OPTIMIZING THE BICYCLE PATH NETWORK AROUND UTRECHT

Bachelor Thesis

G. Andringa

21 October 2019

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Author

Gerben Andringa
G.Andringa@student.tudelft.nl
Student number: 4574095

Coaches

Ir. R. (Rolf) Koster
R.P.Koster@tudelft.nl

Dr. Ir. Y. (Yufei) Yuan
Y.Yuan@tudelft.nl

Institute

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Stevinweg 1, 2628 CN Delft

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Summary

In the region around the city of Utrecht in the Netherlands, there are many capacity problems of the road network, both for national highways and regional roads. For the public transport network, capacity problems are expected as well. These are both at a local level within Utrecht, but also on a regional level in case of almost all train connections.

An evaluation of the locations of the bottlenecks within the road network shows that most problems are situated at the ring around Utrecht and intersections at the road between Utrecht and Amersfoort, the N237, and the N226 between Amersfoort and Leersum.

Over the last few years, bicycle usage for distances up to 25 kilometres has increased. Two developments are important for this increase. First the increase in sold electric bicycles, including speed pedelecs, which give the opportunity to cycle faster without an increase in effort. Second, the rise of bicycle highways: bicycle paths which are designed for fast cycling by providing wide bicycle paths where cyclists have priority over other traffic. The combination of these developments makes it possible for bicycles to compete with cars and public transport.

Three corridors have been chosen to evaluate if an optimization leads to a mode shift. At these corridors, the bicycle paths have been optimized to meet the requirements of a highway. Measures which are applied are for example giving cyclists priority, optimizing the traffic lights to reduce the waiting time for cyclists and changing intersections by adding a tunnel, or changing a crossing into a roundabout.

To evaluate the optimization of these corridors, a model has been set up to estimate the distribution for each trip, based on the disvalue of that trip. This estimation shows that an average increase of 9% for non-electric bicycles and an average increase of 5% for electrical bicycles could take place. This is combined with an average reduction of 12% for car usage and 2% for usage of public transport. For individual trips, the increase in bicycle usage can be even higher, in combination with a larger reduction in car usage.

The analysis shows that an optimization leads to an increase in bicycle usage combined with primarily a reduction in car usage. Therefore, it can be concluded that an optimization of these corridors can unburden the road network.

1. Introduction

In the region around the city of Utrecht in the Netherlands, there are many capacity problems of the road network, both national highways and regional roads, and the public transport network. These problems are expected to become larger in the near future. On the other hand, bicycle usage is changing. People start to use their bike for longer distances. This development might start in the region around Utrecht as well, if the network provides the requirements for such change. If the network does, it might reduce problems in other networks.

1.1 Developments in bicycle usage

There are various developments in the usage of bicycles which are interesting with an eye on the capacity problems of other transport modes:

- Bicycle usage could increase by 28% due to electrical bicycles and improvements in the bicycle path network (Ministry of Infrastructure and the Environment, 2017a).
- 40% of all sold bicycles is electric, only 34% was a regular bicycle. Electric bicycles are used for longer distances (Musch, 2019)
- As of 2017, the number of pedelecs in the Province of Utrecht has increased with 86%. At the moment, there are 142.2 speed pedelecs per 100.000 inhabitants (Statistics Netherlands, 2019)
- Bicycle usage to get to a station, or from a station to a destination will increase with 15-30% as more people use public transport (Ministry of Infrastructure and the Environment, 2017a).

1.2 Bicycle infrastructure development

The infrastructure for bicycles is improving as well, and as stated in the previous paragraph, this could lead to an increase in bicycle usage. At multiple locations in the Netherlands, bicycle highways have been realised or are being planned to let bicycles compete with cars. Examples are the F35 in Overijssel and the Bicycle Highway network in Gelderland.

The F35 has been used as inspiration for the design of the optimized bicycle paths within the evaluated network, an example of the appearance of this bicycle highway is given in figure 1.

Figure 1, appearance of bicycle highway F35 in Overijssel

The Bicycle Highway network in Gelderland has been used to know more about the reasons for commuters to cycle. A brief explanation of these two reference projects is given in Appendix A.

1.3 Stakeholders

As for every project, stakeholders are involved. This research does not focus on the administrative planning of bicycle routes. Because of this, an overview of the influence of each stakeholder is not given. However, the list below mentiones the stakeholders and why they are interested in the realisation of bicycle highways.

1.3.1 Authorities:

All mentoned authorities are responsible for some part of the road network. By adding fast bicycle paths to the transport network, the number of cars might reduce and thereby the amount of congestion, which is beneficial for these stakeholders as they do not have to change the roads to reduce congestion.

- Province of Utrecht: The province of Utrecht is responsible for the spatial planning in the province, including roads and bicycle paths. Another responsibility is the regional public transport, although this is outsourced. This autority has planned several bicycle highways. (Province Utrecht, 2019a).
- Ministry of Infrastructure and Water Management: This ministry is responsible for the national infrastructure in the Netherlands and benefits from a road network with enough capacity for the transport demand (Government of the Netherlands, 2019a).
- Municipalities, which are among other responsible for roads and bicycle paths in their municipality. Municipalities in the province Utrecht work together with the province of Utrecht.

1.3.2 Public transport companies

These companies are not directly involved in the planning of bicycle highways, but benefit of them within peak hours, as persons who would normally use crowded trains or buses can now take their bicycle. This improves the level of comfort for those travellers who still use public transport, which is positive for these companies

- Synthus: carries out the regional bus lines in the province Utrecht and local buses in Amersfoort (Province Utrecht, 2019b).
- Qbuzz (U-OV): carries out the local buses in Utrecht and some regional buses; carries out the tram network in Utrecht (Province Utrecht, 2019b).
- NS: responsible for the trains at the main railway network of the Netherlands

1.3.3 Consumers:

- Travelers (commuters): these use the transport networks (road, public transport and bicycle) and benefit from a well working transport system which services their needs.

1.3.4 Bicycle organisations

These organisations provide a lot of information to authorities and can support them in the planning of bicycle routes.

- Fietsersbond: The Fietsersbond looks after the interests of bicycles and stimulates authorities for bicycle friendly developments (Fietsersbond, 2019).
- ANWB: gives advice about many mobility related topics (mainly road and bicycle traffic) and looks after the interests of its members.

1.3.5 Other indirect related stakeholders

- Residents: These are affected by the transport networks, for example due to the emission of gasses and noise. *This research does focus on a possible reduction of cars, but not on the environmental effect of this development.*

1.4 Main and sub-questions

The problems around Utrecht and the new role of bicycles combined give an opportunity to solve parts of the congestion in the region around Utrecht, this leads to the main question of this report:

Does an optimization of the bicycle network around Utrecht lead to an increase in bicycle usage in combination with a reduction of the usage of cars and public transport and how large could these changes be?

This main question will be split up in three segments:

- How do the road and public transport network look like and where are the bottlenecks?
- Which corridors could be appropriate for a mode change to bicycles and which improvements do these corridors need for this mode change?
- How large is the mode change due to these changes?

These segments form respectively the chapters 2, 3 and 4, followed by a conclusion and recommendation in chapter 5.

1.5 Research area

This research focusses on the region around Utrecht and bottlenecks within the region. Bottlenecks within the city of Utrecht, or other villages, are not taken into consideration.

A realistic length for fast cycling routes is 20-25 kilometre (Royal HaskoningDHV, 2017). Research has shown that trips of cyclists who use an electric bike are usually 20% longer than non-electric bicycles (Ministry of Infrastructure and the Environment, 2017b). For electric bicycles, the same research area, but a higher average speed is used.

To determine the research area, a circle has been drawn with a radius of 20 kilometre, as trip distances will mostly be longer than the heaven-wide distance. Based on this circle, a map has been drawn with the research area. Some parts of the research area are slightly beyond the 20-kilometre range as these municipalities are largely within the area, but not completely (Mijdrecht, Leersum, Leusden, parts of Amersfoort). Other municipalities who only share a small part of their land with the 20 km range are not part of the research. The research area is visible in figure 2.

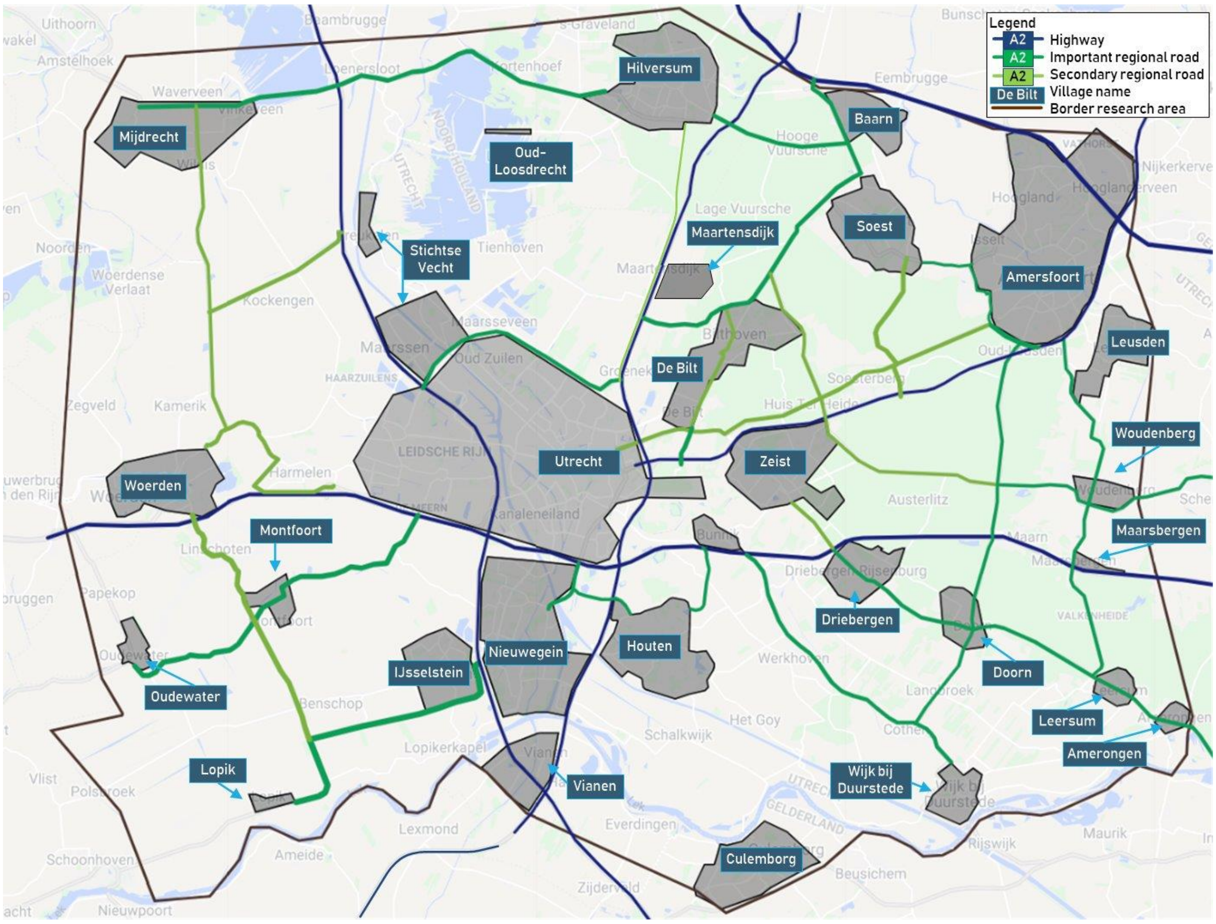

Figure 2, research area and nodes within this area

1.5.2 Large nodes

In the case of some large municipalities, such as Utrecht or Amersfoort, it is possible to cycle a long distance within the municipality itself. Because of that, it is not realistic to see the village as one node in the network. For example, a trip by bike from the eastern part of Utrecht to the southern part of Amersfoort is 21 kilometres, but a trip from the southern part of Utrecht to the northern part of Amersfoort is almost 28 kilometres long.

The municipalities which are devided into several parts are listed below:

- Amersfoort: divided into Amersfoort North, Middle and South (figure 4)
- De Bilt: divided in Bilthoven, De Bilt and Maartensdijk (see main map of reserach area, figure 2)
- Nieuwegein: divided into Nieuwegein North and South (figure 3)
- Utrecht: divided into Utrecht North, East, South and West (figure 3)
- Utrechtse Heuvelrug: divided into Amerongen, Driebergen, Doorn, Leersum and Maarsbergen (see main map of research area, figure 2)

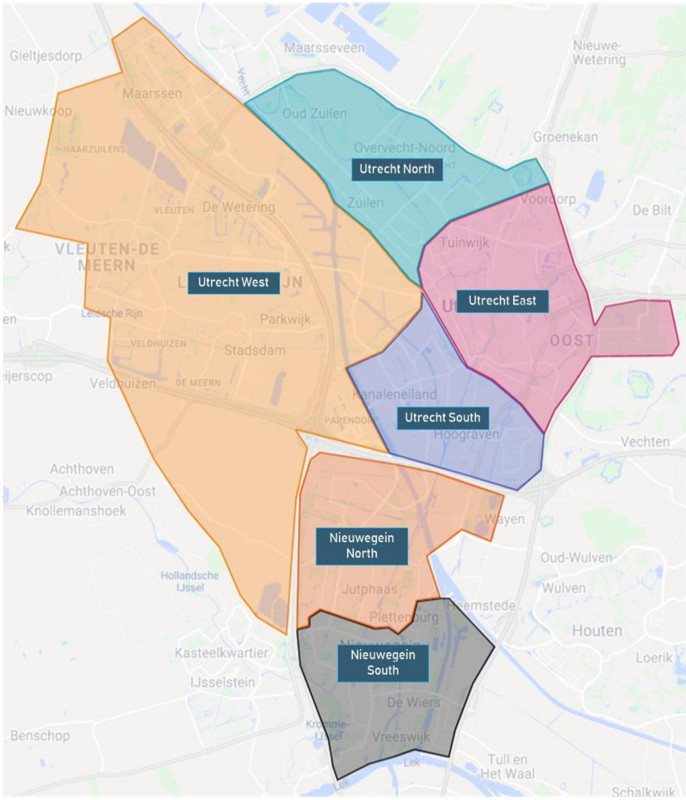

Figure 3, map of different parts of Utrecht and Nieuwegein

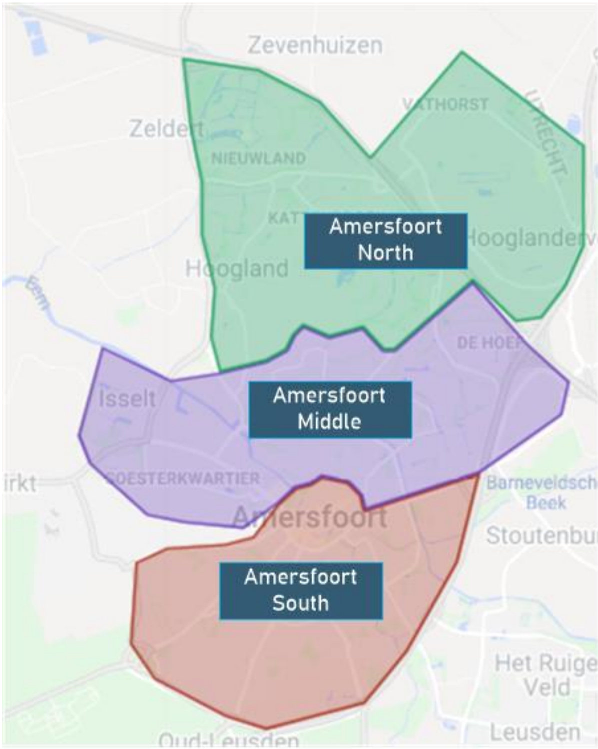

Figure 4, map of different parts of Amersfoort

2. Methodology

This chapter describes the methodology of this research. The research is divided in three parts, first an anlysis of the current situation, followed by measurements to improve parts of the network. The last part is a model to compare the current situation with the situation after the improvements have been realized.

2.1 Analysis of current situation

The first part of this research evaluates the current situation. Which nodes form the network and do these nodes have a special function? What type if links connect these nodes?

Knowing the links and nodes of the network does not directly result in knowing where the problems are. This will be done by studying data and literature of the network. For example, the Province Utrecht provides maps with the bottlenecks in the road network. Google Maps provides also data about locations with a high risk of congestion and actual congestion.

This analysis results in three corridors with multiple bottlenecks and these corridors are interesting for an evaluation of a mode shift.

2.2 Optimizing the bicycle path network

This mode shift does not happen without any changes, it requires an optimization. That is the second part of this research. It is done by studying which solutions are recommended by literature and which are used in reference projects.

This results in a rough design of the improved network, which means that for the critical points solutions will be suggested, but these will not include detailed data such as all dimensions. For example: if a tunnel is suggested, the dimensions of the height of the tunnel and percentage of the slopes will not be given.

Improvements based on the following aspects are considered, of which some are related:

- Directness: *the route length compared to the length of a straight line between nodes*
- Intersections without priority, *both with and without traffic lights*
- Road safety: *preventing conflicts with other road users*
- Social safety: *creating a social safe atmosphere, for example by streetlights*
- Smoothness of the route: *preventing sharp turns*
- Width: *creating enough space to overtake other cyclists*
- Road surface: *a flat road surface improves the smoothness and safety*
- Uniformity: *a uniform route is easier to understand for the users*
- Snow and ice-free: *this reduces the number of accidents*
- Attractiveness: *an attractive route stimulates travellers to take their bicycle*

2.3 Estimation of mode shift

To estimate the mode shift, a model is used. The model calculates the percentage and number of commuters using a certain transport mode (bicycle, electric bicycle, car or public transport). Appendix E.1 gives a more detailed explanation, but the main information is given here as well. A quick overview of the steps of the model:

1. Determine the disvalue of each trip for each transport mode, based on the distance, duration and several other parameters.
2. Determine the distribution over the transport modes for all individual trips via a logit model, using the disvalues and parameter μ.
3. Determine the number of commuters travelling from one node to another, using data from Statistics Netherlands and individual municipalities.
4. Determine the number of commuters travelling from one node to another for each transport mode via a gravity model, using data from steps 2 and 3.

2.3.1 Determination of disvalue

The first part of the analysis consists of an analysis using a logit model. This model compares different modalities based on their disvalue and provides the distribution of the different transport modes. The higher the disvalue of a trip with a certain transport mode, the less attractive it is to make the trip with that transport mode. The disvalue is always based on the duration of a trip and other trip related costs such as costs per kilometre for fuel.

This analysis compares the following transport modes for all evaluated trips. Table 1 (next page) gives an overview of the used values for each transport mode.

Bicycle

Both regular non-electric bicycles and electric bicycles are part of the evaluation. For both bicycle types, the disvalue for the current situation and the improved situation is calculated. Appendix E.1.1 gives a more elaborated explanation to this.

The duration of a trip by bicycle is calculated based on the speed and the number and type of intersections along the route. The speed is distinguished in three values
(speed normal bicycle / electric bicycle):

- Speed within urban areas (14.7 / 14.7 km/h) (Fietsersbond, 2019b)
- Speed outside of urban areas (17.7 / 19.3 km/h) (SWOV, 2014)
- Speed at optimized bicycle path (19.6 / 23.3 km/hj) (SWOV, 2014)

Car

For cars, the trip length and duration are determined with Google Maps. An arrival time of 9:00 am at Thursday, October 31, has been used. This does include the morning peak hour. For each trip, the disvalue is calculated for both the average duration and the maximum duration, to compare bicycles with cars which experience congestion.

Public Transport

For Public Transport, trips are determined using 9292.nl with an arrival time between 8:30 and 9:00 am. Normally, the travel advice arriving just before 9:00 am has been chosen, but there are situations where this travel advice is much longer than other possibilities to get from one place to another. Therefore, this time range has been chosen. Delays have not been considered.

Walking

For walking, the disvalue is based on the disvalue of cycling, which is, including health effects, 10.16 – 0.23 x distance. With an average walking speed of 5 km/h, this gives €9.01/hour.

