaning the higher this factor is, the more weight is laid upon the travel time or the distance. The test is run for three different γ parameters and compared with the original. The γ parameters used are one, three and five. The results of this analysis can be seen in Appendix A. sensitivity. From these results it can be seen that for scenario 1, when γ becomes smaller multiple routes change towards more urban centres in the Netherlands such as Amsterdam. When the γ parameters increases exactly the opposite happens. Instead of giving results relaying on population centres, it gives increasing favour towards the great-circle distance, giving municipalities that lay close together preference.

For scenario 2, the exact same test is performed only now looking at the travel time as a cost instead of the great-circle distance. When decreasing the γ parameter to one it can be seen that again there is lean towards the major population centres. However, a strange thing occurs. Namely, that Meierijstad is getting more attention, this can be due to the fact that the centre of this municipality is located fairly close to a motorway which decreases the travel time. When increasing the γ parameter it can be seen that the favour for smaller travel time increases and only municipalities are gotten which lay closely together. Different municipalities are gotten than for scenario 1. This can be explained by the fact that if two municipalities lay closely together such as Papendrecht and Dordrecht the travel time by car may be bigger due to a river between them. The behaviour of the model is expected but it can be seen that the model is sensitive to a change of the γ parameter.

5.1.1.2 α parameter

The α parameter influences the weight that the cost factor has on the outcome. It is important to check whether this really is the case or not. Therefore multiple different α parameters are used to check this. The α used for scenario three in the report is 0.0315 the α parameters used to check whether the model behaves accordingly are 1, 0.01 and 0.0001, the outcomes can be seen in Appendix A. sensitivity. The bigger α parameter should increase the weight of the distance which is also what can be seen only municipalities which lay closely together are brought forward. Decreasing the α parameter should also decrease the influence of the distance. It can be seen that Urk-Amsterdam is a proposed route which lay in great-circle distance closely together but in travel time not, due to the IJsselmeer between them. When the α parameter is at its smallest only routes from Amsterdam are proposed seeing that this is the municipalities with the largest amount of job and the exponent is made small enough that it is comparable for each distance.

For scenario four the α parameters used are the base value which is 0.000385, when the model is set to seconds in stead of minutes, and to test the behaviour of the model 1, 0.001 and 0.00001, In this scenario the cost is the travel time by car. It can be seen that when the α parameter is larger the model will propose municipalities that can be quickly travelled to by car. Decreasing it the distance becomes less important until the amount of jobs present takes the overhand, as can be seen with the smallest α parameter for which all of the corridors proposed are from Amsterdam to the rest of the country. The behaviour of the model is expected but it can be seen that it is sensitive to a change of the α parameter.

5.1.2 Potential gravity model for jobs

It can be seen what will happen if instead of the exponential decay function the gravity model is used. The formula is changed to include the number of jobs outside of the city instead of the populations of the two municipalities multiplied. Multiple things can immediately be seen when looking at the outcomes. The first thing is that the corridors provided are more spread out of the country and not only centred around the Randstad and especially Amsterdam. Providing more routes connecting a bigger municipality with a smaller neighbouring municipality, this means that the distance might be weighing more heavily compared to when using the exponential decay function. It can thus be said that the amount of jobs per municipality weighs less than the distance.

5.1.3 Exponential decay function using population

When implementing in the exponential decay function, the number of jobs is replaced by the populations multiplied with each other. When looking at the results the opposite happens as in the previous analysis, The populations become more important when compared to the base situation and the distance is less important. This can be attributed to the fact that when looking at the exponential decay function. The impact of the distance is halved when doubling the distance. However in both situations multiple routes keep showing up, such as ‘s Gravenhage-Westland.

5.2 what could be a possible route for BRT?

In this chapter a possible route will be outlined for the corridor Ridderkerk-Rotterdam and ‘s Gravenhage- Westland, which were previously determined to be one of the most promising routes. In Figure 17 the areas of interest can be seen.

Figure 17: areas of interest

5.2.1 Route 1 ‘s Gravenhage-Westland

Currently no quick connection exist between ‘s Gravenhage and Westland whilst form the analysis it looks like there would be a demand to have a high capacity public transit connection. ‘s Gravenhage has around 550.000 inhabitants and has work for around 270.000 (CBS, 2023) and is build up with the city of Den Haag. The municipality Westland has 112.000 inhabitants and 65.000 places to work(CBS, 2023), in contrary to ‘s Gravenhage, Westland is build up with multiple smaller cities and villages such as ‘s Gravenzande and Naaldwijk. In Figure 18 the municipality of Westland can be seen with al of its cities.

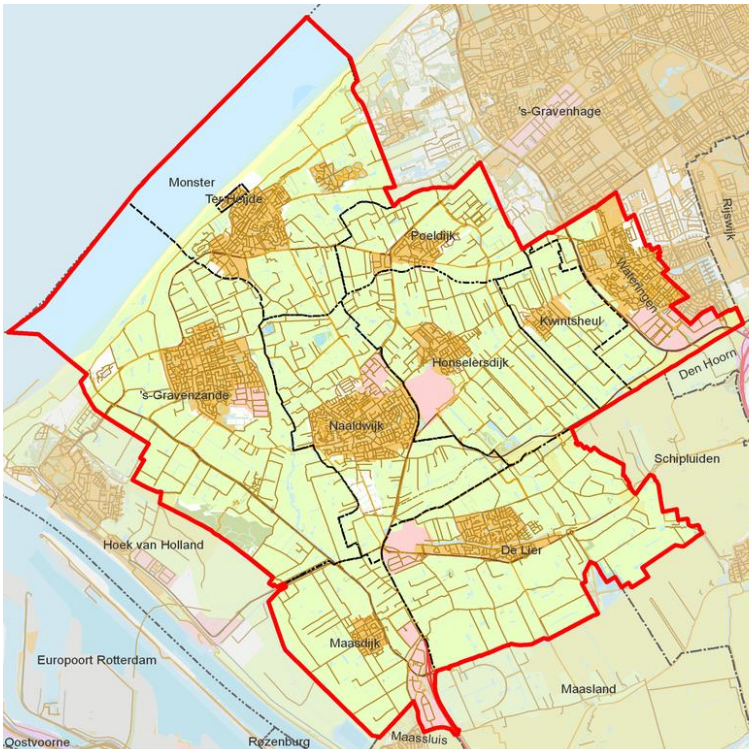

Figure 18: cities and villages in the municipality Westland(van Aalst, 2012)

The route can start at multiple locations. In Den Haag, the most obvious one is at train station Den Haag Centraal. This station is located next to the city centre and the “office district” where among others Dutch ministries are located. Additionally the rest of the city of Den Haag and surrounding municipalities can be accessed from here by tram, bus or metro and the rest of the Netherlands by train. Making it a valid option to start or end the BRT route. In Westland it is more difficult to determine where the route should go seeing it has no clear urban centre. The two most populace places are Naaldwijk and ‘s Gravenzande, which are comparable in size. It needs to be decide if both need to be connected or only one of the two. Naaldwijk has the advantage that the business park is being redeveloped into the horiculture hub of the Netherlands (Gemeente Westland, 2020). Meaning there will be a bigger attraction towards it. Therefore, it route can go from Den Haag towards Naaldwijk and onwards to Maassluis where it can connect with the metro network of Rotterdam further enhancing the connectivity. This can be the main branch where at Poeldijk a second branch can split and go through Monster and ‘s Gravenzande towards Hoek van Holland to connect with the metro network as well as the ferry towards Britain. Thus two lines can be generated one from Hoek van Holland to Den Haag and one from Maassluis towards Den Haag.

In Figure 19, the potential routes can be seen. This route will also cross station Den Haag Moerwijk and Den Haag Holland Spoor. In total the route from Den Haag Centraal towards Maassluis is 24.5 km long and the branch from Poeldijk towards Hoek van Holland is 13.9 km long, in total the new route will be 38.4 km long.

It is also important to see if these routes will improve the public transit travel time or will only increase capacity. The current public transit times can be taken through google maps and the future travel time can be determined by looking at how long a car would take traversing the route and multiplying it with a reduction factor. This can be done since a bus will drive the same speed as a car only it will have to slow down, wait and speed up more often due to the stops (Tirachini, 2013). This factor can be determined by looking at bus routes and dividing the car travel time by the bus travel time. When this is done for a large enough sample, in this case 75 interurban routes, an average value of how quick a bus drives compared with a car can be found. The 75 routes which are compared can be seen in Appendix B. Bus travel time factor. It can be concluded that interurban buses in the Netherlands drive on average at 83.36% of the velocity that cars do on the same route. Now multiplying the car travel time with this factor the bus travel time can be determined. An overview of the current public transit times compared with the travel times if there is a BRT system can be seen in Table 1 for the routes taken in Figure 19, a satellite picture of the route can be seen in Appendix C: satellite images of the routes. On the route 12 stops can be placed on the main branch and 5 on the branch towards Hoek van Holland. These stops are located further apart than normal bus stops to facilitate quicker movement of the bus. The stops are placed at either existing train stations such at Den Haag Holland Spoor or close to intersections to increase accessibility into the rest of the suburbs. One stop is placed between Maasdijk and de Lie, where a P+R can be build to also be able to connect these cities, the placing of the stations is a suggestion.

