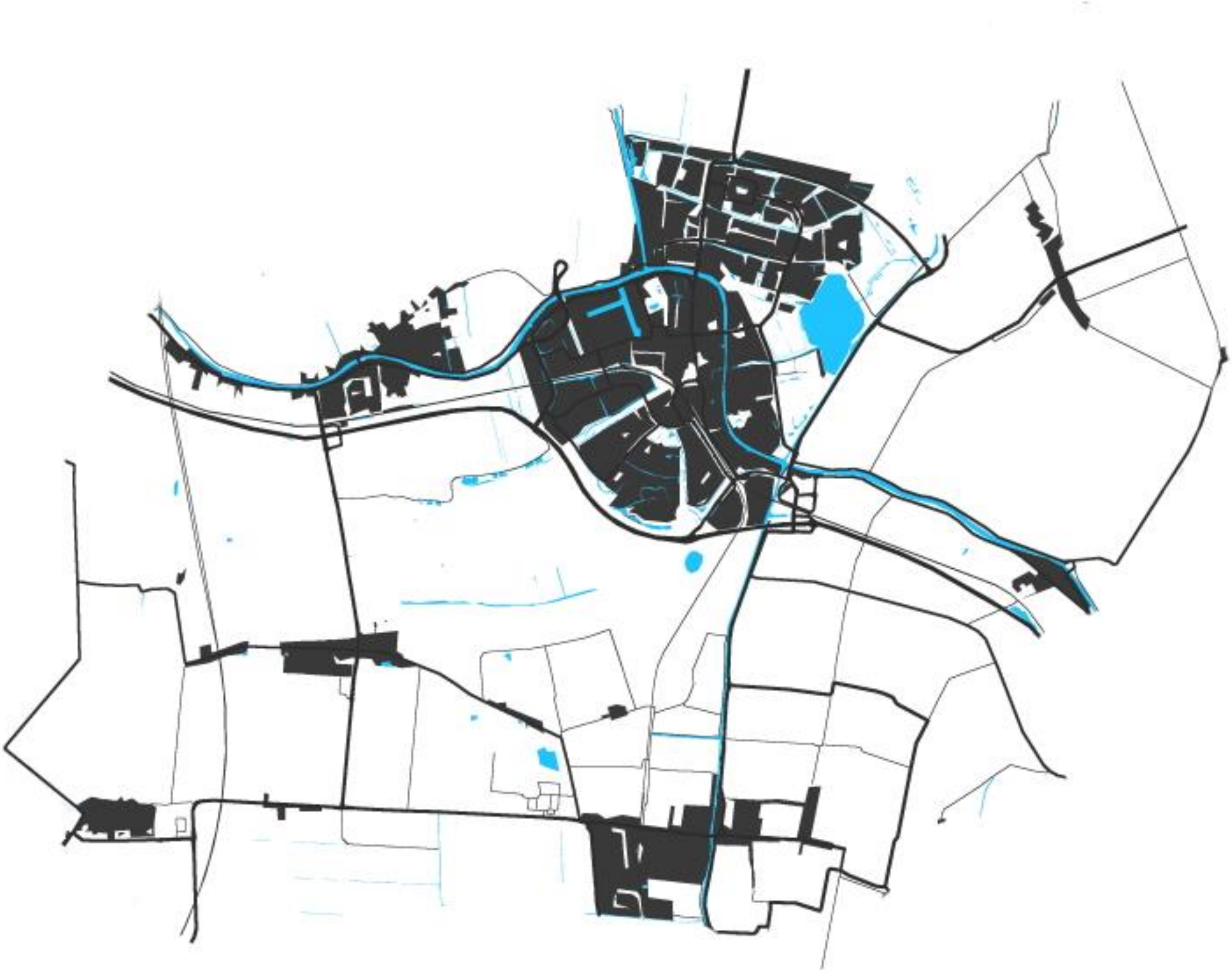
R. Krutzen

Safe cycling network for the municipality of Alphen aan den Rijn

Developing a 3-level cycling network suitable for all cyclists.



Monday, 18 October 2021

TU Delft

Safe cycling network for the municipality of Alphen aan den Rijn

Developing a 3-level cycling network suitable for all cyclists

By

R. Krutzen

Monday, 18 October 2021

In partial fulfilment of the requirements for the degree of

Bachelor of Science
In Civil Engineering

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Supervisors: Dr. Ir. A. Gavriilidou
Dr. Ir. Y. Yuan

Cover image: Map of the municipality of Alphen aan den Rijn (Google Maps, 2021)

Preface

This bachelor thesis is the last component to complete the bachelor's degree in civil engineering at Delft University of Technology. The focus of this report is within the department transport and planning. The assignment arose from the vision of the cyclists' union that was drawn up in 2019. It proposes to design a network of 3 levels for a municipality of your choice. The designed network must be suitable for all cyclists, without major diversions for vulnerable cyclists. In this report, the network is designed for the municipality of Alphen aan den Rijn. Alphen aan den Rijn was chosen here because of its rapidly growing size, in terms of number of inhabitants but also in surface area. This gives the opportunity to look at the network within smaller villages and the connection between them. In addition, Alphen aan den Rijn is the city in which I grew up, which makes this a fairly well-known area for me, although I have learned many new things about Alphen aan den Rijn during this research.

If someone is interested in carrying out this assignment for another municipality, they can find information about the methodology in chapter 2. This report also contains information about Alphen aan den Rijn and the stakeholders in this project, which can be found in chapter 3. Chapter 4 discusses the classification of network levels, followed by network design evaluation and solutions in chapter 5. Finally, readers interested in evaluating different network solutions may find this in chapter 6.

I would like to thank my supervisors, dr. Ir. A. Gavriilidou and dr. Ir. Y. Yuan, and fellow students who provided me with feedback and support where necessary during this research.

R. Krutzen

Delft, October 2021

Summary

This bachelor thesis focuses on creating a safe cycling network for the municipality of Alphen aan den Rijn. The cyclists' union has drawn up a vision for 2040 in which irritations and conflicts, due to an increase in bicycle traffic and bicycle types in the same network, are reduced. In this vision, a three-level separate network has been created. This vision has been drawn up for the whole of the Netherlands but report only focuses on designing the bicycle network for the municipality of Alphen aan den Rijn.

This leads to the main question*: “Which bicycle network design should be implemented for the municipality of Alphen aan den Rijn in order to comply with the vision of the Cyclists’ Union for the year 2040?”*. The answer is found based on a literature study supported by five analyses: a historical-morphological-, stakeholder-, MoSCoW-, site-, and a multicriteria analysis.

The historical morphological analysis shows that the future boundaries of the municipality of Alphen aan den Rijn will not deviate from the current ones. The stakeholder analysis provides the stakeholder with the highest priority, which is the municipality of Alphen aan den Rijn.

For the village of Koudekerk aan den Rijn, sub-area of the municipality of Alphen aan den Rijn, the current network is evaluated and redesigned. A distinction is made between three network levels: 1. the vulnerable cyclist, 2. the skilled cyclist, and 3. the fast cyclist. The distribution over the three levels is based on vehicle type and age with a sidenote: when cyclist comply to the rules of a certain network level, they may use it. The current network appears to fulfil all requirements for the main network (level 2), but adjustments are needed to meet the requirements for level 1 and level 3.

Three designs have been made for network level 1 and 3: The serpent, The branch, The split, The worm, The tripod and The extension respectively. The six designs are evaluated by a multicriteria analysis, based on five design criteria: cohesion, directness, safety, usability, and cost. The analysis results in a highest score for The serpent for level 1 and The tripod for level 3. This yield that The serpent and The tripod should be implemented for the village of Koudekerk aan den Rijn to comply with the vision of the cyclist union for 2040.

For a complete answer to the main questions the other subareas should be worked out. Other recommendations for future work are the elaboration of a three-level network for other municipalities in the Netherlands or an elaboration of the enforcement of a three-level bicycle network.

Contents

1. Introduction

This chapter introduces the design issue addressed in this report. It states the problem that arises within the design area, the questions answered throughout the report and the parties involved with the project. Finally, the general structure of the report is described.

1.1 Problem description

Since 2015 there have been complaints about an increase in bicycle traffic and an increase in the diversity of bicycle types all over the Netherlands (Ministerie van Infrastructuur en Milieu, 2015). The Dutch start cycling at an early age, when a child can walk, it is already good to put it on a balance bike (ANWB, 2021). With this bike and at such a young age, the child is not yet participating in traffic. The ANWB advises that a child on a bicycle only participate in traffic from the age of four (ANWB, 2021), although research shows that there is a greater risk of bicycle-related injuries within the first two years of cycling when a child starts cycling at 4 to 5 years old instead of 6 to 7 years old (K. Schrøder Hansen, 2005). Therefore, all age groups from six years and older are considered desirable to be present on the bicycle roads. In addition, there is the great diversity in the type of vehicle used, such as the cargo bike, a tricycle, or the electric bicycle. When the e-bike was introduced, it was mainly used by the elderly. It is still popular among the elderly, but nowadays the e-bike is also becoming an interesting mode of transport for the younger generation, as a means of transport to work (de Haas, 2021). The groups, with difference in age, type of vehicle and thus speed, all use the same network at the moment. This leads to irritations and conflicts arising within the same network (Ministerie van Infrastructuur en Milieu, 2015), whereby children (9-12 years) and the elderly (65+ years) form the most vulnerable group (L. Zeuwts, 2016). These conflicts and irritations within the network are in addition to current conflicts involving other means of transport.

The diverse user group is what the Fietsersbond calls the 'Bicycle family'. The Fietsersbond is the Cyclists' Union in the Netherlands, who are currently striving to increase 'cycling happiness' in the Netherlands. Cycling happiness encompasses the fast, safe, and comfortable feeling of users in the cycling network. To increase this cycling happiness the arising irritations and conflicts should be reduced. For this the cyclist's union has written a vision for 2040 in which the vulnerable users mentioned above are given priority. For them, a separate network should be designed with a lower permitted speed and more safety requirements. But it doesn't stop there because the fast cyclists are also separated from the main network. This results in a three-level separated network of bicycle roads. Where the first level is considered for the vulnerable cyclist, the second level is suitable for the skilled cyclist and the last level is suitable for the fast cyclists (Fietsersbond, 2021). The cyclists' union sees this as a vision applicable to the whole of the Netherlands, but the designs are not all there yet. Therefore, this report focuses on designing a three-level bicycle network for the municipality of Alphen aan den Rijn.

1.2 Research question

This report deals with the question*: "Which bicycle network design should be implemented for the municipality of Alphen aan den Rijn in order to comply with the vision of the Cyclists' Union for the year 2040?"* To answer this question, a literature- and data analysis study is performed. This study explicitly and only looks at the bicycle network within the municipality of Alphen aan den Rijn. The local residents of the municipality of Alphen aan den Rijn who cycle are seen as the main users of this network.

The following sub-questions have been formulated to be able to answer the main question, these are divided into four topics that follow the structure of the report:

Topic: Municipality of Alphen aan den Rijn in the past, present, and future

1. How far does the area that belongs to the municipality of Alphen aan den Rijn extend?
2. What growth is expected within the municipality of Alphen aan den Rijn?
3. Where is the current bicycle network situated?
4. Who are involved with the design of the new bicycle network?

Topic: Classification of the different levels and their needs

5. Which division of the local cyclists over the three network levels is considered?
6. What are the requirements and wishes per network level?

Topic: Evaluation of the current network

7. To what extend does the current network meet the requirements set by the users of each network level?

Topic: Developing a new design

8. What are possible adaptations to the current network to meet the set criteria?
9. To which design criteria should these network adaptations be evaluated?

The first sub-question provides insight into the boundaries of the area in which the network described in the main question must be designed. The second sub-question will provide insight into where additional bicycle paths may have to be added through expected new neighbourhoods in the municipality. The current location of the cycle paths is described in sub-question three. For the current situation, it must first be analysed whether it is not already the desired network described in the main question. But before it is possible to carry out this analysis, it must be clear based on which requirements it should be evaluated. This follows from: which parties are involved and their influence in the requirements and wishes. A stakeholder analysis is carried out in sub-question four, to provide these insights. The local cycling residents are seen as one stakeholder in this analysis, but they must be divided over the three network levels since they have their own requirements and wishes per category, which is done in sub-questions five and six. The current network is the evaluated on these requirements. For areas that do not comply, possible adjustments must be designed. Each adjustment must meet the requirements mentioned above, so that it meets the vision of the cyclists' union. These adaptations should be evaluated by design criteria, which are ranked through the priority given by the stakeholder analysis. For the evaluation, a multi-criteria analysis is performed, which results in the most suitable solution with the most important stakeholders taken into account. The parts of the current network that meet the requirements and the most suitable adjustments in the network that follow from the multi-criteria analysis together form the answer to the main question.

1.3 Stakeholders

There are many stakeholders involved in this project who either have a say in what the network design should look like, build the road, or make use of it. These stakeholders are ANWB, BOVAG, Fietsersbond, GGD, RAI, SWOV, VVN, the local police, the local residents, the government, and the municipality of Alphen aan den Rijn. As mentioned above, this report analyses these stakeholders to see which parties should be more or less taken into account in the design. The method for this is described in section 2.3 and the implementation thereof in section 3.3.

1.4 Reading guide

These sub questions have been converted into topics that are covered in the report. The methods for finding the answers are discussed in the next chapter. Starting the research, it is important to first look at where the boundaries of the municipality of Alphen aan de Rijn are located, what further growth is expected within these lines and what the current network looks like (chapter 3). Hereafter it is desirable to look at the parties that are involved. It is examined what the division of the local cyclist into the network levels is. Simultaneously, it is useful to look at the requirements and wishes that apply to each level (chapter 4). By comparing the requirements and wishes with the current network, it is possible to see where the adjustments in the network are required. This allows for a design adaptation to be drawn up (chapter 5). Finally, the new network must be evaluated based on design criteria (chapter 6). After the evaluation, the conclusion provides the answer to the main question, which is followed by a brief discussion (chapter 7) and suggestions for future work (chapter 8).

2. Methodology
As stated in the introduction this chapter includes the methods for finding the answers to all sub question, which then leads to the answer to the main question. The study is literature based supported by various analyses: a historical-morphological-, stakeholder-, MoSCoW-, site-, and a multicriteria analysis. Table 1 provides an overview of which assessment applies to which sub question. In the rest of this chapter an explanation is given on how the analysis are performed and how they contribute to answering the sub questions.

Table 1 Overview of the assessments and the sub question they apply to.

Sub question	***Literature study***	***H-M analysis****	***Stakeholder analysis***	***MoSCoW method***	***Site analysis***	***Multicriteria analysis***
1	***X***					
2	***X***	***X***				
3	***X***					
4	***X***		***X***			
5	***X***					
6	***X***			***X***		
7	***X***					
8					***X***	
9						***X***

** Historical-Morphological analysis*

2.1 Literature study
The literature study helps to answer the first seven sub questions. The first four questions relate to background information to analyse the project area. Sub questions one and three are answered with information from OpenStreetMap and the municipality of Alphen aan den Rijn. The answers to the other two questions are obtained from Topotijdreis and the website of each stakeholder. Sub question five and six relate to the classification of the user groups and their needs within the network. The vision of the Fietsersbond in combination with design guidelines from the CROW form the basis for this. CROW is the name of the knowledge platform for, among other things, design guidelines for the bicycle traffic network. Previously, the abbreviation stood for 'Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek' (CROW, 2021), which can be translated to Centre for Regulations and Research in Ground, Water, Road Construction and Traffic Engineering. This results in a list of requirements and wishes, which should be ordered to indicate where the priorities lie. This is done by implementing the MoSCoW-method, which is explained in paragraph 2.4. From these prioritized requirements and wishes follow criteria per level that must be met. These criteria form the answer to sub question seven and the basis for the site analysis that is explained in paragraph 2.5.