Table 1, overview of aspects of disvalues for evaluated transport modes

Modality: Car	
Aspect	Disvalue in Euro
Duration of trip without delays	10.16 / hour
Costs of car	0.19 / kilometre
Congestion (delays)	Same disvalue as duration
Modality: Public transport	
Aspect	Disvalue in Euro
Duration of trip without delays	Bus, tram, metro: 8.51 / hour Train: 12.63 / hour
Costs of trip	Determined via journey planner (9292)
Delays	Not considered
Trip to PT station	Depending on value of time for modality used to get to the station
Waiting	Part of duration of transfer
Transfer	5 minutes + 1.5 x total waiting time above 5 minutes
Modality: Bike (non-electric)	
Aspect	Disvalue in Euro
Duration of trip without delays	Normal road: €10.16 Comfortable: €7.42
Costs of bicycle	€0.10/kilometre
Health effect	€ -0.23 x distance
Effort	€0.25/kilometre
Modality: Bike (electric)	
Aspect	Disvalue in Euro
Duration of trip without delays	Normal road: €10.16 Comfortable: €7.42
Costs of bicycle	€0.24 / kilometre
Health effect	€ -0.23 x distance
Effort	€0.25/kilometre
Walking	
Duration of trip	€9.01/hour

2.3.2 Calculating the distribution

The distribution is calculated using the following formula (TU Delft, 2017): $p_{ijm} = \frac{e^{\mu * V_{ijm}}}{\sum_{m=1}^{4} e^{\mu * V_{ijm}}}$

An overview of the terms in this formula:

- P_{ijm}: Percentage of commuters using transport mode m between locations i and j
- V_{ijm}: Disvalue of transport mode m for a trip between i and j
- μ: -0.291, parameter for sensitivity of commuters to the disvalue.

2.3.3 Estimating the number of users for each mode per trip

The logit model provides information about the disvalue of transport modes and uses this to provide the distribution of the transport modes. However, it does not provide an estimation of the number of commuters using a certain transport mode. This is calculated by a gravity model which uses the distribution, calculated with the logit model and the real number of commuters beteen two nodes, given by Statistics Netherlands (2019a).

$$c_{ijm} = p_{ijm} * c_{ij}$$

- c_{ijm}: Number of trips between i and j with transport mode m
- p_{ijm}: percentage of trips between i and j with transport mode m (from logit model)
- c_{ij}: number of trips by commuters between i and j (Statistics Netherlands, 2019).

2.3.4 Comparison of current and new situation

The analysis gives a distribution in percentages and in numbers. At each corridor, several locations have been chosen at which the optimized situation is compared with the current situation. Here, the distributions are compared. This is done for several scenarios:

Situation 1	Situation 2	Where?
Current, average duration for cars	Optimized, average duration for cars	Overview: main report All numbers: Appendix H.1
Current, maximum duration for cars	Optimized, average duration for cars	Overview: main report All numbers: Appendix H.2

2.4 Demarcation

2.4.1 Analysis of current situation

The analysis of the current situation does give an overview of bottlenecks but does not couple values to these bottlenecks.

2.4.2 Optimizing the bicycle path network

Design, level of detail

This research focusses on the bicycle path network. It does mention ways to improve intersections at certain points of a bicycle path, but these are not that detailed. For example, it will be mentioned if a tunnel is a good solution, but the dimensions of this tunnel will not be given. This is because this research in principle does not focus on a single link, but an entire network in the region.

2.4.3 Estimation of mode shift

Traveller types

This research focusses on commuters only. For this group, data are known for the number of persons living in an area and working in the same or another area. Besides, this is a group which makes the same trip multiple times a week, in contrast to for example tourists. Although students who do not live in the villae where they study make the same trip as well multiple times a week, they are not considered because of a lack of data.

Transport modes

Four transport modes have been considered: bicycle, electric bicycle, car and public transport. Transport modes such as mopeds and speed pedelecs have not been considered, because the percentage of commuters who use these modes is small and little data are available.

Walking is not included as mode to get from one node to another, but it is included as part of a trip by public transport.

Car users are both the drivers of a car and passengers of a car. The estimated number of cars might therefore be higher than the real number of cars.

Analysed trips

The network consists of 38 nodes, including nodes which have several parts. A full analysis of trips from every node to all other nodes would result into 1.444 trips. The analysis is performed for those routes which contain multiple bottlenecks. For the analysis, trips have to satisfy the following conditions, which leads to a total number of 156 trips:

- Maximum length of 25 kilometres.[1]
- At least 50% of the route uses an optimized bicycle path.[2]
- The evaluated route does not have to be the shortest route but is at most 15%[3] longer than the shortest route, if the longer route is expected to be faster.

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[1] Some longer trips (up to 28.5 km) are evaluated as well. These trips have an important node (Utrecht, Amersfoort, Hilversum) as start or destination.

[2] A few short routes (length around 10 kilometre) are evaluated as well. These use the optimized bicycle paths for at least 40%

[3] The speed at the optimized route is 11% higher than at a non-optimized route outside of urban areas and 33% than in urban areas. Besides, intersections are optimized as well which leads to an even higher average speed. Because of this, 15% is assumed to be a distance which does not costs extra time.

Time reduction in estimation
The estimation is a rough estimation. Each intersection with traffic lights has been given the same waiting time and the same reduced waiting time in the optimization. The same counts for intersections without traffic lights and without priority for cyclists. In reality, there are differences between the intersections. One of the main reasons for this is the amount of traffic which uses the intersection, and the main directions of these users.

Cyclists reducing speed
It is assumed that cyclists do not reduce their speed at intersections where they have priority. In reality, they can do this to get have a better view at other traffic, or to drive more comfortable through turns of a roundabout. This results in the loss of a few seconds. This speed reduction has been ignored.

Intersections where cyclists have priority in the current situation are because of this not included in the analysis.

Moment of analysis
The calculation to estimate the mode shift is based on an arrival around 9:00 am at Thursday October 31th. For cyclists, it does relatively not matter if a trip is planned during morning peak hours or evening peak hours or at another moment. There can be a small difference, for example because of waiting times for traffic lights, but these differences are small.

For cars and public transport, it is different. The amount and direction of congestion during morning peak hours is mostly different than during evening peak hours. Because evening peak hours are not considered, there are no commuters who choose to use their bicycle to avoid evening peak hours.

For public transport, the available bus lines during the morning peak hours is different than during the evening peak hours. This is mainly visible in the connection between Amersfoort and Utrecht. During morning peak hours, there are buses from Amersfoort to Utrecht. Therefore, less commuters cycle. From Utrecht to Amersfoort, more commuters cycle because there are no fast bus lines present.

Combination of modalities
It is possible to use multiple modalities for a single trip. For example, cycling to a train station, going by train to another train station and from there by foot to the final destination. Another possibility is to drive by car to a P+R hub and from there going by public transport to the final destination. Except for walking to a public transport station, these combinations are not investigated in this research.

Weather effects
Weather effects have not been considered. For all transport modes, weather effects can lead to a longer duration of a trip. For bicycles, both electric and non-electric, rain or other forms of precipitation leads to a high level of discomfort. Because of that, commuters might choose another transport mode if it rains which influences the distribution.

3. Current transport networks

This chapter describes the current transport networks in the region. For cars (road network) and public transport (train, bus and tram), the network is described in combination with bottlenecks of those networks. For bicycles, the corridors which are investigated are mentioned. These corridors are based on the bottlenecks of the road and public transport network.

3.1 Road network

The investigated network has three road types which have different functions within the network. A map is visible at the next page, figure 5:

1. National highways: These roads are the roads of the highest order within the system. They serve both national and regional traffic. Utrecht acts as a major node for the national highway system as three highways intersect (A2, A12 and A27) and one starts in Utrecht (A28). This leads to a lot of traffic driving around Utrecht, using multiple of these highways.
2. Primary regional roads: These roads are the most important regional roads and connect villages with the national highway system, and with each other.
3. Secondary regional roads: These roads support the other roads and can therefore be seen as secondary roads.

3.1.1 Bottlenecks of road network

The road network has several bottlenecks. The map at the next page, figure 6, shows the locations of these bottlenecks with colours. These are explained below.

Regional roads

For regional roads, the map uses data from the Province Utrecht (2014 and 2017) which shows the number of vehicle loss hours. The data from the Province Utrecht distinguishes between the morning and evening peak hours. Figure 6 does not make this distinction but shows an average of the problems.

Highways

For highways, data from Google Maps (2019) has been used to find the locations with delays. This does not give a certain value for the number of vehicle loss hours, but it gives an overview of locations which suffer from congestion. This data has been compared with data from Rijkswaterstaat (2018), which gives vehicle loss hours as well.

Figure 6 shows the location of the bottlenecks.

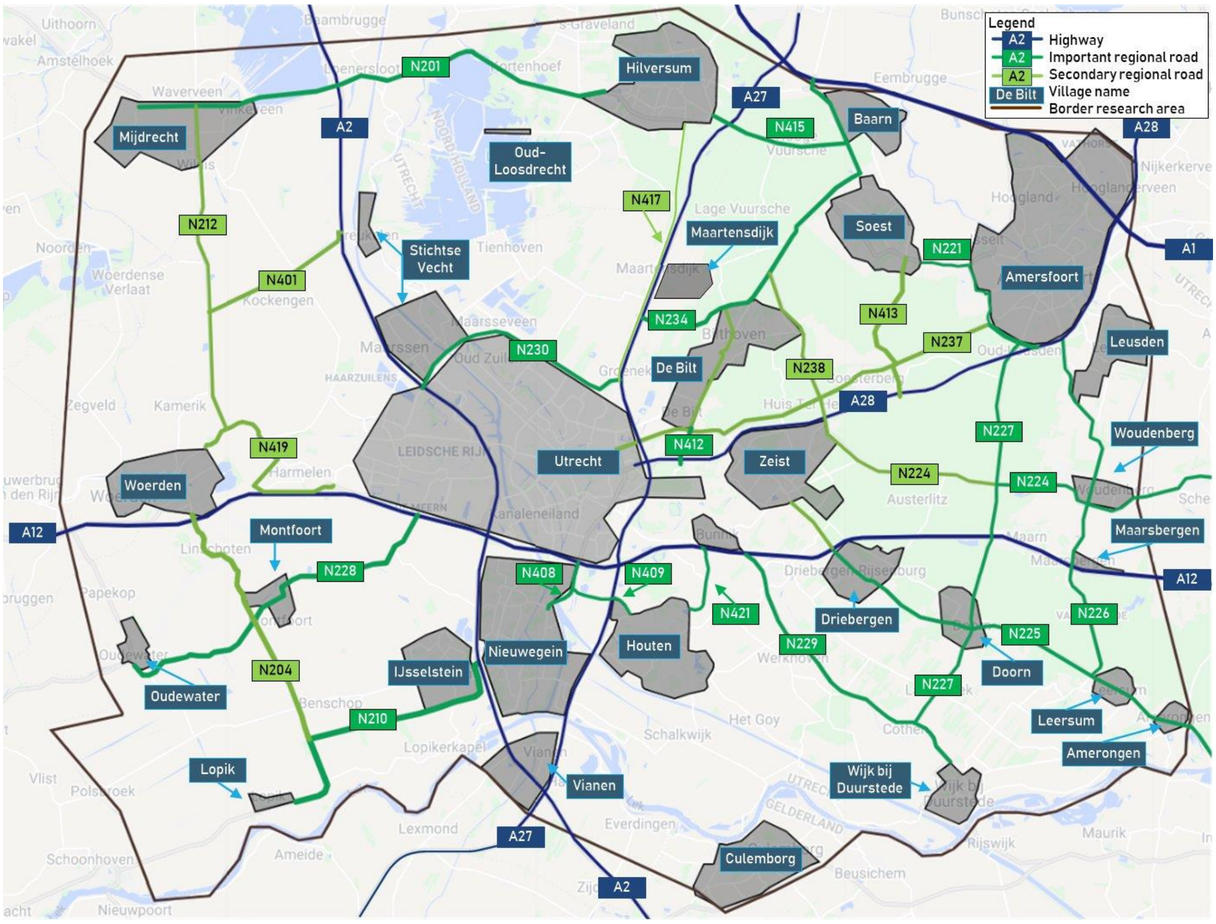

Figure 5, map of the road network within the research area

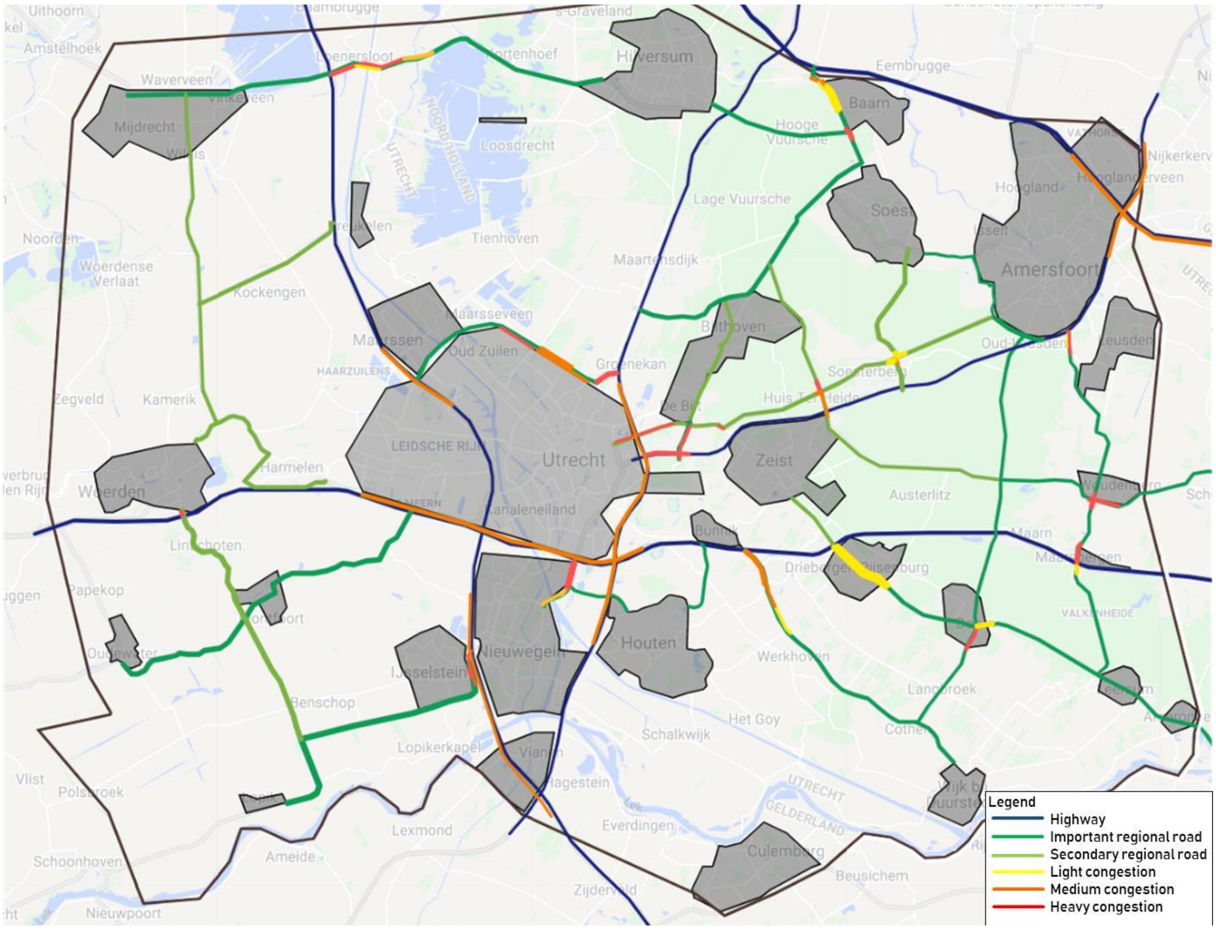

Figure 6, map with bottlenecks of the road network

Bottlenecks road network

The map shows the largest delays on a network scale to be at the southern and eastern part of Utrecht, mainly the connection between Utrecht and Nieuwegein (N408), and the network between Utrecht (Utrecht Science Park) and De Bilt.

These problems can be seen as two different corridors which are attached to each other at the eastern side of Utrecht:

- North South: from IJsselstein, Houten, Nieuwegein and Vianen to Utrecht, via the A27 and N408, and further to Hilversum via the A27. The route length from the southern places to Utrecht is less than 20 kilometres. The same counts for the route from Utrecht to Hilversum. By looking at this corridor as one long corridor, people from Houten might cycle to Hilversum as well (or even from Nieuwegein with pedelecs).
- Utrecht to Amersfoort. The route between Utrecht and De Bilt is the N237, but this road goes further to Amersfoort. Multiple intersections at this route are bottlenecks as well. The route from the centre of Utrecht to the centre of Amersfoort is 20 kilometres, which means that it is a good length to cycle.

Other bottlenecks in the network are:

- The N226 from Amersfoort to the municipality Utrechtse Heuvelrug, which includes the villages Leersum and Amerongen. Multiple intersections of this corridor have delays. The distance Amersfoort Amerongen, via the N226, is 23.5 kilometres, which is an interesting distance for bicycles. Therefore, this route is analysed.
- The N201 between Hilversum and Mijdrecht. This road has major problems around Loenersloot. This road is the regional road which suffers from most delays (Province Utrecht, 2017). The main function of this road is to connect the municipalities De Ronde Venen, Hilversum and Wijdemeren with highway A2, which leads to Amsterdam and Utrecht. Because the amount of regional traffic between these municipalities is low[4], this route is not analysed.
- The N221 which connects Soest and Baarn with highway A1. Because of the location of this bottleneck – close to Baarn and between the village and the highway – it is not expected that a mode change using bicycle paths within the research area would reduce the congestion. Therefore, this route is not further analysed.
- The N229 which connects Wijk bij Duurstede and the smaller villages Odijk and Werkhoven with highway A12. This route serves mostly persons driving to the highway (Statistics Netherlands, 2019a), and is therefore not further analysed.

[4] Statistics Netherlands (2019a) states that approximately 500 persons use this road for regional traffic between De Ronde Venen and Hilversum or Wijdemeren.

3.2 Public transport network

3.2.1 Train network

For the train network, capacity problems do not only depend on the regional train connections, but even more on connections on a larger scale. For example, the only intercity stations within the region are Utrecht Central Station and Amersfoort (and Amersfoort Schothorst). Solving capacity problems of the train network would be hard to do with bicycles, although it could be possible at smaller distances.

The map below, figure 7, shows the train lines with expected capacity problems. The analysis used to produce this map (Ministry of Infrastructure and the Environment, 2017) uses two scenarios for the expected economic development.