Table 1: travel times current situation and with BRT route 1 ‘s Gravenhage-Westland

	Current PT travel time (min)	Current amount of transfers	Off peak car travel time (min)	Potential BRT travel time (min)
Maassluis – Den haag	47	1	37	44
Naaldwijk – Den Haag	48	1	24	29
Hoek van Holland- Den Haag	62	1	36	43
‘Gravenzande – Den Haag	43	1	29	35

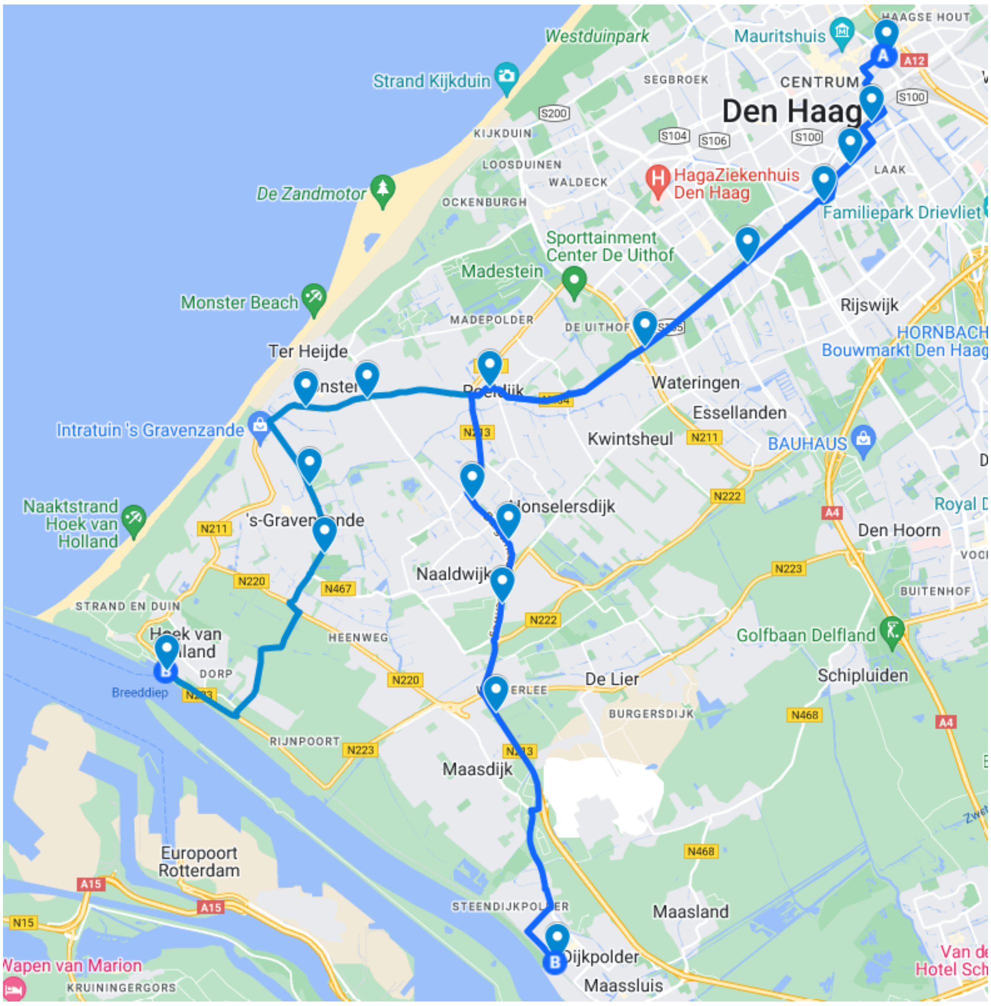

Figure 19: route between 's Gravenhage and Westland

5.2.2 Route 2 Rotterdam Ridderkerk

Between Rotterdam and Ridderkerk there is only a connection present to the suburbs of Rotterdam. It could be beneficial to include a connection towards the city centre of Rotterdam. In Rotterdam around 650.000 people live and there is work for around 390.000 (CBS, 2023) the municipality is mostly build up with the city of Rotterdam and the Harbour. There are also smaller cities such as Hoek van Holland. Ridderkerk has 48.000 people living there with place for 21.000 to work (CBS, 2023). There are three smaller towns in the municipality Ridderkerk, Slikkerveer and Bolnes that have grown together.

For the route it has already been mentioned that there is currently already a connection present towards the suburbs of Rotterdam namely to Zuidplein and Kralingse Zoom but it might be useful to get a connection towards the city centre as well. Therefore the start point will be the bus terminal at Rotterdam Central station. For Ridderkerk the bus can go through the centre and end at the carpool place Ridderkerk Oudelande where there is enough space for the busses to turn and where this existing parking space can be expanded into a full fledge P+R. The line can also be extended into Hendrik-Ido-Ambacht or Alblasserdam if deemed necessary. To form this connection multiple routes can be taken, depending on where the Meuse will be crossed. This can be done either through the Maastunnel or over the Erasmus- or Brienenoordbrug. The Erasmusbrug and the Maastunnel are located in the city centre of Rotterdam, they only have two lanes in each direction meaning if a BRT system would be implemented here one of the lanes needs to be sacrificed. This will lead to a poorer connection between north and south or the busses need to run in between the morning rush hour making them less effective. Therefore, the only logical option is to send the busses over the Brienenoordbrug at the A16.

The route is 15.64 km long and start at the current carpool parking just south of Ridderkerk and goes through the city of Ridderkerk and past P+R Beverwaard on to the parallel bus lane next to the A16. It joins this motorway just before the bridge and exits it at the Erasumus University the path continues along the waterfront goes north passing Metro station Oostplein and continues towards the central station. In Table 2, an overview of the travel times can be seen. From this table it can be seen how long it takes nowadays to go from the carpool Ridderker Ouderwaard towards Rotterdam centraal. Once a BRT route is implemented the travel time can be reduced by 19 minutes. This uses the route shown in Figure 20, a satellite picture can be seen in Appendix C: satellite images of the routes. On the route thirteen stops could be placed of which seven are located in Rotterdam and six in Ridderkerk. These stations are placed either at existing P+R, such as is the case at Beverwaard, close metro stops such as to Oostplein, the university, a football stadium or to intersections to increase the connect ability with the rest of the suburbs, the placing of the stations is a suggestion.

Table 2: travel times current situation and with BRT route 2 Ridderkerk-Rotterdam

	Current PT travel time (min)	Current amount of transfers	Off peak car travel time (min)	Potential BRT travel time (min)
Ridderkerk-Rotterdam	40	1	18	21

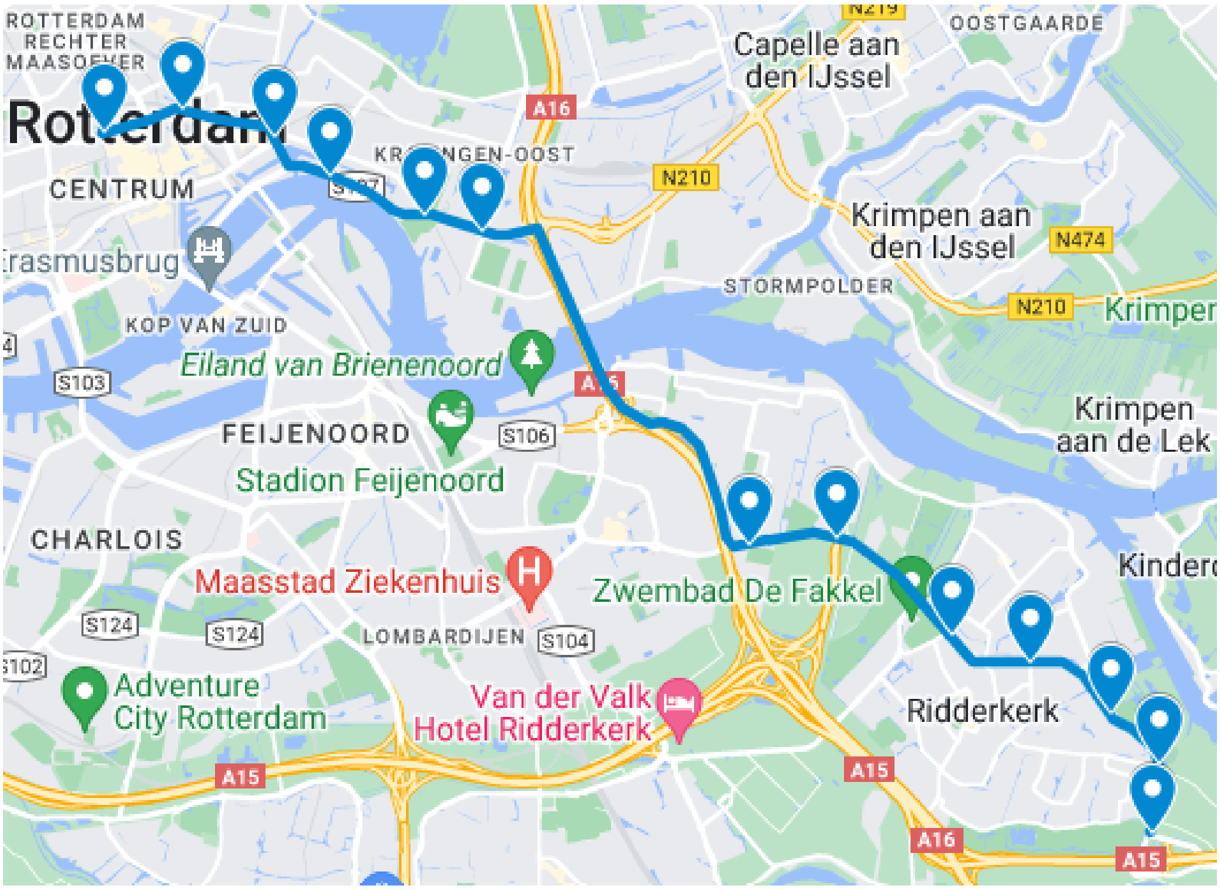

Figure 20: route between Ridderkerk and Rotterdam

5.3 What does the current infrastructure look like along this route and are changes needed along this route?

In this chapter it will be looked at both routes to see where potential infrastructural changes are necessary. It will also briefly be looked at if certain characteristics from the examples discussed in chapter 2.3 can be copied.