2.2 Historical-morphological analysis
A Historical-morphological analysis is intended to understand the complex urban system (Crowther, 2016). This involves looking at the development of the urban area over the years. This is done by studying maps from a certain time span side by side and recognizing patterns. In this research the years 1958, 1968, from 1980 up to 2010 with steps of five years, 2013, 2014 and 2021 are assessed. The larger time jump between 1958, 1968 and 1980 is due to the availability of the geographical maps via Topotijdreis. The years 2013 and 2014 are specially indicated because during that new year transition a merger of municipalities occurred (Plaatsengids.nl, 2020), which means a clear change in the number of villages belonging to the municipality of Alphen aan den Rijn. The map data used for this analysis comes from Topotijdreis, but all maps are own representations with a reduction of the map information to the extend of the municipality of Alphen aan den Rijn. The patterns found in the assessment help in predicting the growth of the urban system in the future. Common occurring patterns are the shape of the development, which can be a long a line,

known as ribbon development, or from one point circular outward, known as point development, or a scattered pattern, known as leapfrogging development (Brody, 2013). In addition, it can be striking whether the developments are limited or not, which can have an impact on the density of the resulting urban area (Shore, 2020). The predictions made with this analysis are very simplified as the developments depend on many factors and can therefore not be seen as a fixed picture of the future.

2.3 Stakeholder analysis

The stakeholder analysis shows which parties are involved in the project. It provides an overview of the power and the interest in this project. The power here refers to the influence of the party in the project. The power and interest are both ranked from -- to ++, with a literature study motivation to support the values given per stakeholder. The result of this analysis is a graph with the relation of power to interest, in which it is clear in one respect which stakeholders have more priority within this project. This is even though every stakeholder must still be included in the design.

2.4 MoSCoW-method

After all requirements and wishes have been drawn up, they must be given the correct hierarchy, for this the MoSCoW method is used. In this method, the requirements and wishes within a project are divided into four categories: the Must, Should, Could and Would categories, which are in the name represented by the capital M, S, C and W (ProductPlan, 2021). This then indicates which requirements <u>must</u> really be met. What requirements <u>should</u> be ensured in the project. What requirements <u>could</u> possibly be incorporated into the project. And finally, the requirements that <u>would</u> be nice to add in the project. It goes without saying that the must category has more priority than the should, the should more than the could and the could more than the would category, so this immediately shows the hierarchy in the requirements and wishes.

2.5 Site analysis

This analysis is used to evaluate the current bicycle network. This involves setting up design criteria per network level following from the requirements. After that, it is checked for each level which parts of the current network meet the design criteria. At the same time, it becomes clear which parts do not comply and therefore need to be adapted. After that, it should not be forgotten that overlap can occur, so parts of the network meet multiple levels. Here it must then be decided for which level(s) these paths serve, in order to create three separate and still self-connected networks. The analysis results in one topographical map per level, indicating which parts meet the design criteria.

2.6 Multicriteria analysis

There are multiple design solutions for creating a three-level bicycle network. The possible network routes are based on the main origin and destinations of the user group. These solutions are each compared to each other by a multi-criteria analysis. The design criteria used in this analysis are cohesion, directness, safety, usability, and costs. The result of the stakeholder analysis is considered to determine, which stakeholders have higher priority and therefore have more predominance in the distribution of weighting factors over the various design criteria. For each criteria the weighting factor is multiplied by the score of the alternative, the sum of these results gives the final score for each alternative. The ‘best’ solutions per network level are combined with the already existing sufficient cycling network for level 2, which provides the answer to the main question. The ‘best’ refers to the solution with the highest score in total for all design criteria.

3. Municipality of Alphen aan den Rijn in the past, present, and future

This chapter is the first step into the content of this research, here is explored what the project area looks like. This includes analysis of the urban system, which is a historical morphological analysis. This is followed by a look at the current bicycle network. After which all stakeholders with their interest and motivation are displayed. Finally, a few reference projects are mentioned, from which the necessary experience and knowledge can be gained.

3.1 Urban system

The historical maps from 1958 and 1968, show there is a ribbon development occurring for the villages Alphen aan den Rijn, Aarlanderveen and Zwammerdam, which are part of the municipality Alphen aan den Rijn since respectively 1918 and 1964 (Plaatsengids.nl, 2020). A ribbon development is the building of houses along an existing linear barrier (Designing Buildings Ltd., 2020), it is also known as linear settlement (3D geography, 2021). Alphen aan den Rijn and Zwammerdam develop along the river ‘de Rijn’, while Aarlanderveen develops along a road in between two polders. In **Error! Reference source not found.** this ribbon d evelopment is shown. The maps 1958, 1968, 1980, 1990, 2000, 2014 and 2021 are combined in one map with a colour gradient. The starting year 1958 is displayed the darkest and the most recent map the lightest. The limits of the municipality throughout the years are in accordance with those from the landscape biography (Landschap & stad, 2020). All maps separated per year are included in appendix B.

From 1968 onward there is a point development from the city centre outwards, which is bound by the train tracks until 1990. A point development is more commonly known as nucleated settlement, which is the dense building of houses from a certain point outward (3D geography, 2021). After 1990 the development of the urban area starts at the south side of the train tracks. This still is a point development recognizable by the circular extension from one point. This time the point around which the expansion is taking place is not the city centre but the main connection between the city centre and the new city districts. Once again, the urban development is limited, this time by the N11 motorway, which was put into use in 2000 (Rijkswaterstaat, 2021). This demarcation is a conscious choice to keep urban development under control and to make smart use of space. Alphen aan den Rijn is located in the middle of the 'green heart' of the Netherlands, where it is important to preserve this natural landscape (Gemeente Alphen aan den Rijn, 2021). Therefore, the plans of the municipality nowadays mostly include redevelopment of existing neighbourhoods within the set limits, which is the growth expected until 2040.

In Figure 2 the population throughout the years is shown. The change in population in 2014 is very striking but very clearly explainable by the merger with the municipalities of Boskoop and Rijnwoude (Plaatsengids.nl, 2020), which is also clearly visible in the maps because of the surrounding villages that are suddenly present. Today, the municipality of Alphen aan den Rijn has an area of 13,250 hectares. The boundary of this area, and thus the extent to which the area belonging to the municipality of Alphen aan den Rijn extends, is shown in figure 3, which also shows the current bicycle network described in the next section.

From this analysis it can be assumed that the existing boundaries of the municipality of Alphen aan den Rijn will not expand any further. The developments within these boundaries will mainly consist of redevelopment of existing neighbourhoods. The bicycle network therefore does not need to provide a larger surface area with origins and destinations.

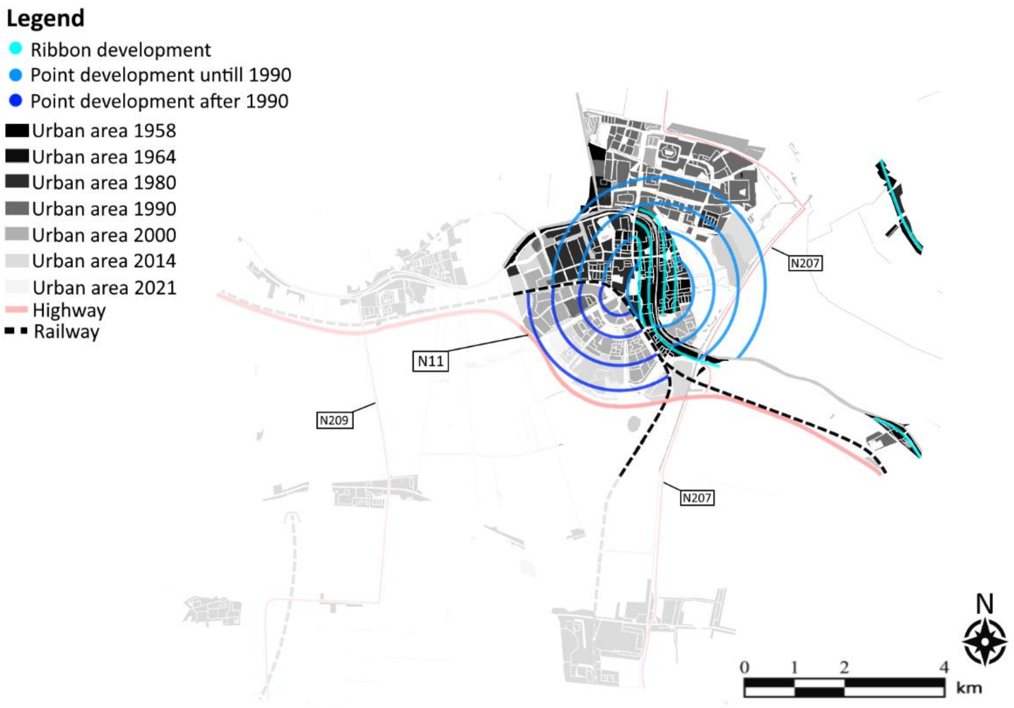

Figure 1 Historical-morphological maps showing the occurring ribbon- and point developments (Own work, with use of maps from Topotijdreis and OpenStreetMap).

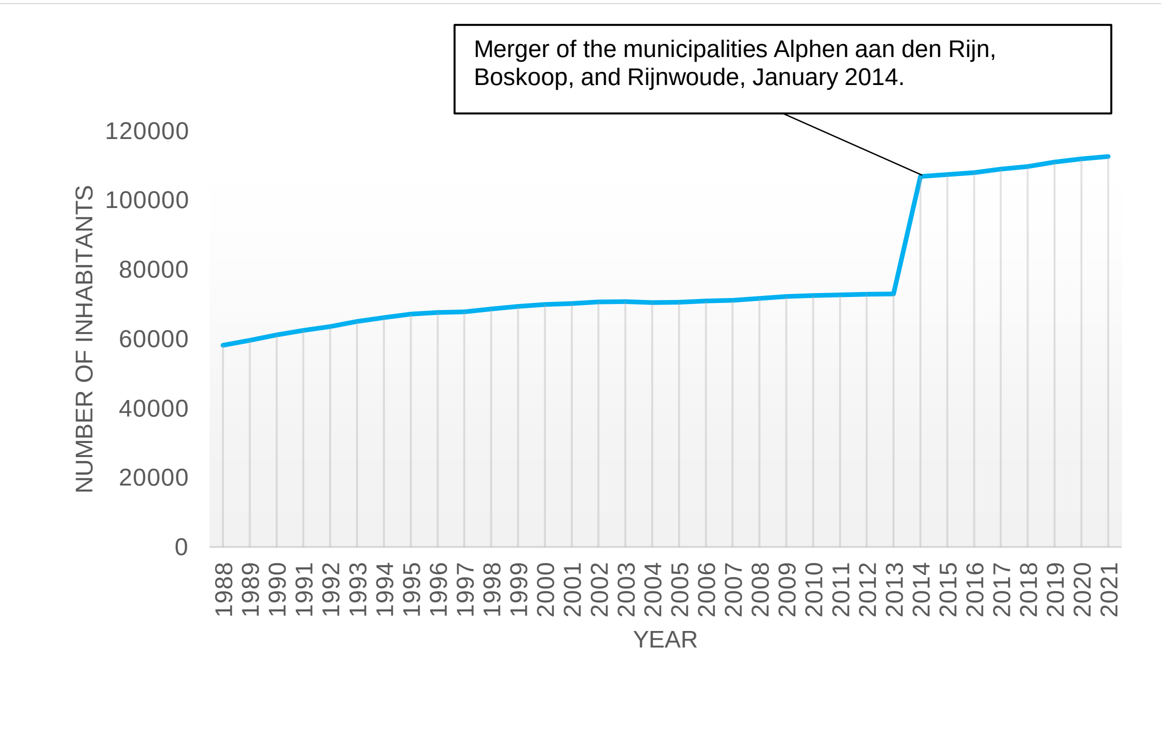

Figure 2 Population of the municipality Alphen aan den Rijn from 1988 till 2021. (CBS, 2021)

3.2 Current bicycle network

The data from OpenStreetMap is used to determine what the current bicycle network looks like. Figure 3 indicates which national, regional, and local cycling routes are within the project area. As can be seen the cycle paths are in the rural as well as the urban areas. The numbers in the figure indicate numbered cyclist junctions automatically generated by OpenStreetMap's bicycle map. A more detailed map is provided in appendix C, where the network is displayed per geographical zone. This network is evaluated in chapter 5.1 Evaluation of the current network, based on the established design criteria.

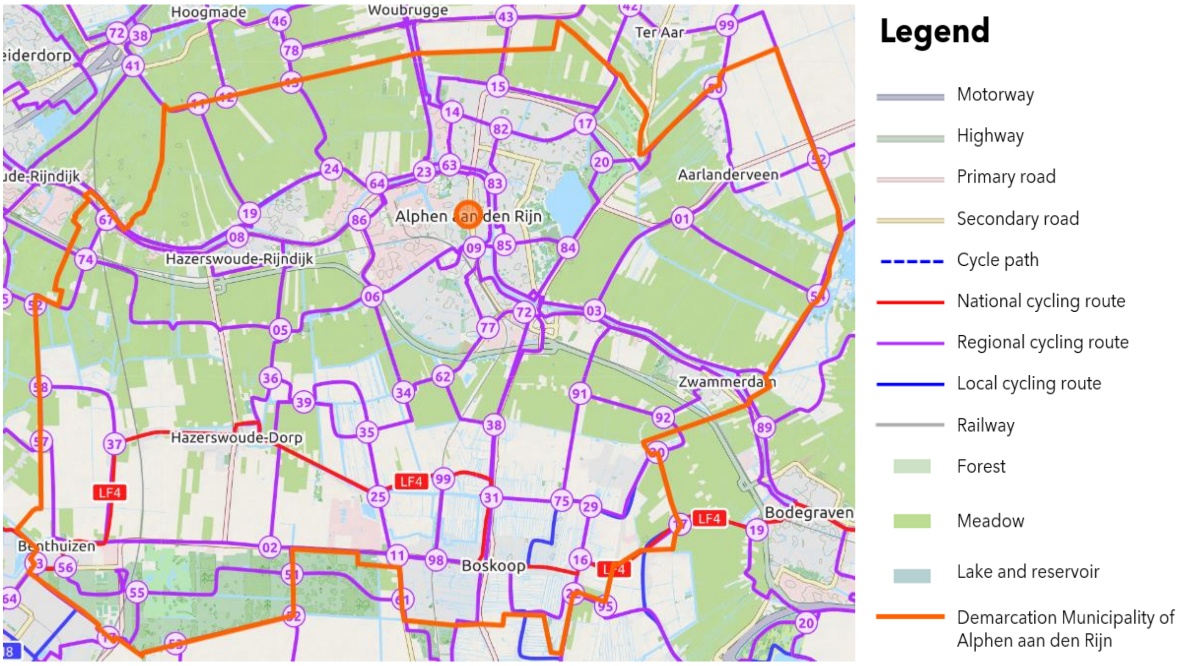

Figure 3 Bicycle network of the municipality of Alphen aan den Rijn. (OpenStreetMap, 2021)

3.3 Stakeholders

Many parties are involved in this project, whom all have some form of interest or power. It is important to map out which of these many stakeholders require the most attention and therefore are prioritized to the others. A list of all stakeholders, with their motivation on the scale of interest or power in the project, can be found in appendix D.

