Safe Cycling in Rotterdam

Designing a safe bicycle route from the centre of Rotterdam to Schiedam

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by

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TU Delft

Preface

This report is written as a bachelor final project for the bachelor Civil Engineering at the Delft University of Technology.
The report can be read by everyone who is interested in bicycle paths or Transport and Planning in general without any previous knowledge.
Specialists interested in the applied methodology can refer to Chapter 3, while the analyses are detailed in Chapter 4. Decision-makers can find the research results in Chapter 8. Those interested in exploring alternative options can refer to Chapter 6. It is also beneficial to review the considerations leading to this design in Chapter 7. The requirements and preferences for this design are outlined in Chapter 5. Finally, Appendix A contains the project schedule, Appendix B lists the streets where the Municipality of Rotterdam plans to reduce the speed limit to 30 km/h, Appendix C includes the results from the traffic safety checker and the locations of the so-called black spots, and Appendix D photographs depicting the current situation in Rotterdam can be found.
I would like to thank my supervisors and examiners Kuldeep Kavta, Shadi Sharif Azadeh, and Yufei Yuan for guiding this project. Additionally, I want to express my gratitude to my fellow students Casper Polet, Daan van de Brug, Jarno Jorritsma, and Maïssae El Aazizi for reviewing my work every week.

Brigitte Nauta
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Summary

Traffic safety, particularly the safety of cyclists, is a big problem in Rotterdam. Between 2011 and 2020, Rotterdam has the most traffic fatalities per 100.000 inhabitants to Utrecht, Amsterdam, and The Hague (Verkeersveiligheidsvergelijker, 2021).

This research aims to address this problem by investigating the following research question: *What type of (re)design can improve safety on the bicycle route between the center of Rotterdam and Schiedam?* Three different designs were developed for this purpose. They were evaluated using a multi-criteria analysis based on the criteria of safety, accessibility, sustainability, social impacts, aesthetics, future-proofing, and costs. The bombings during World War II had a significant impact on the current infrastructure of Rotterdam. Currently, many roads still have a speed limit of 50 km/h, although the municipality of Rotterdam is in the process of changing this. By 2025, the speed limit on many roads will be reduced to 30 km/h. An example is that many of these roads now have separated bicycle paths. The primary requirement for the new design is that it should be safer for cyclists than the current design. This can be achieved by, among other things, ensuring that bicycle paths are sufficiently wide, ensuring that the road surface is smooth and non-slippery, and minimizing obstacles.

After comparing the three designs using the multi-criteria analysis, Design 3 ”Green Environment” scored the highest (see Table 1). In this design, more space is allocated for greenery, such as planting grass on tram tracks and vegetation alongside roads. Furthermore, this design addresses bicycle safety by implementing maximum widths for bike paths (2.25 meters) and ensuring that sidewalks are at least 2 meters wide.

Table 1: Total scores of the three different designs

Design	**Total score**
Design 1: Minimal & Functional	143
Design 2: Space for cyclists and pedestrians	168
Design 3: Green environment	169

Therefore, it is recommended to choose Design 3 ”Green Environment.” However, future research should also examine intersections along this route, and it is advisable to address other routes in Rotterdam as well.