5.3.1 Route 1 ‘s Gravenhage-Westland

Currently, on the route between ‘s Gravenhage and Westland on the route laid out, there are not many bus lanes present. In total there is around six hundred meters of bus lane just east of Naaldwijk and only for entering a crossing. To ride a reliable BRT system on this route there is a need for more bus lanes, seeing the traffic can get hold up here easily. Here a problem arises. Most of the route is currently build up out of a two-way street. Only some parts go over streets with four lanes in total. This means that in most places extra bus lanes need to be constructed and the road needs to be widened. The spatial fitting of the BRT route will thus become more difficult. Especially seeing that along most of the route property is build up against the roads. It can also be looked into turning a normal road into a bus only road, however research is necessary into the accessibility of the surrounding properties and smaller cities they might connect.

In Den Haag, the route follows mostly the Erasmusweg this road is very wide and in most places four lanes with on street parking. Two lanes can be turned into bus lane or the on street parking can be removed. Along some the route there is also space to reserve the current infrastructure and make the road wider this however does remove green space. In Westland most of the route is closed in by property or a drainage channels here more adaption is needed to make a BRT service fit, therefore further studies is necessary if it is wanted to either remove property, relocate the channel or have the busses mixed in with traffic this is one of the main hurdles of implementing the BRT system that it crosses mostly build up area with small roads. Another hurdle is located in Westland as well that is two intersections on the N-roads with Turbo roundabouts, with traffic lights. The easiest way to overcome this hudle is to make bus only on and off ramps and give them their own traffic lights to ensure priority. An overview of the current infrastructure along the route can be seen in Figure 21. This is the route when going along existing roads it can also be looked at building bus only roads as was the case in Cambridgeshire this could for example be done to skip over Poeldijk to decrease the travel time between Naaldwijk and Den Haag. Other characteristics of the Cambridgeshire busway can also be copied especially the multiple faces of the busway. This means the infrastructural changes, meaning it sometimes mixes with traffic, goes over bidirectional bus lanes or has two bus lanes. It can also be looked at how branching is approached at this busway.

Figure 21: road characteristics along the route 's Gravenhage-Westland

A rough estimate of the price can be quickly determined. The cost per kilometre when looking at comparable projects in other high income countries is 10.380.042 dollar (ITDP, 2017) or around 9.500.000 euros, The cost used to come towards this average did vary between 4 million upwards of 18 million. Using the average cost however the proposed route, with a length of around 39 km, would cost rounded up around 400 million euros, laying down LRT here could be 1.5-3.9 times as expensive (ITDP, 2017). If only the route along Naaldwijk is constructed which has a length of 25 km the cost would boil down to 250 million euros. For the total project the capital investment is large making it maybe necessary to build it in phases where Maaslsuis-Naaldwijk-Den Haag would be advised to do as phase one. It has to be said that the average was calculated six years ago making it probably less than that it would cost nowadays due to inflation. This cost excludes further infrastructural changes such as building a park and ride facility and changes such as laying down more cycling paths.

For the bus stops it can either be chosen to heighten the platform or lower the busway, as is the case in Nantes, to facilitate platform level boarding. When lowering the busway the stop can remain at the same height as the rest of the sidewalk lowering the chance of somebody tripping over and being more accessible from each direction. However, when doing this on a road where also normal cars will drive past it can also enhance the chances of accidents happening when a car swerves a bit and gets stuck with their tyres in the ditch. Heightening the stop to create platform level boarding is the normal way of working in the Netherlands, making it more recognizable as a bus stop and when located next to a normal road keeping the whole road at the same level. Therefore, it is advisable to keep with the trend in the Netherlands and heighten the stops.

5.3.2 Route 2 Ridderkerk-Rotterdam

Along the route from Ridderkerk to Rotterdam there are already some bus lanes present for example in Ridderkerk on the Rotterdamseweg there is on most places a one lane bus lane. Which between some intersections disappears but on most of the Rotterdamseweg there is an only one bus lane. This needs to be increased into one in each direction seeing the current buses will use them as wel as the future BRT buses. The route continues on a bus only onramp onto the A16 and mixes with traffic on the bridge. Here the hard shoulder can turned into a bus lane, with a barrier between the bus lane and normal traffic, to make the bus travel more reliable. In Rotterdam itself the beginning of the route goes over a four lane road of which maybe two could be turned into bus lanes or the road can be expanded, this does remove some green space, however just as has been done in Nantes trees can be planted as a median. Once the bus goes towards Oostplein onwards to the central station. The route passes along a tram line, making it more difficult to fit in the busses along the same route with a bus lane, without turning the whole street into a public transit only street. Therefore, it needs te be determined in a further analysis if mixing the buses with normal traffic is an option or if the buses can run on the tramways, which usually is undesirable since a BRT bus will drive more quickly than a tram (KIM, 2020), it can also be looked at rerouting the buses, however, this will increase travel time. This route could for example drive longer along the Meuse until the Hospital and than go on the S100 northwards. An overview of the current infrastructure along the route can be seen in Figure 22.

Figure 22: road characteristics along the route Ridderkerk-Rotterdam

The cost of this route can be determined the same way as was done for 's Gravenhage-Westland and with a length of 16 km the cost will come down towards 160 million euros in total excluding to cost to rebuild the carpool into an P+R and other changes to connect the stations with the rest of the city. Building an LRT system here could cost 1.5-3.9 times as much as BRT depending on the circumstances (ITDP, 2017).

5.4 What role can the BRT system play in the regional mobility and urban developments?

A BRT system can be used to connect major cities together it can also be used in order to connect the hinterland of a city with itself. When BRT is implemented the bus cannot drive past everybody's home, therefore there are predefined stops for people to go too. But can these stops play a bigger role in urban development? Ibraeva et al (2020) describe transit oriented development (TOD) as follows, land-use and transport planning that makes sustainable transport modes convenient and desirable, and that maximizes the efficiency of transport services by concentrating urban development around transit stations. However there is no such thing as set in stone definition. It can broadly be seen as "careful coordination of urban structure around the public transport network"(Hickman and Hall, 2008). There is also something know as transit adjacent development (TAD) this is development which "lacks any functional connectivity to transit, whether in terms of land-use composition, means of station access, or site design"(Transit Cooperative Research Program, 2002).

There are many characteristics in what can make a successful TOD such as density and distance to transit stops, but also characteristics based upon the frequency, speed and capacity of the transit mode (Knowles et al., 2020). When a BRT system is implemented at one of the stations a TOD can be build. This means high density, mixed-use planning around the station with good walking and cycling access to the rest of the development, encouraging the use of the transit towards and away from the development and minimizing the use of cars. Confirming this is a study looking at development around BRT lines in Latin America by Rodriguez and Vergel-Tovar (2018). They saw that stops where development is oriented towards transit, were more likely to have a higher ridership than other stops that where placed in existing infrastructure. Also the development around the stations increased significantly, increasing the density and the value of property. One of the disadvantages of a BRT base TOD is that economic development may be constrained because BRT is less locational rigid and permanent than Rail services (Dittmar and Poticha, 2004), although it has to be said that the rigidity of the BRT line is dependent on how extensive it is build.

For BRT there is also another burden to tackle namely the first and last mile problem this is the problem of getting the passengers from the transit hub towards their destination (Wang, 2017). Decreasing the door to door travel time is one of the most important things in creating a well used transit system (Loxton et al., 2019). Therefore, it is important when designing a Transit system to already look at how to deal with this problem. There can be multiple solutions to tackle this and are depended on the characteristics of the surroundings. If the station is a hub between smaller towns or if it is a station in a TOD different approaches need to be taken in tackling the problem. For regional hubs it can be thought of to connect them with good cycling paths to the nearest towns to make it easy for people to cycle towards the stop. This symbioses between BRT and bicycles is especially important in the case of the Netherlands since more than 25% of daily trips are made by cycling (Rijksoverheid, 2018), this means this approach can not blindly be copied into less cycling oriented countries. Next to this a park and ride facility can be build in order to incentivise people to take the bus and minimizing the amount of cars in the city. For visitors it can be thought of to provide rental services for shared mobility especially for bikes and scooters since these are most preferred by the Dutch public (van Kuijk et al., 2022). These do have the problem that you want to park them closely to your destination which is sometimes not allowed or other people can use them, making it not guaranteed that you have a ride back. If there are a lot of people coming from the same area it can also be looked at connecting regional buses to the BRT stop to make it a real transit hub. These regional buses can connect the areas not connected with the BRT to it making the threshold to take the route lower.

BRT can thus play a role in urban development by providing high frequency and capacity services to other parts of the city or country making it an attractive place to live close by. This is especially the case once the area around the stations are designed with transit in mind and allow for easy access. A BRT system can in the regional mobility connect two major urban parts together. However these are most of the time already well connected its main advantage is to connect smaller town centres with there bigger neighbour in order to facilitate easy and fast transport and lower the pressure on the road network. The first and list mile problem at these stations can be tackled by stimulating cycling, providing shared mobility, building a park and ride and if possible connecting regional busses to the line.