Figure 4 shows an overview of these stakeholders, which clearly shows that the municipality of Alphen aan den Rijn itself has the highest power and interest. It is up to the municipality to build a safe and good bicycle network as they are the local road authority. They are therefore of the highest priority in this project. It also becomes clear that the ANWB, BOVAG, SWOV, VVN, cyclist's union and RAI provide a supporting role in the project due to their medium power and high interest. A collaboration to transfer knowledge from these parties to the municipality can be beneficial. It is useful for the municipality to collaborate with these parties. These parties have a great deal of knowledge about the subject discussed and some represent a corresponding group of individuals who notice the consequences of changes.

In addition, there is a need for informing the cycling local resident, non-cycling local resident and the police, as they have little power but large interest. These are individuals who can only speak for themselves and their own experience. However, they do experience the most consequences of change in the network and must therefore be taken into account in the design. This can be done by properly informing what is going to happen and giving the opportunity to respond to it.

Lastly, there is the group of stakeholders which has the lowest of priority as they have low power and low interest. The government is in this category as seen from the letter to parliament it appears that bicycle paths must remain under the management of the local road authorities. They therefore have low power in this project, their interest is also small because this project has an impact on too small a scale.

No stakeholders belong to the 'keep satisfied' category. This is the category of stakeholders who have a lot of power but actually no interest in the project. Normally these can get in the way of the project and must therefore be kept satisfied. This is not the case now since all parties with power are interested in the project.

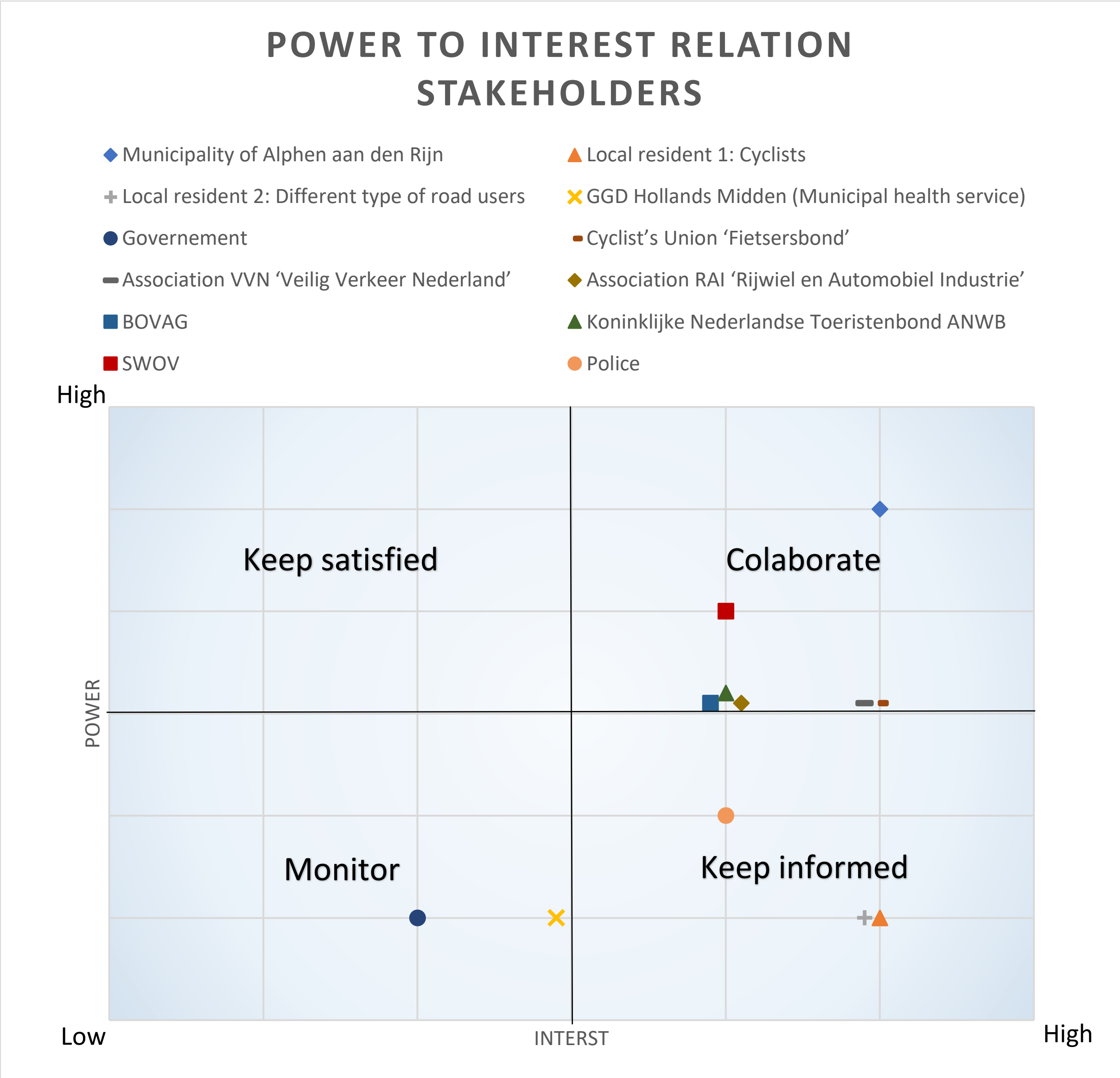

Figure 4 Stakeholder analysis scatter plot showing the priority for each stakeholder.

4. Classification of the three levels

As mentioned in the introduction there is a great variety in users of the cycling network. The distinction can be made in age, type of vehicle and speed. In this chapter it is first looked at the type of vehicles and which age group uses them. After looking at the great diversity in users, they are selected for the right category keeping in mind the speed differences. Lastly de requirements per level are lined up.

4.1 Type of vehicles and users

In this report only vehicles that are supposed to be present on a bicycle road are considered, this includes the electric bike, granny bike, mountain bike, racing bike, children's bicycle, mother bike, city bike, beach cruiser, hybrid bike, recumbent, moped, Speed pedelec, disabled vehicle, scooter, folding bike, cargo bike for freight, cargo bike for people transports and tandems (CROW, 2010). To clarify which vehicles are being discussed, all these vehicles are shown in Appendix E Vehicle types with an example photo. The users of each vehicle deviate in age. Therefore, user groups are divided by age and assigned to the respective vehicle. The age groups are classified as: children (<12 years old), young adults (12-30 years old), adults (31-60 years old) and elderly (>60 years old) (CROW, 2010). Teenagers (12-20 years old) and young adults (20-30 years old) are often seen as separate groups, but since they can use the same vehicles, they are grouped together here. In addition, it is indicated whether you should have a certain kind of skill to use the vehicle. Finally, the disabled vehicles have been added, these are not tied to an age category, their user group can be categorized as disabled people. Table 2 lists the vehicle types and which user groups are applicable to them.

Table 2 User groups per vehicle type

Vehicle type	User group
Electric bike	Young adults, adults, and elderly (de Haas, 2021)
Granny bike	Young adults, adults, and elderly
Mountain bikes	Young adults and adults (Barber, 2016)
Racing bike	(Skilled) young adults and adults
Children's bicycles	Children
Mother bikes	Young adults and adults, both with children
City bikes	Young adults, adults, and elderly
Beach cruisers	Young adults and adults
Hybrid bikes	Young adults and adults
Recumbent	(Skilled) young adults and adults
Moped	Young adults and adults
Speed pedelec	Young adults and adults
Scooter	Elderly
Folding bikes	Young adults and adults
Cargo bike for freight	Young adults and adults
Cargo bike for people transportation	Young adults and adults
Tandems for joint cyclists	Young adults, adults, and elderly
Disabled vehicles	Disabled person

4.1.1 Level 1: The vulnerable cyclists

The first network level has the highest priority and consists of the vulnerable cyclists. The vulnerable cyclist is referred to children and elderly. Looking at all the users mentioned above, this includes the following: elderly with an electric bike, granny bike, city bike, tandem or scooter. Young adults and adults with their children on a mother bike or cargo bike and children alone on a children's bike also belong to this category. Older people are categorized as vulnerable because their ability to perceive and react is reduced at a later age (Davidse, 2007). In addition, they often experience greater injuries in the event of an accident. Children are vulnerable because they have not yet fully developed cognitive skills, their attention is still too short (CROW, 2010).

This network should provide a safe route within the villages. So, children can safely cycle from home to school and the elderly can reach their shopping and daily activities within the village. If these activities take place outside the village, they are expected to be capable enough to use the level two network.

4.1.2 Level 2: The skilled cyclists

The second level serves for the skilled cyclist. This does not mean the advanced trained cyclist but the cyclist who is able to cycle on the main network without incurring extra risk. This category includes young adults and adults with a Granny bike, mountain bike, city bike, beach cruiser, hybrid bike, folding bike or tandem. Disabled people with their vehicles, although considered to be vulnerable, are allowed to use the level 2 network. Their vehicles protect them, and their speed is compatible of the other users in this network.

The level 2 network functions as the main network, it handles the most users and covers all origins and destinations.

4.1.3 Level 3: The fast cyclists

The last network level is suitable for the fast and advanced cyclists. The main users can be depicted as (skilled) young adults and (skilled) adults with an electric bike, racing bike, recumbent, cargo bike for freight, speed pedelec or moped. As all these vehicles indicate, the speed on these roads is considerably higher compared to the other two levels.

The level 3 network mainly functions between villages, these roads are constructed as a kind of highway for cyclists.

4.2 Requirements per network level

Due to the difference in users per level there are different requirements for each level. The requirements vary from speed limitation and dimensions of the infrastructure to the allowance of level crossings with the railway. All requirements are included in Table 3. Quantitative values can be assigned to requirements 1 till 4. For all others, it is simply determined whether the requirement applies in that particular network. The requirements are divided into four categories according to the MoSCoW method. The Must, Should, Could and Would categories are shown as columns in the table. It follows that the first column has more priority than the second and so on. Table 3 clearly shows level 1 has stricter requirements, compared to the other two levels. There are more requirements within the must category for this level and fewer of the current regulations are allowed. This leads to the first seven requirements to be of most importance for the evaluation of the current network in chapter 5.

4.3 Changing levels as an user

Not all levels extend from origin to the desired destination. Everyone can use the main network, the level 2 network, but the minimum and maximum traffic speed must be met. It is hereby a choice of the vulnerable cyclist, the cargo and fast cyclist to use the main network, which is sometimes necessary to cover the last few metres. The main network must therefore reach all destinations and origins. A user who falls into the level 2 category who cycles the minimum speed of the level 3 network may use this. They are also allowed to use the network for vulnerable cyclists, but they must adjust to the regulations. This means they must adjust their speed to the speed limit and are not allowed to overtake other cyclists. Users of the level 3 network are not allowed to use the level 1 network and the other way around. Regulations for compliance with these rules are not part of this bachelor's thesis and can therefore be elaborated in another study.

Table 3 Requirements for each network level categorised with use of the MoSCoW-method.

Requirement	**Must**			**Should**			**Could**			**Would**		
Network level	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
1. Maximum speed limit motorised vehicles on the same road [km/h]	20	30	60									
2. Lower and upper speed limit bicycle network users [km/h] (CROW, 2010)	12 - 20	15 - 25	>25									
3. Minimum width of the bicycle path [m] (CROW, 2015)*	2	1.7	1.7									
4. Minimum radius for bends [m] (Fietsersbond, 2017)	5	10	14									
5. Overtaking allowed	No				Yes	Yes						
6. Agricultural vehicles allowed	No				Yes	Yes						
*7. Obstacles** allowed*	No				Yes	Yes						
*8. ISA*** on all vehicles*				Yes	Yes	Yes						
9. Non cycling motor vehicles have less priority				Yes	No	No						
10. Railway level crossing allowed	No							Yes	Yes			
11. Small detours allowed					No		Yes		Yes			
12. For the most part of the network separated lanes from car traffic										Yes	No	No

**A width of 2 metres makes it easy to cycle side-by-side for two people. A width of 3 metres allows for side-by-side cycling and easily overtaking.*
***Obstacles among other include: dangerous berms, road poles, high curbs and vehicles parked on the road.*
****Intelligent speed assist: The maximum speed of the road is registered and maintained by the vehicle. This ensures that no one can drive faster than the maximum speed (European Transport Safety Council, 2021).*

5. Design

In this chapter the current design is evaluated by the twelve requirements stated before. Based on this evaluation, it can be decided what adjustments should be made to the network. These are then applied in three alternative ways per network level within the project area, which will be evaluated in the next chapter based on a multi-criteria analysis.

5.1 Evaluation of the current network

The municipality of Alphen aan den Rijn has a large surface area, which can be divided into different geographical zones. These zones correspond to the boundaries of the villages that are part of the municipality of Alphen aan den Rijn. Koudekerk aan den Rijn, the orange geographical zone in figure 5, is addressed in this report. The other geographical zones can be worked out following the same methodology.

Of the residents in Koudekerk aan den Rijn, 28% is 65 years or older, which is a very large proportion for which a level 1 network is desirable (Kadastrale Kaart, 2020). In addition, Koudekerk aan den Rijn is located between Leiden and Alphen aan den Rijn, which is an important connection for a level 3 network. Koudekerk aan den Rijn has a clear distinction between the rural area and the residential area (Alle Cijfers, 2020), which helps with a good separation of these two network levels. Because there is a good representation of all user groups and a clear separation between residential- and rural areas, it is decided to address the design for Koudekerk aan den Rijn.

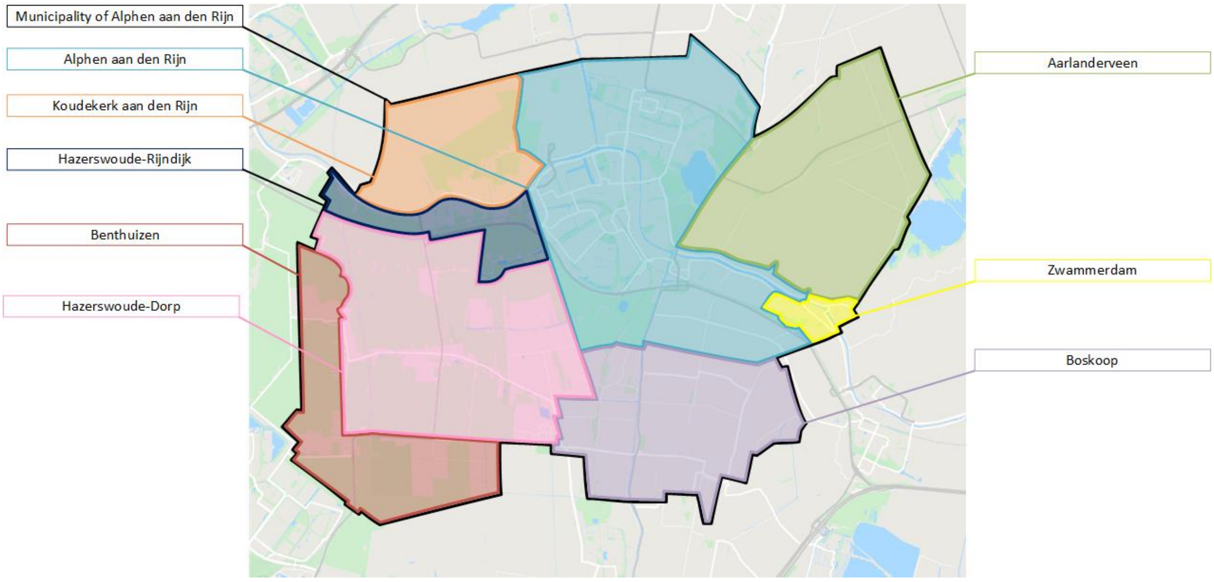

Figure 5 Municipality of Alphen aan den Rijn with the division into geographical zones. (Own work; background image (Google Maps, 2021), data of the boundary of the subareas and the demarcation of the municipality of Alphen aan den Rijn comes from OpenStreetMap).