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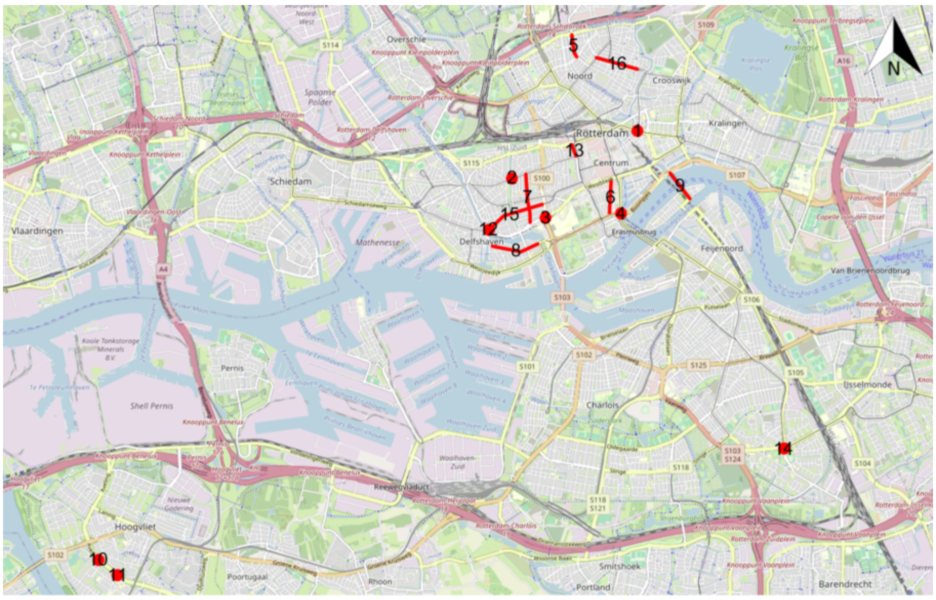
1
Introduction

Traffic safety, particularly the safety of cyclists, is a big problem in Rotterdam. Between 2011 and 2020, Rotterdam has the most traffic fatalities per 100.000 inhabitants compared to Utrecht, Amsterdam, and The Hague (Verkeersveiligheidsvergelijker, 2021). Additionally, traffic safety have consistently ranked in the top 3 concerns of Rotterdam residents (Gemeente Rotterdam, 2023b).

Since 2019, the municipality of Rotterdam has been trying to address residents' feelings of traffic insecurity through the Verkeersveiligheidsprikker. The Verkeersveiligheidsprikker is a survey among Rotterdam residents in which they can register their top three locations in the city where they feel the most unsafe in terms of traffic safety. This way, the municipality knows which locations need improvement. This survey was also conducted in September and October 2023. By the end of 2023, the first sixteen locations were announced, see Figure 1.1. Notably, many of these locations are situated west of the centre of Rotterdam, making a safe cycling route towards Schiedam almost impossible.



1. Intersection Goudsesingel – Meent – Jonker Fransstraat
2. Intersection Heemraadssingel – 2e Middellandstraat
3. Rochussenstraat – 's Gravendijkwal
4. Erasmusbrug – Vasteland
5. Rodenrijsestraat
6. Schiedamse Vest
7. Cleas de Vrieselaan
8. Willem Buytewechstraat
9. Willemsbrug
10. Aveling – Baarsweg – Holwinde
11. Aveling – Lengweg
12. Lage Erfbrug – Nieuwe Binnenweg
13. Kruisplein
14. Spinozaweg – Molenvliet – Pascalweg
15. Nieuwe Binnenweg (Delfshaven part)
16. Zaagmolenstraat

Figure 1.1: Sixteen most dangerous places in Rotterdam according to residents (Gemeente Rotterdam, 2023c) (Original map from Open Street Map, 2024)

This contention is further substantiated by the creation of a route via Google Maps, 2024 from the centre of Rotterdam to Schiedam. It results in four different routes, all passing by at least one of the locations, as shown in Figure 1.2. This report will primarily focus on route 1, as it is the shortest route in terms of distance and time, making it the most logical choice. Also the municipality of Schiedam expressed a desire in 2020 to create more space for cyclists on the Rotterdamsedijk (Gemeente Schiedam, 2020a), which can also be considered in this route planning. Furthermore, in 2024, the municipality of Rotterdam declared its intention to decrease the speed limit on additional streets from 50 km/h to 30 km/h. This includes Vierambachtstraat, 1ste Middellandstraat, 2nd Middellandstraat, and West-Kruiskade, which constitute a substantial segment of route 1 (highlighted in yellow in figure 1.2) (Gemeente Rotterdam, 2024). To effectively convey a reduction in speed to road users, a design focused on 30 km/h is essential.