For the route ‘s Gravenhage-Westland this means that it is possible to have an urban expansion of the smaller towns without necessarily increasing the traffic density on the road. Around the BRT station buying out for example some greenhouses and increasing density to create a TOD can be a possibility, this creates possibility to work further away from the big city whilst still having a good connection to it. Around some stations an P+R can be build, to increase the ridership and the connectivity an example of where this can happen is between Maasdijk and Lierop the route does not touch these towns but creating an P+R for cars and a good cycle network makes sure these people can still use the BRT service.

The route between Ridderkerk and Rotterdam already crosses mostly urban area, making it more difficult to expand. However, around stations the neighbourhood can be redeveloped to increase density, make space for bike storage and make the station more easily accessible for the rest of the city by connecting it to the cycling network are possibilities to increase ridership. The final station on the line can be made into an P+R for the people that are going to Rotterdam but do not want to travel by car into the city.

6 Conclusion

To conclude, a framework has been made that takes population, car travel time, current travel time by train, presence of metro and tram and job opportunities into account to predict where there might be a possibility to implement a BRT system in the Netherlands. Using the model four routes came forward, namely: Rotterdam-Zoetermeer, ‘s Gravenhage-Westland, Ridderkerk-Rotterdam, Eindhoven-Veldhoven and Utrecht-Vijfheerenlanden. Two lines were analysed in more detail, to see what a rough outline could be of a route, which are ‘s Gravenhage-Westland and Ridderkerk-Rotterdam.

The route between ‘s Gravenhage and Westland has a total length of 38.8 km and branches of towards Naaldwijk and ‘s Gravenzande, both branches will also connect with the metro towards Rotterdam in Maassluis and Hoek van Holland respectively, it is estimated the route will cost around 400 million to construct and will save from Naaldwijk towards Den Haag centraal 19 minutes and from ‘s Gravenhage 8 minutes compared with current public transit times.

The route between Ridderkerk and Rotterdam is 15.6 km long, it is estimated that it will cost around 160 million euros to construct. The route can in an ideal situation save 19 minutes compared with the current situation. For both routes big infrastructural changes are necessary. On these routes there can also be looked to build Transit Oriented Developments around the bus stations and it is important to make sure the stations are accessible by walking or biking to increase ridership. A particular feature of any BRT system in the Netherlands is that it would need to build bicycle parking around stations, to encourage the use of bicycles as a feeder to the public transport network. On some places Park and rides can be build when the station is located farther from the urban centres to increase accessibility.

7 Discussion

During the project multiple assumptions and simplifications needed to be made in order to get a working model. One of the first things that will be discussed is that municipalities are used instead of cities. This can lead to problems seeing that for example in Westland there are multiple cities of the same size. In this research, a simplified analysis was made in deciding how to connect each city, however, in reality, more variables need to be considered in such decisions, such as the attractiveness of each city for different trip purposes, current level of services with different modes, modal split and so fort. For most of the municipalities in the Netherlands the approach developed in this research works fine, seeing that only one city or one major city is present but for some this does not work. Therefore to make the model more accurate cities can be used instead of municipalities. This will also decrease another problem, namely that for all of the calculations coordinates where used that where in the middle of the municipality. This matters seeing the major urban centre might be in one of the corners of the municipality, as is the case with the municipality of Deventer where the city itself lays in the bottom right of the area and the rest is mostly farmlands, forest and a few smaller urban towns. This skews the results, meaning the travel time and distance are not accurate for the real life situation.

Next to this the travel time between each municipality was determined using OSRM. This software determines the shortest path and with the speed limits calculates a travel time, meaning an off-peak travel time is gotten. This can be used as a cost to see if it is a feasible driving distance. However rush-hour travel time would also have been interesting to look at seeing that if the travel time in rush is more than in off-peak seeing people might be tempted to switch. However this data could not be found.

The number of transfers as a variable to influence the ranking of the corridors was not included. This would have been an interesting criteria to implement seeing that, when there are more transfers the resistance to travel increases. If this was implemented routes where the train is slightly quicker than the car but it needs a lot of transfers to get to the destination could have been brought forward.

Next to this, the model only uses train travel time since the API used did not include bus travel times and the APIs that could do this where behind a pay wall. This leads to the case that the model proposes routes that have already a quick connection, without telling that there is one. Making it necessary to manually look at the top routes to see if a BRT connection can be feasible here or if the current bus network is already frequent and quick. This is for example the case between Dordrecht and Papendrecht. Other things that the model also does not include via the API are the Waterbuses, metro or tram networks. The Metro and Tram networks where manually included seeing that only Den Haag, Rotterdam, Utrecht and Amsterdam have a Tram or Metro and the connections made with these to neighbouring Municipalities are limited, however, it would be better if the model would automatically include these connections.

At the same time the equations used in the model can be seen as rather basic. For a first study of which routes could have potential the formulas used give a clear idea. Further study into the full potential needs to be done in order to get a definitive answer if there is potential for BRT. Next to this the formulas use a cost factor of which the weight is determined by the α and γ parameters. The γ parameter was determined from literature and the α parameter was fitted. However, as can be seen from the small sensitivity analysis done both of these parameters influence the outcome greatly. When changing them only a bit the major outcomes will not change much, however, if they are changed by halving or doubling them for example the outcomes are completely different, therefore, the model is fairly sensitive towards these values. It was also tested what would happen if the equations where switched. It could be seen that the gravity model weighs distance more than the exponential decay function. Therefore, it can be said that using both equations and comparing the results a balance is found between weighing the distance and the population or the job opportunities.

Additionally, for the job opportunities function an exponential decay function was used. However, there could also have been chosen to use a linear, stepped or logistic decay. Other functions might lead to different results which may be better, therefore it can be looked in the future if another decay function might provide better results.

Finally the routes that are proposed are made with a limited level of detail, meaning that if it is decided that there is need for a BRT connection on the corridor, a more in depth analysis has to be made in order to get a route which can substantiated. The method proposed in this research has the value of providing a general guideline about which OD pairs to look at first. Moreover, the method is generalisable if modellers want to include other variables as indicators of the attractiveness of an area for BRT this is possible.

8 Recommendations and further studies

In this research it was only looked at the different municipalities within the Netherlands, it might be interesting to look at the municipalities just outside of the border to connect the border regions. This means that an Maastricht/Heerlen-Aachen or Geleen-Maasmechelen could be a promising connection but it is not known form the analysis.

As previously mentioned it might also be a more realistic approach to look at city level instead of looking at a municipal level. A different scale level for the model might also be interesting to look at for example looking at only a certain region and determining connections on a neighbourhood level, where routes such as connecting the high tech campus in Eindhoven with the city centre might come forward.

For future use of the model it might be a good idea to look at an API which includes car travel times and public transit times for each mode of transportation. This could for example be the Google Maps API, however, for this API payment is necessary making it less viable for a first analysis. But for a more in depth analysis it is recommended to look into using an API like this.

Moreover the model focusses on routes where high ridership can be achieved. No routes which connect two smaller cities or are longer but can still be profitable are found. This means that there might be unfound routes where BRT could work, more research can be done to adapt the model to provide these routes.

Next to this, the framework build is more an initial look at what might be interesting OD pairs to investigate further. Therefore it is necessary to do more thorough investigation if the connections proposed are viable and, if so, what could be the best routes to follow. The routes where now determined using educated guessing but it might be better to do some more research into this and see what the best route could be.

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10 Appendices

Appendix A. sensitivity

In this appendix the outcomes of the sensitivity analysis are displayed used in chapter 5.1.1. Figure 20 till 23 are about the sensitivity for scenario one where in the gravity model the γ parameter is changed and the cost used is the great-circle distance. In figure 24 till 27 the results for scenario two can be seen where the γ parameter in the gravity model is changed with the cost being the driving time.

In figure 28 till 31 the outcomes can be seen for scenario 3 where the α parameter is changed in the exponential decay function, with the cost being the great-circle distance. In figure 32 till 35 the outcome can be seen for scenario 4 where the α parameter is changed in the exponential decay function, with the cost being the driving time.