For each road section in the area, it is checked whether it complies with the level 1, 2 and 3 network. The road sections are assessed on the basis of requirements 1, 3, 4 and 7 from table 3, because these requirements have quantitative values and are therefore measurable. Requirement number 2 and 11 are not applicable because the division into levels has not yet been made in the current network. Requirement number 5 and 6 can’t be used as this results in a complete rejection of all road sections for the level 1 network. In addition, these are also only required for the level 1 network and therefore not important for the assessment of the other two levels. Number 8 of the requirements is not applicable because it affects the vehicle and not the network. Requirement 10 does not apply since no railway runs through this subarea. Finally, requirement number 12 is not included since this is more of a wish.

The level 1 network is desirable in the residential area, therefore only the roads sections within this area are analysed. For the level 3 network, only the rural area is looked at, including the connection with neighbouring villages and towns. Lastly the analysis for the level 2 network is done on all road sections within the boundaries of the village of Koudekerk aan den Rijn.

For the level 1 network, there are many roads that do not meet the requirements. These roads are shown in Figure 6. The evaluation of the road section indicated in figure 6, the Koningin Julianastraat, is further described here. For all other road sections, the evaluation is performed following the same steps.

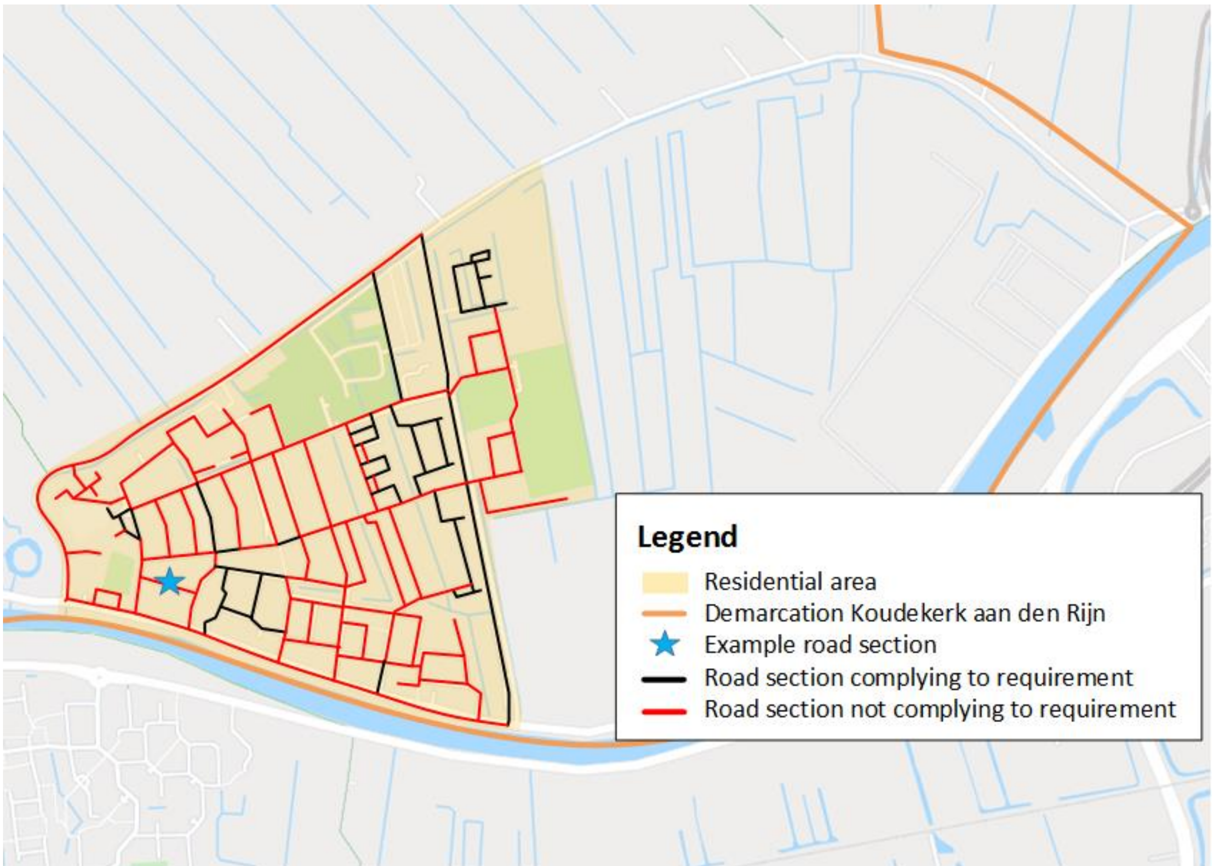

Figure 6 Evaluation of the current network to requirements 1, 3, 4 and 7 of network level 1: vulnerable cyclist. (Own work; background image (Google Maps, 2021), data of the boundary of the village Koudekerk aan den Rijn comes from OpenStreetMap).

As can be seen in the street view in Figure 7 there is no separate bicycle path on this road section. The cyclist uses the same road as the car, which is why requirement number 1 is applicable. The maximum speed on this road section is 30 km/h for cars. This means that the road section does not comply to the first requirement. Requirement number 3 and 4 are related to the dimensions of the bicycle path. Since there is no separate cycle path, the dimension of the entire road surface of this section is considered. The width of the road is 5 metre excluding the parked cars along the road (Google Maps, 2021). For cycling both ways a width of 4 metres is required, so the minimum width is met. The radii of the bents at each side are larger than 5 metres, they therefore comply to requirement 4. The radii are approximate with the satellite maps and measured dimensions in google maps, see Figure 8. Lastly there are no obstacles allowed in this network level. It is allowed to park cars on the side of the road here. Looking at street views of Google maps over several years it can be concluded this happens often. These cars can be seen as obstacles in the level 1 network. This road section therefore also does not meet requirement number 7. With requirement number 1, it could already be concluded that this road section does not comply with the level 1 network. Most of the road sections are rejected for this reason.

Figure 7 Street view Koningin Julianastraat (Google Maps, 2020).

Figure 8 Approximation of the curve radii of the bends in the network, crossroad Koningin Julianastraat and Willem de Zwijgerlaan (Own work, dimensions and background image (Google Maps, 2021)).

It appears that the current bicycle roads within the boundaries of Koudekerk aan den Rijn all meet the requirements for the level 2 network. This makes a lot of sense because these are the requirements on which the current network design is based.

The current network in the rural area is assessed to the same four requirements for the level 3 network. The same method as for the level 1 network applies. The current network lacks mostly in meeting requirement number 3. All insufficient road sections are between 1.5 and 3 metre wide with traffic from both directions. This width must be a minimum of 3.4 metre.

Figure 9 provides an overview of all road sections complying to the requirements of the level 3 network in the rural area.

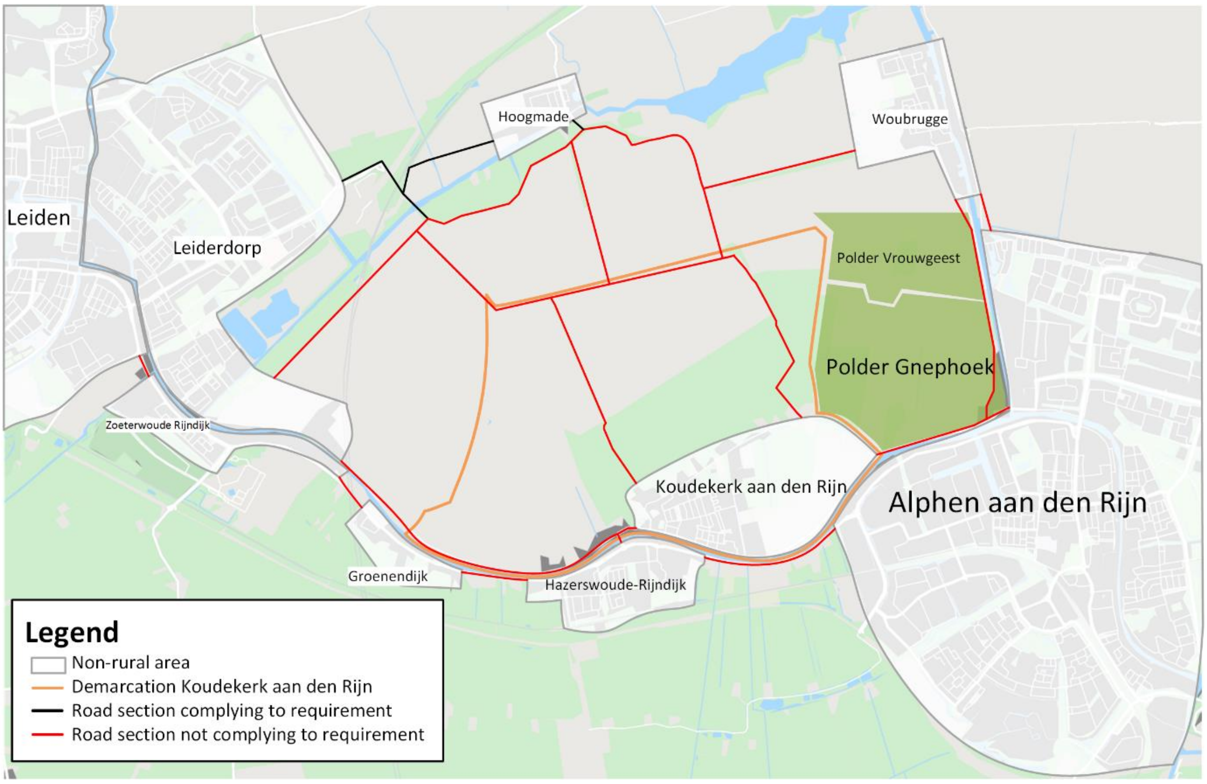

Figure 9 Evaluation of the current network to requirements 1, 3, 4 and 7 of network level 3: fast cyclist. (Own work; background image (Google Maps, 2021), data of the boundary of the village Koudekerk aan den Rijn comes from OpenStreetMap).

The basis of each network design solution is the current network, all these roads already meet the level 2 requirements. However, Koudekerk aan den Rijn is a small village, so there is little room to build extra paths along the existing roads for the other levels. Therefore, each design alternative assigns existing road section to one of the three network levels. Those road sections should be adapted to the requirement of the level. First the level 1 network alternatives are provided. Followed by alternatives for a level 3 network. These are both assessed in chapter 6.

5.2 Design solutions network level 1

The level 1 network is needed for small distance travels within the residential area. For this it is important to know where the destinations for this user group are within Koudekerk aan den Rijn. For the children in this user group, the destinations are primary school and sports facilities. For the elderly, these destinations are elderly care, sports facilities, physio, funeral homes, the general practitioner, and the supermarket. These destinations within the boundaries of Koudekerk aan den Rijn are shown together with the design alternatives in Figure 11, Figure 12 and Figure 13. Near these facilities, a bicycle path must be laid out that provides a safe connection for these users. An example of a desired road image is shown in Figure 10 Asphalt is used because it is easier to drive on at lower speeds. The motor vehicles are not allowed or have speed limit of 20 km/h. It is not allowed to overtake other road users.

Figure 10 Road example for network level 1 (Zwarte weg, Zwolle) (background image (Google Maps, 2020))

5.2.1 Design alternative 1: The serpent

The first design alternative focuses on close proximity to all destinations for the vulnerable user group. This creates a winding route that resembles the path a snake would follow, which is where the name of this alternative comes from. This does mean that a large part of what is now the current network must be converted to the level 1 network. This also means that the vulnerable user coming from the southeast who needs to be in the northeast of the village only has a possible safe route via a relatively large detour.

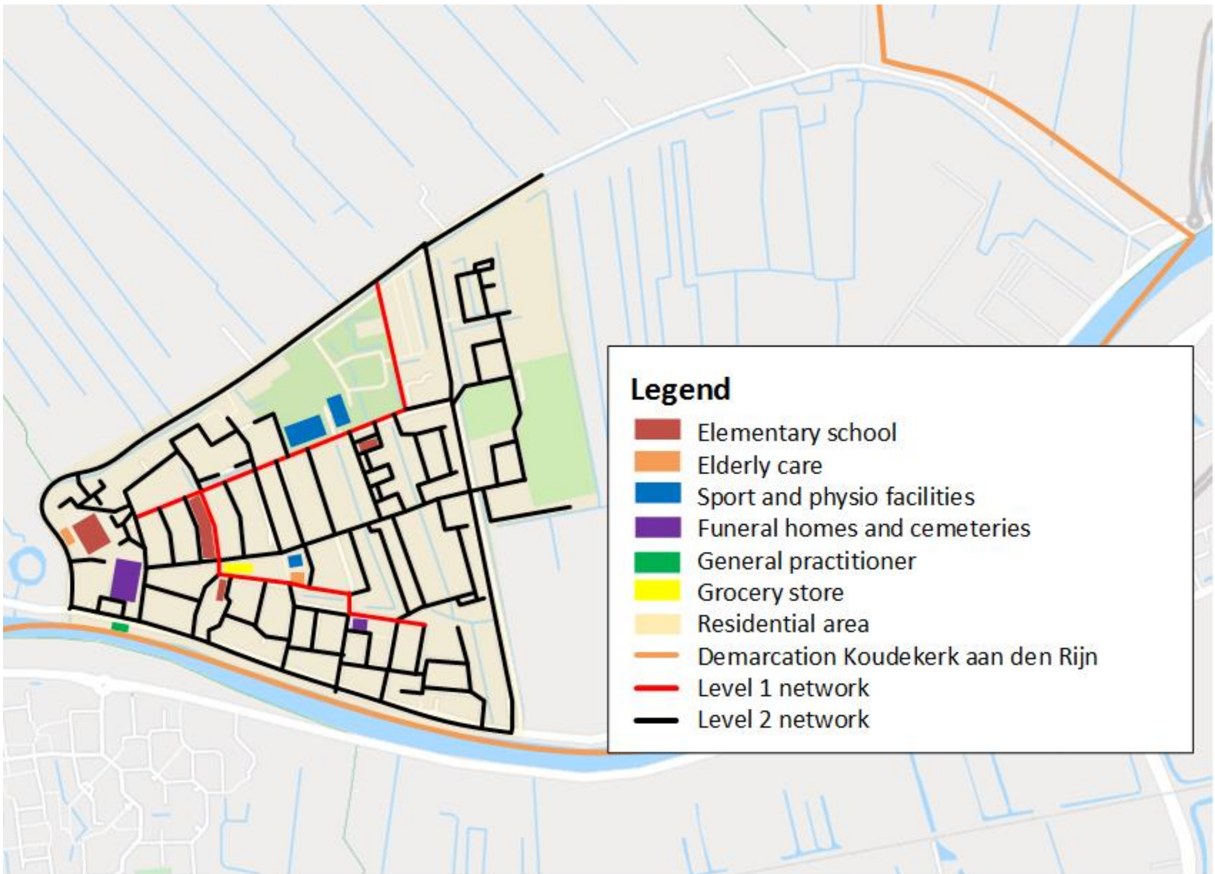

Figure 11 Design alternative 1: The serpent (Own work, data of the boundary of the village Koudekerk aan den Rijn comes from OpenStreetMap).