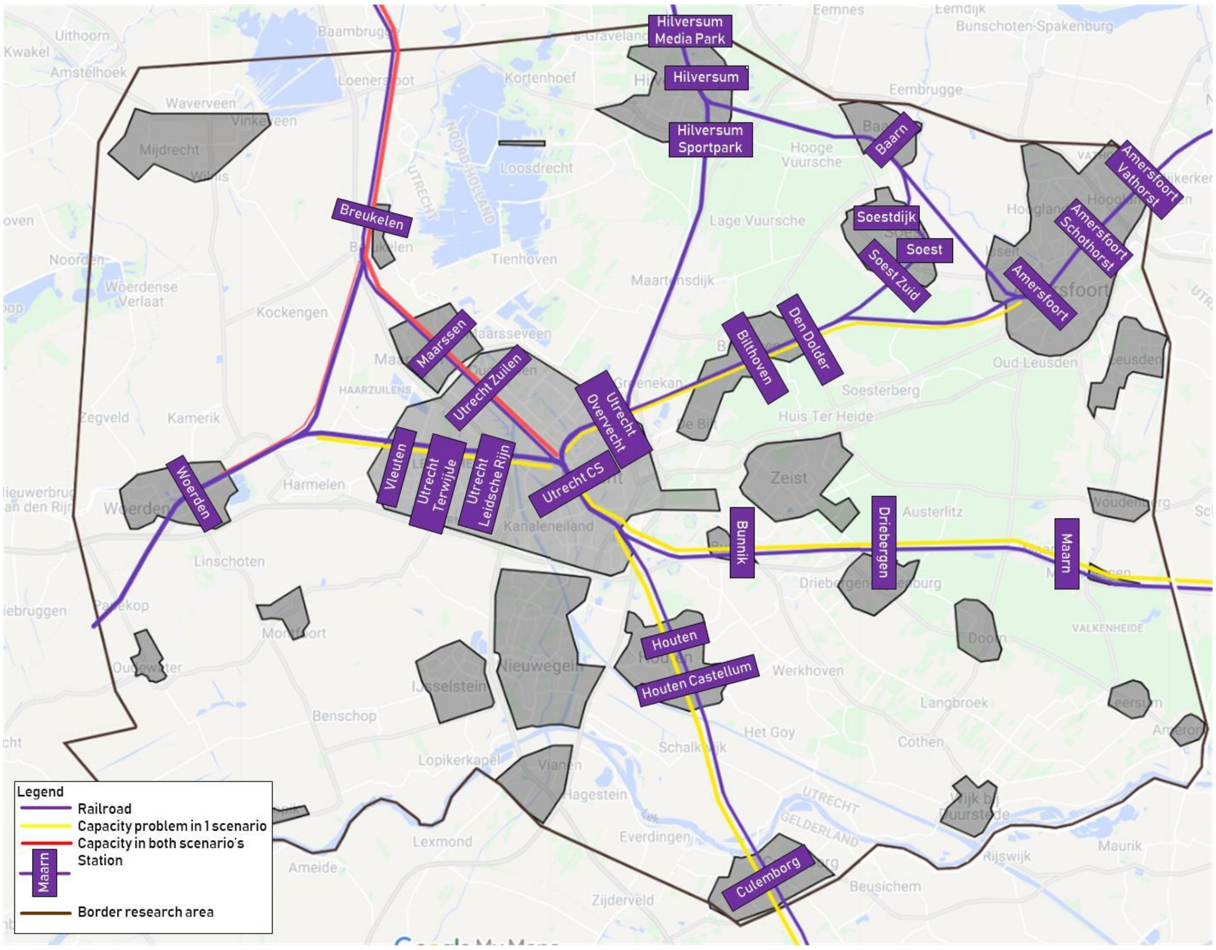

Figure 7, map showing the train network within the research area and expected bottlenecks

The red lines are the connections Woerden-Breukelen and Utrecht-Amsterdam. The distance between Woerden and Breukelen is small enough to cycle. However, the roads at this route do not suffer from capacity problems. Therefore, this route is not analysed for a mode change to bicycle.

The route Utrecht Amsterdam suffers at both the train and road network from capacity problems. However, this distance from Utrecht (Central Station) to the south of Amsterdam is approximately 35 kilometres, which is too much for regular bicycles and electric bicycles. This distance might be interesting for pedelecs. Nonetheless, this route is not analysed in this research.

3.2.2 Bus network

There is a large bus network within the province of Utrecht. This includes local buses (U-OV) and regional buses. Although a map for the regional bus network could be given, there is little data bout the bottlenecks within this network. Within Utrecht and the connection between Utrecht and Nieuwegein/IJsselstein, there are bottlenecks (BRU, 2014). For other connections, this information is unknown. Besides, at large parts of the area, buses use the normal road and do not have a dedicated bus lane. So, congestion at the roads, leads to delays of the buses. Because of these reasons, bottlenecks of this network are not be used as main input to determine the bicycle corridors to be optimized.

For the estimated number of users of each transport mode, buses are considered if they provide the fastest connection for public transport.

3.2.3 Tram network

There are two tram lines within the Province of Utrecht:

- The SunIJ tram line which connects Utrecht Central Station with Nieuwegein and IJsselstein. This tram line has capacity problems. The nodes which this tram connects are also part of the North-South bicycle corridor, so a change in passengers of the tram is part of this research (BRU, 2014).
- The Uithoflijn, which connects Utrecht Central Station with the Utrecht Science Park. This tram line is a local line, and still being tested. Therefore, this line does not take part in this research.

3.3 Bicycle corridors

In the previous chapter, the road and railway network have been evaluated. This resulted in three corridors which might be interesting for a mode change to bicycles to solve the bottlenecks in mainly the road network. These corridors are:

- North south corridor: IJsselstein, Nieuwegein, Vianen and Houten via Utrecht to Hilversum, optional via De Bilt.
- Utrecht – Amersfoort via De Bilt with a connection to Zeist
- Amersfoort – Amerongen (Utrechtse Heuvelrug) with connections to Leusden and Woudenberg.

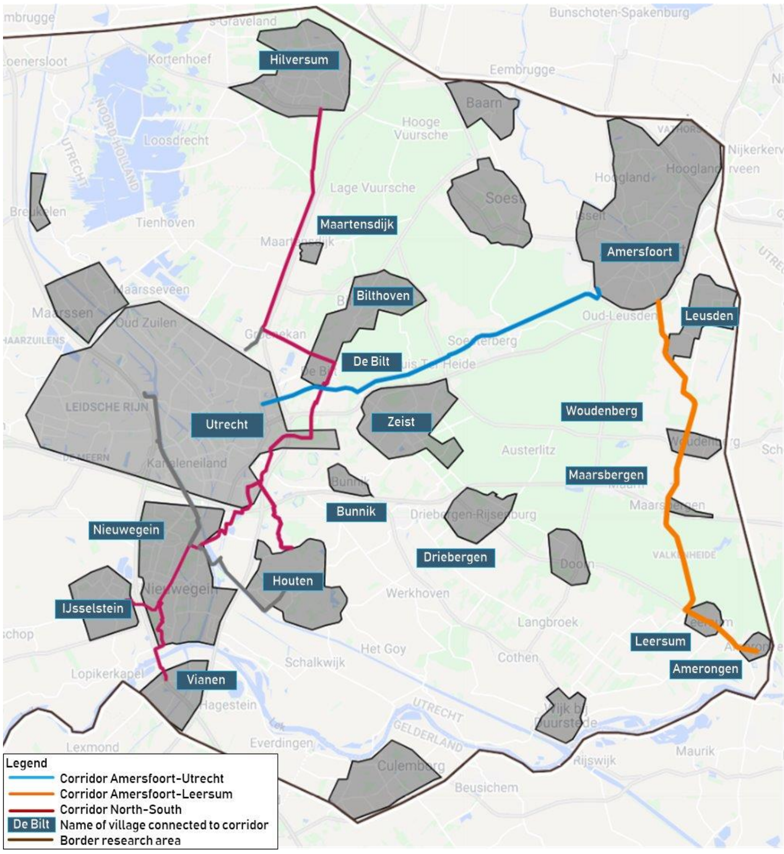

Figure 8, map showing the evaluated bicycle corridors

Figure 8 gives an overview of these corridors. It is expected that these corridors at the moment do not meet the requirements to unburden the road and public transport networks, otherwise, improvements are not needed. The measurements to improve these corridors are mentioned in the next chapter.

4. Changing the bicycle paths

This chapter describes the requirements for a bicycle highway and explains which measures are taken to transform the current bicycle paths in a bicycle highway.

There are both general improvements which applied along all routes where they are not present yet and improvements for specific locations such as intersections.

4.1 Requirements and general optimization

For a cycling highway, there are many requirements to make a route a good bicycle highway. These aspects are explained below in combination with a description of the way how the optimized route fulfils these requirements.

For determining these aspects, an evaluation of Tibs (2018) has been used in combination with a few added aspects. For each aspect, the requirements are, unless otherwise mentioned, based at CROW (2016). Appendix C provides a more detailed explanation

4.1.1 Directness

The optimized cycling route should be as direct as possible. The route length compared to the length of a straight line between nodes should be, if possible, 1.1.

4.1.2 Intersections without priority

The amount of these intersections should be as low as possible, as cyclists might have to wait. In case of intersections with traffic lights, the waiting time can be reduced by placing sensors which determine cyclists approaching the intersection. Chapter 4.2 gives an overview of changed intersections.

4.1.3 Road safety

Conflicts between cyclists and other traffic or objects at or next to the road have to be prevented. Road safety can be improved by making sure that cyclists have at least 40 meters sight to see objects and other traffic in time, so they can brake if required.

4.1.4 Social safety

Social safety does not make it possible to cycle faster, but if cyclists consider a route to be socially unsafe, they are less tended to use the route, and will use another transport mode. A social safe bicycle path can be realized by providing enough lighting and enough overview around the road

4.1.5 Streetlights

The presence of working streetlights improves both social and road safety, as road users can see other traffic and objects. Especially as not all cyclists have lights, although they have to.

4.1.6 Smoothness

The route has to be designed for a speed of at least 30 km/h to support higher speeds. Turns shall not be too sharp but must have a radius of at least 20 meters. Slopes should not be too steep[5] as this slows the cyclists down. At logical locations, for example in urban areas, a lower design speed can be used.

[5] For bicycle paths, the maximum percentage is based at the height difference. The smaller the height difference, the higher the maximum percentage of a slope.

4.1.7 Width
The bicycle path has to be at least 4 meters wide, to provide enough space to safely overtake slower cyclists.

4.1.8 Road surface
The road surface should be either asphalt or concrete and flat. Other road surfaces such as element hardenings should only be used at logical locations, because these are not appropriate.

4.1.9 Uniformity
If a route has a uniform appearance, the route explains itself as the course of the route can be recognized. Besides, it makes the route safer and more attractive, as users of the route know what to expect.

4.1.10 Snow and ice-free
Snow and ice create dangerous situations for cyclists. Therefore, snow and ice at the route should be prevented (Regio Twente, 2014).

4.1.11 Attractiveness
If a route is more attractive, more travellers will use it. Attractiveness is no independent aspect, as it depends on the above-mentioned aspects. However, attractiveness says also something about the landscape around the route. For example, a route next to a large road for cars is less attractive than a route through a beautiful forest.

Figure 9 gives an example of how a bicycle highway could look like.

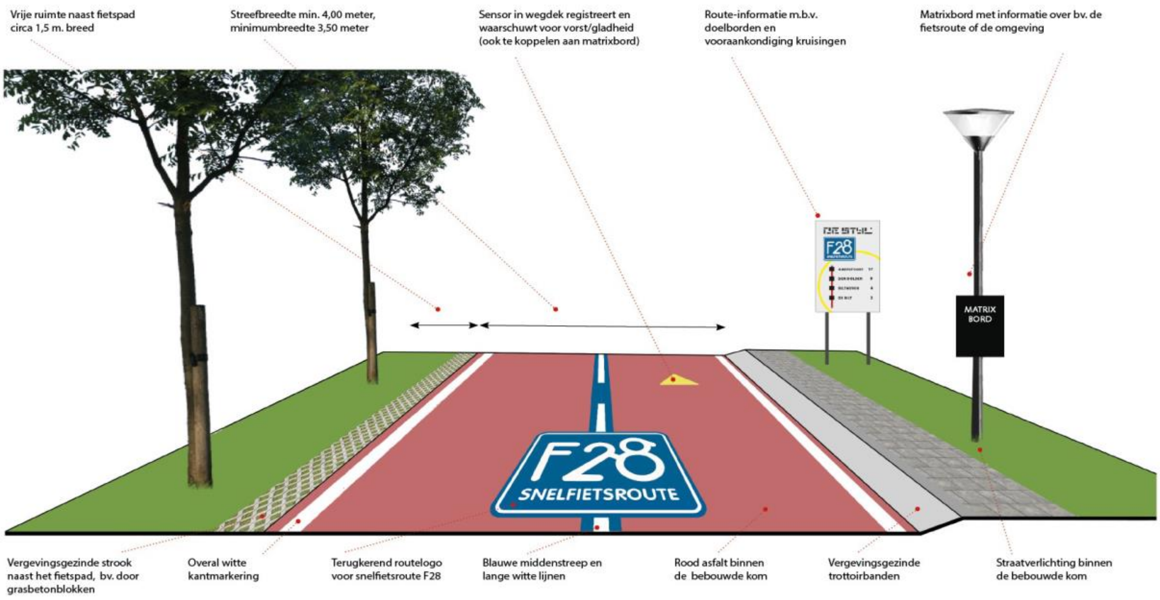

Figure 9, example of appearance of bicycle highway. Clear markings at the road surface, route information and street lights are present (M. Pol and C. Hendriksen, 2018)

4.2 Measures of individual corridors

The previous chapter gave an overview of general improvements along the three corridors. This chapter gives a short overview of the improvements of the individual corridors. A list of all measurements is available in Appendix D.

4.2.1 Corridor Amersfoort – Utrecht

This corridor follows the N237. Due to this, the route has many intersections with traffic lights where cyclists have to wait. The main focus along this corridor is reducing this waiting time. This is done by:

- Optimizing the traffic lights by using upstream sensors to let the traffic light system know that cyclists are approaching and by giving the cyclists a green light unless other traffic has to cross the bicycle path.
- Transform intersections into even intersections by adding a tunnel or bridge. As a result of this, cyclists do not have to wait anymore to cross the roads.

Figure 11 (next page) gives an overview of the changes.

4.2.2 Corridor Amersfoort - Leersum

This corridor follows the N226. The number of traffic lights along this route is relatively small with only three intersections with traffic lights (including one with two locations with traffic lights). At most other intersections, cyclists have already priority and warning signs are placed. Measurements which are taken:

- At the intersection with the entrance and exit roads of the A28, the traffic lights will give cyclists priority.
- At three roundabouts, cyclists get priority.
- At one intersection with traffic lights, a tunnel for cyclists is added.

Figure 10 gives an overview of the changes.

Figure 10, map of improvements at corridor Amersfoort-Leersum

4.3.3 Corridor North-South

This corridor has a lot of different improvements. Like the other corridors, traffic lights are optimized at multiple locations. Other measurements are:

- Transforming crossings to roundabouts to give cyclists priority and improve safety
- Transform streets shared with cars into bicycle streets to show car users that bicycles have priority.

Figure 12 (next page) gives an overview of the changes.

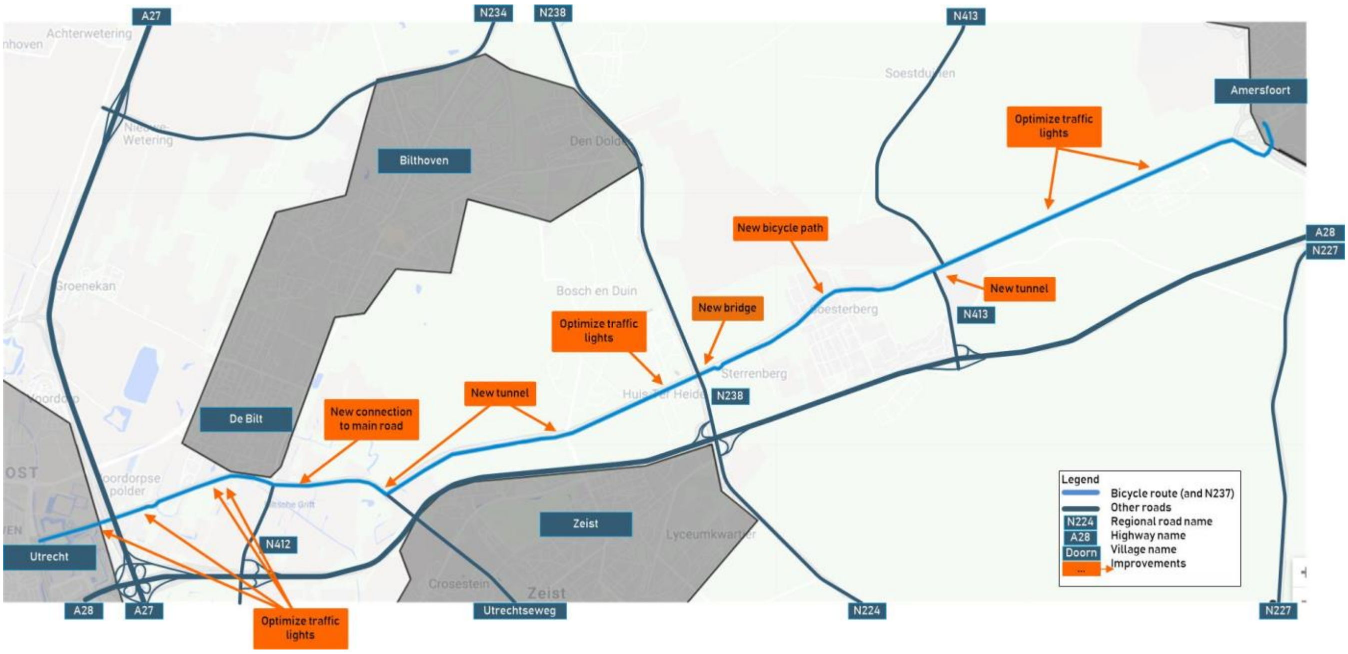

Figure 11, overview of the changes along the corridor Amersfoort-Utrecht

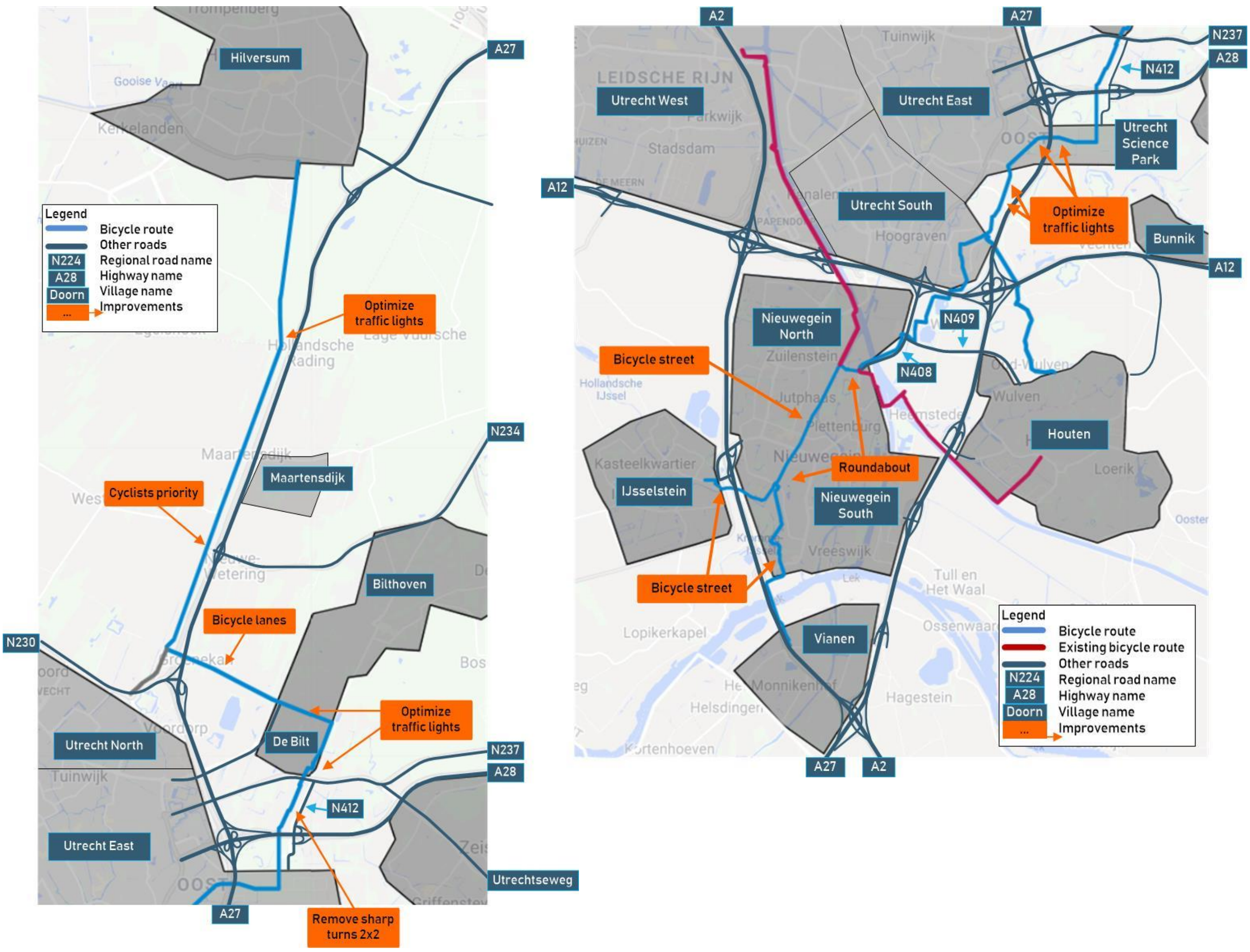

Figure 12, map of improvements at the corridor North-South. Left: the route between Hilversum and the Utrecht Science Park, right: the part between Vianen, IJsselstein and the Utrecht Science Park

5. Estimation of mode shift

The previous chapter described how the bicycle path network is optimized. That does not answer the question if this leads to a mode shift. This chapter estimates the number of commuters using each transport mode.