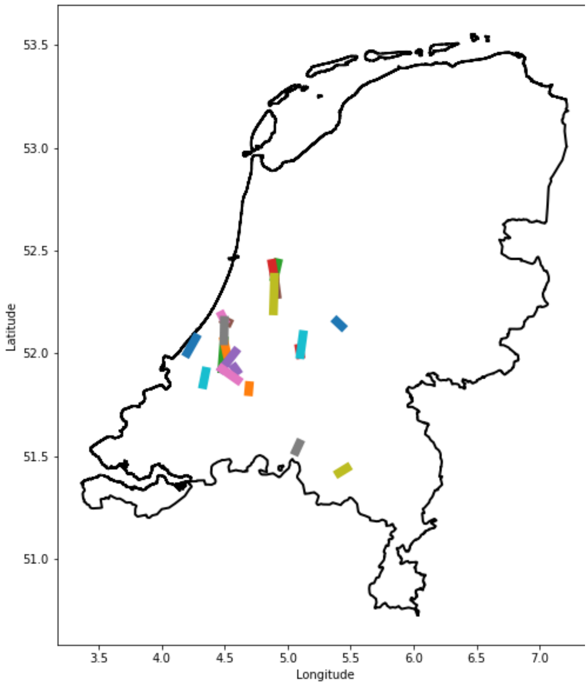

Figure 23: scenario 1 γ=2 (base)

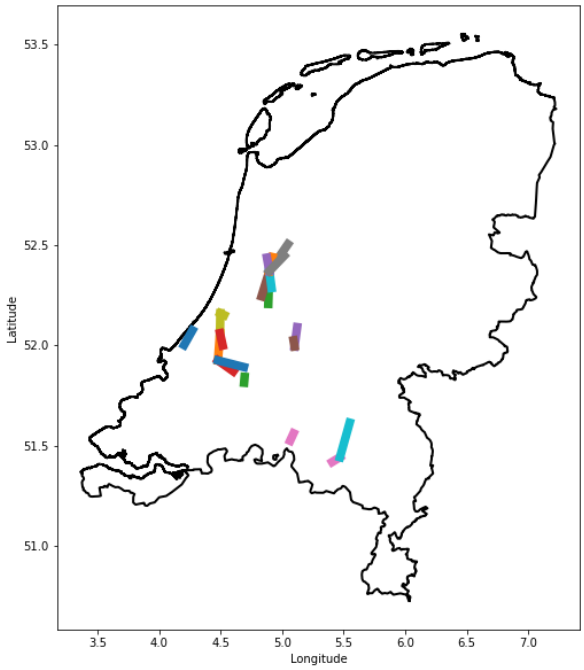

Figure 24: scenario 1 γ=1

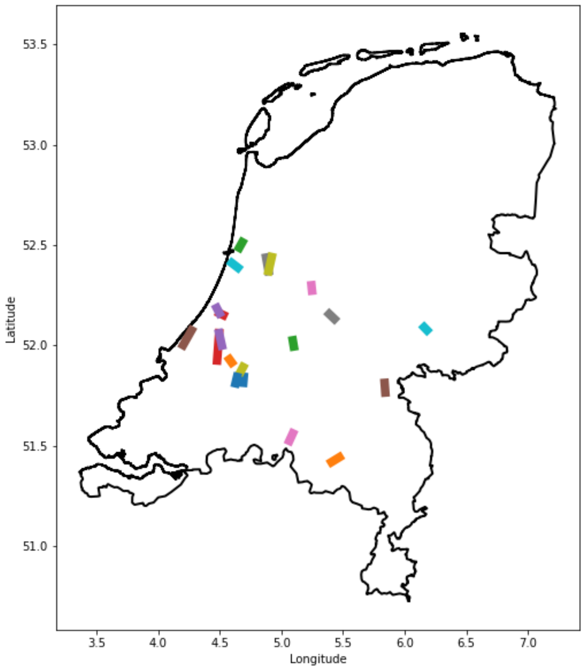

Figure 25: scenario 1 γ=3

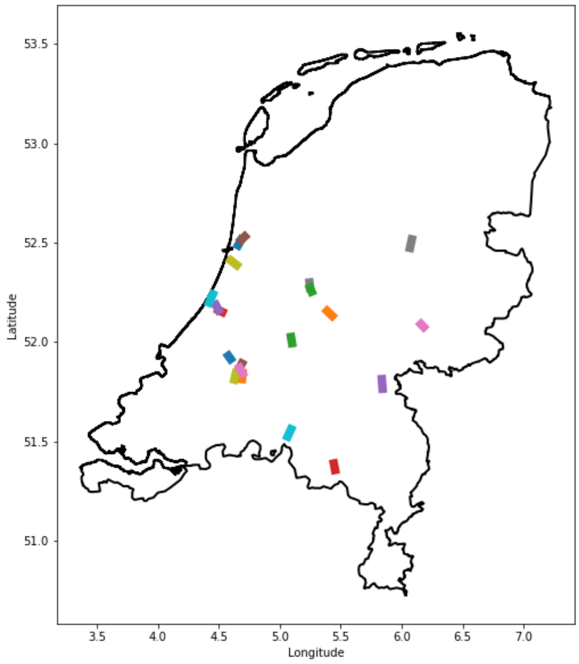

Figure 26: scenario 1 γ=5

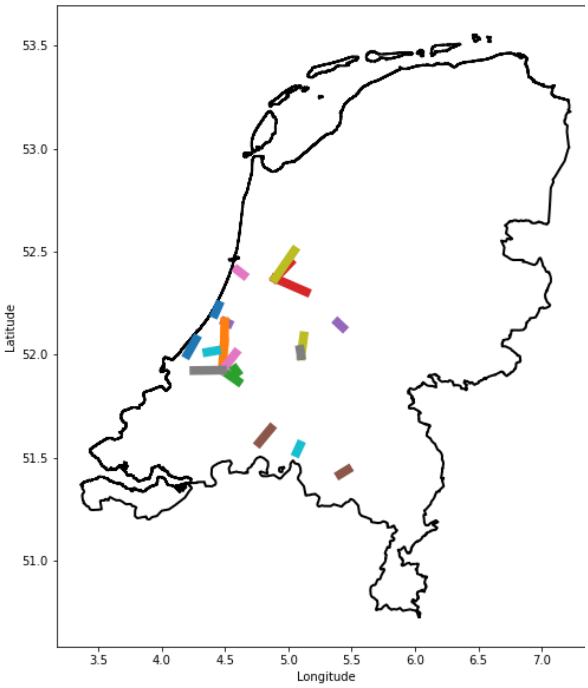

Figure 27: scenario 2 γ=2 (base)

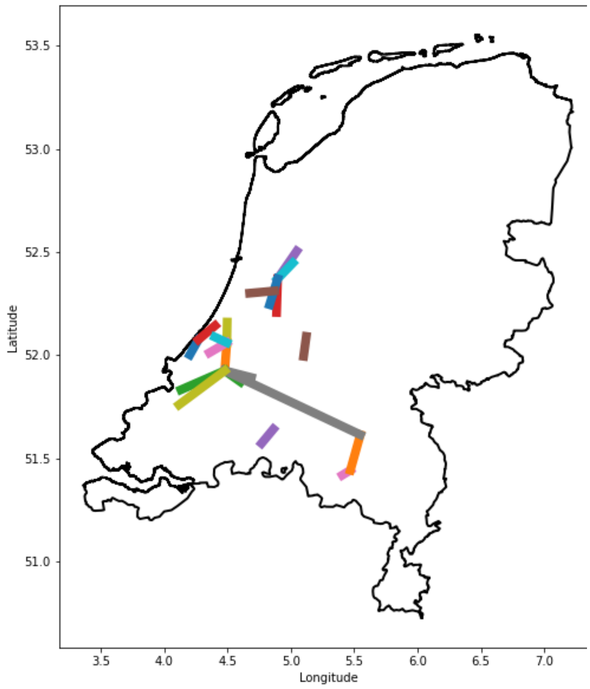

Figure 28: scenario 2 γ=1

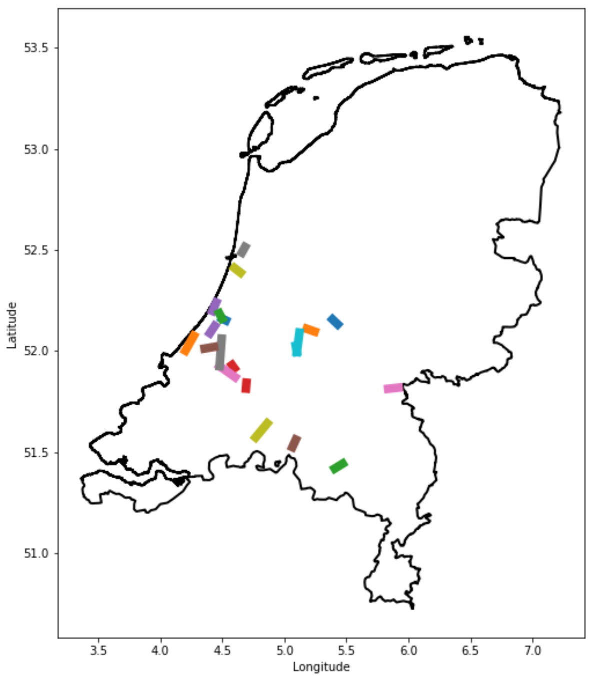

Figure 29: scenario 2 γ=3

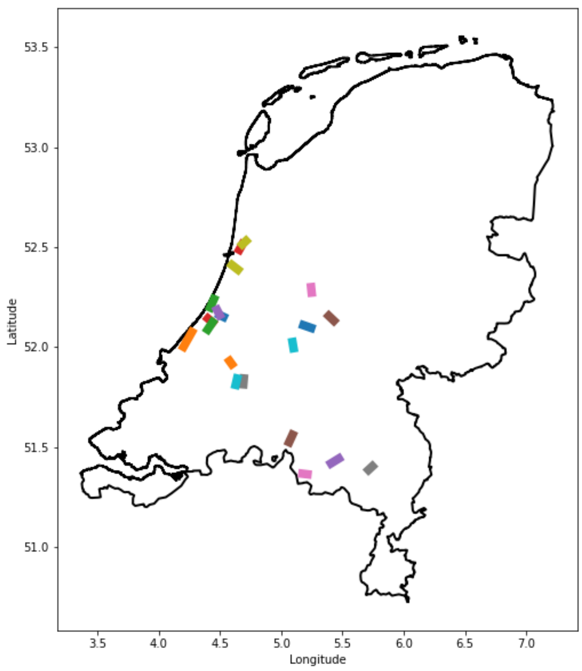

Figure 30: scenario 2 γ=5

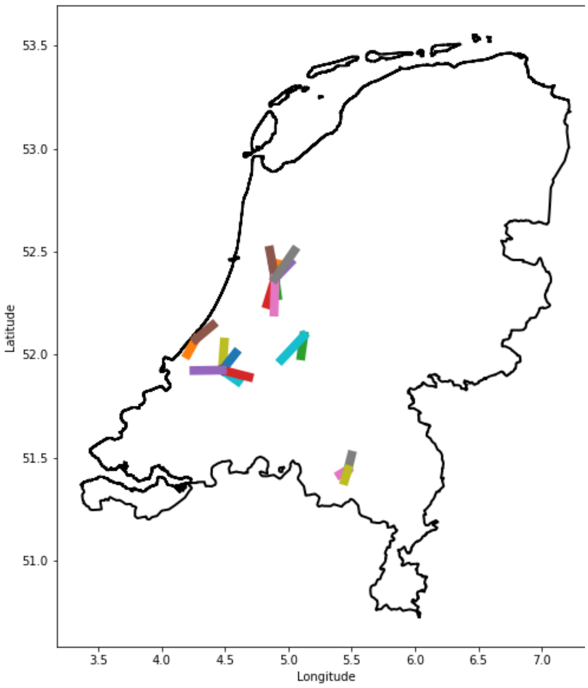

Figure 31: scenario 3 α=0.0315 (base)