5.2.2 Design alternative 2: The branch

The second design alternative still has the focus to connect as many of the previously discussed destinations as possible. In contrast to design alternative 1, this design does not go around the village centre but straight through. This makes for a slightly more direct connection. The consequence of this is that the level 2 network would have to take a detour to reach the desired destination. As can be seen in Figure 12 this route through the middle of the city contains a couple side streets in order to connect to the destinations. This gives the branching structure to which the network is named.

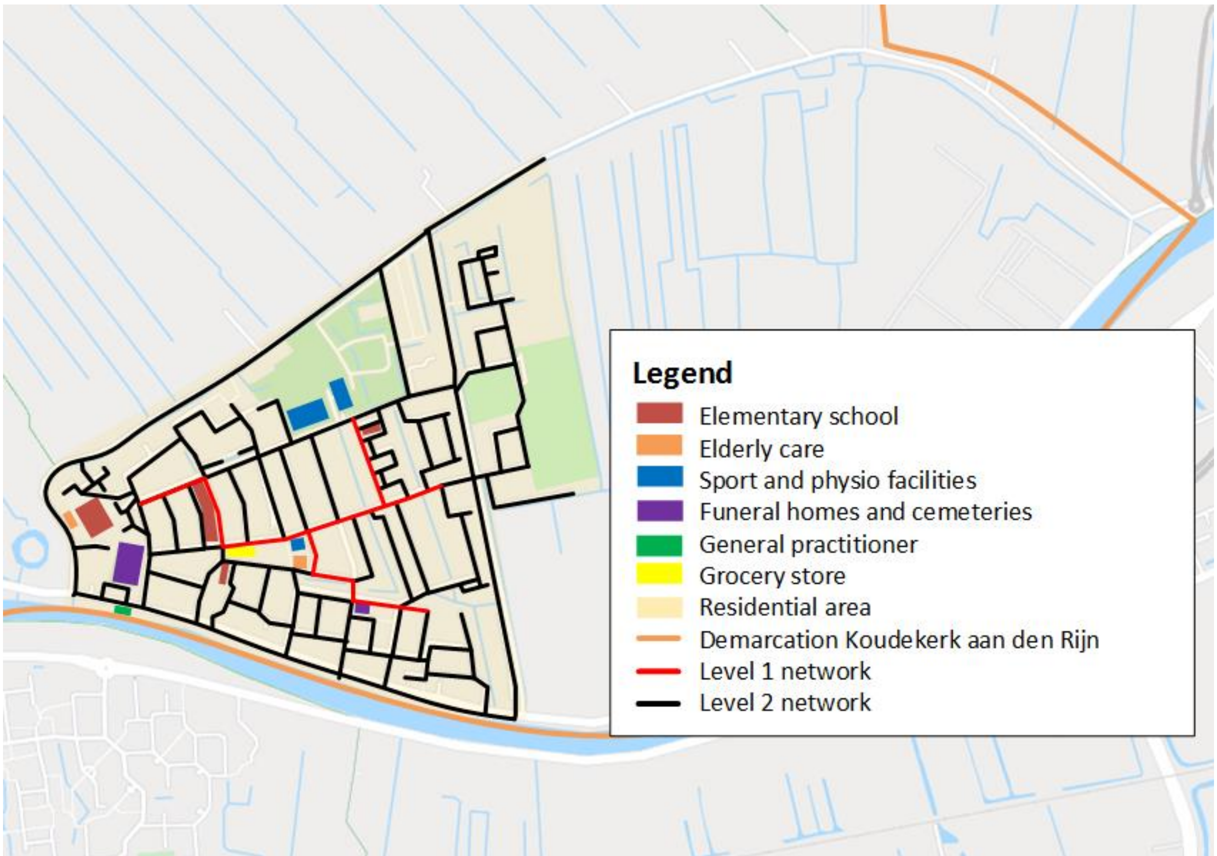

Figure 12 Design alternative 2: The branch (Own work, data of the boundary of the village Koudekerk aan den Rijn comes from OpenStreetMap).

5.2.3 Design alternative 3: The split

The last alternative has another approach, it has a simple structure and focuses on the same distance from each origin and destination to this network. This does mean that this network does not exactly run along all destinations, which means that vulnerable users always have to make use of the level 2 network for the first and last part to their journey. The central placed road sections of the current network are used. This does not necessarily mean that level 2 users have to make a lot of detours, because the level 1 network is minimalistic.

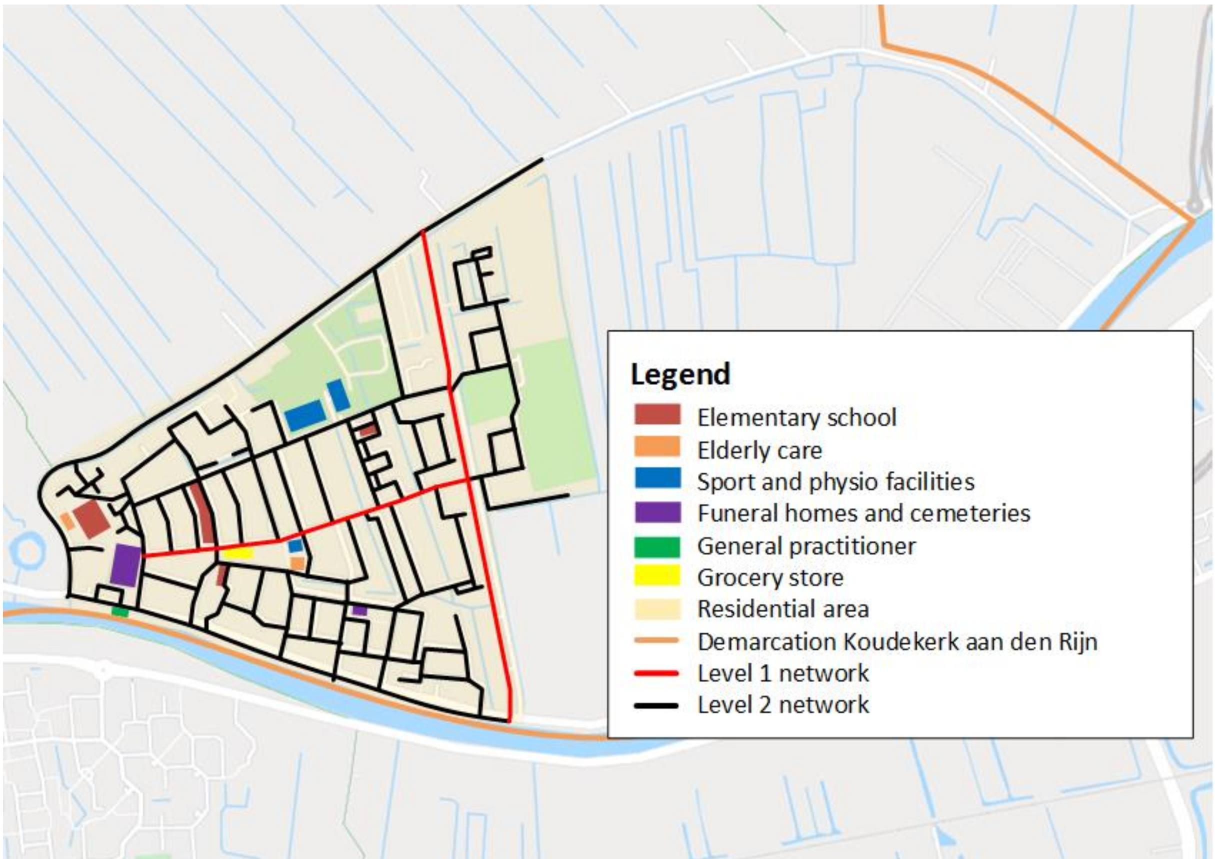

Figure 13 Design alternative 3: The split (Own work, data of the boundary of the village Koudekerk aan den Rijn comes from OpenStreetMap).

5.3 Design solutions network level 3

The network for fast cyclists, level 3, is intended to cover greater distances at a rapid pace. This creates a connection between neighbouring villages. For each design alternative, it is described which villages are connect with constructing the fast-cycling route. An example of a fast bicycle network desired road image is shown in Figure 14.

Figure 14 Road example of a level 3 fast cycling network (photo: W.J. te Morsche) (Movares adviseurs & ingenieurs, Provincie Overijssel, 2018)

5.3.1 Design alternative 1: The worm

The focus of design alternative 1 lies on connecting the city of Leiden and the village of Alphen aan den Rijn. A new cycle path is constructed at the east side of Koudekerk aan den Rijn. This is shown in as the dotted line that runs between the polder Vrouwgeest and polder Gnephoek. This new road connects to the existing road Notweg, which continues to the Rijn. A bicycle bridge at this point brings the opportunity to connect to the road Staalweg that turns into the cycle path Dijkslootpad. Dijkslootpad is of the main bicycle connections in the north area of the village Alphen aan den Rijn.

Figure 15 Design alternative 1: The worm (Own work, data of the boundary of the village Koudekerk aan den Rijn comes from OpenStreetMap).

5.3.2 Design alternative 2: The tripod

The tripod focusses on a connection between neighbouring villages. It still connects the city of Leiden with the village of Alphen aan den Rijn, but this alternative takes a detour along Woubrugge. This is via existing roads that need to be adjusted to the requirements of the fast cyclist network. This ensures that no completely new road section have to be constructed. Resulting in no land loss for the existing green polder area. The network enters the village Alphen aan den Rijn in the upper northwest corner. This route is a relatively large detour compared to the design in alternative 1. The village of Koudekerk aan den Rijn is also directly connected to this network. This branch creates a third path in the network, similar to a tripod, which is where the name comes from.

Figure 16 Design alternative 2: The tripod (Own work, data of the boundary of the village Koudekerk aan den Rijn comes from OpenStreetMap).

5.3.3 Design alternative 3: The extension

Design alternative 3 extents the already existing main road section to the Rijn, where it runs along the water to 's-Molenaarsbrug. This bridge makes the connection to Alphen aan den Rijn. A new road section has to be constructed through a small part of the polder Vrouwgeest, which can be seen in Figure 17. The construction of such an extension ensures a bicycle path that is as straight as possible, meaning as few bends as possible. This ensures that the high speeds that are desirable on these roads are easily maintained, which benefits driving comfort.

Figure 17 Design alternative 3: The extension (Own work, data of the boundary of the village Koudekerk aan den Rijn comes from OpenStreetMap).

6. Evaluation of the design solutions

This chapter includes two multicriteria analyses over the obtained design alternatives. First, all criteria are described with an explanation of their importance. The criteria are then weighed against each other, using the result from the stakeholder analysis as a guideline. After weighing the criteria, the three alternatives for both level 1 and level 3 are scored per criteria. Subsequently, the results of the analysis are discussed.

6.1 Assessment criteria

The six design alternatives are scored on the basis of five design criteria: cohesion, directness, safety, usability, and cost. The first three follow from the main requirements for cycling infrastructure according to CROW (CROW, 2016). Usability relates to the other two main requirements stated in the design guide bicycle traffic, which are comfort and attractiveness. The latter two are difficult to quantify without the experience of the users, so it has been converted to usability here, which addresses the complexity of the network. Finally, cost has been added as a design criterion. Instead of a cost-benefit analysis, in which the exact costs must be drawn up, it has been chosen here to include it as a design criterion. An estimate for the costs per alternative is compared here. All the criteria are scored on a scale of one to five, where one is related to the worst and five the best. In this way it is prevented that an unconscious preference in design criteria is already made here. A five-point scale is a symmetric scale that allows for nuance (Joshi, Kale, Chandel, & Pal, 2015). In addition, this has a clear neutral value for when an alternative is judged neither positive nor negative. As a result, the design with the highest score will be the most desirable.

For cohesion a score of one indicates no cohesion: the infrastructure does not connect to all origins and destinations of the user group. A score of five describes complete cohesion: the infrastructure connects to all origins and destinations of the user group. For each design alternative, this design criterion is scored per network level, then an equal average of these levels is taken. This average indicates the general score regarding cohesion for the entire network within that alternative. Cohesion is important for every network to avoid having to switch too many times between the different levels.

Directness speaks for itself, the network provides the most direct route possible. For this design criteria a score of one indicates that major detours must be taken to arrive at the desired location. A score of five indicates that this network contains the most direct routes. This design criterium is also scored per level and the average is taken, but the average is not evenly distributed over the levels. The second level has more priority following from a stricter requirement regarding detours, see table 3. There should not be too many detours in the network, otherwise the network will not be used as intended leading to no separation of user groups.

Safety is a broad concept. With the new design an improvement must be made on the safety by separation of the three network levels. For this criterion the amount of intersections with other network levels is used. An intersection is counted when three or more roads converge at one point involving multiple networks. However, this does depend on the length of the network being constructed, so the number of intersections is divided by the length of the assessed network level. A score of one indicates there are relatively none to almost no crossings with other network levels and five indicates there are a lot of crossings with the other network levels.

Usability is about the simplicity of the implementation of the network, this also involves looking at whether the network is easy to understand and use. A score of one means the network is difficult to understand, use and implement. A score of five is the opposite: a network that is easy to understand, use and implement. When there is uncertainty about the separation of the networks, it may occur that people do not use the correct network, which also means that no separation of users occurs.

Finally, an estimate of the costs is included in the analysis. For this, the number of kilometres of the existing network that must be adjusted and the number of kilometres of a completely new road that must be constructed are taken into account. It is more expensive to build a completely new road than to rebuild an existing road. These values are obtained for each alternative, the score depends on the comparison between the found values. Scoring one on a scale of five reflects an expensive to implement network design alternative. A five reflects the cheapest network design alternative.

These criteria are not all equally important in the eyes of different stakeholders. It follows from the stakeholder analysis that the municipality of Alphen aan den Rijn should have the highest priority when choosing between the alternatives. The weighting factors are therefore drawn up from their point of view with the supporting parties in mind.

The weighting factors are assigned by first making a comparison between all design criteria. Each time, two design criteria are examined to determine which one is more important. This distribution can be seen in Table 4. If the design criteria in the first column is more important than the relevant design criteria in the first row, a 1 follows in the corresponding cell. Conversely, if this design criterium is not more important, a zero follows in the corresponding cell. When criteria are considered equal, a value of a half is assigned.

For a comparison of cohesion with the other design criteria it follows that there is more priority in cohesion than directness and usability but less than safety and cost. Cohesion is considered more important to directness, as it is more important for the municipality that everyone can get to the desired destination than that the route to it is the shortest. For the local cyclist, these would score equally as a deficiency in one of the two will be equally detrimental to them. The main goal is to positively affect the safety of the bicycle network, it is therefore higher prioritised compared to the cohesion, which matches the user’s priority. Cohesion is more important to the municipality than usability. Discomfort in the usability does not directly negatively affect the effectiveness of the network and is therefore of less priority. The user would benefit equally from these criteria, they would therefore score them equally. Finally, the costs for a project are of great importance to the municipality because they will be the largest investors. This is in contrast to the user, who would not mind if a project cost a lot and therefore, they find cohesion more important. For directness, all other criteria are of more importance to the municipality of Alphen aan den Rijn. From the perspective of the local cyclist this criterion would have scored much higher. The safety criterion is equally important as the cost, but more important compared to usability. This yield from the main goal. Lastly the cost is more important to the municipality compared to the usability.

After determining the priority, the sum in each row is taken. This score indicates how important the design criterion is compared to the others. Since this results in a 0 value for directness, to all criteria 1 is added. This score is divided by the sum of all scores and multiplied by 100 to form a percentage of the whole. Resulting in a 20% contribution for cohesion, 6,67% for directness, 30% for safety, 13,33% for usability and 30% for costs, which add up to 100%.