Chosen trips

All trips which meet the conditions which are mentioned below are evaluated:

- Maximum length of 25 kilometres.[6]
- At least 50% of the route uses an optimized bicycle path.[7]
- The evaluated route does not have to be the shortest route but is at most 15%[8] longer than the shortest route, if the longer route is expected to be faster.

This leads to a total number of 156 trips. A list of all trips is provided in Appendix F. A list of the used addresses of each node is provided in Appendix G. These addresses are used because using transport hubs, such as a train station, would strongly influence a single transport mode, in the case of a train station public transport.

5.1 Calculating the distribution

At the next pages, graphs and tables based on the model show the distribution in three different situations, namely:

- The current situation with an average trip duration for cars
- The current situation with the maximum trip duration for cars
- The optimized situation with an average trip duration for cars

Appendix H gives an overview of all values (both percentages and numbers) for all transport modes at several locations of the corridors.

5.1.1 Distribution in general

It is visible that the distribution differs for all corridors. The differences between the situations appear to be quite constant with an increase for bicycles around 9% and for electric bicycles around 5%. A reason for this could be the size of the dataset – as it contains 156 trips, divided over three corridors – in combination with rounding the distribution.

When looking at the size of the mode shift between a maximum duration for cars in the current situation, and an average duration in the new situation, the changes are smaller, because more commuters use other transport modes, such as bicycles, at the moment, so less commuters will change. Interesting enough, in this situation, the number of cyclists decreases at a few trips because of less congestion for cars,

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[6] Some longer trips (up to 28.5 km) are evaluated as well. These trips have an important node (Utrecht, Amersfoort, Hilversum) as start or destination.
[7] A few short routes (length around 10 kilometre) are evaluated as well. These use the optimized bicycle paths for at least 40%
[8] The speed at the optimized route is 11% higher than at a non-optimized route outside of urban areas and 33% than in urban areas. Besides, intersections are optimized as well which leads to an even higher average speed. Because of this, 15% is assumed to be a distance which does not costs extra time.

5.1.2 Corridor Amersfoort-Utrecht

Figure 13 shows the distribution of the transport modes at the corridor Utrecht-Amersfoort. The mentioned values are the average values for the whole corridor. Table 2 gives an overview of the changes in number of commuters per transport mode.

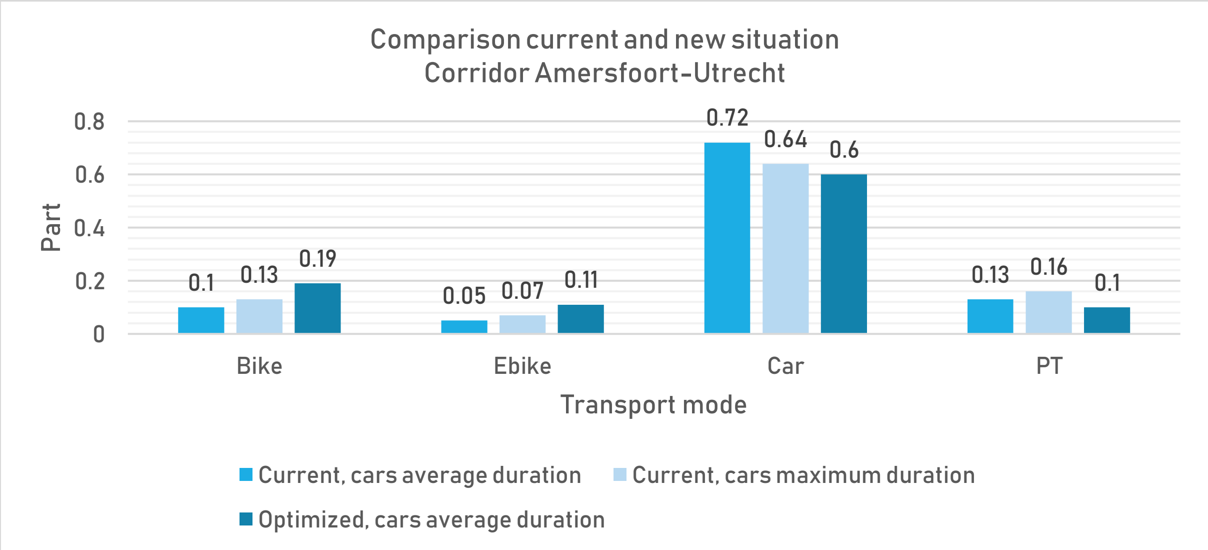

Figure 13, Comparison distribution in current and new situation corridor Amersfoort-Utrecht

Table 2, changes per mode for the corridor Amersfoort-Utrecht

Location	Bike	Electric bike	Car	Public Transport	Car real
Intersection with N412 (East)	+1.126 *+795*	+647 *+478*	-1.515 *-572*	-255 *-707*	2.324
Intersection Vollenhoven (east)	+1.155 *+814*	+667 *+493*	-1.547 *-576*	-270 *-736*	1.004
Stichtse Rotonde (west)	+1.324 *+932*	+772 *+571*	-1.777 *-650*	-314 *-857*	850

The number of reduced cars is at Intersection Vollenhoven and near the Stichtse Rotonde larger than the measured number of cars. This is because a large part of the cars uses the A28, a highway parallel to the N237 at which measurements are done.

A reason for the large increase in bicycles could be the improvement of many intersections.

5.1.3 Corridor Amersfoort-Leersum

Figure 14 shows the distribution of the transport modes at the corridor Utrecht-Leersum. The mentioned values are the average values for the whole corridor. Table 3 gives an overview of the changes in number of commuters per transport mode.

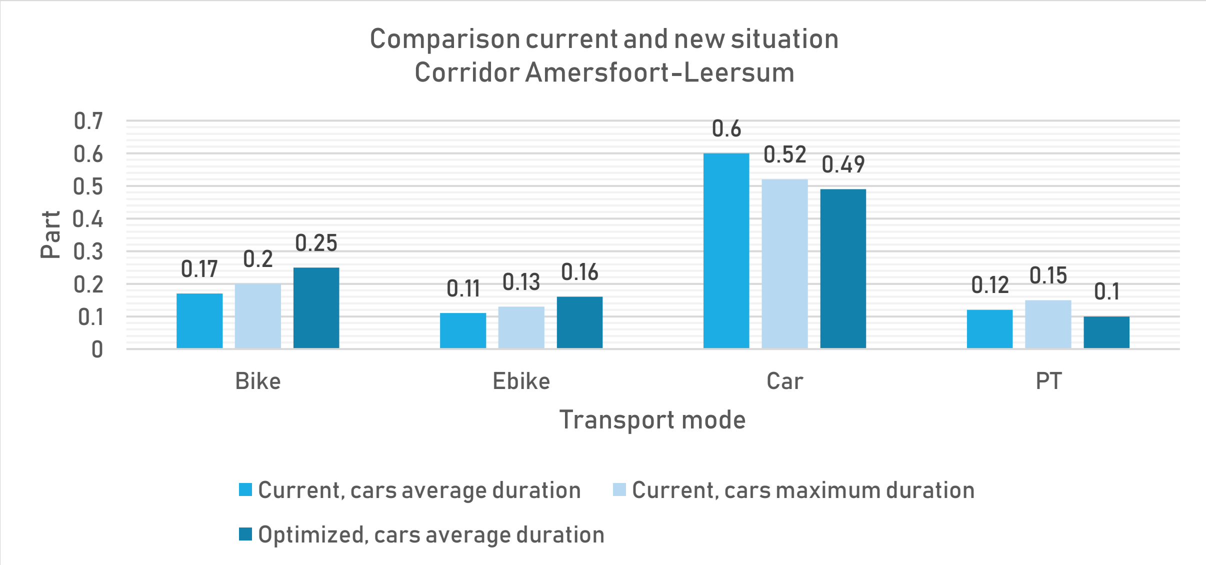

Figure 14, Comparison distribution in current and new situation corridor Amersfoort-Leersum

Table 3, changes per mode for the corridor Amersfoort-Leersum

Location	Bike	Electric bike	Car	Public Transport	Car real
Intersection with A28 (south)	+119 *+72*	+86 *+55*	-165 *-41*	-44 *-86*	1.397
Intersection with N224 (south)	+101 *+56*	+68 *+41*	-152 *-43*	-22 *-56*	1.247
Intersection with N225 (north)	+100 *+57*	+65 *+41*	-151 *-55*	-19 *-47*	879

Compared to the other corridors, this corridor has relatively more cyclists. However, the number of evaluated trips within the research area is smaller, with the result that the numbers are quite low.

5.1.4 Corridor North-South

Figure 15 shows the distribution of the transport modes at the corridor Utrecht-Leersum. The mentioned values are the average values for the whole corridor. Table 4 gives an overview of the changes in number of commuters per transport mode.

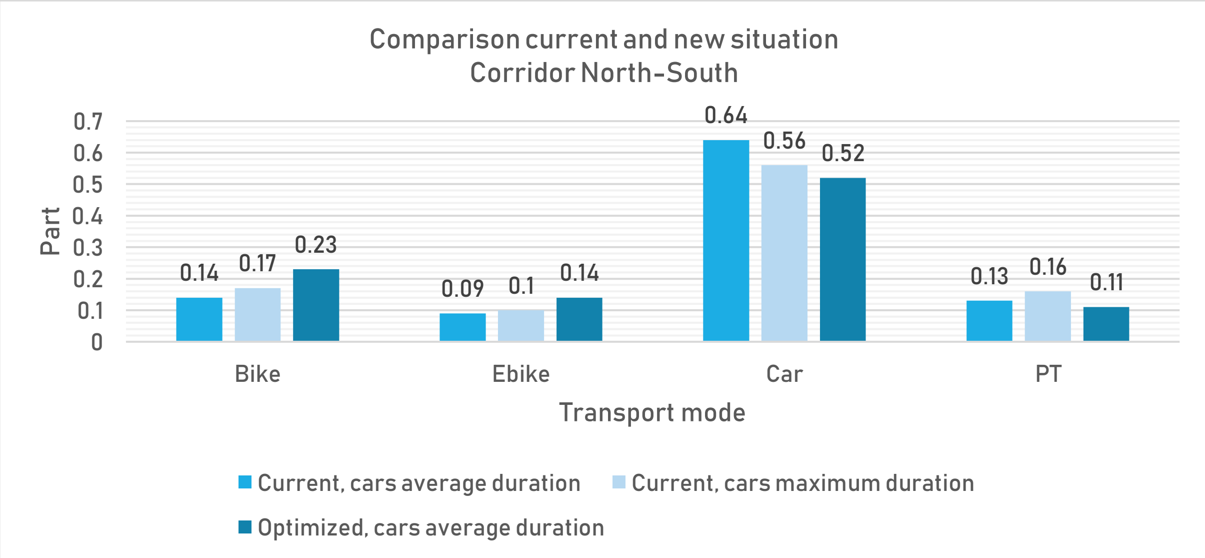

Figure 15, Comparison distribution in current and new situation corridor North-South

Table 4, changes per mode for the corridor North-South

Location	Bike	Electric bike	Car	Public Transport	Car real
N408, bridge over Amsterdam-Rijnkanaal	+358 *+271*	+249 *+199*	-469 *-224*	-133 *-243*	1.849
Bicycle path Utrecht Science Park – De Bilt, parallel to N412	+373 *+273*	+236 *+180*	-508 *-199*	-99 *-257*	1.266
Intersection with N234	+648 *+392*	+422 *+271*	-899 *-248*	-173 *-417*	778
Intersection with Vuurse Dreef	+601 *+371*	+388 *+255*	-832 *-249*	-157 *-381*	585

The number of reduced cars at the intersections with the N234 and Vuurse Dreef is larger than the measured number of cars. This is because a large part of the cars uses the A27, a highway parallel to the N417 at which measurements are done.

5.1.5 Individual scale of trips

At an individual scale of the trips, in case of an average morning peak hour, the following can be said:

- The maximum increase for non-electric bicycles is 14.8% (Hilversum-Bunnik)
- The maximum increase for electric bicycles is 9.0% (Hilversum-Bunnik)
- The maximum decrease for cars is 19.7% (Bunnik-Maartensdijk)
- The maximum decrease for public transport is 6.5% (Zeist-Hilversum)

6. Discussion

This chapter discusses results of the report. Aspects which are already mentioned in the demarcation, chapter 2.4, are not repeated in this chapter.

6.1 Choice of bicycle corridors

Three corridors have been chosen to optimize within this research. For each corridor, a route has been chosen, based on existing bicycle routes and the vicinity of multiple nodes. That a route in this research has been chosen does not mean that this route is the best route between nodes. For example, the planned bicycle highway between Utrecht and Amersfoort follows the train tracks instead of the N237, which is more comfortable because the path is not next to a main road for cars, but the route is less direct and not interesting for commuters between Amersfoort and Zeist.

6.2 Changes of bicycle network

6.2.1 Changes are general

Chapter 4 gave an overview of the changes in the bicycle network. These changes are used in chapter 5 to make an estimation of the distribution in the optimized situation. However, these changes are general changes in favour of bicycles. It is not known if for example traffic lights are already optimized and if they can be optimized. The suggested improvement does therefor not have to be the best improvement for an intersection. To find the best solution, these intersections have to be evaluated at a local level with more detail than given in this report.

6.2.2 Possible increase due to economic benefits

This research focusses on an increase in bicycle usage as the result of optimizing the bicycle infrastructure. Health benefits for cyclists have been considered as well. However, financial stimulus, such as a reward for cycling instead of using a car, has not been considered. Tibs (2018) shows that giving a reward or higher mileage allowance to those who cycle to work instead of using their car would make it even more attractive to cycle.

6.3 Estimations by the model

6.3.1 Trip duration bicycles

The duration of a trip as calculated by the model depends on the speed and the number of intersections. For the speed, higher values are possible. Goudappel Coffeng (2018) states that especially electric bicycles often reach speeds above 25 km/h, but that such speeds are not realistic for a traffic model. In this research, a speed of 23.3 km/h for electric bicycles has been used. This could be an underestimation. The same counts for the speed within urban areas. the used 14.7 km/h is the average speed within Utrecht, this might be different in other urban areas.

Another important factor for the duration is the waiting time at intersections. In this research, a standard value has been used for the current waiting time and for the waiting time in the optimized situation. In some cases, the used value is too low and in others too high.

These two factors influence the duration, which influences the disvalue, which influences the usage of bicycles

6.3.2 Trip choice for public transport

For each trip by public transport, one route has been evaluated although multiple different routes are possible in many cases. Commuters can use another route with another disvalue because of several reasons which can also be comfort related. For example, one can work in a train but not in a bus.

6.3.3 Costs of cars and bicycles

The costs of cars and bicycles are rough estimations. The costs/kilometre for electric bicycles are in this analysis higher than the costs for cars. It is expected that the costs for cars are higher.

6.3.4 Errors due to parameter μ

An important parameter is μ, which cannot be determined in such way that the model exactly describes the reality. It is estimated that 24.1% of the commuters use their bicycle, which is 26.8% in reality. As a result of this, the real number of cyclists could be 11.2% higher. In case of public transport, the estimated percentage is 13.6%, which is 10.8% in reality. This means there is an overestimation of 33.3%. However, the mentioned real percentages are the average percentages for the Netherlands, and they do not have to be exactly the same for the research area.

6.3.5 Increase of bicycle usage

The increase for non-electric bicycles is with 9% larger than the 5% increase of electric bicycles. Electric bicycles are faster, which reduces the required time and due to that the disvalue. However, their costs are estimated as €0.14/km higher than the costs for non-electric bicycles. This explains the difference.

7. Conclusion and recommendations

In the region around Utrecht, there are several locations in the road network with a lot of congestion. These bottlenecks are mainly situated at the highways and regional roads at the south-eastern side of Utrecht and as well at many intersections of regional roads such as the N236 and N226, further away from Utrecht. The train network might get capacity problems at the full network. The three corridors with multiple bottlenecks which seemed to be most feasible for a mode shift to bicycle usage have been chosen to be further evaluated.

At these corridors, several measurements have been applied to improve the bicycle paths, which makes cycling more comfortable and makes it possible to cycle with higher speeds. This are improvements such as broadening the bicycle path and adding streetlights, but also measurements at the scale of individual intersections to optimize the flow of cyclists and improve the safety.

To analyse if the effect of these changes, a model has been set up. This model calculates for every trip by bicycle, electric bicycle, car or public transport the disvalue. It uses the disvalue to determine the distribution of commuters over these transport modes. This has been done for several scenarios which are compared.

When comparing an average morning peak hour without the optimization with an average morning peak hour with an optimized bicycle network, the usage of non-electric bicycles increases with 9%. The usage of electric bicycles increases with 5%, which means that the total increase of bicycle usage is 14%, in combination with a decrease of 12% for car usage and 2% for public transport. These percentages are average values for the corridors. In the case of individual bicycle trips between nodes, the increase lays between 3 and 23%, in combination with a decrease of car usage between 2 and 19% and decrease of public transport up to 7%.

Especially at the corridor between Utrecht and Amersfoort and the North-South corridor, an optimization leads to hundreds of extra cyclists. For the third corridor, between Amersfoort and Leersum, the relative increase is comparable, but the number of extra cyclists is about less than a quarter of the number at the other routes.

The analysis shows that an optimization leads to an increase in bicycle usage combined with primarily a reduction in car usage. Therefore, it is recommended to optimize the bicycle routes as it unburdens the road network. This counts most for the route between Utrecht and Amersfoort and at the North-South corridor. However, for a better estimation of the mode shift due to an optimization of a corridor, a more detailed design and analysis at a corridor-scale are needed and therefore recommended.

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Appendix A: Reference projects

Below, two reference projects are mentioned. These routes are used as inspiration for the routes which are optimized within this research.

1.2.1 Bicycle highway F35

This new bicycle route with a total length of 62 kilometre will connect several places in the eastern part of the province Overijssel in the Netherlands. A part has been realized already, and another part is planned to be build. A large part of this route follows the route of the railroad between Nijverdal and Enschede. As a result of this, the number of intersections is small. There are several reasons why this route has been built. One of those reasons, which is applicable to the region of Utrecht as well, is to provide an alternative for trips by car and a smooth connection between those places where people live and where they work, or where they can change to public transport for longer trips.

Figure 16, appearance of bicycle highway F35

This route has been designed as being one route from the start till the end. Along the whole route, the same elements can be found: Red asphalt of at least 4 meters wide in combination with a line of concrete of 0.3 meters wide at both sides of the road. The streetlights along the whole route are the same, and at a lot of places, the logo of the route is visible. Figure 16 gives an example of the appearance of this route.

Bottlenecks of the bicycle route have been solved by building new bridges and tunnels, as uneven intersections are preferred (Province Overijssel, 2019).

This route has mainly served as inspiration for the design of the optimized route.

1.2.2 Bicycle highway network Gelderland south

Between and around the cities Arnhem, Nijmegen, Ede and Wageningen in the province of Gelderland in the Netherlands, there are multiple bicycle highways. These connect the centres of the cities with surrounding areas. Reasons to realize this network were:

- Some persons depend on their bicycle to travel. Because of this, safe bicycle routes are needed.
- Because bicycles become faster (partly because of electric bikes) and can therefore compete with cars at some distances. This reduces the number of cars at roads.
- Bicycles can be used to get from a station to one's destination. If good bicycle paths are provided, travellers are willing to cycle a longer distance.

(Royal HasoningDHV, 2017)

A benefit of this project is that parts of it already exist for several years. These parts have been evaluated, which provide data which can be used in new projects, such as in this research. For example, a research carried out under the users of some of the bicycle highways (For example: Tibs, 2018). This could be used within this research, to know more about the reasons for persons to cycle.