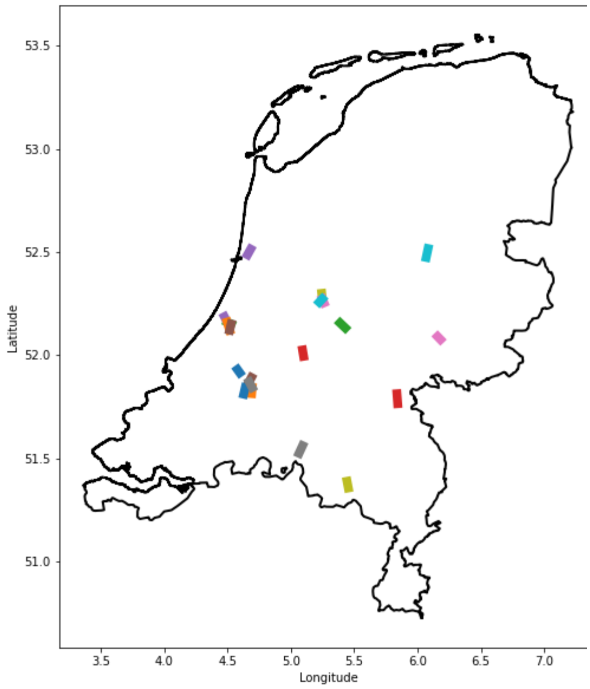

Figure 32: scenario 3 α=1

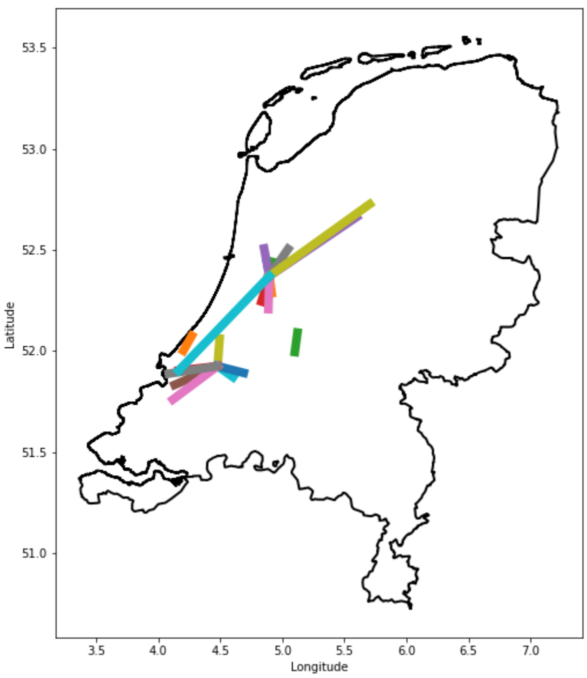

Figure 33: scenario 3 α=0.01

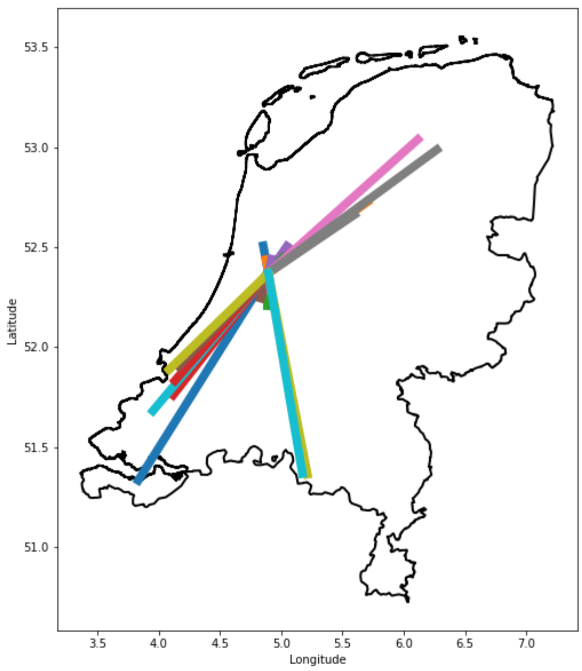

Figure 34: scenario 3 α=0.0001

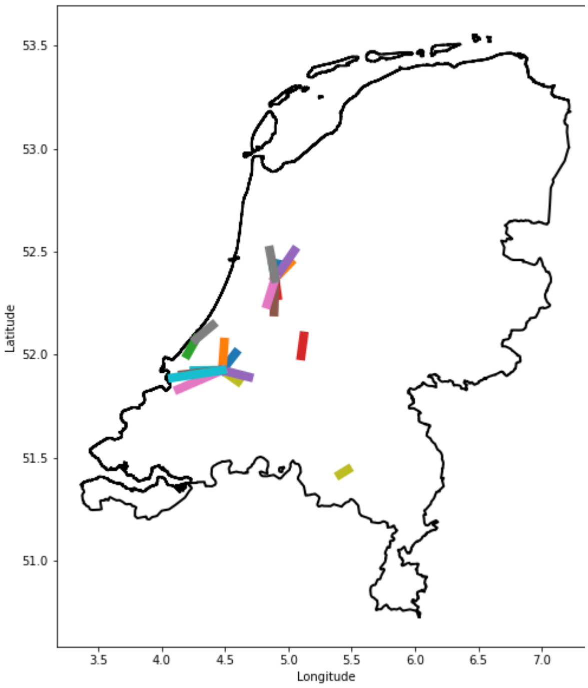

Figure 35: scenario 4 α=0.000385 (base)