Table 4 Determination of weighting factors per design criteria

	Cohesion	Directness	Safety	Usability	Cost	Score	Weighting factor
Cohesion		1	0	1	0	3	20,00%
Directness	0		0	0	0	1	6,67%
Safety	1	1		1	0,5	4,5	30,00%
Usability	0	1	0		0	2	13,33%
Costs	1	1	0,5	1		4,5	30,00%

6.2 Score per design criteria

An explanation is given for each score assigned per criteria. The score per criteria is multiplied by the weighting factors. The sum of these results gives the score per design alternative. This score is divided by 100 resulting in a value between 1 and 5 for the whole design. A score of 1 is the lowest and equals the worst design and a score of 5 indicates the best design.

6.2.1 Cohesion

The cohesion is determined by the connection of the network to the origins and destinations. For the level one network these destinations are the specified places within the residential area. These are all displayed in the design alternatives figures. The Serpent connects to the most destinations in close proximity, which results in the highest score. The split connects to the least of these destinations, which results in the lowest score. Nevertheless, this design alternative does connect to just less than half and therefore scores 2 in stead of 1. The branch connects to more than half of the destinations and therefore scores higher than the medium value. The scores are provided in Table 5.

Table 5 Level 1 cohesion score per alternative with motivation.

Design alternative	**Score**	**motivation**
The serpent	5	The network connects to 11 of the 13 destinations.
The branch	4	The network connects to 9 of the 13 destinations.
The split	2	The network connects to 5 of the 13 destinations.

For the level 3 network the scores are depended on the connection to neighbouring villages. When the network connects to multiple it scores higher in this regard. The most important connection that is needed is the one with Alphen aan den Rijn. This is achieved with design the worm and the extension, but they do not connect to more neighbouring villages. This leaves them with an average score of 3. The tripod does connect to multiple neighbouring villages and therefore score a bit higher. Table 6 provides the scores assigned per alternative.

Table 6 Level 3 cohesion score per alternative with motivation

Design alternative	**Score**	**motivation**
The worm	3	This network connects to the village of Alphen aan den Rijn.
The tripod	4	This network connects to Koudekerk aan den Rijn and Woubrugge.
The extension	3	This network connects to the village of Alphen aan den Rijn.

6.2.2 Directness

Directness translates into the necessary detours emerging due to the newly constructed network. This also looks at the affect on the level 2 network because it is affected in this respect by the construction of the new designs. For the level 1 network the serpent causes the largest detours, only in the level 1 network. The branch network seems to have the smallest detours in both network levels. All scores are provided by Table 7.

Table 7 Level 1 directness score per alternative with motivation

Design alternative	**Score**	**motivation**
The serpent	1	Major detours are required for the level 1 network. No detours are required for the level 2 network
The branch	4	No detours are required for the level 1 network. Some small detours are required for the level 2 network.
The split	3	Medium detours are required for the level 1 network. No detours are required for the level 2 network

For the level 3 network only, the tripod contains a larger detour and therefore score lowest, which can be seen in Table 8. The other two design have a fairly direct rout for the connection between Alphen aan den Rijn and Leiden.

Table 8 Level 3 directness score per alternative with motivation

Design alternative	**Score**	**motivation**
The worm	5	No detours are required in the level 2 and 3 network.
The tripod	2	A detour in the level 3 network is required to get to the desired destination. No detour is required for the level 2 network.
The extension	4	There is a small detour in the level 3 network compared to design alternative 1: The worm. No detour is required for the level 2 network.

6.2.3 Safety

The amount of intersections for each design alternative stated in Table 9 for level 1 and Table 10 for level 3. These also include the length of the network. It is best to have the least amount conflicts between different network levels. A network with the least intersections and the greatest length scores the best, which can be found in Table 9 and Table 10.

Table 9 Level 1 safety score per alternative with motivation

Design alternative	**Score**	**motivation**
The serpent	3	There are 24 intersections over a length of 1520 m.
The branch	2	There are 24 intersections over a length of 1290 m.
The split	4	There are 17 intersections over a length of 1685 m.

Table 10 Level 3 safety score per alternative with motivation

Design alternative	**Score**	**motivation**
The worm	3	There are 5 intersections over a length of 6030 m.
The tripod	5	There are 3 intersections over a length of 7560 m.
The extension	4	There are 5 intersections over a length of 7240 m.

6.2.4 Usability

Usability is determined by the complexity in using and implementing the network. Here the network levels are compared to each other. One score lower when it is more complex and score best when is super easy to use and implement. The scores can be found in Table 11 and Table 12.

Table 11 Level 1 usability score per alternative with motivation

Design alternative	**Score**	**motivation**
The serpent	3	This road winds around the centre of the village, it is a continuous line except for 1 small side branch. The network is of moderate difficulty to understand and implement.
The branch	2	This network as the name suggests has many branches, making this network difficult to implement and use compared to the other two design alternatives.
The split	5	This network consists of only two main roads and thus provides a super easy structure to use and implement compared to the other two design alternatives.

Table 12 Level 3 usability score per alternative with motivation

Design alternative	**Score**	**motivation**
The worm	4	Although this network is no straight line it still is a continuous road which makes this structure easy to use and implement compared to the other two network levels.
The tripod	3	Due to the multiple roads in this network not forming a continuous line this structure is more complex to use and implement compared to the other two design alternatives.
The extension	5	This network consists of continuous road and thus provides a super easy structure to use and implement compared to the other two design alternatives.

6.2.5 Cost

There are many indicators that influence costs. Here, therefore, only consideration is made between the alternative which design is the most expensive or the cheapest. For this, the number of kilometres of road section that needs to be adjusted and newly constructed are shown in Table 13 and Table 14. The possible additional construction costs for a bridge have also been taken into account for the design alternative The worm. This is therefore very expensive and results in the lowest scores. However, if this bridge is not built, the costs would be comparable to those of The extension and therefore end up with a score of 3. Constructing new road sections is considered more expensive. For the level 3 network, The tripod yields the highest score with no new road sections to be built. For the level 1 network the difference is less and therefore the score closer to each other. The shortest route requires the least cost, which is why The branch comes out with the highest score for the level one network.

Table 13 Level 1 cost score per alternative with motivation

Design alternative	**Score**	**motivation**
The serpent	3	1520 m of road has to be adjusted, including 24 intersections.
The branch	4	1290 m of road has to be adjusted, including 24 intersections.
The split	2	1685 m of road has to be adjusted, including 17 intersections.

Table 14 Level 3 cost score per alternative with motivation

Design alternative	**Score**	**motivation**
The worm	1	4680 m of road has to be adjusted and 1350 m has to be newly constructed. A new bicycle bridge is constructed in this design alternative making this one the most expensive.
The tripod	4	7560 m of road has to be adjusted. No new road sections have to be constructed. This results in the least expansive design alternative although it is still not for free.
The extension	3	4970 m of road has to be adjusted. 2270 m of new road section has to be constructed. No additional constructions are necessary in this design alternative.

6.3 Assessment results

The score per criteria is multiplied by the weighting factors. The sum of these results gives the score per design alternative. This score is divided by 100 resulting in a value between 1 and 5 for the whole design. A score of 1 is the lowest and equals the worst design and a score of 5 indicates the best design. The calculations are provided in appendix F.

The final scores from the multicriteria analysis for network level 1 are: a score of 3.3 for The serpent and a score of 3.1 for The branch and The split, see Table 15. These values are very close to each other, even though the alternatives are all given different values per criteria. The serpent scores average on most criteria, only exceeds in cohesion and lacks in directness. Due to the low interest of the municipality in the directness of the network this alternative scores highest. When all weighting factors are neglected, this alternative comes in last. When the priority is based on the local cyclist this alternatives scores second. The calculations with the different weighting factors are included in appendix F. This shows that the wishes of the municipality do influence the choice of design. This leads to The serpent to be the most desirable design alternative for a level 1 network.

Table 15 Final scores for the design alternatives of a level 1 network.

	The serpent	The branch	The split
Total	3,3	3,1	3,1

The multicriteria analysis for network level 3 results in a score of 2.4 for The worm, 3.7 for The tripod and 3.3 for The extension. The tripod overall scores above average, but the main reason for the highest score sits in the score for safety and costs. The municipality has a high priority for both these criteria. The worm scores low due to the low score in cost, which is affected by the construction of the bridge. When considering no bridge and continuation along the same line as the extension alternative, this design comes closer to the other two alternatives with a score of 3.0. When considering a different stakeholder as priority such as the cyclist or excluding al weighting factors the extension scores best. This follows from the calculations included in appendix F. Still, according to this multicriteria analysis, the tripod would be de most desirable solution for a level 3 network for the municipality of Alphen aan den Rijn.

Table 16 Final scores for the design alternatives of a level 3 network.

	The worm	The tripod	The extension
Total	2,4	3,7	3,3

As a result, form both multicriteria analysis follows that design alternative The serpent and The tripod are most desirable for the implementation of a level 1 and level 3 network for the municipality of Alphen aan den Rijn. For a complete three level network design these two must be combined with a level 2 network. This level 2 network consists of all roads in the current network that are not assigned to either the level 1 or the level 3 network.

7. Conclusion

This report deals with task of designing a bicycle network that corresponds to the question: *“Which bicycle network design should be implemented for the municipality of Alphen aan den Rijn in order to comply with the vision of the Cyclists’ Union for the year 2040?”* To answer the main question of the report, nine sub questions are formulated. From these sub questions can be concluded:

The area that belongs to Alphen aan den Rijn extends to the municipality borders of Alphen aan den Rijn. This contains the subareas: village of Alphen aan den Rijn, Koudekerk aan den Rijn, Hazerswoude-Rijndijk, Hazerswoude-Dorp, Benthuizen, Boskoop, Aarlanderveen and Zwammerdam. The boundaries of the municipality of Alphen aan den Rijn will not deviate from the current ones in the near future. The developments within these boundaries will mainly consist of the redevelopment of already existing neighbourhoods. The origins and destination for bicycle traffic within the municipality of Alphen aan den Rijn will therefore be in the same range as the current ones. The current bicycle network within the municipality of Alphen aan den Rijn consists of local, regional, and national routes. The paths are located in both the rural and urban areas.

The stakeholder analysis shows the municipality of Alphen aan den Rijn itself has the highest power and interest and therefore the highest priority within this project. Other key stakeholders are: ANWB, BOVAG, SWOV, VVN, cyclist’s union and RAI. They provide a supporting role for making decisions in relation to this project. The cycling local resident, non-cycling local resident and the police, should be well informed as they have little power but large interest. Lastly the government and the GGD are involved with the design of the new bicycle network. They have the lowest priority as they have low power a low interest in this project.

The local cyclist is divided over three network levels. The first network level is for the vulnerable cyclist, including elderly and children. The level 2 network is intended for the skilled cyclist, which forms the main network. Everyone who does not classify in the category of the first or third level may use this network. The level three network is for the fast cyclist with and without freight transport. The distribution over the three levels is based on vehicle type and age with a sidenote: users may switch between levels when they comply to the regulations of that network level.

There are in total 12 requirements per network level, the quantitative requirements relate to: maximum speed limit of motorised vehicles and users of the bicycle network, dimensions of the cycle path including minimum width and radius of bends. The other requirements relate to allowing of overtaking, agricultural vehicle, obstacles, ISA, level crossing with railway, and small detours. Lastly there are the requirements for prioritizing bicycle users and separation from car traffic.

For the current network evaluation and new design, the subarea Koudekerk aan den Rijn is addressed. The current network does not comply with requirement number 1, maximum speed of the motor vehicle on the same road, of the level 1 network. For the level 2 network all road sections in the current network suffice. The current network does not comply to the level 3 network requirement number 3, minimum width of the cycle path.

Adjusting certain roads in the urban area to the maximum speed limit will help comply to the requirements of level 1. A widening of the road surface in the rural area would make the network compliant with the level 3 network. In addition, there must be a clear separation in this network by allocating roads for each network.

The three network designs for network level 1 and level 3 are based on the allocation of road sections. This results in the six design alternatives: The serpent, The branch, The split, The worm, The tripod, and the extension. The design alternatives are assessed by five design criteria: cohesion, directness, safety, usability, and cost. The serpent and The tripod are the best design alternatives, for the implementation of a level 1 and level 3 network for the municipality of Alphen aan den Rijn, according to the multicriteria analysis. The most important criteria for the municipality of Alphen aan den Rijn are safety and costs

Looking back at the main question the evaluation and redesign must be further elaborated for the other subareas of the municipality of Alphen aan den Rijn in order to provide a complete answer. However, it can be concluded that the serpent and the tripod design should be implemented for the village of Koudekerk aan den Rijn in order to comply with the vision of the cyclist union for 2040.

8. Future work

The design solution only focusses on the sub area Koudekerk aan den Rijn. The evaluation and redesign for the other sub-areas within the municipality of Alphen aan den Rijn are needed for a complete answer to the main question. This research can be tackled similarly to the method described in this report. In addition, an elaboration of a network design with separated levels can be applied to other municipalities in the Netherlands or when desirable even abroad. To take the research in a different direction, it is possible to look at what the enforcement of a three-level network should look like. As a last recommendation a user survey can be conducted researching the exact wishes of the users for a three-level network.

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Appendix A Planning

Figure A.1 provides an overview of the planning during the bachelor thesis. It includes all deadlines and the process of each task can be monitored. This schedule may be adjusted over time, should it become apparent that additional research is necessary and possible.