Appendix B: Large map of road network

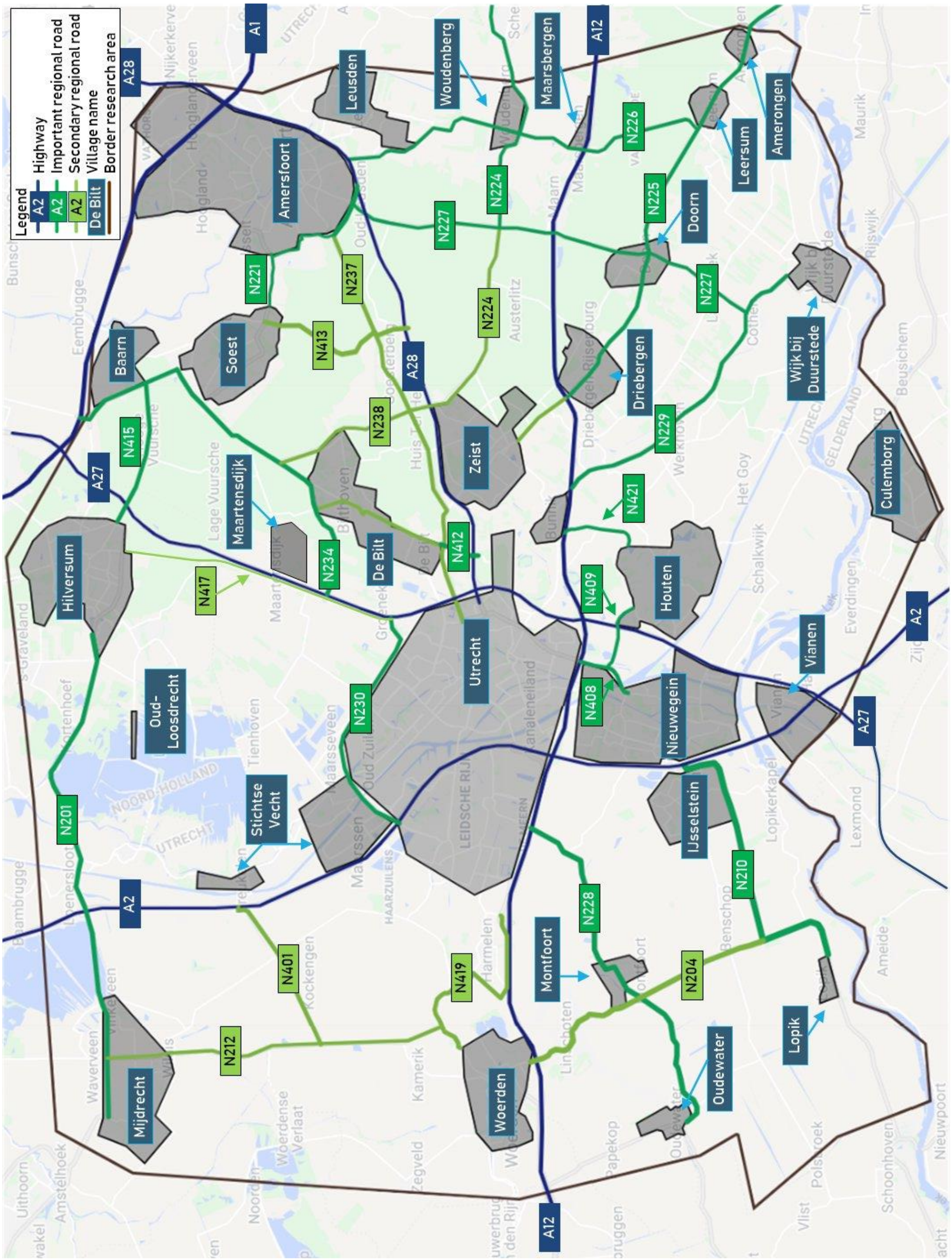

Figure 17, large map of the road network within the research area

Appendix C: Requirements and general optimization

C.1 Requirements and general optimization

For a cycling highway, there are many requirements to make a route a good bicycle highway. These aspects are explained below in combination with a description of the way how the optimized route fulfils these requirements.

For determining these aspects, an evaluation of Tibs (2018) has been used in combination with a few added aspects. For each aspect, the requirements are, unless otherwise mentioned, based at CROW (2016).

C.1.1 Directness

A cycling highway should be as direct as possible. Directness is measured using the detour factor, which is the length of the route between two locations divided by the exact distance (straight line) between those locations. For normal bicycle networks, the detour factor should be 1.2. For cycling highways however 1.1, as these routes have to provide a fast connection between locations.

C.1.2 Intersections without priority

This is, as the aspect says, the number of intersections without priority for cyclists. This includes intersections with traffic lights if bicycles have to brake for these lights. The target is to maximize the flow for cyclists. They have as much as possible priority over cars. The number of stops should be minimized. However, it is better to have one intersection with a relatively longer waiting time, than two with shorter waiting times.

There are three types of Measures which are applied to optimize these intersections:

- Optimizing the traffic lights in favour of cyclists.
- Changing the type of an intersection, without changing levels, for example changing a crossing into a roundabout.
- Changing an even intersection into an uneven intersection, by adding a tunnel or bridge.

A map of all changed intersections is present in the next paragraph. A short elaboration is available in Appendix C.

C.1.3 Road safety

The road safety contains the chance for conflicts between bicycles and other road users, which can be cars, but also other cyclists. For safety, it is important that cyclists and other road users have enough sight to see other road users.

Cyclists should have at least 40 meters sight to stop in time to prevent accidents. Conflicts between cars and cyclists can be avoided by minimize the part of the road which is used by both cyclists and cars. If a road has to be shared, the road layout has to tell users which part belongs to cyclists. Using red bicycle lanes in combination with clear markings can show this. Another option is using a bicycle street: it looks like a wide bicycle path, where cars are allowed but have to drive slowly.

Figure 18, if a road has to be shared by cars and cyclists, use a clear layout of the road surface (M. Pol and C. Hendriksen, 2018)

Especially at parts of the corridor between Utrecht (Soesterberg) and Amersfoort, but also between Leersum and Amersfoort, there are many houses next to the bicycle path, with a parking spot next to the house. Cars which leave this parking spot and drive to the main road have to cross the main road. Cyclists do not always expect these cars, and car drivers do not have enough sight to see cyclists. It is important to create enough sight for both cyclists and car drivers, to prevent conflicts.

Conflicts with hard objects, such as poles or trees close to the road, should be minimized as well, because these objects can be harmful to cyclists if they cycle against it.

C.1.4 Social safety

Social safety contains multiple aspects (CROW, 2006). These aspects do not make it possible to cycle faster, but if cyclists consider a route to be socially unsafe, they are less tended to use the route, and will use another transport mode.

- Ability for cyclists to have an overview: if there are many bushes next to a path, cyclists cannot see what happens behind it and if someone would come out of them. The same counts for dark tunnels.
- Other persons: if other persons are present, people will feel safer at night
- Appearance: if there are many broken objects next to the road, it looks unsafe.

C.1.5 Streetlights

Streetlights are crucial for (social safety) along the route. Due to these lights, cyclists are able to see other cyclists and the surroundings of the bicycle path. Although bicycles must have lights, not all do have them. Especially at bicycle highways with fast cycling travellers, conflicts between slow cyclists without lights and fast cyclists should be prevented. Besides, a route without streetlights can feel unsafe at night. Therefore, it is important that streetlights are present and if the main route does not have streetlights, an alternative route should have streetlights to guarantee a social safe route.

Because of this, at all locations along the corridors without sufficient lightning, streetlights are added.

C.1.6 Smooth route

To be able to cycle with relatively high speeds compared to normal bicycle paths, the bicycle route has to support those higher speeds. Therefore, the route has to be designed for a speed of at least 30 km/h. Turns shall not be too sharp but must have a radius of at least 20 meters.

Slopes should not be too steep[9] as this slows the cyclists down. At logical locations, for example in urban areas, a lower design speed can be used.

C.1.7 Width

The bicycle path has to be wide enough to provide enough space for cyclists to overtake each other. Overtaking is common because of speed differences between cyclists. With a width of 4 meters, this can be done safely. Unless it is not possible at a location, the existing bicycle paths have to be broadened to 4 meters.

C.1.8 Road surface

The road surface should be either asphalt or concrete and flat. Other road surfaces such as element hardenings should only be used at logical locations, because these are not appropriate for bicycle highways as there is a higher risk for height differences between single elements.

C.1.9 Uniformity

If a route has a uniform appearance, the route explains itself as the course of the route can be recognized. Besides, it makes the route safer and more attractive, as users of the route know what to expect. The road is made uniform by using the same bicycle path layout along the route: red asphalt with a concrete line of 0.3 meters wide at both sides, between the asphalt and the roadside

C.1.10 Snow and ice-free

Snow and ice create dangerous situations for cyclists. Therefore, snow and ice at the route should be prevented (Regio Twente, 2014). The province of Utrecht is responsible for this at all the evaluated bicycle routes.

[9] For bicycle paths, the maximum percentage is based at the height difference. The smaller the heigth difference, the higher the maximum percentage of a slope.

C.1.11 Attractiveness

This tells if the route is attractive to use. If a route is more attractive, more travellers will use it. Attractiveness is no independent aspect, as it depends on the above-mentioned aspects. However, attractiveness says also something about the landscape around the route. For example, a route next to a large road for cars is less attractive than a route through a beautiful forest.

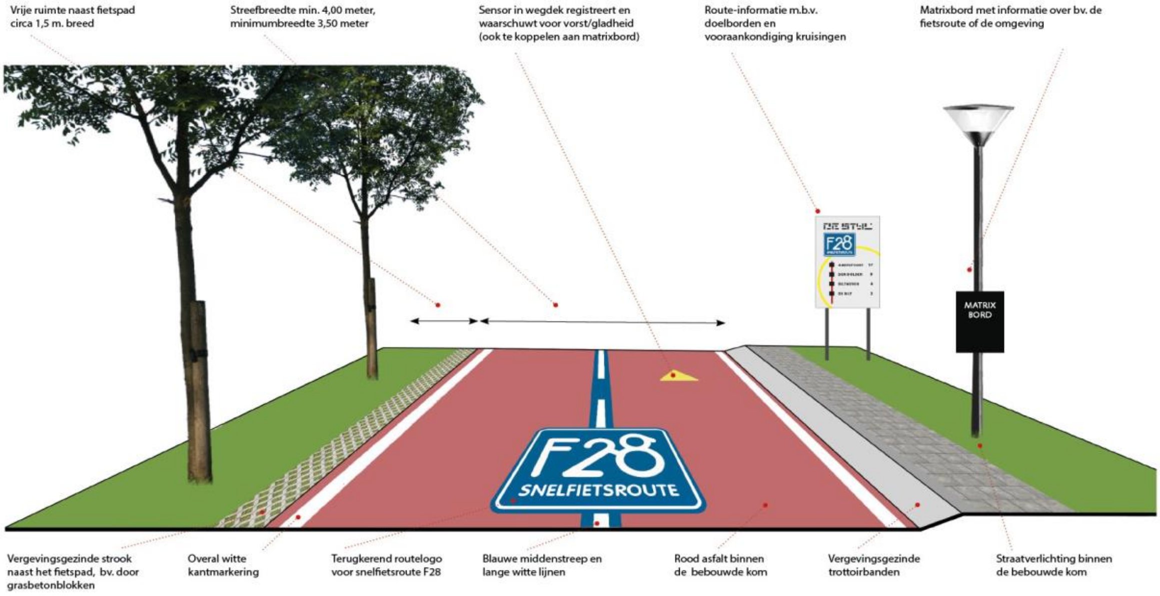

Figure 19, example of appearance of bicycle highway. Clear markings at the road surface, route information and street lights are present (M. Pol and C. Hendriksen, 2018)

Appendix D: Measures to improve the bicycle path network

This appendix describes the changes at all three corridors.

D.1 Corridor Utrecht Amersfoort

General data start to end:

- Distance: 15.4 km
- Detour factor: 1.03

D.1.1 Utrecht – Intersection Vollenhoven

Start: N237, 73.0
End: N237, 77.3
Length: 4.3 km
Detour factor: 1.05

This part of the corridor has a bicycle path at both the left and the right side of the main road. The route at the left side is for a large part shared with cars and uses streets within the village De Bilt. The route at the right side does share a part with cars as well but has less intersections and crossing access roads. Therefore, the bicycle path on the right has been chosen to optimize.

Tables 5 and 6 lists the measures which are simulated in this research.

Table 5, improvements between Utrecht and Intersection Vollenhoven, part 1

Location (kilometre of N237)	Type of intersection/problem	Measure
73.6	Intersection with traffic lights, crossing road: Archimedeslaan	Optimize traffic lights in favour of cyclists: only red if cars have to cross the bicycle path.
74.2	Intersection with traffic lights, crossing road: Veldzichtlaan	Optimize traffic lights in favour of cyclists: only red if cars have to cross the bicycle path.
74.3	Intersection without traffic lights, crossing road: access to car company	Add traffic signs and road markings to show that cyclists have priority
74.6	Intersection without traffic lights, crossing road: access to company	Add traffic signs and road markings to show that cyclists have priority
74.7 – 74.8	Sharing the road with cars	Transfer into bicycle street, use red asphalt. Cars can use the street, but it belongs to cyclists

Table 6, improvements between Utrecht and Intersection Vollenhoven, part 2

Location (kilometre of N237)	Type of intersection/problem	Measure
75.3 (1)	Intersection with traffic lights, crossing road: access to company (KNMI)	Optimize traffic lights in favour of cyclists: only red if cars have to cross the bicycle path.
75.3 (2)	Intersection with traffic lights, crossing road: Wilhelminalaan	Optimize traffic lights in favour of cyclists: only red if cars have to cross the bicycle path.
75.9	Intersection, but tunnel for cyslists is present	No Measures needed
76.0 – 77.3	Sharing the road with cars and trucks of company (Planta Groencentrum)	Add an extra connection from the parallel road (bicycle path) to the main road. As a result, trucks only have to use the bicycle path between 76.0 and 76.2 (see figure 20) For the shared part: use coloured asphalt, red for cyclists

Figure 20, location of a new connection between the parallel road and the main road (N237), to connect Planta Groencentrum with the main road

D.1.2 Intersection Vollenhoven

This is an important intersection used by traffic between Utrecht, De Bilt, Amersfoort and Zeist. For the bicycle path at the left side, a tunnel is present to underpass the Amersfoortseweg. However, to cross the Utrechtseweg, which cyclists using the optimized bicycle path have to do, no tunnel or bridge is available, but traffic lights instead. To optimize this, a new tunnel is added, see figure 21. This leads to a new intersection for cyclists. For safety, sight should be optimized, although it is not expected that the minimum sight of 40 meters will be available. Therefore, cyclists cannot drive with their usual speed at this intersection.

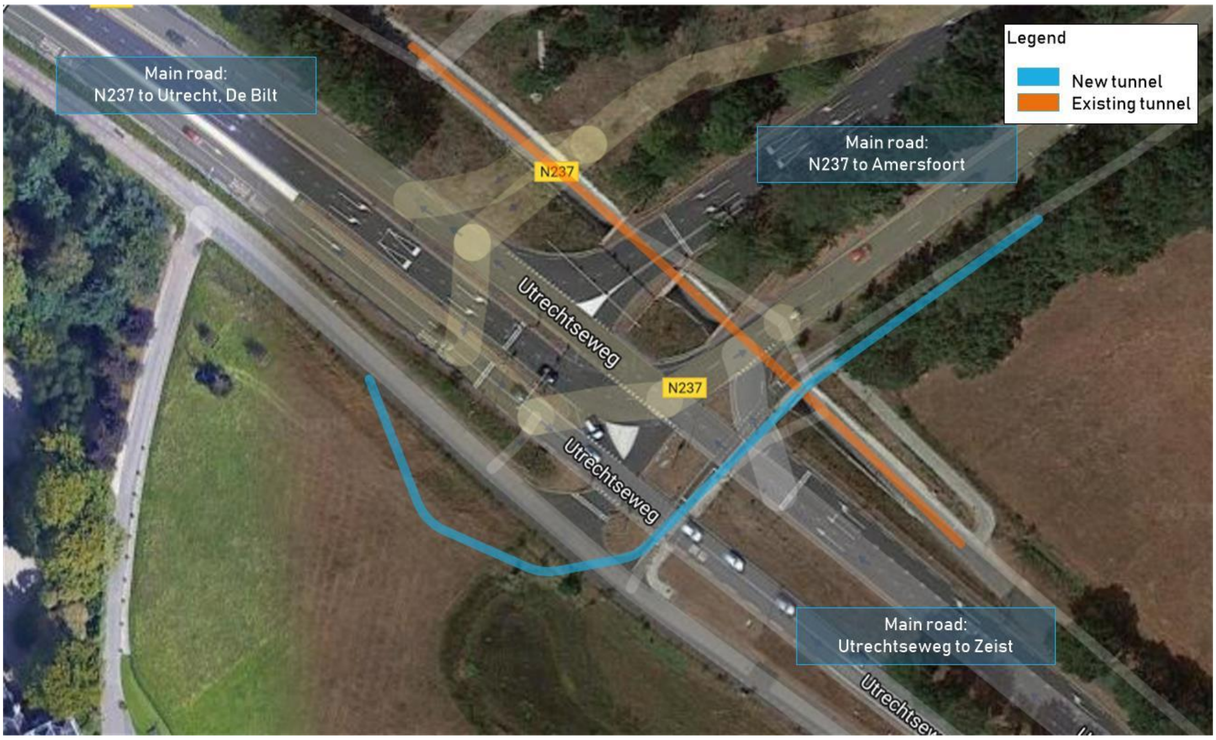

Figure 21, existing and new tunnel at Intersection Vollenhoven

D.1.3 Intersection Vollenhoven – Soesterberg

This part of the route has a bicycle path at both sides of the main road.

Start: N237 77.4
End: N237 82.7
Length: 5.3 km
Detour factor: 1.02

Table 7, comparison between bicycle paths at the left and right side

Aspect	Left side	Right side
Number of intersections without priority	3	4
Number of intersections with priority (including exits)	19 (of which 16 in 2 kilometres)	7
Sharing the road with cars	58%	5%

The right side will be optimized as this path has less intersections and is barely used by cars, compared to the left side which functions as route to houses and companies as well. Table 8 gives an overview of the improvements.

Table 8, measures between Intersection Vollenhoven and Soesterberg

Location (kilometre of N237)	Type of intersection/intersection	Measure
79.7	Intersection with traffic lights. Crossing road: Panweg to Zeist	Tunnel for bicycles
81.0	Intersection with traffic lights. Crossing road: Prins Alexanderweg to Huis ter Heide	Optimize traffic lights in favour of cyclists. Prevent braking cyslists. (Not enough space for a tunnel)
81.4	Intersection with traffic lights, crossing road: N238 to A28 and Zeist	See heading
81.6 – 81.8	Bicycle path around tank stop	To improve (social) safety: streetlights have to be placed next to the bicycle path
82.2	Intersection with traffic lights, crossing road: Universumlaan	Optimize the traffic lights in favour of cyclists. Prevent them from braking.
82.3	Intersection without traffic lights, crossing road: Maanlaan	Close this exit for cars. This will improve safety for both cyclists at the bicycle path and cars at the N237. Cars who used to use this road can use the Universumlaan or Kerklaan which is only two minutes longer.

D.1.4 Intersection with N238

This intersection is a bottleneck for car traffic. However, due to the traffic lights, cyclists will have to wait as well. An optimization of the traffic lights in favour of the cyclists could lead to even more congestion for cars. Using a different level for cars and bicycles can optimize both the flow of cyclists and the flow of cars.

Due to a lack of space (mainly width), a tunnel would require narrow entrances which creates an unsafe social environment. A bridge does not lead to an unsafe social environment but requires longer slopes because of a larger difference in height than a tunnel requires. Nevertheless, a bridge is considered to be the best option for an uneven intersection. The location is visible in figure 22.

Both a bridge and a tunnel reduce the accessibility of the McDonalds which is situated next to the current bicycle path. Next to this, it would be harder but not impossible to reach the bicycle crossing of the N237. This crossing cannot be created at a higher or lower level, also because of a lack of space.

An alternative is the realisation of a tunnel at the other side of the McDonalds. However, this alternative requires major interventions such as buying land and realising an alternative for the existing Ericaweg.