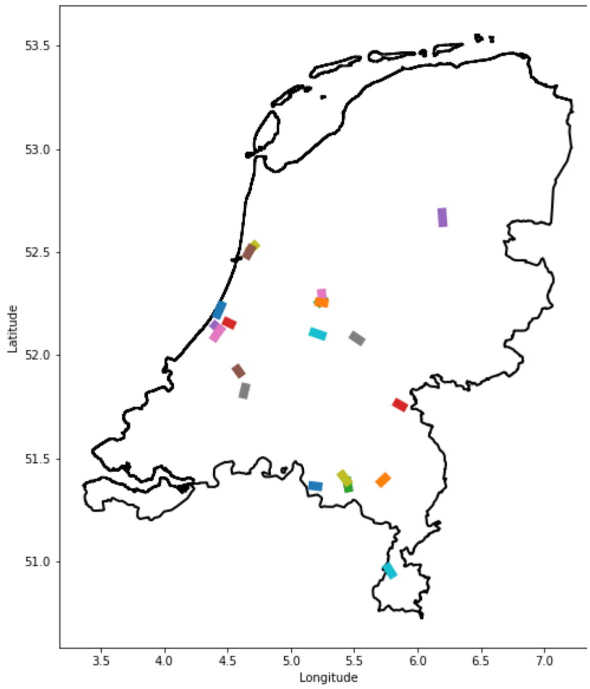

Figure 36: scenario 4 α=1

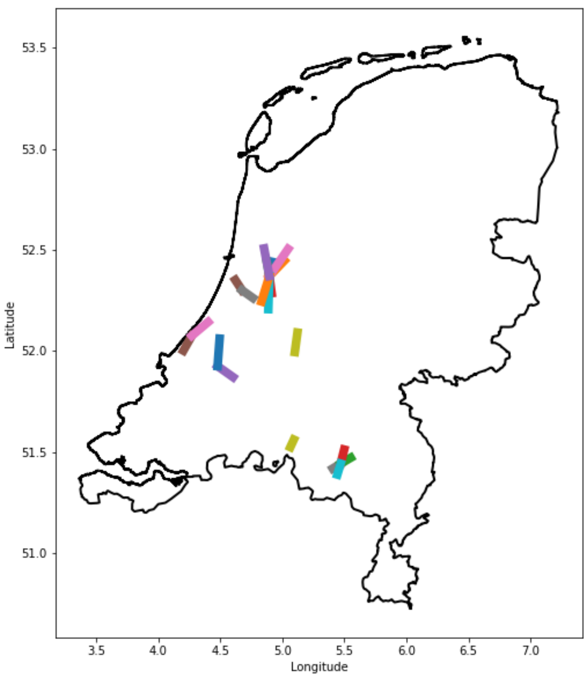

Figure 37: scenario 4 α=0.001

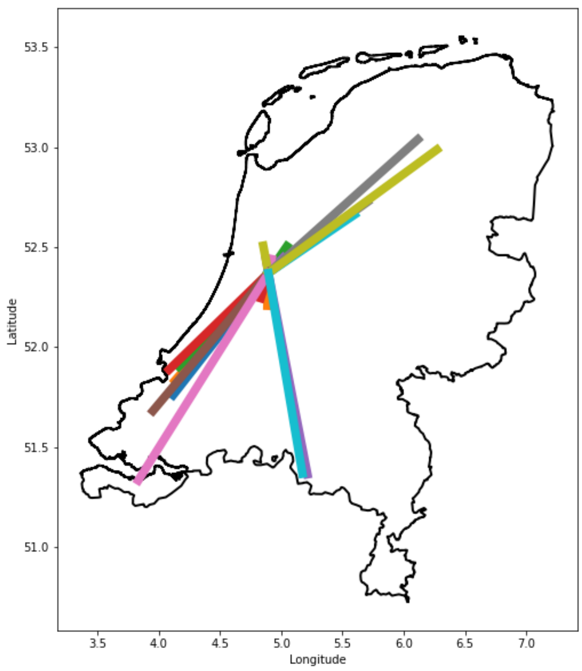

Figure 38: scenario 4 α=0.00001

It was also tested if the switching of the equations used had an effect on the outcome. In Figure 39 and Figure 40 it can be seen what happens if the gravity model is used with jobs in the function instead of population. In Figure 41 and Figure 42 it can be seen what happens with the results when using the exponential decay function where the number of jobs is exchanges with population.

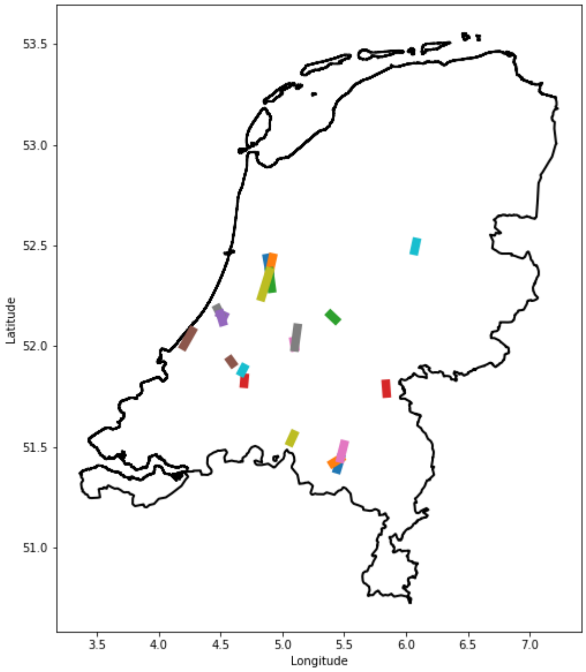

Figure 39: gravity model using jobs and distance as a costs

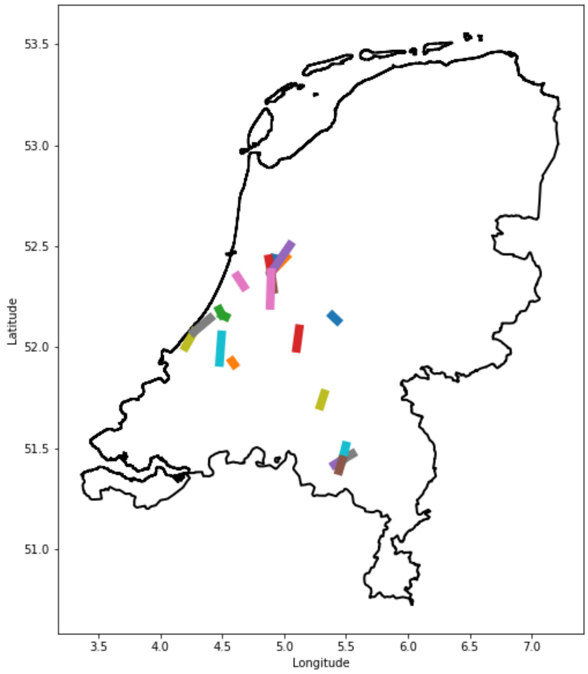

Figure 40: gravity model using jobs and car travel time as a costs

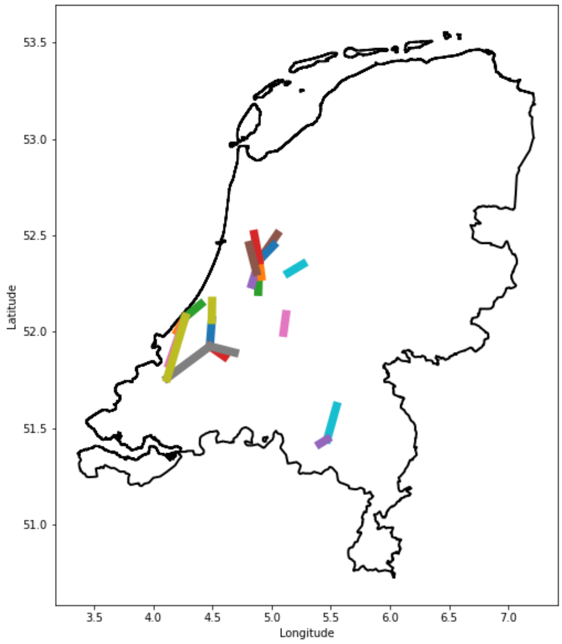

Figure 41: exponential decay function using population and distance as a cost

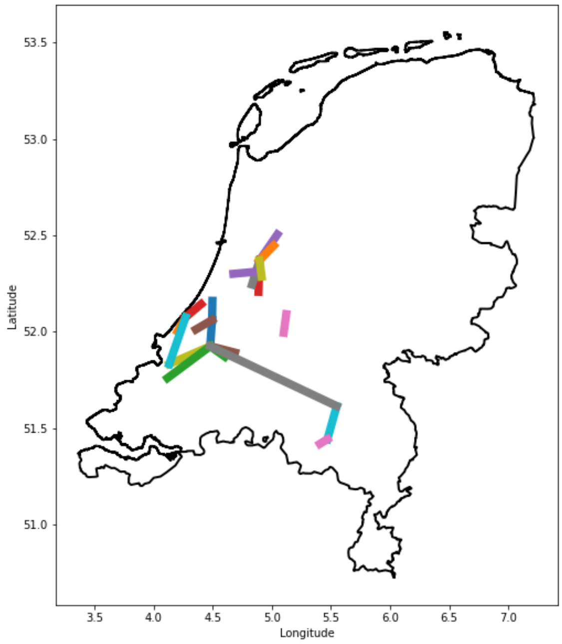

Figure 42: exponential decay function using population and car travel time as a cost

Appendix B. Bus travel time factor

In this appendix the factor with which the bus is slower than the car will be determined. For 75 routes in the Netherlands between cities the travel time by bus was compared with the travel time by car. In Table 3 the car travel time can be seen compared with the bus travel time towards the same points. On average the busses in the Netherlands ride 0.8362 slower or take 1.196 times as long to get to the same point. This appendix is used in chapter 5.2

Table 3: car travel time compared with bus travel time

Route	car	bus	difference factor
Nieuwegein-Houten	21	15	1.4
Oss-Uden	20	24	0.833333
Uden-Veghel	16	14	1.142857
Uden-Eindhoven	34	45	0.755556
Helmond-Eindhoven	24	42	0.571429
Heerhugowaard-Alkmaar	13	13	1
Castricum-Alkmaar	27	35	0.771429
Groningen-Haren	13	13	1
Assen-Rolde	9	10	0.9
Enschede-Hengelo	18	18	1
Enschede-Haaksbergen	23	25	0.92
Enschede-Doetichem	61	87	0.701149
Doetichem-Groenlo	29	46	0.630435
Groenlo-Borculo	13	29	0.448276
Deventer-Epse	13	9	1.444444
Deventer-Zutphen	27	30	0.9
Zutphen-Eefde	8	8	1
Zutphen-Brummen	15	16	0.9375
Dieren-Eerbeek	12	13	0.923077
Apeldoorn-Arnhem	37	44	0.840909
Apeldoorn-Ede	38	55	0.690909
Ede-Wageningen	22	12	1.833333
Ede-Veenendal	21	22	0.954545
Veenendaal-Wageningen	25	41	0.609756
Veenendaal-Amersfoorts	37	43	0.860465
Eindhoven-Sint-Oedenrode	25	28	0.892857
Den Bosch - Sint-Odenrode	28	39	0.717949
Den Bosch- Oss	22	40	0.55
Den Bosch-Drunen	16	19	0.842105
Drunen-Tilburg	30	62	0.483871
Kaatsheuvel-Tilburg	22	29	0.758621
Tilburg-Loon op Zand	18	24	0.75
Oosterhout-Breda	15	25	0.6
Breda-Dongen	20	42	0.47619
Breda-Utrecht	60	76	0.789474
Nieuwegein-Utrecht	26	31	0.83871
Utrecht-Ijsselstein	29	23	1.26087