Bachelor Thesis: Safe cycling network for the municipality of Alphen aan den Rijn

Technical University of Delft

R.Krutzen

Start project: ma, 30-8-2021

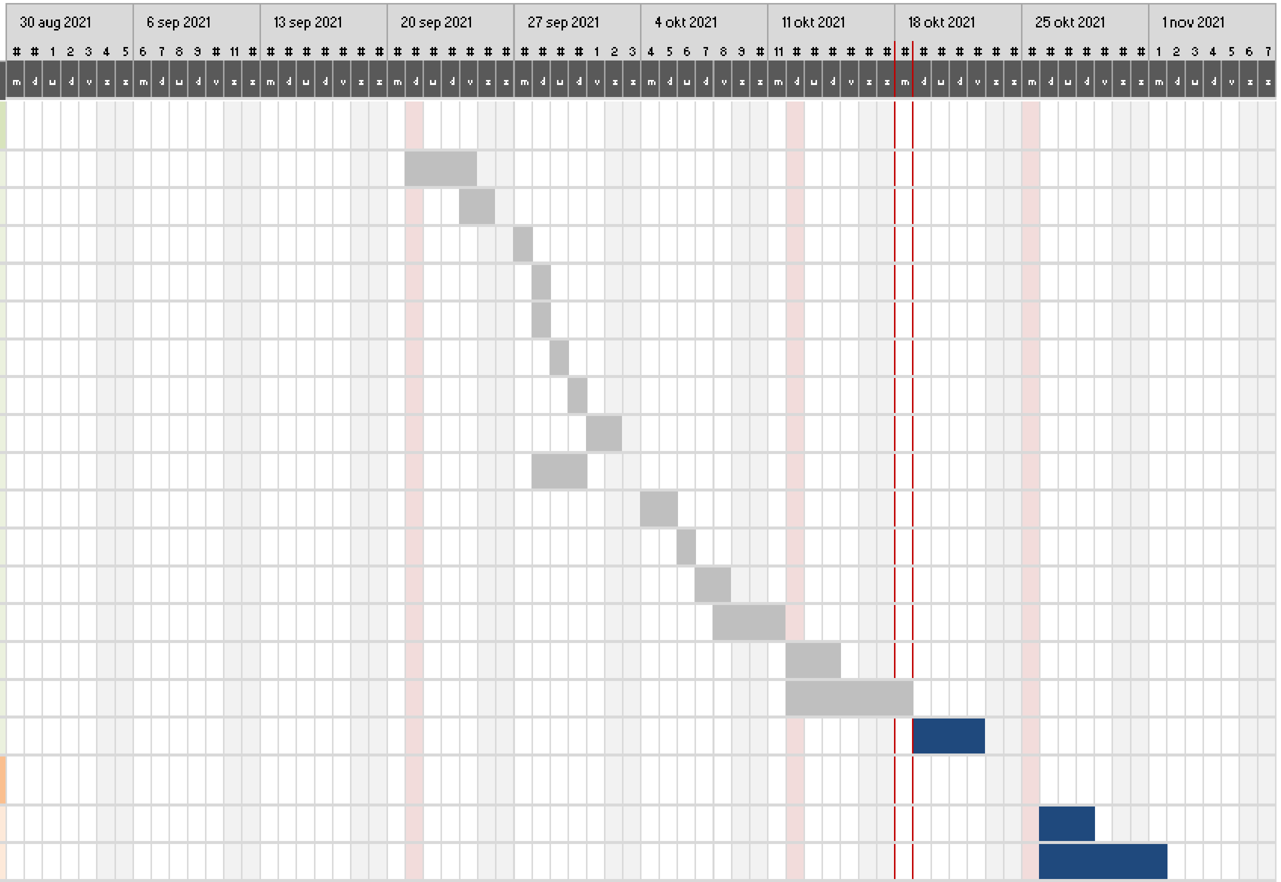
Start week displayed: 1

30 aug 2021 | 6 sep 2021 | 13 sep 2021 | 20 sep 2021 | 27 sep 2021 | 4 okt 2021 | 11 okt 2021 | 18 okt 2021 | 25 okt 2021 | 1 nov 2021

TASK	PROGRESS	START	FINISH
Startnotitie			
Work plan	100%	30-08-21	3-09-21
Feedback + improve	100%	6-09-21	8-09-21
Methodology & Design Approach	100%	8-09-21	10-09-21
Mid-term report			
Analysis of the project area	100%	13-09-21	15-09-21
Feedback + improve	100%	13-09-21	15-09-21
Classifiation users	100%	15-09-21	17-09-21
Prepare presentation	100%	18-09-21	21-09-21

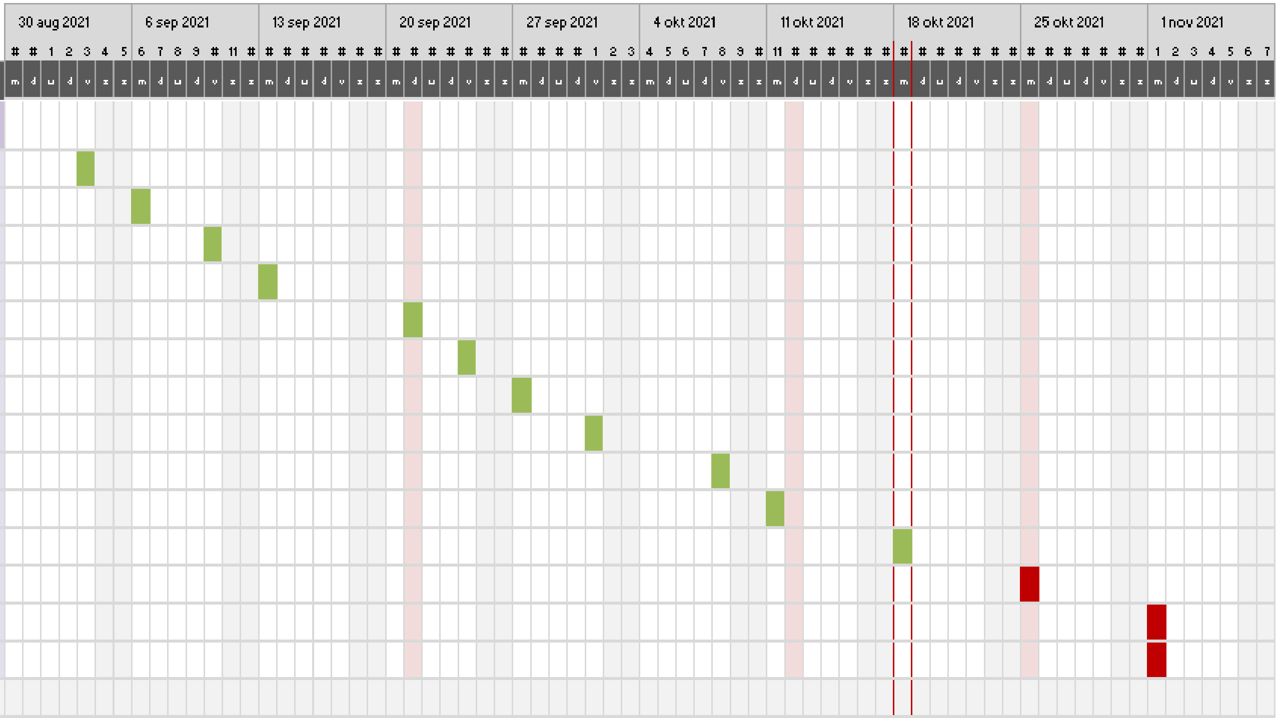
Start week displayed: 1

TASK	PROGRESS	START	FINISH
Final report			
Feedback + improve from mid-term presentation	100%	21-09-21	24-09-21
Program of requirements	100%	24-09-21	25-09-21
Setting up criteria	100%	27-09-21	27-09-21
Evaluate current network	100%	28-09-21	28-09-21
Design alternative 1	100%	28-09-21	28-09-21
Design alternative 2	100%	29-09-21	29-09-21
Design alternative 3	100%	30-09-21	30-09-21
Evaluate design	100%	1-10-21	2-10-21
Feedback + improve	100%	28-09-21	30-09-21
Improve design	100%	4-10-21	5-10-21
Conclusion & Discussion	100%	6-10-21	6-10-21
Summary	100%	7-10-21	8-10-21
Elevator pitch	100%	8-10-21	11-10-21
Feedback + improve	100%	12-10-21	14-10-21
Finishing the report	100%	12-10-21	18-10-21
Presentation	0%	19-10-21	22-10-21
Evalutation + addition			
Self-evaluation	0%	26-10-21	28-10-21
Addition	0%	26-10-21	1-11-21



Start week displayed: 1

TASK	PROGRESS	START	FINISH
Deadlines			
Work plan	100%	3-09-21	3-09-21
Review work plan	100%	6-09-21	6-09-21
Methodology & design approach	100%	10-09-21	10-09-21
Review methodology & design approach	100%	13-09-21	13-09-21
Mid-term presentation	100%	21-09-21	21-09-21
Mid-term report	100%	24-09-21	24-09-21
Review mid-term report	100%	27-09-21	27-09-21
Preliminary results for report	100%	1-10-21	1-10-21
Draft summary/report	100%	8-10-21	8-10-21
Review draft summary/report	100%	11-10-21	11-10-21
Final report	100%	18-10-21	18-10-21
Final presentation	0%	25-10-21	25-10-21
Self-evaluation	0%	1-11-21	1-11-21
Addition (if relevant)	0%	1-11-21	1-11-21



Appendix B Historical-Morphological analysis

This appendix includes the historical maps of the years 1958, 1968, from 1980 up to 2010 in steps of five years, 2013, 2014 and 2021.

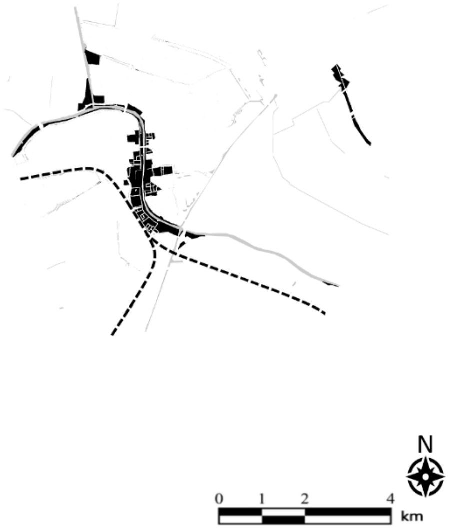


Figure B 1 Alphen aan den Rijn 1958

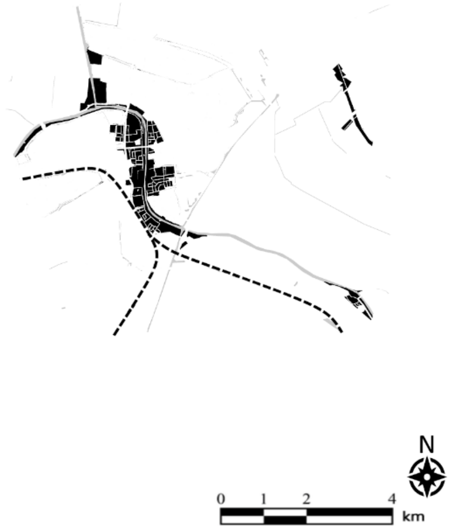


Figure B 2 Alphen aan den Rijn 1968

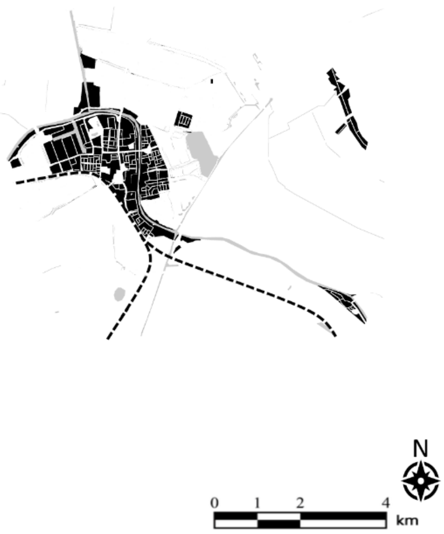


Figure B 3 Alphen aan den Rijn 1980

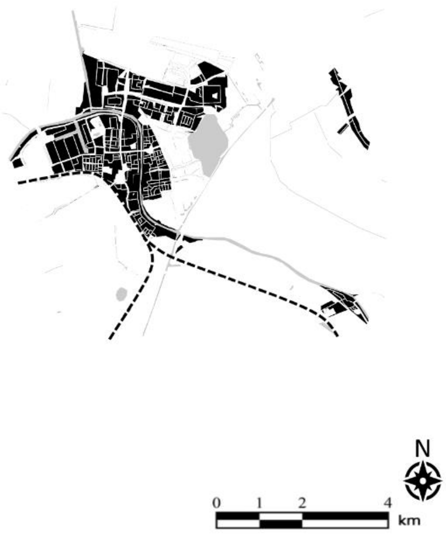


Figure B 4 Alphen aan den Rijn 1985

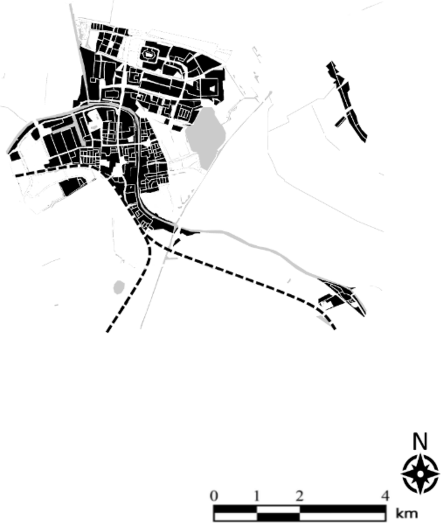


Figure B 5 Alphen aan den Rijn 1990

Figure B 6 Alphen aan den Rijn 1995

Figure B 7 Alphen aan den Rijn 2000

Figure B 8 Alphen aan den Rijn 2005

Figure B 9 Alphen aan den Rijn 2010

Figure B 10 Alphen aan den Rijn 2013

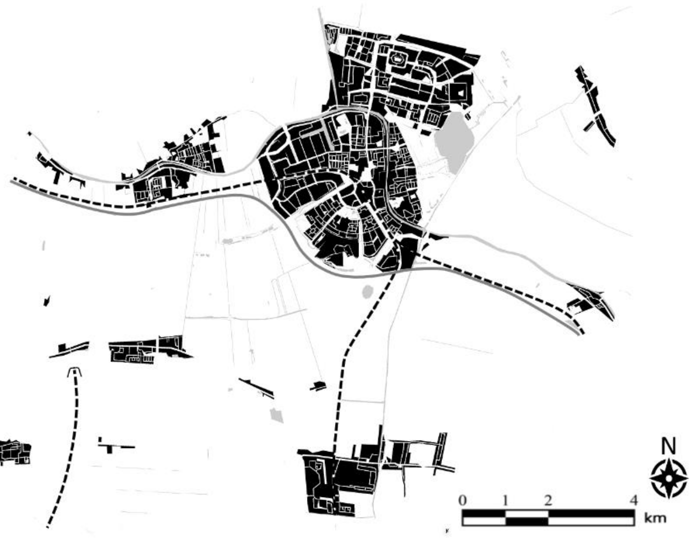


Figure B 11 Alphen aan den Rijn 2014

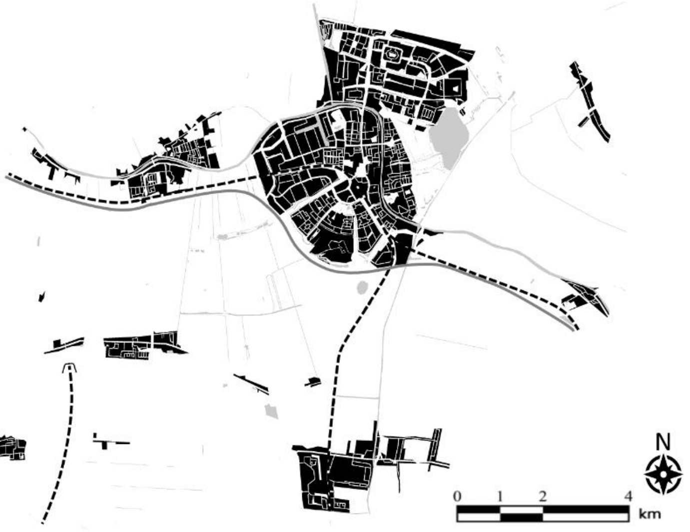


Figure B 12 Alphen aan den Rijn 2021

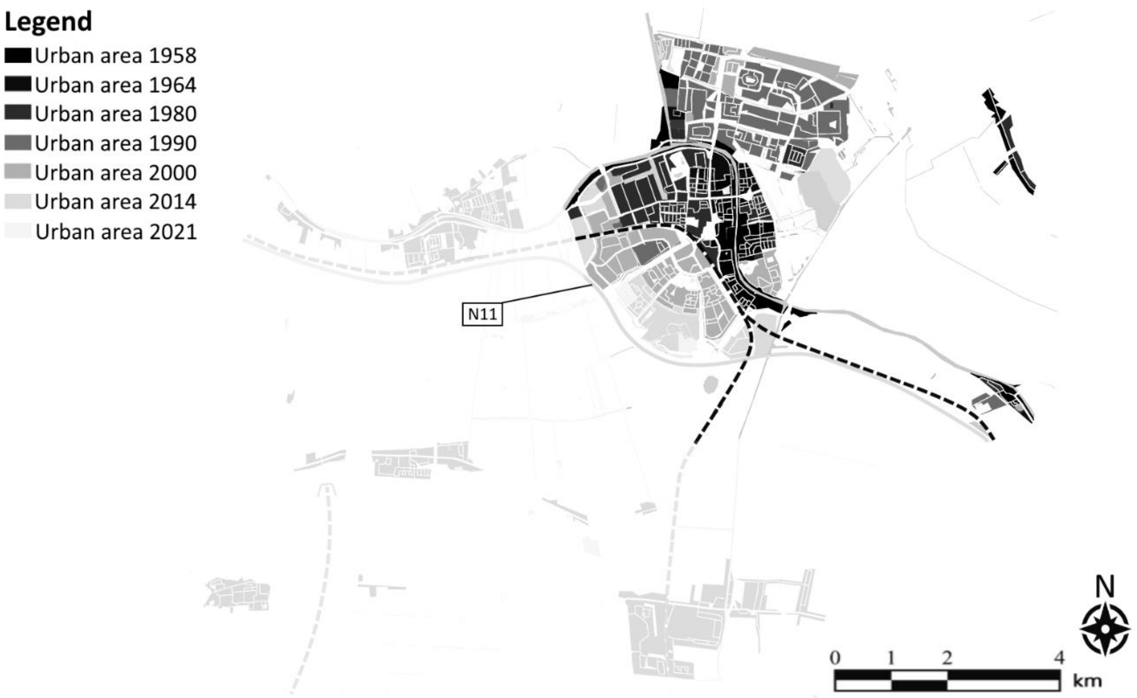


Figure B 13 Combination of the maps 1958, 1968, 1980, 1990, 2000 and 2014 with a colour gradient. Furthest back in time is displayed the darkest, the most recent the lightest.