Figure 1.2: Four different cycling routes from the center of Rotterdam to Schiedam according to Google Maps, 2024 (Original map from Open Street Map, 2024)

1.1. Research question

The aim of this report is to design a safe bicycle route from the centre of Rotterdam to Schiedam. This is done based on the following research question:

What type of (re)design can improve safety on the bicycle route between the centre of Rotterdam and Schiedam?

This is done based on the following sub-questions:

- Which analysis methods can be used for the (re)design of roads, and which analysis methods are relevant for the (re)design of the bicycle routes in this project?

  A comprehensive analysis of the problem is crucial to eventually achieve a good design. This analysis focuses on the current situation and identifies the existing shortcomings. Without a clear understanding of the problem, it is impossible to address it. An effective analysis method is determined by examining reference projects in the literature review.

- What is the historical, current, and future development of the area?

  For creating a new design, it is important to have a good understanding of the area. Past events can have a significant impact. Additionally, key locations that need to be preserved become apparent, it becomes clear who currently uses the roads, and what the 'black spots' in the network are. Identifying the 'black spots' will be done using the Verkeersveiligheidsprikker and STAR data. Looking towards the future can provide clarity on what should be avoided in the redesign.

- Who are the stakeholders, and what are their requirements and wishes?

  Stakeholders have a significant influence on the final realization, so it is important to consider their opinions as well. By answering this question, it becomes clear which stakeholders have a lot of influence in this area and what their requirements and wishes are. It is important to incorporate these requirements and wishes into the new design in order to persuade the stakeholders to choose this design.

- What are different types of bicycle paths, and how do they perform in improving safety?

  Based on the current designs, it can be determined which characteristics a safe design should have and which it should not have. This is important when creating a new design. The final designs, which are made according to the guidelines of the CROW Kennisbank, must then also be assessed for safety. The CROW disseminates expertise on infrastructure and mobility, and providing practical solutions that are immediately applicable in practice. They achieve this by making knowledge available through an online knowledge base, in guidelines, and through practical advice (CROW Kennisbank, 2023).

1.2. Stakeholders

There are several stakeholders involved in this project, each with their own perspective on how they believe the new designs should be formulated. These stakeholders include the municipality of Rotterdam, the municipality of Schiedam, the Fietsersbond, the ANWB, the government, RET, and local residents. In paragraph 4.2, a more in-depth analysis is conducted on the requirements and wishes of the stakeholders.

1.3. Reading guide

After reading this chapter, the objective of this project has become clear. In the following chapter, Chapter 2 Literature Review, similar projects and background information will be examined. Chapter 3 describes the methodology used to approach this project. Subsequently, various analyses will be conducted in Chapter 4, from which a program of requirements and wishes can be derived in Chapter 5. Based on this, the designs will be developed in Chapter 6, from which the optimal design will be selected in Chapter 7 through a Multi Criteria Analysis. Finally, in Chapter 8, the conclusions and recommendations will be presented. The schedule for composing this report can be found in Appendix A. In Appendix B, street names are listed where the municipality of Rotterdam is reducing the speed limit from 50 km/h to 30 km/h, in Appendix C, results from the traffic safety survey and the black spots identified by the municipality of Rotterdam are presented, and in Appendix D photographs illustrating the current situation in Rotterdam are presented.

2 Literature review

In this chapter, comparable projects are analyzed. This involves examining not only the solution implemented, but also the methodologies employes in the research. Furthermore, the development of the city of Rotterdam and the criteria for a safe bicycle path are explored.

2.1. Case study: Alphen aan den Rijn

Krutzen, 2021 conducted a study on how to design a safe cycling network for the municipality of Alphen aan den Rijn. This study is highly pertinent to the current research, as it addresses a similar objective in a different location. The study by Krutzen, 2021 includes a historical-morphological analysis, a stakeholder analyses, a MoSCoW analysis, a site analysis, and a multi-criteria analysis.