Hlversum-Bussum	10	27	0.37037
Zeewolde-Hardewijk	18	20	0.9
Hardewijk-Nunspeet	15	25	0.6
t Harde-Epe	13	15	0.866667
Epe-Zwolle	21	30	0.7
Amsterdam-Purmerend	29	26	1.115385
Nieuw-Vennep- Hoofddorp	12	10	1.2
Hoofddorp-Haarlem	24	31	0.774194
Breda-Gorichem	30	48	0.625
Den Haag- Schevenignen	16	22	0.727273
Spijkenisse-Hellevoetslsuis	18	31	0.580645
Tiel-Wageningen	41	48	0.854167
Wageningen-Rhenen	27	39	0.692308
Enschede-Oldenzaal	21	25	0.84
Oldenzaal-Weerselo	12	15	0.8
Oldenzaal-Denekamp	15	21	0.714286
Oldenzaal-Almelo	28	33	0.848485
Emmen-Assen	33	41	0.804878
Heerenveen-Joure	15	16	0.9375
Alkmaar kop-Afsluitdijk	62	88	0.704545
Bodegraven-Reeuwijk	10	14	0.714286
Hilversum-Laren	16	20	0.8
Amersfoort-Soest	18	13	1.384615
Dronten-Lelystad	31	40	0.775
Emmeloord-Heerenveen	31	47	0.659574
Lemmer-Heerenveen	22	43	0.511628
Joure-Sneek	20	24	0.833333
Sittard-Geleen	10	13	0.769231
Sevenum-Venlo	21	31	0.677419
Sevenum-Horst	9	10	0.9
Horst-Venray	18	17	1.058824
Venray-Overloon	10	9	1.111111
Helmond-Gemert	19	31	0.612903
Gemert-Boekel	10	18	0.555556
Heesch-Oss	11	9	1.222222
Oss-Berghem	8	10	0.8
Oss-Lith	13	16	0.8125
Average			0.83627

Appendix C: satellite images of the routes

In this appendix the satellite images of the route are shown. In the report itself the map view with the route is shown but to see better in what for surroundings the routes lay the satellite images will be provided here. In Figure 43 The route between ‘s Gravenhage and Westland Is shown

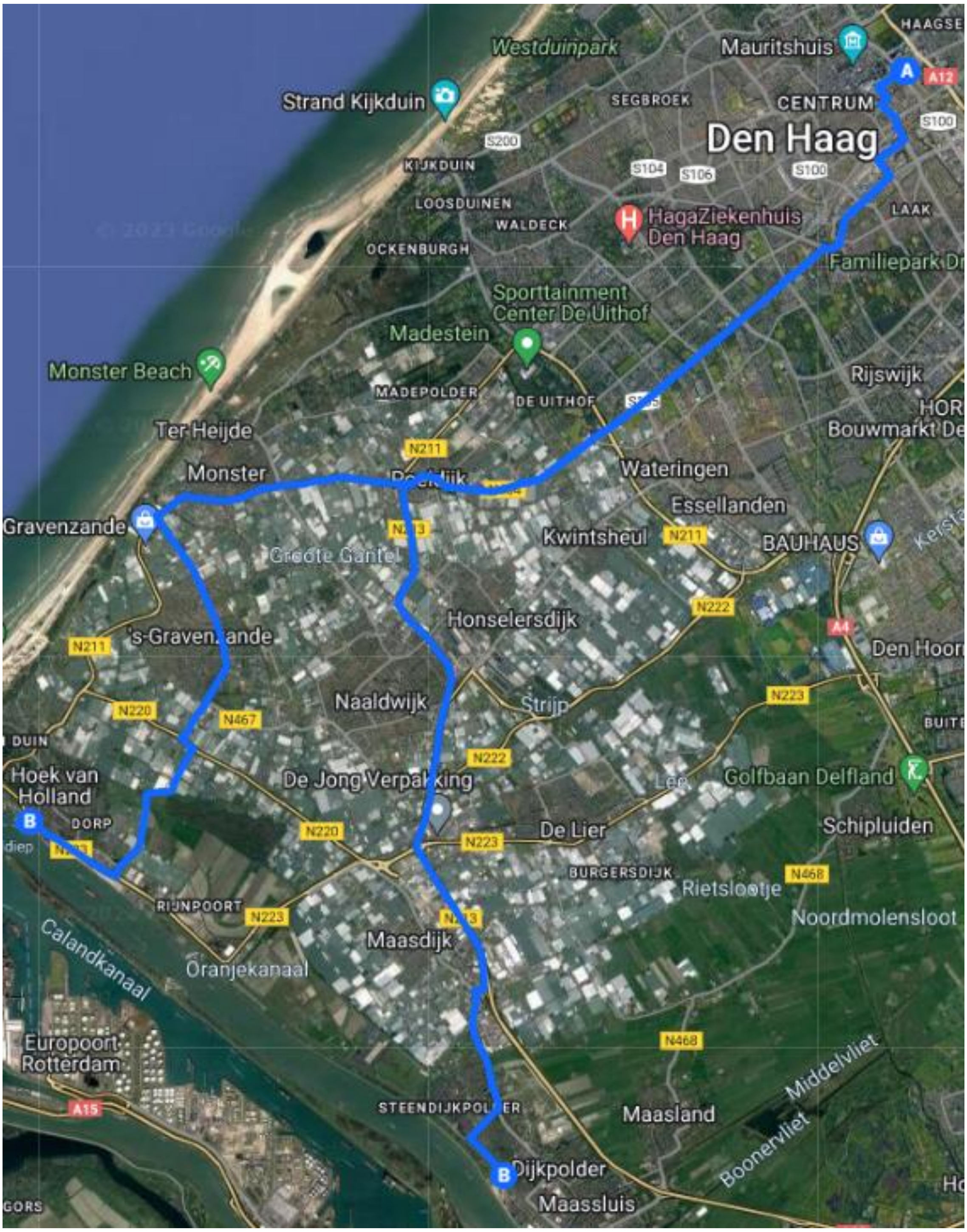

Figure 43: satellite image of the route between 's Gravenhage and Westland

In Figure 44 the route between Ridderkerk and Rotterdam can be seen.

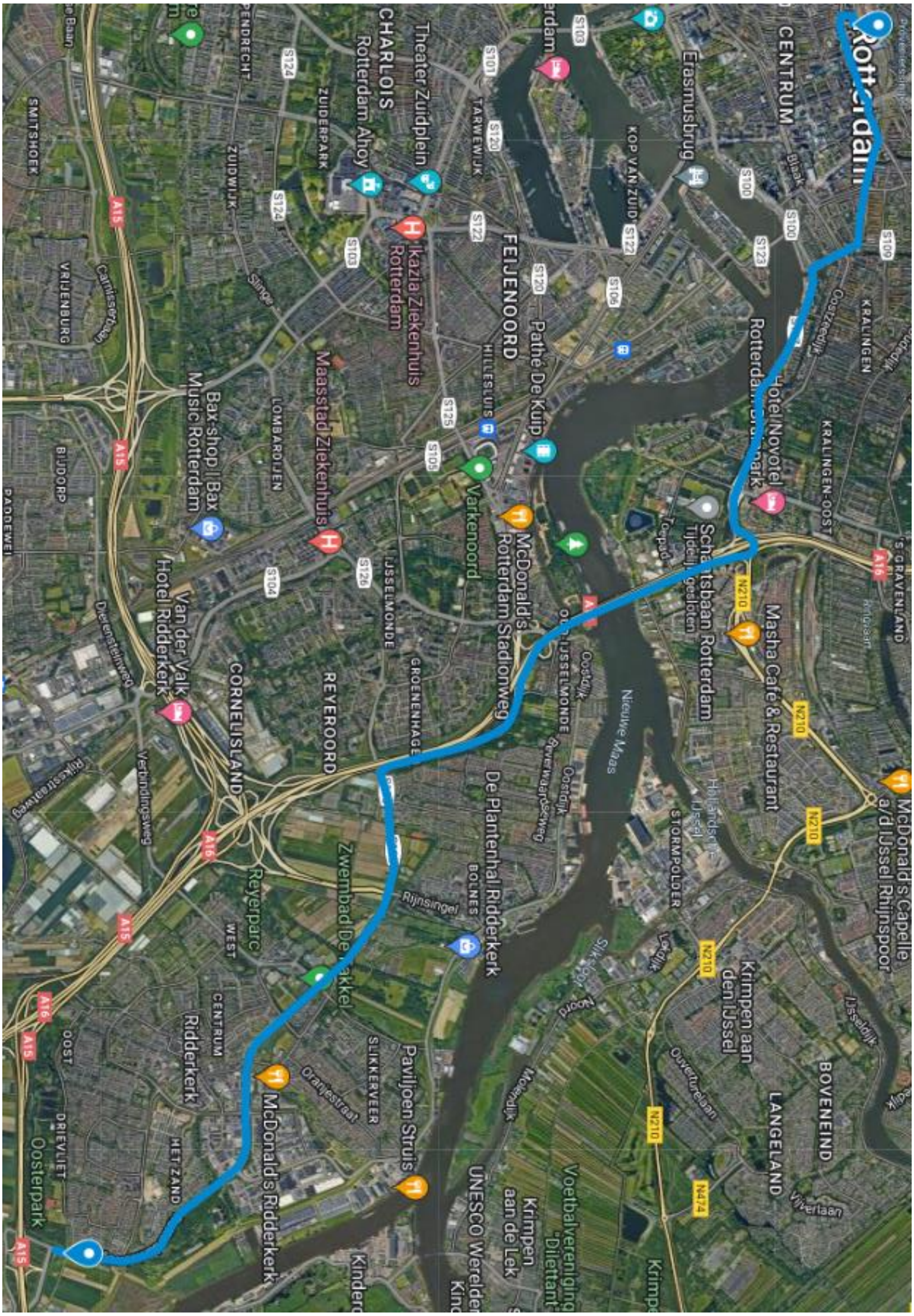

Figure 44: satellite image of the route between Ridderkerk and Rotterdam