Appendix C Detailed map of the current bicycle network

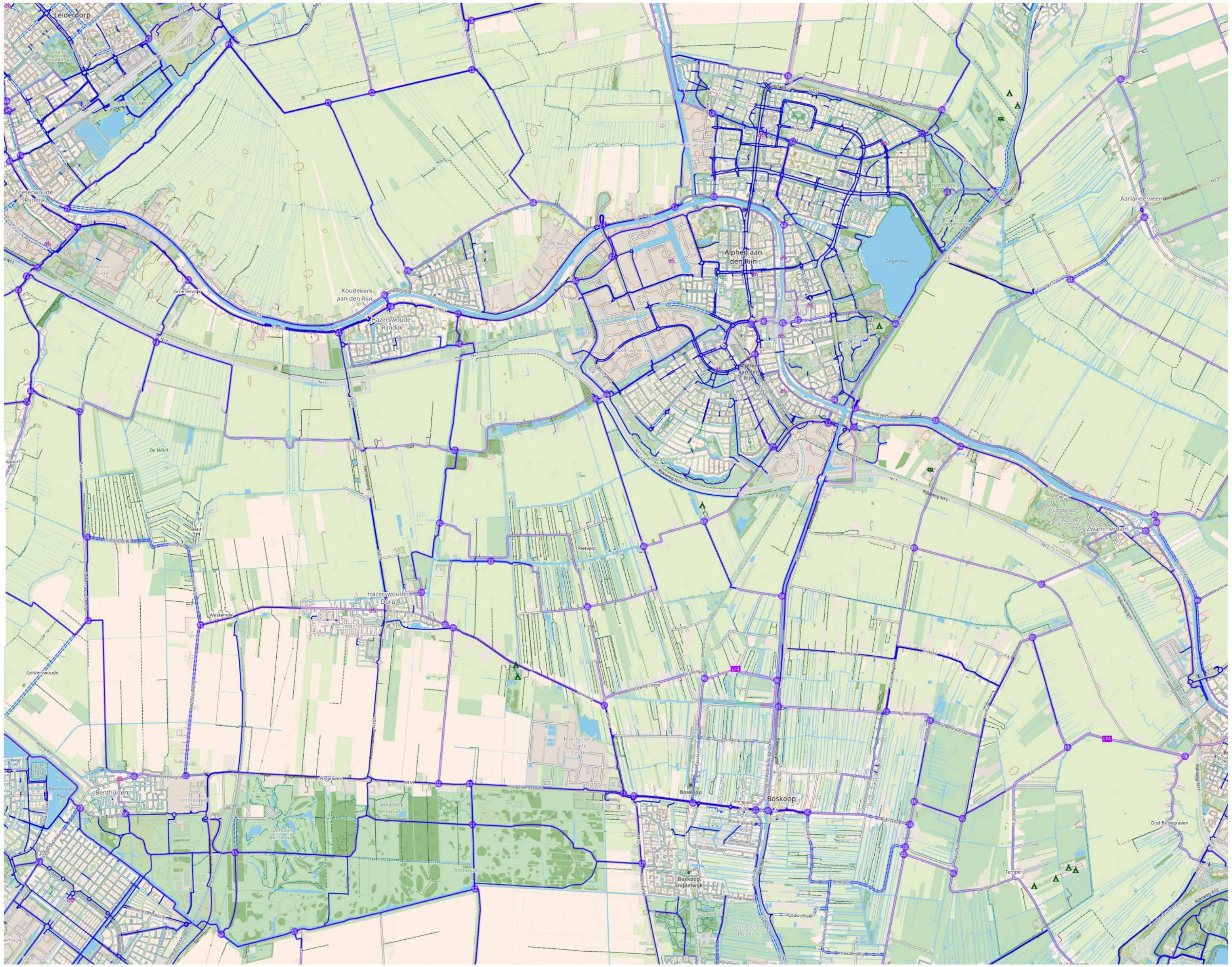


Figure C 1 Detailed map of the bicycle network of the municipality of Alphen aan den Rijn (CyclOSM, 2021)

Appendix D Stakeholder analysis

Table D 1 Stakeholder analysis scoring interest and power, with motivation (part 1).

Stakeholder	Interest	Power	Motivation
Municipality of Alphen aan den Rijn	++	++	The municipality of Alphen aan den Rijn is the project area in which the new design should be realized, which is why they are very interested in this project. They also have the greatest power since they are the local road authorities who bear the responsibility for a safe and good infrastructure within the municipality (Rijksoverheid, 2021).
Local resident 1: Cyclists	++	--	The local users of the cycle path experience the most effects of the changes that come from this project. They may have to change routes to be able to carry out their daily activities. This project should improve the situation for all of them in some respect compared to the current situation. They therefore have a very great interest in this project. However, they have no power to decide and implement the changes in the network themselves, which means that their power is very low.
Local resident 2: Different type of road users	++	--	All other locals which use another type of transport are influenced by the changes in the network as well. With a separated system, it is possible that more kilometres of bicycle paths may be built, which may result in more cross overs. It can also have the effect that more people take the bicycle for their daily activities, which leads to a decrease in the traffic of other types of transport. It can therefore have positive and negative consequences, which have a direct impact on this stakeholder. This ensures that they have a great interest in the project, but just like the cycling local residents, they have little power in this project for the same reasons.
GGD Hollands Midden (Municipal health service)	+/-	-	The GGD Hollands Midden is committed to good health for the inhabitants of the region (GGD Hollands Midden, 2021). As cycling is an important contributor for better population health (P. Oja, 2011), the municipal health service has an interest in this project. This interest is medium as it is uncertain whether this project services in getting more people to cycle. They do not have much power over the implementation of the network and are therefore ranked less than average in power.

Table D 2 Stakeholder analysis scoring interest and power, with motivation (part 2).

Stakeholder	Interest	Power	Motivation
Government	+/-	--	According to the road authorities, it is undesirable for the government to take over the power (Ministerie van Infrastructuur en Milieu, 2015). The local road authorities must retain responsibility, so the government does not have the decisive role in this project, but they have average power since they can still influence decision-making. They are interested in this project on a greater scale, but not on such a small scale as described in this report, so they therefore have low interest here.
Cyclist's Union 'Fietsersbond'	++	+/-	The cyclist union has drawn up the vision for 2040 that the new network must fulfil. The cyclist's union is therefore very interested in this project since it can help to partly realize that vision. They also have a supporting role in researching and informing the municipality and the government in this project. So, they have very high interest and medium power.
Association VVN 'Veilig Verkeer Nederland'	++	+/-	The Association VVN aims to make traffic as safe as possible throughout the Netherlands (VVN, 2021). The separate system that is designed in this report should lead to less internal conflicts in the bicycle network, which corresponds to a higher safety. This results in a high interest the VVN. The VVN has a moderate influence as it provides a supporting role in providing information and the contributions to safety.
Association RAI 'Rijwiel en Automobiel Industrie'	+	+/-	RAI represents the interests of manufacturers of all kinds of vehicles, including mopeds, light mopeds, and bicycles (Koninklijke RAI Vereniging, 2021). Given a new layout of the bicycle network, it is possible that more people start cycling, which influences the demand from these manufacturers, which results in their interest being higher than average The RAI Association is also in consultation with the municipality about a traffic solution for the future, which overs them a supporting role with medium influence on the project.

Table D 3 Stakeholder analysis scoring interest and power, with motivation (part 3).

Stakeholder	Interest	Power	Motivation
BOVAG	+	+/-	This branch organization focuses on mobility in all shapes and forms. BOVAG has an interest in this project as they offer space for knowledge sharing and support for innovation (BOVAG, 2021). BOVAG has a supporting factor as they are also put in close contact with municipalities to contribute to an integral traffic solution for the future (Ministerie van Infrastructuur en Milieu, 2015). Through this supporting factor they have some influence in the project but do not determine the exact outcome. Their power is therefore average, but their interest is higher than average.
Koninklijke Nederlandse Toeristenbond ANWB	++	+/-	The ANWB aims that everyone can travel with a carefree and pleasant feeling (ANWB, 2021). This corresponds to cycling happiness, which is described in the vision of the cyclists' union.
SWOV	+	+	The SWOV conducts research into road safety, the aim of which is to contribute to road safety by sharing this knowledge (SWOV, 2021). With this scientific information, SWOV has a major influence on the decision-making of the municipalities in new traffic plans. They also have more than average interest in the project as it should contribute to road safety and provides new insights for further scientific research
Police	+	-	For the police, this project can lead to changes in enforcement. It is therefore important that they are well informed about the new regulations and how they should be applied. The new concept should also be easy to maintain. This is a point that can be included in the research into a new design. However, this is not discussed further in this study. The police have a more than average interest in the project and a low power in decisions for the new design.

Appendix E Vehicle types

Table E 1 Vehicle types with representative photo (part 1).

 **(Nederlandersfietsen, 2021)**	 **(Nederlandersfietsen, 2021)**
Electric bike	Granny bike
 **(Nederlandersfietsen, 2021)**	 (Nederlandersfietsen, 2021)
Children’s bicycle	Mother bike
 **(Nederlandersfietsen, 2021)**	 (Decathlon, 2021)
Mountain bike	Racing bike

Table E 2 Vehicle types with representative photo (part 2).

 **(Nederlandersfietsen, 2021)**	 **(Fiets.com, 2021)**
Beach cruiser	Speed pedelec
 **(Nederlandersfietsen, 2021)**	 (Nederlandersfietsen, 2021)
Hybrid bike	Recumbent
 **(Fast & Furious Scooters, 2021)**	 (Nederlandersfietsen, 2021)
Scooter	Folding bike

Table E 3 Vehicle types with representative photo (part 3).

 **(Nederlandersfietsen, 2021)**	 **(Pham, 2014)**
Tandem	Disabled vehicle
 **(Nederlandersfietsen, 2021)**	 (Narasimhan, 2019)
City bike	Moped
 **(Fietsgoed.nl - Scholten, 2021)**	 (Yourlease fietsabonnement, 2021)
Cargo bike for freight	Cargo bike for people transport

Appendix F Multicriteria analysis

This appendix includes the calculations of the multicriteria analysis for three cases. The case in which the municipality of Alphen aan den Rijn has highest priority. The case in which the local cyclists have highest priority and lastly the case when no weighting factors are applied.

F.1 Multicriteria analysis with Municipality as highest priority

Table F 1 Multicriteria analysis network level 1 weighting factors by preference of the municipality.

Level 1							
		The serpent		The branch		The split	
Criteria	**Weight factor**	**Score**	**Score*WF**	**Score**	**Score*WF**	**Score**	**Score*WF**
Cohesion	20,00	5	100,0	4	80,0	2	40,0
Directness	6,67	1	6,7	4	26,7	3	20,0
Safety	30,00	3	90,0	2	60,0	4	120,0
Usability	13,33	3	40,0	2	26,7	5	66,7
Costs	30,00	3	90,0	4	120,0	2	60,0
Total score	100		3,3		3,1		3,1

Table F 2 Multicriteria analysis network level 3 weighting factors by preference of the municipality.

Level 3							
		The worm		The tripod		The extension	
Criteria	**Weight factor**	**Score**	**Score*WF**	**Score**	**Score*WF**	**Score**	**Score*WF**
Cohesion	20,00	3	60,0	4	80,0	3	60,0
Directness	6,67	5	33,3	2	13,3	4	26,7
Safety	30,00	2	60,0	4	120,0	3	90,0
Usability	13,33	4	53,3	3	40,0	5	66,7
Costs	30,00	1	30,0	4	120,0	3	90,0
Total score	100		2,4		3,7		3,3

F.2 Multicriteria analysis with local cyclist as highest priority

Table F 3 Multicriteria analysis network level 1 weighting factors by preference of the local cyclists.

Level 1							
		The serpent		The branch		The split	
Criteria	**Weight factor**	**Score**	**Score*WF**	**Score**	**Score*WF**	**Score**	**Score*WF**
Cohesion	20,00	5	100,0	4	80,0	2	40,0
Directness	20,00	1	20,0	4	80,0	3	60,0
Safety	33,33	3	100,0	2	66,7	4	133,3
Usability	20,00	3	60,0	2	40,0	5	100,0
Costs	6,67	3	20,0	4	26,7	2	13,3
Total score	100		3,0		2,9		3,5

Table F 4 Multicriteria analysis network level 3 weighting factors by preference of the local cyclists.

Level 3							
		The worm		The tripod		The extension	
Criteria	Weight factor	Score	Score*WF	Score	Score*WF	Score	Score*WF
Cohesion	20,00	3	60,0	4	80,0	3	60,0
Directness	20,00	5	100,0	2	40,0	4	80,0
Safety	33,33	2	66,7	4	133,3	3	100,0
Usability	20,00	4	80,0	3	60,0	5	100,0
Costs	6,67	1	6,7	4	26,7	3	20,0
Total score	100		3,1		3,4		3,6

F.3 Multicriteria analysis without preference in design criteria

Table F 5 Multicriteria analysis network level 1 without weighting factors.

Level 1							
		The serpent		The branch		The split	
Criteria	Weight factor	Score	Score*WF	Score	Score*WF	Score	Score*WF
Cohesion	20,00	5	100,0	4	80,0	2	40,0
Directness	20,00	1	20,0	4	80,0	3	60,0
Safety	20,00	3	60,0	2	40,0	4	80,0
Usability	20,00	3	60,0	2	40,0	5	100,0
Costs	20,00	3	60,0	4	80,0	2	40,0
Total score	100		3,0		3,2		3,2

Table F 6 Multicriteria analysis network level 3 without weighting factors.

Level 3							
		The worm		The tripod		The extension	
Criteria	Weight factor	Score	Score*WF	Score	Score*WF	Score	Score*WF
Cohesion	20,00	3	60,0	4	80,0	3	60,0
Directness	20,00	5	100,0	2	40,0	4	80,0
Safety	20,00	2	40,0	4	80,0	3	60,0
Usability	20,00	4	80,0	3	60,0	5	100,0
Costs	20,00	1	20,0	4	80,0	3	60,0
Total score	100		3,0		3,4		3,6