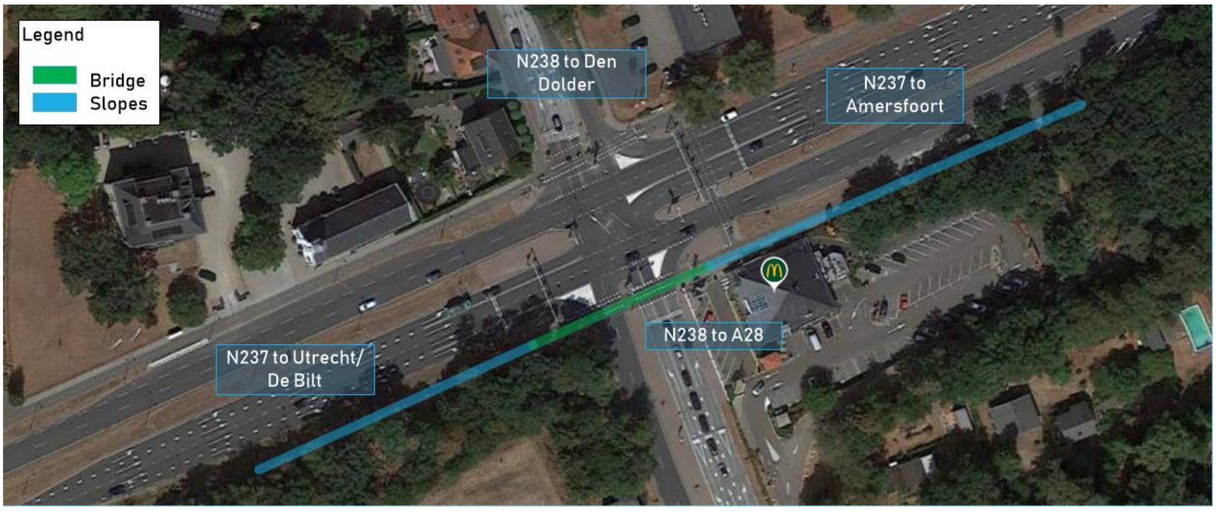

Figure 22, intersection with N238; a bridge is added

D.1.5 Soesterberg

Start: N237 82.7
End: N237 84.0
Length: 1.3 km
Detour factor: 1.05

The bicycle path at the right side of the N237 prior to Soesterberg goes through the centre of Soesterberg. Therefore, it cannot be used for faster cycling. Due to sharing the road with cars without bicycle lanes, the road safety is doubtful.

The bicycle path at the left side prior to Soesterberg keeps following the N237, but in the form of a parallel road used by bicycles, cars and trucks which want to reach the industrialized northern part of Soesterberg. Some of these trucks park along this parallel road. Because of these aspects, the safety of this road can be seen as doubtful as well.

Because both options are not suitable for a fast bicycle connection between Amersfoort and Utrecht, a new route has to be realized. This can be done directly to the right of the N237. The N237 has a tunnel in Soesterberg. The bicycle path remains at ground level above the slope with grass at the right side of the N237. Where the N237 is in the tunnel, the bicycle path is placed at the tunnel.

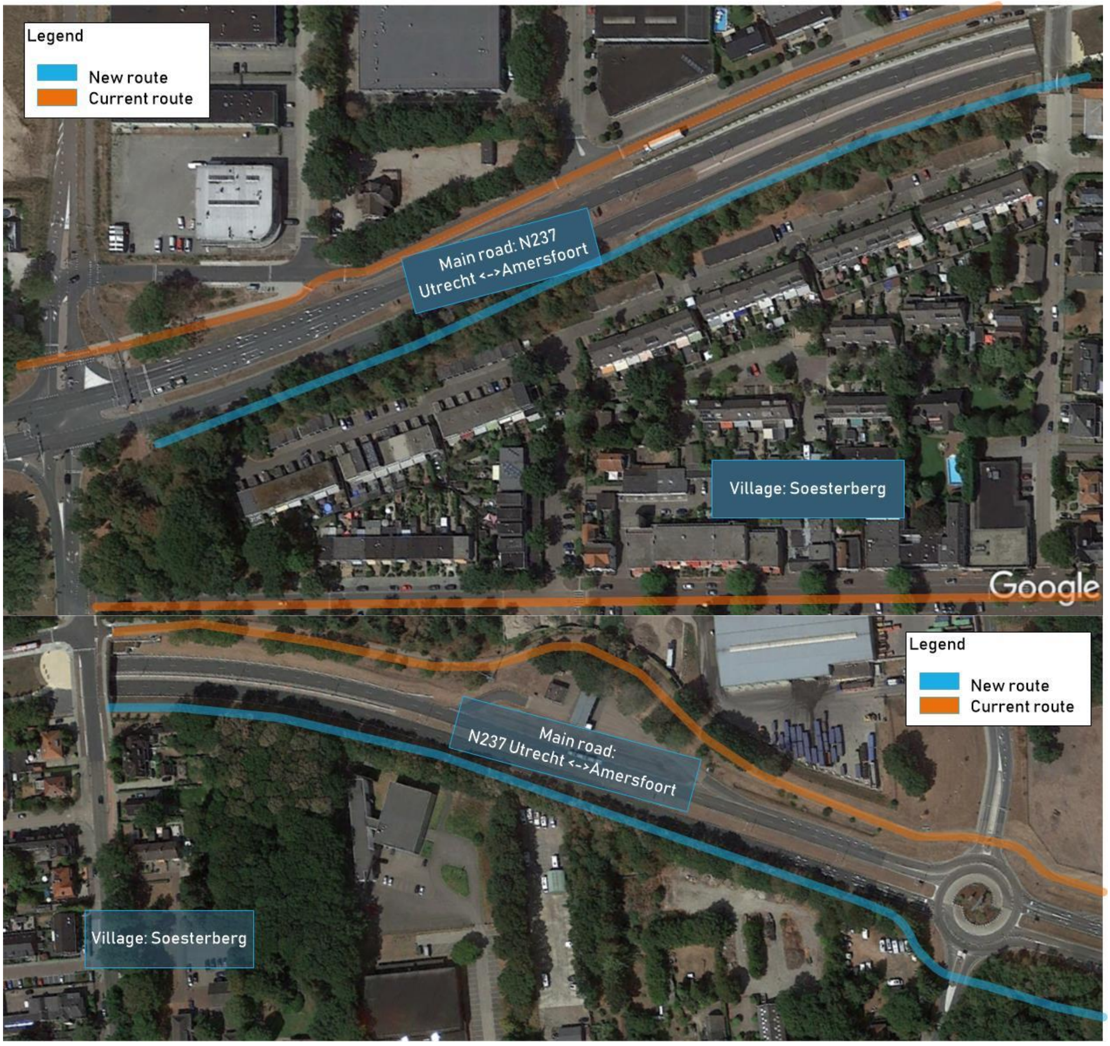

Figure 23, new bicycle path through Soesterberg. The bicycle path follows the N237, but stays at ground level. Above the western side of the tunnel, below the eastern side

D.1.6 Soesterberg – intersection with N413

Start: N237 84.0
End: N237 84.9
Length: 0.9 km
Detour factor: 1.0

The bicycle path at the right side is used as the optimized route. Table 9 gives an overview of the improvements.

Table 9, measures between Soesterberg and the intersection with the N413

Location (kilometre of N237)	Type of intersection	Measure
84.5	Intersection with traffic lights. Crossing road: N413 (connects Soest and Soesterberg to the A28)	Tunnel to underpass the intersection. As the entrances of the tunnel will be close to the N237, barriers to prevent cars from entering it will be necessary.
84.6	Access to companies/shops	Access is closed. Cars can still access the parking area via the other entrance.

D.1.7 Intersection N413 – Amersfoort

Start: N237 84.9
End: N237 88.3
Length: 3.4 km
Detour factor: 1.0

Both the bicycle path at the left side and the path at the right side are crossed by an amount of fifty access roads to houses or companies. Besides, both bicycle paths are too small (less than 3 meters).

The bicycle path at the right side is broadened to 4 meters. However, to do this space is required, which is not available in the current situation. To create space, the bicycle path at the left side is removed which makes it possible to shift the main road several meters to the left.

This does not solve the problem of the many crossing access roads, but as space is redistributed, it is possible to create enough sight for safe crossings.

Table 10 gives an overview of the changed intersections.

Table 10, measures between intersection with N413 and Amersfoort

Location (kilometre of N237)	Type of intersection	Measure
86.1	Intersection with traffic lights, crossing road: Laan van Blussé van Oud Alblas	Optimize traffic lights in favour of cyclists: only red if cars have to cross the bicycle path.
86.6	Intersection without traffic lights, crossing road: access road to multiple companies	Add traffic signs and road markings to show that cyclists have priority
86.9	Intersection without traffic lights, crossing road: Bosweg	Add traffic signs and road markings to show that cyclists have priority
87.0 (2x)	Intersection without traffic lights, crossing road:	Add traffic signs and road markings to show that cyclists have priority

	entrance and exit to Zon en Schild	
87.4	Intersection with traffic lights, crossing road: access road to Zone n Schild	Optimize traffic lights in favour of cyclists: only red if cars have to cross the bicycle path.

D.2 Corridor Amersfoort Utrechtse Heuvelrug

General data (start to end):

- Distance: 14.7
- Detour factor: 1.1

D.2.1 Route Amersfoort – Leusden South

Start: N226 49.1
End: N226 52.0
Length: 2.9 km
Detour factor: 1.04

Table 11, overview of measures between Amersfoort and Leusden South

Location (kilometre of N226)	Type of intersection/problem	Measure
49.1	Intersection with traffic lights, crossing road: exit and entry of A28	Optimization of traffic lights: when possible green for bicycles. Nevertheless, the number of waiting cars should be monitored because of a short exit of the highway.
49.2	Intersection with traffic lights, crossing road: Dodeweg (exit and entry of A28)	Optimization of traffic lights: when possible green for bicycles.
49.5	2x Intersection without traffic lights. 2 streets connected to the N226	Guarantee sight to see cars from a minimum distance of 40 meters. Measures to let cars which come out of the street slow down: speed bumps and traffic signs
50.0	Intersection with traffic lights. Crossing road: Groene Zoom	Tunnel to underpass the Groene Zoom.
51.6	Intersection with traffic lights, crossing road: Prinses Margrietlaan	Optimize traffic lights in favour of cyclists.

D.2.2 Route Leusden South – Woudenberg

Start: N226 52.0
End: N226 55.3
Length: 3.3 km
Detour factor: 1.13

Table 12, list of measures between Leusden South and Woudenberg

Location (kilometre of N226)	Type of intersection/problem	Measure
52.1	Intersection with traffic lights, crossing road: bus lane	These lights are only red if a bus crosses the bicycle path and do therefore not have to be optimized. The curves are yet too sharp and should be given a larger radius
52.7	Roundabout	Cyclists do not have priority in the current situation. This is changed to having priority. Curves are sharp. Less sharp crossings would lead to a less save intersection and are therefore not changed
54.1	Intersection without traffic lights. Crossing road: Ekris	Cyclists have priority and warning traffic signs are placed. No Measures are needed.

D.2.3 Woudenberg

Start: N226 55.3
End: N226 56.3
Length: 1.0 km
Detour factor: 1.02

Table 13, overview of measures within Woudenberg

Location (kilometre of N226)	Type of intersection/problem	Measure
55.3	Roundabout	Cyclists have priority and warning traffic signs are placed. No Measures are needed.
55.4-55.6	Road is shared with cars of inhabitants of street	Clear bicycle lanes are present, but cars park at these lanes. This should be prevented by placing extra parking spots.
55.8	Roundabout	Cyclists have priority and warning traffic signs are placed. No Measures are needed
55.8-56.1	Road is shared with cars of inhabitants of street	Clear bicycle lanes are present, no Measures needed
56.1-56.3	Road is shared with cars of inhabitants of street	No clear bicycle lanes present. Nonetheless, the number of expected cars is very small.

D.2.4 Route Woudenberg – A12

Start: N226 56.3
End: N226 58.9
Length: 2.6 km
Detour factor: 1.06

Table 14, overview of measures between Woudenberg and the A12

Location (kilometre of N226)	Type of intersection/problem	Measure
Whole route	Bicycle path is shared with local traffic	Path is designed as wide bicycle path, therefore no extra Measures needed
56.3	Roundabout	Cyclists have priority and warning traffic signs are placed. No Measures are needed.
57.3-57.4	Trucks use parallel road due to truck company	Placing extra warning signs to improve safety of cyclists
57.4	Intersection without traffic lights, crossing road: Griftdijk	Traffic signs and a bump are present. No Measures needed
58.6	Intersection with traffic lights, crossing road: Haarweg	Optimizing in favour of cyclists is preferable. However, this is hard because of the large amount of traffic flows coming together. Therefore, no time saving is expected
58.9	Intersection (for cars roundabout) without traffic lights, crossing road: exit of A12	Cyclists do not have priority at the moment. Change this into cyclists with priority

D.2.5 Route A12 – Leersum

Start: N226 58.9
End: N226 63.5
Length: 4.6 km
Detour factor: 1.07

Table 15, overview of measures between the A12 and Leersum

Location (kilometre of N226)	Type of intersection/problem	Measure
59.0	Intersection (for cars roundabout) without traffic lights, crossing road: entrance of A12	Cyclists do not have priority at the moment. Change this into cyclists with priority
60.6	Intersection without traffic lights, crossing road: Scherpenzeelseweg	Cyclists have priority and warning traffic signs are placed. No Measures are needed.
61.2	Intersection without traffic lights, crossing road: Valkenheide	Cyclists have priority and warning traffic signs are placed. No Measures are needed.
61.7	Access to parking area	Cyclists have priority, but there are no traffic signs and markings which tell this. These should be added.
63.5	Roundabout	Cyclists have priority. Turns are sharp, creating more space for turns is preferable, see figure 24

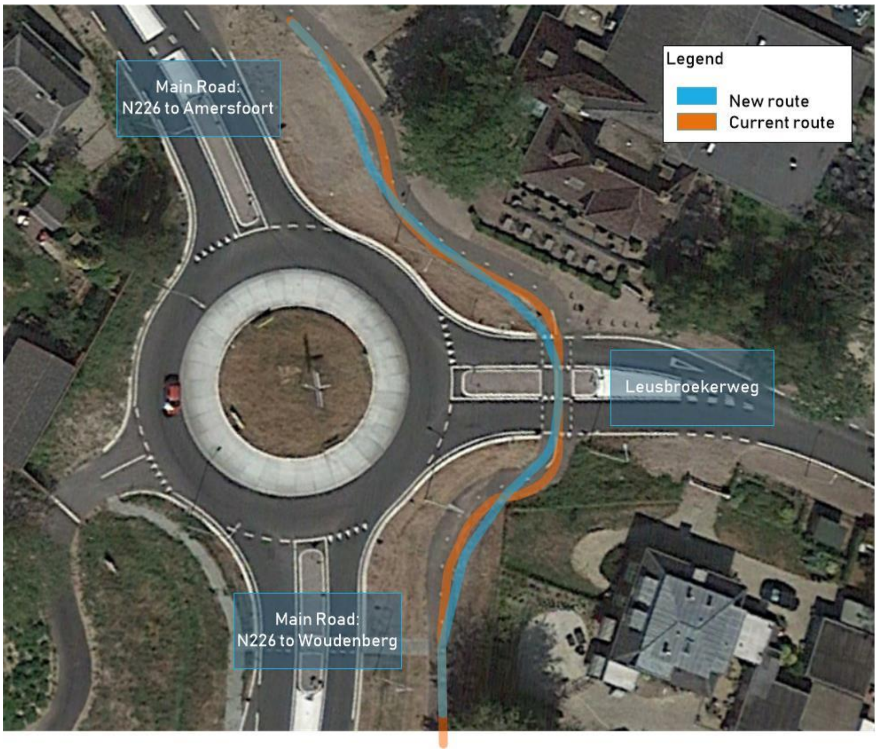

Figure 24, changed bicycle path

D.2.6 Route Leersum – Amerongen

Start: N225 25.3
End: N225 29.0
Length: 3.7 km
Detour factor: 1.03

The first 1.5 kilometre of this route is through Leersum. Here, a bicycle path at both sides of the main road (N225) is present. However, both paths are at most 2.00 meters wide and made out of street tiles. This has to be changed into asphalt. Widening the bicycle paths would be good, but there is no space available as long as other parts of the road are not removed. Because of this, the optimization of the bicycle paths in Leersum will be limited.

In Amerongen, the paths are as well at most 2.00 meters wide, but they are made out of asphalt. Widening the paths is not possible, unless trees are removed.

At the whole route, cyclists have already priority, which means that no Measures have to be taken to give cyclists priority.

D.3 Corridor North South

In contrast to the corridor between Utrecht and Amersfoort and the corridor between Amersfoort and Utrechtse Heuvelrug, this corridor consists of multiple connected parts which form a north south corridor. The full length from Vianen to Hilversum is 33 kilometres, which is too long for regular and electric bicycles. However, this route can be interesting for commuters who only want to use a part of the route, for example from IJsselstein to Utrecht South, or from Hilversum to Utrecht North. Those distances are, via this route, respectively 9.5 and 16 kilometres long.

D.3.1 Vianen – Nieuwegein South

Start: Vianen Lekbrug, Vianen
End: Geinbrug, Nieuwegein
Length: 3.9 km
Detour factor: 1.18

Within Vianen, the bicycle path does not have to be optimized as it matches the requirements already. All Measures are in Nieuwegein, therefore, only street names are used for the locations.

Table 16, overview of measures between Vianen and Nieuwegein South, part 1

Location (all in Nieuwegein)	Type of intersection/problem	Measure
Intersection Lekboulevard and Liesmonde,	Sharp turn	Create more spaces for cyclists
Waterbies,	Narrow bicycle path, no asphalt or concrete	Road should be broadened, and asphalt or concrete should be used for the road surface
Intersection Waterbies Zonnebloemstraat	Intersection without traffic lights	Cyclists have priority, traffic signs and signs at the road are present, no Measures needed
Zonnebloemstraat	Normal street, not optimized for cyclists	Transform into bicycle street
Intersection Zonnebloemstraat, Rietput	Crossing cyclists have priority, but a fluent connection between the bicycle corridors is needed.	
Intersection Geinoord, bicycle path	No priority for cyclists	Some road markings to let cars slow down are present, but markings and signs which tell that cyclists have priority have to be placed
Intersection Parkhout, Geinoord	Intersection without traffic lights. Cyclists have to cross the road followed by a turn to the left	Change into a roundabout with priority for cyclists.
Intersection Geinbrug, Doorslag/IJsselsteinseweg	Intersection without traffic lights. Cyclists to Vianen and (from) IJsselstein have to cross the road. See figure 25 (next page)	Change into a roundabout with priority for cyclists.

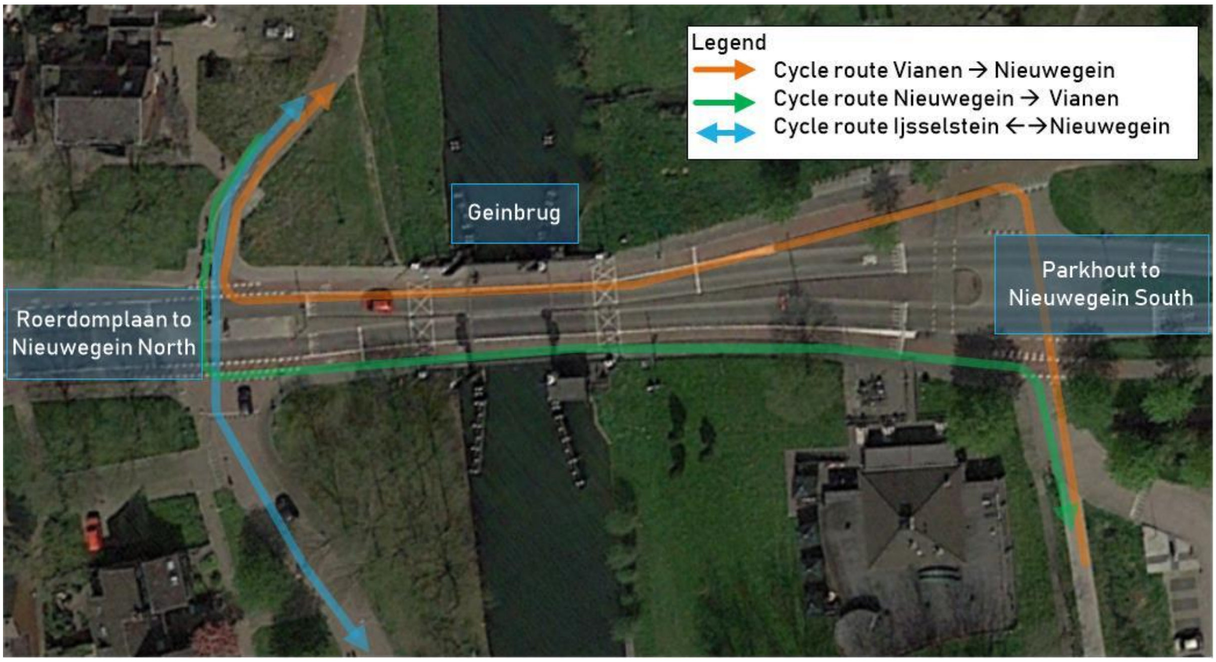

Figure 25, current bicycle flows around the Geinbrug

D.3.2 IJsselstein – Nieuwegein South

Start: Utrechtseweg, IJsselstein
End: Geinbrug, Nieuwegein
Length: 1.9 km
Detour factor: 1.3

Table 17, overview of measures between IJsselstein and Nieuwegein South

Location	Type of intersection/problem	Measure
Intersection with Utrechtseweg (IJsselstein)	Uneven intersection	No Measures needed
Intersection bicycle path, Herentalsstraat/Oude Utrechtseweg (IJsselstein)	Sharp turn for cyclists, no priority for cyclists.	Change intersection
Oude Utrechtseweg (Nieuwegein)	Road does not look like bicycle path	Use red asphalt
IJsselsteinseweg (Nieuwegein)	Road shared with cars	Clear bicycle lanes and markings present, no Measures needed
Intersection Geinbrug, Doorslag/IJsselsteinseweg	Intersection without traffic lights. Cyclists to Vianen and (from) IJsselstein have to cross the road.	Change into a roundabout with priority for cyclists.

D.3.3 Nieuwegein South – Nieuwegein North

Start: Geinbrug, Nieuwegein
End: Intersection Structuurbaan/Plettenburgerbaan, Nieuwegein
Length: 3.3 km
Detour factor: 1.1

Table 18, overview of measures between Nieuwegein South and Nieuwegein North

Location (all in Nieuwegein)	Type of intersection/problem	Measure
Intersection Noordstedeweg	Intersection without traffic lights and priority	Give cyclists priority instead of cars (in case of much car traffic: use traffic lights)
Herenstraat 108-75	Road shared with cars, many exits of houses and companies	Separate cars and cyclists or create bicycle street
Herenstraat 75 – Symfonielaan	Road shared with local car traffic	Transfer road into bicycle road (make use of colours of the road surface)
Intersection Symfonielaan, Utrechtseweg	Intersection with traffic lights, no clear route indication	Use clear route indicators and road marks, especially for traffic coming from the bridge.
Intersection Structuurbaan Newtonbaan	Intersection without traffic lights, bicycle corridor has to cross the road	Change current intersection into a roundabout

D.3.4 Nieuwegein North to Utrecht Lunetten (train station)

Start: Intersection Structuurbaan/Plettenburgerbaan, Nieuwegein
End: Utrecht Lunetten (train station)
Length: 5.0 km
Detour factor: 1.3

Table 19, overview of measures between Nieuwegein North and Utrecht Lunetten

Location (Utrecht unless otherwise stated)	Type of intersection/problem	Measure
Intersection bicycle path with Laagravenseweg (Nieuwegein)	Uneven intersection *A new part of this intersection will be even with traffic lights for cars and cyclists (Fietsersbond Nieuwegein, 2018)*	Tunnel is already present *Using a tunnel instead of the planned even intersection*
Intersection Ravensewetering and bicycle path	Intersection without traffic lights	Give cyclists priority
Intersection Furkabaan	Intersection without traffic lights	Give cyclists priority
Streets Goeree and Treek	Normal streets with speed bumps to reduce speed of cars	Transfer into bicycle street
Intersection Furkaplateau	Intersection without traffic lights	Give cyclists priority

D.3.5 Houten – Utrecht Lunetten (train station)

Start: Houten, Oud Wulfseweg (4)
End: Utrecht Lunetten (train station)
Length: 3.6 km
Detour factor: 1.2

This route is designed as bicycle connection between Houten and Utrecht. As a result of this, all intersections are already optimized in favour of cyclists. The road surface is less than 4 meters wide (3.90 meter, including a concrete strip of 0.3 meters at each side). Broadening the road surface is the only Measure which could be done to further optimize this connection.

D.3.6 Utrecht Lunetten (train station) – Utrecht Science Park

Start: Utrecht Lunetten (train station)
End: Utrecht Science Park western entrance, Weg van de Wetenschap
Length: 2.9 km
Detour factor: 1.16

After crossing the railroads to Houten and Bunnik, this part of the route follows the route of the Uithoflijn, a tram line which connects Utrecht Central Station with the Utrecht Science Park.

Table 20, overview of measures between Utrecht Lunetten and the Utrecht Science Park

Location (all in Utrecht)	Type of intersection/problem	Measure
Intersection Maarschalkerweerdpad, Koningsweg	Intersection with traffic lights	Optimize traffic lights in favour of cyclists.
Intersection Laan van Maarschalkerweerd, Mythylweg	Intersection with traffic lights	Optimize traffic lights in favour of cyclists.
Intersection Weg van de Wetenschap, Weg naar Rijnauwen	Intersection with traffic lights	Optimize traffic lights in favour of cyclists.
Intersection Weg van de Wetenschap, Sorbonnelaan	Intersection with traffic lights	Optimize traffic lights in favour of cyclists.

D.3.7 Utrecht Science Park

Start: Utrecht Science Park, western entrance, Weg van de Wetenschap
End: Utrecht Science Park, northern entrance, Upsalapad (near Tunnel)
Length: 1.8 km
Detour factor: 1.5

At the Utrecht Science Park, the only change will be the road surface into asphalt or concrete. At all intersections except for the crossing with the tram/bus line, cyclists have already priority.

Two routes are possible, via the Cambridgelaan or the path parallel to the tram/bus line. The second is more crowded than the first one, because of its position between educational institutes such as Utrecht University and the HU University of applied Sciences.

Due to the high amount of buildings, the detour factor is high. However, the route contains of only two straight streets.

D.3.8 Utrecht Science Park – De Bilt

Start: Utrecht Science Park, northern entrance, Upsalapad (near Tunnel)
End: De Bilt, intersection Dorpsstraat with Soestdijkseweg Zuid
Length: 1.7 km
Detour factor: 1.12

Table 21, overview of measures between the Utrecht Science Park and De Bilt

Location	Type of intersection/problem	Measure
Bicycle path between the Utrecht Science Park and de Bilt	4 sharp turns with limited sight	Increasing the turn radii, see figure 26
Intersection with N237	Tunnel is present, but narrow and socially unsafe	New tunnel is being build, no additional measures needed (Province Utrecht, 2019c).

Figure 26, at a few locations between the Utrecht Science Park and De Bilt, turns are too sharp at the moment and therefore changed

D.3.9 De Bilt – Hilversum

Start: De Bilt, intersection Dorpsstraat with Soestdijkseweg Zuid
End: Hilversum, intersection Utrechtseweg, Diependaalselaan
Length: 14.6 km
Detour factor: 1.23

Table 22, overview of measures between De Bilt and Hilversum, part 1

Location	Type of intersection/problem	Measure
Intersection Dorpsstraat Soestdijkseweg Zuid (De Bilt)	Intersection with traffic lights	Optimize intersection as planned by the Municipality De Bilt. (Gemeente de Bilt, 2019)
Intersection Soestdijkseweg Zuid, Groenekanseweg (De Bilt)	Roundabout, cyclists have priority	No Measures required
Dokter Letteplein (De Bilt)	Intersection with traffic lights	Optimize traffic lights in favour of cyclists.
Intersection Groenekansweg Biltse Rading	Roundabout, cyclists have priority	Turn for cyclists coming from De Bilt via the Groenekanseweg is too sharp
Groenekanseweg	Narrow and unclear bicycle lanes	Define clear bicycle lanes by using red asphalt
Intersection Groenekanseweg, N417	Intersection with traffic lights	Use red asphalt for cyclists Give cyclists the possibility to turn right without waiting for a red light
Intersection N417, N234 (Nieuwe Wetering)	Roundabout without priority for cyclists	Give cyclists priority
Intersection N417, Dorpsweg (Maartensdijk)	Roundabout, cyclists have priority	No Measures required
Intersection bicycle path, Tolakkerweg (2x)	Intersection without traffic lights, cyclists have priority	No Measures required
Intersection N417, Vuurse Dreef	Intersection with traffic lights	Optimize traffic lights in favour of cyclists.
Intersection Utrechtseweg Diependaalselaan (Hilversum)	Roundabout, cyclists have priority Bicycle paths are narrow	Broaden the bicycle paths

Appendix E: Description of model

The model calculates the percentage and number of commuters using a certain transport mode (bicycle, electric bicycle, car or public transport) for a total of 156 trips within the network. This appendix describes this model. A quick overview of the steps of the model:

1. Determine the disvalue of each trip for each transport mode, based on the distance, duration and several other parameters
2. Determine the distribution over the transport modes for all individual trips, using the disvalues and parameter μ
3. Determine the number of commuters travelling from one node to another, using data from Statistics Netherlands and individual municipalities
4. Determine the number of commuters travelling from one node to another for each transport mode, using data from steps 2 and 3.

E.1 Determine the disvalue per trip

The first step is to determine the disvalues for each transport mode for a trip. For each transport mode, it is explained how disvalues are calculated. Table 25 (page 64) gives an overview of all costs.

E.1.1 Bicycle

The disvalue per trip for bicycles is based on:

- Value of time €10.16/hour, which is the same as the disvalue for cars
- Reduction for health effects: €0.23/kilometre
- Reduction for higher level of comfort at optimized route: €2.74/hour
- Costs:
    - Non-electric bicycle: €0.10/kilometre
    - Electric bicycle: €0.24/kilometre
- Addition for effort: €0.25/kilometre

Value of time

The value of time of using a bicycle requires extra attention, as there is no standard value for this transport mode. This value is expected to lay in range between €9.80 and €24.85 /hour. This is a large range, and because no large research has been done, it is advised to use the value of cars which is €10.16 for commuters (Decisio, 2017). This has been done in this research.

For the disvalue per trip, the duration of that trip has to be known. The duration is the sum of the following aspects:

- Cycling within urban area with an average speed of 14.7 km/h (for (non-)electric) (Fietsersbond, 2019b).
- Cycling outside of urban areas at non-optimized bicycle path (SWOV, 2014):
    - 17.7 km/h for non-electric bicycles
    - 19.3 km/h for electric bicycles
- Cycling at optimized bicycle path (SWOV, 2014):
    - 19.6 km/h for non-electric bicycles
    - 23.3 km.h for electric bicycles
- Waiting time at intersections along the optimized route:
    - 30 seconds for intersection with non-optimized traffic lights
    - 10 seconds for intersection with optimized traffic lights
    - 10 seconds for intersection without traffic light and without priority

Health effects

Cycling to work improves the health of commuters, which leads to less diseases. Compared to non-cycling commuters, the cycling commuters are 1,3 days less ill. The benefit of this is €0.04/kilometre.

Diseases cost both the society and the ill commuter himself money (costs of visiting a doctor or hospital, required medicines). These are both €0.03/kilometre.

Last, cycling leads to a longer life, which can be estimated as €0.04/kilometre.

The values mentioned above will be subtracted from the value of time for cycling. However, these values are for a situation where only the infrastructure has been improved. If this is combined with stimulating commuters to cycle to improve their health, the values will increase strongly.

An evaluation of the bicycle highway network in Gelderland showed that around 36% of the cyclists cycled to improve their health. Another 26% cycled to improve the environment (Tibs, 2018). This shows that the values which are purely based on changes of the infrastructure might be too low, because health and the environment are a reason to cycle. Therefore, the values are increased with 30% of the difference between the value for health stimulating programs combined with infrastructure projects and the value of a pure optimization of the infrastructure. These values are rounded down to cents. This leads to a total reduction of €0.23/kilometre.

Table 23 gives an overview of the above-mentioned values.

Table 23, health effects of cycling

Values to reduce	Pure infrastructure **Cent/km**	Infrastructure and health program **Cent/km**	For this research **Cent/km**
Labour productivity	4	8	6 (exact 6.4)
Medical expenses commuter	3	5	4 (exact 4.5)
Medical expenses society	2-4 (average 3)	8-12 (average 10)	6
Lifespan	4-5 (average 4.5)	7-10 (average 8.5)	7 (exact 7.05)
Total			23

Costs of accidents have not been considered.

Environmental effects

Cyclists have a positive effect on the environment. Compared to cars and buses, the costs per kilometre of emissions are €1.50 lower and compared to trains €0.22 (Decisio, 2017). Research from Tibs (2018) has shown that commuters chose to cycle because of the environment. However, this is considered for this research as this is not a direct reduction in costs for the users themselves. Besides, it is unknown if environmental effects are compensated in the value of time for trains compared to the other transport modes. (For health effects, the reduction can be used because it is based on research comparing cycling commuters with non-cycling commuters).

Improved bicycle path

If a route is more comfortable, commuters are more willing to use this route. Research has shown that a cycle trip of 20 minutes on a normal bicycle route has the same value as cycling for 27.5 minutes at a more comfortable bicycle route. This has the factor 1.37, which means that the value of time for comfortable cycling routes can be divided by a factor 1.37 which leads to €7.42/hour (without health effects)

Overall Value of Time

The used value of time for bicycles is €10.16 x cycling time in hours – €0.23 x cycling distance. For comfortable parts, the value of time can be divided by 1.37 which leads to €7.42 - €0.23 x cycling distance

Costs

The costs of bicycles will be calculated below. The costs per bicycle are calculated by dividing the total amount of expenses for new (electric) bicycles by the amount of sold (electric) bicycles. This value is divided by the total distance for which the bicycle will be used. This is the distance per year[10] multiplied by the years of usage[11]. This gives the costs per kilometre.

For electric bicycles, the distances for which the bicycle is used are usual around 20% longer than for normal bikes. Because of this, the number of kilometres per person per year of non-electric bicycles has been multiplied by 1.2. The costs of both non-electric and electric bicycles are mentioned in table 24.

Speed-pedelecs are not mentioned in table 24, as for this bicycle type not enough data is available about the distances per year for which people use it and the average costs. A reason for this is that most data is from 2017, and the amount of pedelecs has started to increase strongly after 2017 (Statistics Netherlands, 2019b).

Table 24, costs of bicycles

Type	Cost per bicycle	Kilometres per person per year	Years usage	Costs per kilometre
Non-electric bike	€563.66	844	7	€0.10
Electric bike	€1948.91	1012	8	€0.24

Effort

Cycling is an active transport mode, which means that the longer a trip, the more effort is required. Because of this, cyclists do not want to cycle too long distances to their work. To simulate this effect, a value of €0.25 per kilometre is used (Goudappel Coffeng, 2018).

[10] The mentioned value is the average distance per person per year (Bovag-Rai, 2018), which is not the real distance per year per bicycle.
[11] This is based at the depreciation table of Unigarant (n.d.)

E.1.2 Car

Value of time

For cars, the value of time is €10.16/hour, according to the Ministry of Infrastructure and the Environment (2017b). For the disvalue of a trip, it is required to know the duration. This is determined with Google Maps (2019) for both the average and maximum duration, with an arrival time at 9:00 am at Thursday October 31st, which means that the trip is made during morning peak hours.

Discomfort due to congestion

For congestion, no extra factor will be used. Congestion leads to a longer trip duration and therefore to more costs. This means that the extra amount of discomfort due to congestion will be ignored, which means that the real value of a trip with congestion will be higher than stated in this report. The same counts for waiting times at intersections.

Costs

In this research, only commuters are considered. A part of these commuters leases their car which is expected to be a lot cheaper than driving a private car. For a small medium class private car, Nibud (2018) states the costs to be €0.52/kilometre including fuel. In this research an amount of €0.19/kilometre is used. This amount is the maximum travel compensation as stated by the Government of the Netherlands (2019). For private cars, the costs are assumed to be higher, but for lease cars they are expected to be lower.

Costs of effects on the environment and health, such as the emission of CO_2, NO_x and PM are not taken into consideration as separate value.

E.1.3 Public transport

For Public Transport, trips are determined using 9292.nl with an arrival time between 8:30 and 9:00 am. Normally, the travel advice arriving just before 9:00 am has been chosen, but there are situations where this travel advice is much longer than other possibilities to get from one place to another. Therefore, this time range has been chosen. Delays have not been considered.

Value of time

The value of time for public transport is divided into two groups, stated below (Ministry of Infrastructure and the Environment, 2017b):

- Bus, tram and metro: €8.51/hour
- Train: €12.63/hour

Costs

The costs of a trip will be determined using 9292.nl.

Delays

Delays are not considered.

Transfers

For the duration of a transfer, the hourly disvalue of the transport mode to which is changed is used. A transfer time of 5 minutes is considered to be good, as travellers have time to walk from the place of arrival to the place of departure, and do not have to wait a long time. For shorter or longer transfer times, a penalty is involved:

- Transfer duration = 5 minutes: no penalty
- Transfer duration < 5 minutes: transfer duration is raised to 5 minutes

- Transfer duration > 5 minutes: penalty of 0.5*(transfer duration – 5 minutes)

Transfers are not divided in walking and waiting time (G. Haarsma, 2012).

If another transport mode is needed to get to the station, or from the final public transport stop to the final destination, the value of time for the used transport mode will be used.

E.1.4 Walking

The Value of Time for walking is unknown by a lack of research. Therefore, it is advised to use the value of bicycles (Crow, 2018), which is €10.16 - €0.23 x walking distance. With a walking speed of 5 km/h, this results in a disvalue of €9.01/hour.

A value for effort is not included, as walking is only evaluated as part of a trip by public transport and distances are small.

E.1.5 Overview

Table 25, overview of all costs for all transport modes

Modality: Bike (non-electric) Aspect	 Disvalue in Euro
Duration of trip without delays	Normal road: €10.16 Comfortable: €7.42
Costs of bicycle	€0.10/kilometre
Health effect	€ -0.23 x distance
Effort	€0.25/kilometre
Modality: Bike (electric) Aspect	 Disvalue in Euro
Duration of trip without delays	Normal road: €10.16 Comfortable: €7.42
Costs of bicycle	€0.24 / kilometre
Health effect	€ -0.23 x distance
Effort	€0.25/kilometre
Modality: Car Aspect	 Disvalue in Euro
Duration of trip without delays	10.16 / hour
Costs of car	0.19 / kilometre
Congestion (delays)	Same disvalue as duration
Modality: Public transport Aspect	 Disvalue in Euro
Duration of trip without delays	Bus, tram, metro: 8.51 / hour Train: 12.63 / hour
Costs of trip	Determined via journey planner (9292)
Delays	Not considered
Trip to PT station	Depending on value of time for modality used to get to the station
Waiting	Part of duration of transfer
Transfer	5 minutes + 1.5 x total waiting time above 5 minutes

E.2 Estimating the distribution

E.2.1 Determination of μ

The parameter μ is a parameter for sensitivity to the disvalue. For a low μ (approaching 0), the distribution is uniform: almost all modes have the same number of users. The higher μ, the more travellers chose for the mode with the lowest disvalue.

To determine this factor, data from Statistics Netherlands (2018) has been used. This data gives the distribution over the transport modes for commuting. If only bicycles (electric and non-electric), cars (driver and passenger) and public transport (train, bus, tram, metro) are considered, this leads to the following distribution:

Table 26, number of trips and percentage per transport mode by commuters

Modality	Number of trips per person per year	Percentage
Car (driver and passenger)	93 (87+6)	62.4
Public Transport (train, [bus, tram, metro])	16 (10+6)	10.7
Bicycle	40	26.8
Total	149	100

For each transport mode, a μ has been determined which lets the percentage of that transport mode be similar with the value of the data of Statistics Netherlands. The differences with these real values are mentioned between brackets.

Table 27, μ's as chosen to approach one transport mode

μ chosen to approach	Value of μ	Percentage bicycle (difference)	Percentage car (difference)	Percent public transport (difference)
Bicycle	-0.255	26.8 (0)	58.2 (-4.2)	15.0 (+4.3)
Car	-0.292	24.0 (-2.8)	62.4 (0)	13.6 (+2.9)
Public Transport	-0.377	18.7 (-8.1)	70.6 (+8.2)	10.7 (0)

Based on these three values, two μ's are determined.

- The average of the three values: $\frac{\mu_{bicycle}+\mu_{car}+\mu_{public\ transport}}{3}$
- The weighted average: $\frac{\mu_{bicycle}*p_{bicycle}+\mu_{car}*p_{car}+\mu_{public\ transport}*p_{public\ transport}}{100}$ where p is the percentage of a transport mode

The percentages within the model for each transport mode for both μ's are stated in the table below. The differences with the real values are mentioned between brackets.

Table 28, average μ and weighted average μ

	Value of μ	Percentage bicycle (difference)	Percentage car (difference)	Percent public transport (difference)
For average μ	-0.308	22.9 (-3.9)	64.1 (+1.7)	13.0 (+2.3)
For weighted average μ	-0.291	24.1 (-2.7)	62.3 (-0.1)	13.6 (+2.8)

The weighted average corresponds the best with the real data and is therefore chosen. This means that the number of cyclists can be an underestimation and the number of public transport users an overestimation in the model,

E.2.2 Calculating the distribution

The distribution is calculated using the following formula (TU Delft, 2017): $p_{ijm} = \frac{e^{\mu * V_{ijm}}}{\sum_{m=1}^{4} e^{\mu * V_{ijm}}}$

An overview of the terms in this formula:

- P_{ijm}: Percentage of commuters using transport mode m between locations i and j
- V_{ijm}: Disvalue of transport mode m for a trip between i and j
- μ: -0.291, parameter for sensitivity of commuters to the disvalue.

E.3 Determine number of commuters per trip

Statistics Netherlands (2019a) provides data about the number of persons who live in municipality i and work in municipality j. This data forms the basis of this part of the model. However, some municipalities have been split up, as explained in chapter 1.5.2. The calculation for these municipalities is explained below

In case of trips from a part p of municipality i to municipality j, the number of trips is calculated as follows: $percentage\ inhabitants_p * [\, trips\ from\ i\ to\ j]$

In case of trips to a part p of municipality i from municipality j, the number of trips is calculated as follows: $percentage\ jobs_i * [\, trips\ from\ j\ to\ i]$

E.3.1 Amersfoort

The municipality of Amersfoort provides data about the number of inhabitants and jobs in each neighbourhood in the city. Based on this, the percentage of inhabitants and jobs in each neighbourhood is calculated. A summation of the percentages of the neighbourhoods for each part of Amersfoort within this research (North, Middle, South) gives the percentage of inhabitants and jobs within those parts (Gemeente Amersfoort, 2019). The values are mentioned in table 29.

Table 29, used parts of Amersfoort with their number and percentage of inhabitants and jobs

Part of Amersfoort	Number inhabitants	Percentage inhabitants	Number jobs	Percentage jobs
Amersfoort North	70.630	45.49	19.350	29.84
Amersfoort South	45.482	29.10	28.695	44.24
Amersfoort South	40.163	25.71	16.810	25.92
Total	156.285	100	64.855	100

E.3.2 De Bilt

Statistics Netherlands (2017) provides data about the number of inhabitants per district. The number of jobs per district of De Bilt is unknown. Therefore, the percentage of jobs per district is assumed to be the same as the percentage of inhabitants of the same district. The values are mentioned in table 30.

Some districts of De Bilt with a small number of inhabitants are not used in the research.

Table 30, used parts of De Bilt with the number and percentages of inhabitants

Part of De Bilt	Number inhabitants	Percentage inhabitants	Number jobs	Percentage jobs
De Bilt	15.425	40.24	Unknown	40.24
Bilthoven	17.725	46.24	Unknown	46.24
Maartensdijk	5.180	13.51	Unknown	13.51
Total	38.330	100		100

E.3.3 Nieuwegein

The municipality of Nieuwegein provides data about the number of inhabitants per district. The number of jobs per district of Nieuwegein is unknown. Therefore, the percentage of jobs per district is assumed to be the same as the percentage of inhabitants of the same district (Gemeente Nieuwegein, 2019). The values are mentioned in table 31.

Table 31, used parts of Nieuwegein with the numbers and percentages of inhabitants

Part of Nieuwegein	Number inhabitants	Percentage inhabitants	Number jobs	Percentage jobs
Nieuwegein North	35.993	57.10	Unknown	57.10
Nieuwegein South	27.065	42.92	Unknown	42.92
Total	63.058	~100		~100

E.3.4 Utrecht

The municipality of Utrecht provides data about the number of inhabitants and jobs per district. The total number and percentage per district of Utrecht within the research is visible in the table below (Gemeente Utrecht, 2019). Table 32 gives an overview of these values.

Table 32, used pats of Utrecht with the numbers and percentages of inhabitants and jobs

Part of Utrecht	Number inhabitants	Percentage inhabitants	Number jobs	Percentage jobs
Utrecht East	90.800	25.73	124.517	47.68
Utrecht North	78.872	22.35	23.679	9.07
Utrecht South	66.200	18.76	34.918	13.37
Utrecht West	117.069	33.17	78.051	29.89
Total	352.941	~100	261.165	~100

E.3.5 Utrechtse Heuvelrug

Statistics Netherlands (2017) provides data about the number of inhabitants per district. The number of jobs per district of Utrechtse Heuvelrug is unknown. Therefore, the percentage of jobs per district is assumed to be the same as the percentage of inhabitants of the same district. Table 33 gives an overview of these values.

Table 33, used parts of the Utrechtse Heuvelrug with the numbers and percentages of inhabitants.

Part of Utrechtse Heuvelrug	Number inhabitants	Percentage inhabitants	Number jobs	Percentage jobs
Amerongen	6.930	14.13	Unknown	14.13
Leersum	7.515	15.32	Unknown	15.32
Driebergen-Rijsenburg	18.645	38.02	Unknown	38.02
Maarsbergen and Maarn	5.890	12.01	Unknown	12.01
Total	38.890	79.48		79.48

E.4 Determine the number of commuters per trip per transport mode

This is calculated by multiplying the percentage of commuters using a certain transport mode for a certain trip with the number of commuters who make that trip.

$$c_{ijm} = p_{ijm} * c_{ij}$$

An overview of the terms in this formula is given in table 34.

Table 34, terms in formula gravity model

Term	Explanation	Resource of data for term
c_{ijm}	Number of trips by commuters between i and j with transport mode m	Calculated
p_{ijm}	Percentage of trips between i and j with transport mode m	Logit model
c_{ij}	Number of trips by commuters between i and j	Statistics Netherlands (2019a)

Appendix F: List of evaluated trips

Start	End
Amerongen	Amersfoort North
Amerongen	Amersfoort Middle
Amerongen	Amersfoort South
Amerongen	Leusden
Amerongen	Maarsbergen
Amerongen	Woudenberg
Amersfoort Middle	Amerongen
Amersfoort Middle	Bunnik
Amersfoort Middle	De Bilt
Amersfoort Middle	Leersum
Amersfoort Middle	Maarsbergen
Amersfoort Middle	Utrecht North
Amersfoort Middle	Utrecht East
Amersfoort Middle	Utrecht South
Amersfoort Middle	Woudenberg
Amersfoort Middle	Zeist
Amersfoort North	Amerongen
Amersfoort North	Bunnik
Amersfoort North	De Bilt
Amersfoort North	Leersum
Amersfoort North	Maarsbergen
Amersfoort North	Utrecht East
Amersfoort North	Utrecht South
Amersfoort South	Amerongen
Amersfoort South	Bunnik
Amersfoort South	De Bilt
Amersfoort South	Bilthoven
Amersfoort South	Houten
Amersfoort South	Leersum
Amersfoort South	Maarsbergen
Amersfoort South	Nieuwegein North
Amersfoort South	Utrecht North
Amersfoort South	Utrecht East
Amersfoort South	Utrecht South
Amersfoort South	Woudenberg
Amersfoort South	Zeist
Bilthoven	Amersfoort South
Bilthoven	Houten
Bilthoven	Ijsselstein
Bilthoven	Nieuwegein North
Bilthoven	Nieuwegein South
Bilthoven	Vianen
Bunnik	Amersfoort North
Bunnik	Amersfoort Middle

Start	End
Bunnik	Amersfoort South
Bunnik	Hilversum
Bunnik	Ijsselstein
Bunnik	Maartensdijk
Bunnik	Vianen
De Bilt	Amersfoort North
De Bilt	Amersfoort Middle
De Bilt	Amersfoort South
De Bilt	Hilversum
De Bilt	Houten
De Bilt	Ijsselstein
De Bilt	Leusden
De Bilt	Nieuwegein North
De Bilt	Nieuwegein South
De Bilt	Utrecht East
De Bilt	Vianen
Driebergen	Hilversum
Hilversum	Bunnik
Hilversum	De Bilt
Hilversum	Driebergen
Hilversum	Houten
Hilversum	Houten long
Hilversum	Maartensdijk
Hilversum	Utrecht North
Hilversum	Utrecht East
Hilversum	Zeist
Houten	Amersfoort South
Houten	De Bilt
Houten	Bilthoven
Houten	Hilversum
Houten	Hilversum long
Houten	Ijsselstein
Houten	Maartensdijk
Houten	Utrecht East
Houten	Vianen
Ijsselstein	Bunnik
Ijsselstein	De Bilt
Ijsselstein	Bilthoven
Ijsselstein	Houten
Ijsselstein	Utrecht South
Ijsselstein	Zeist
Leersum	Amersfoort North
Leersum	Amersfoort Middle
Leersum	Amersfoort South

Start	End
Leersum	Leusden
Leersum	Maarsbergen
Leusden	Amerongen
Leusden	De Bilt
Leusden	Leersum
Leusden	Maarsbergen
Leusden	Utrecht East
Leusden	Utrecht South
Leusden	Wijk bij Duurstede
Leusden	Zeist
Maarsbergen	Amerongen
Maarsbergen	Amersfoort North
Maarsbergen	Amersfoort Middle
Maarsbergen	Amersfoort South
Maarsbergen	Leersum
Maarsbergen	Leusden
Maarsbergen	Woudenberg
Maartensdijk	Bunnik
Maartensdijk	Hilversum
Maartensdijk	Houten
Maartensdijk	Utrecht North
Maartensdijk	Utrecht East
Maartensdijk	Zeist
Nieuwegein North	Amersfoort South
Nieuwegein North	De Bilt
Nieuwegein North	Bilthoven
Nieuwegein North	Vianen
Nieuwegein South	De Bilt
Nieuwegein South	Bilthoven
Utrecht East	Amersfoort North
Utrecht East	Amersfoort Middle
Utrecht East	Amersfoort South
Utrecht East	De Bilt
Utrecht East	Hilversum
Utrecht East	Houten

Start	End
Utrecht East	Leusden
Utrecht East	Maartensdijk
Utrecht East	Vianen
Utrecht North	Amersfoort Middle
Utrecht North	Amersfoort South
Utrecht North	Hilversum
Utrecht North	Maartensdijk
Utrecht South	Amersfoort North
Utrecht South	Amersfoort Middle
Utrecht South	Amersfoort South
Utrecht South	Ijsselstein
Utrecht South	Leusden
Utrecht South	Vianen
Vianen	Bunnik
Vianen	De Bilt
Vianen	Bilthoven
Vianen	Houten
Vianen	Nieuwegein North
Vianen	Utrecht East
Vianen	Utrecht South
Vianen	Zeist
Wijk bij Duurstede	Leusden
Woudenberg	Amerongen
Woudenberg	Amersfoort Middle
Woudenberg	Amersfoort South
Woudenberg	Maarsbergen
Zeist	Amersfoort Middle
Zeist	Amersfoort South
Zeist	Hilversum
Zeist	Ijsselstein
Zeist	Leusden
Zeist	Maartensdijk
Zeist	Vianen

Appendix G: List of street names and trips

In the table below, the used addresses to plan the trips are mentioned. These locations are near the centre of every node and can therefore represent a trip from one node to another.

These addresses have been chosen instead for good accessible locations such as train stations, as that would strongly influence the trip length of trips by public transport as travellers do not have to go to a station anymore.

Node	Address
Amerongen	Koenestraat 1
Amersfoort North	Tonnekreek 40
Amersfoort Middle	Paladijnenweg 253
Amersfoort South	Arnhemseweg 90
Bunnik	Dorpsstraat 47
De Bilt	Hessenweg 119
Bilthoven	Emmaplein 11
Driebergen	Traaij 8
Hilversum	Emmastraat 2
Houten	Stationserf 95
Ijsselstein	Utrechtsestraat 67
Leersum	Rijksstraatweg 108
Leusden	De Biezenkamp 8
Maarsbergen	Haarweg 28
Maartensdijk	Maertensplein 31
Nieuwegein North	Hermesburg 55
Nieuwegein South	Hattemerschans 10
Utrecht North	Andesdreef 14
Utrecht East	Prins Hendriklaan 1
Utrecht South	Reggestraat 50
Vianen	Voorstraat 70
Wijk bij Duurstede	Karolingersweg 167
Woudenberg	Dorpsstraat 27
Zeist	Emmaplein 2

Appendix H: Results of model

This appendix shows the results of the model to compare different situations.

H.1 Comparison current and new situation with average duration for cars

H.1.1 Distribution and number of commuters using each transport mode

	Distribution, current				Numbers, current				Distribution, new				Numbers, new			
Utrecht-Amersfoort	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT
N412	0.1	0.05	0.73	0.12	1146	620	8627	1457	0.19	0.11	0.6	0.1	2272	1267	7112	1202
Vollenhoven	0.1	0.05	0.72	0.13	1195	649	8791	1533	0.19	0.11	0.6	0.1	2350	1316	7244	1263
Stichtse Rotonde	0.1	0.06	0.72	0.13	1474	811	10497	1853	0.19	0.11	0.6	0.11	2798	1583	8720	1539
Average	0.1	0.05	0.72	0.13					0.19	0.11	0.6	0.1				
Amersfoort-Leersum																
A28	0.17	0.11	0.56	0.16	269	174	897	262	0.24	0.16	0.46	0.14	388	260	732	218
N224	0.17	0.11	0.62	0.11	213	134	780	141	0.25	0.16	0.5	0.09	314	202	628	119
N226	0.18	0.12	0.62	0.08	225	147	793	105	0.26	0.17	0.51	0.07	325	212	642	86
Average	0.17	0.11	0.6	0.12					0.25	0.16	0.49	0.1				
North-South																
N408 bridge	0.14	0.09	0.59	0.18	581	361	2464	736	0.23	0.15	0.48	0.15	939	610	1995	603
Lunetten, station	0.17	0.11	0.6	0.12	1434	965	5127	1029	0.24	0.16	0.5	0.1	2058	1388	4251	857
USP	0.11	0.07	0.69	0.13	475	284	2932	567	0.2	0.12	0.57	0.11	848	520	2424	468
N417	0.13	0.08	0.67	0.13	1119	651	5643	1069	0.22	0.13	0.54	0.1	1882	1136	4586	876
N234	0.14	0.08	0.64	0.13	1029	608	4673	951	0.23	0.14	0.52	0.11	1677	1030	3774	778
Vuurse Dreef	0.13	0.08	0.66	0.13	864	495	4240	835	0.23	0.14	0.53	0.11	1465	882	3408	678
Average	0.14	0.09	0.64	0.13					0.23	0.14	0.52	0.11				

H.1.2 Differences in distribution and number of commuters using each transport mode

	Change in distribution				Change in numbers			
Utrecht-Amersfoort	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT
N412	0.09	0.06	-0.13	-0.02	1126	647	-1515	-255
Vollenhoven	0.09	0.06	-0.12	-0.03	1155	667	-1547	-270
Stichtse Rotonde	0.09	0.05	-0.12	-0.02	1324	772	-1777	-314
Average	0.09	0.056667	-0.12333	-0.02333	1201.667	695.3333	-1613	-279.667
Amersfoort-Leersum	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT
A28	0.07	0.05	-0.1	-0.02	119	86	-165	-44
N224	0.08	0.05	-0.12	-0.02	101	68	-152	-22
N226	0.08	0.05	-0.11	-0.01	100	65	-151	-19
Average	0.076667	0.05	-0.11	-0.01667	106.6667	73	-156	-28.3333
North-South	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT
N408 bridge	0.09	0.06	-0.11	-0.03	358	249	-469	-133
Lunetten, station	0.07	0.05	-0.1	-0.02	624	423	-876	-172
USP	0.09	0.05	-0.12	-0.02	373	236	-508	-99
N417	0.09	0.05	-0.13	-0.03	763	485	-1057	-193
N234	0.09	0.06	-0.12	-0.02	648	422	-899	-173
Vuurse Dreef	0.1	0.06	-0.13	-0.02	601	387	-832	-157
Average	0.088333	0.055	-0.11833	-0.02333	561.1667	367	-773.5	-154.5

H.2 Comparison current situation with maximum duration for cars with new situation with average duration for cars

H.2.1 Distribution and number of commuters using each transport mode

	Distribution, current				Numbers, current				Distribution, new				Numbers, new			
Utrecht-Amersfoort	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT
N412	0.12	0.07	0.65	0.16	1477	789	7684	1909	0.19	0.11	0.6	0.1	2272	1267	7112	1202
Vollenhoven	0.13	0.07	0.64	0.16	1536	823	7820	1999	0.19	0.11	0.6	0.1	2350	1316	7244	1263
Stichtse Rotonde	0.13	0.07	0.64	0.16	1866	1012	9370	2396	0.19	0.11	0.6	0.11	2798	1583	8720	1539
Average	0.13	0.07	0.64	0.16					0.19	0.11	0.6	0.1				
Amersfoort-Leersum	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT
A28	0.2	0.13	0.48	0.19	316	205	773	304	0.24	0.16	0.46	0.14	388	260	732	218
N224	0.2	0.13	0.53	0.14	258	161	671	175	0.25	0.16	0.5	0.09	314	202	628	119
N226	0.21	0.13	0.55	0.1	268	171	697	133	0.26	0.17	0.51	0.07	325	212	642	86
Average	0.2	0.13	0.52	0.15					0.25	0.16	0.49	0.1				
North-South	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT
N408 bridge	0.16	0.1	0.54	0.2	668	411	2219	846	0.23	0.15	0.48	0.15	939	610	1995	603
Lunetten, station	0.19	0.13	0.53	0.15	1642	1097	4559	1256	0.24	0.16	0.5	0.1	2058	1388	4251	857
USP	0.13	0.08	0.62	0.17	575	340	2623	725	0.2	0.12	0.57	0.11	848	520	2424	468
N417	0.17	0.1	0.58	0.16	1405	817	4905	1354	0.22	0.13	0.54	0.1	1882	1136	4586	876
N234	0.18	0.1	0.55	0.16	1285	759	4022	1195	0.23	0.14	0.52	0.11	1677	1030	3774	778
Vuurse Dreef	0.17	0.1	0.57	0.16	1094	627	3657	1059	0.23	0.14	0.53	0.11	1465	882	3408	678
Average	0.17	0.1	0.56	0.16					0.23	0.14	0.52	0.11				

H.2.2 Differences in distribution and number of commuters using each transport mode

	Change in distribution				Change in numbers			
Utrecht-Amersfoort	Bike	Ebike	Car	PT	Bike	Ebike	Car	PT
N412	0.07	0.04	-0.05	-0.06	795	478	-572	-707
Vollenhoven	0.06	0.04	-0.04	-0.06	814	493	-576	-736
Stichtse Rotonde	0.06	0.04	-0.04	-0.05	932	571	-650	-857
Average	0.063333	0.04	-0.04333	-0.05667				
Amersfoort-Leersum								
A28	0.04	0.03	-0.02	-0.05	72	55	-41	-86
N224	0.05	0.03	-0.03	-0.05	56	41	-43	-56
N226	0.05	0.04	-0.04	-0.03	57	41	-55	-47
Average	0.046667	0.033333	-0.03	-0.04333				
North-South								
N408 bridge	0.07	0.05	-0.06	-0.05	271	199	-224	-243
Lunetten, station	0.05	0.03	-0.03	-0.05	416	291	-308	-399
USP	0.07	0.04	-0.05	-0.06	273	180	-199	-257
N417	0.05	0.03	-0.04	-0.06	477	319	-319	-478
N234	0.05	0.04	-0.03	-0.05	392	271	-248	-417
Vuurse Dreef	0.06	0.04	-0.04	-0.05	371	255	-249	-381
Average	0.058333	0.038333	-0.04167	-0.05333				