The historical-morphological analysis is employed to gain a deeper understanding of the complexity of the network (Crowther, 2016). The study utilizes maps from Topotijdreis to identify patterns that may contribute to predicting the growth of the urban system in the future.
Subsequently, a stakeholder analysis is conducted to gain understanding of the stakeholders involved in the project. These stakeholders are evaluated based on power and interest, with prior literature review aiding in their categorization.
The MoSCoW analysis provides clarity on the requirements that the project must fulfill and their respective priorities. Requirements are categorized into: Must, Should, Could, and Would. those in the Must category hold the highest priority and Would the lowest.
The site analysis identifies areas in the current design that fail to meet the specified requirements and therefore require solutions.
Finally, various designs are generated. The multi criteria analysis serves as the foundation for selecting the optimal design. Krutzen, 2021 utilized the criteria cohesion, directness, safety, usability, and costs. Weight factors, derived from the requirements and preferences of stakeholders, are employed to descern the most significant criteria. These factors are multiplied by the criterion scores and aggregated to obtain a total score. The design with the highest score is integrated with components of the current design still meeting requirements.

2.2. Case study: Fast cycle network in Amersfoort

de Jong, 2020 conducted a study on how to make long-distance and high-speed cycling more attractive. This was achieved by designing a high-speed cycling network through the city of Amersfoort, which should also connect to the existing cycling network in the province of Utrecht.

de Jong, 2020 used a three-step approach: establishing requirements, analyzing and mapping the current network, and redesigning the cycling network in Amersfoort.
The criteria for the cycle path were determined using CROW guidelines. Additionally, other requirements were identified by examining the needs of modern bicycles, such as speed pedelecs and cargo bikes, and by looking at reference projects. The plans of the municipality of Amersfoort and the province

of Utrecht were also considered.
In the analysis, the current network was mapping using MS Visio. The various networks were drawn on a background map from the Fietserbond. Subsequently, important connections within and outside Amersfoort were defined, and it was assessed on which connections higher speeds (>20 km/h) were already being achieved.
Finally, a redesign was developed, incorporating the requirements form the first step and the analysis from the second step to identify an optimal route. Ultimately, two routes were selected and further developed so that this process can be applied to the rest of the high-speed cycling routes in the future.

2.3. A little bit of history of Rotterdam and current developments

On May 14, 1940, Rotterdam was bombed, which had a significant impact on the city. Only a few buildings in the city center emerged relatively unscathed, including Het Witte Huis, the Schielandshuid, the city hall, the post office, the HBU building, the Atlanta hotel, the municipal libary, the exteriour of the Laurenskerk, and parts of the Bijenkorf and the Schouwburg. The Bijenkorf and Schouwburg were later demolished. (van Giersbergen & Spork, 2016) (Historisch genootschap Roterodamum, 2024)
Despite the complete destruction of the city center, debris clearance began immediately. This process took into account pre-war plans for city expansion, resulting in the filling in of the Rotterdamse Schie, Schiedamsesingel, Blaak, and Kolk. (van Giersbergen & Spork, 2016)
Four days after the bombing, the city architect Witteveen was commissioned to design a reconstruction plan, building on the earlier pre-war plan. However, due to significant criticism, he withdrew, and Cornelis van Traa took over the task. (van Giersbergen & Spork, 2016)

Reconstruction could only truly commence after liberation. Priority was given to the ports and the construction of the business and shopping center over housing and cultural facilities. The port expanded westward, increasingly distancing itself from the city. The housing shortage was addressed by constructing new, modern residential areas on the city's outskirts. To connect these neighborhoods, new roads were built, leading to the creation of the so-called 'ruit' around Rotterdam in the 1970s, a network of grade-separated four- and six-lane highways including the Van Brienoord bridge and the Benelux tunnel. (van Giersbergen & Spork, 2016)
In the current city, the post-World War II reconstruction is prominently reflected by the dominant role of

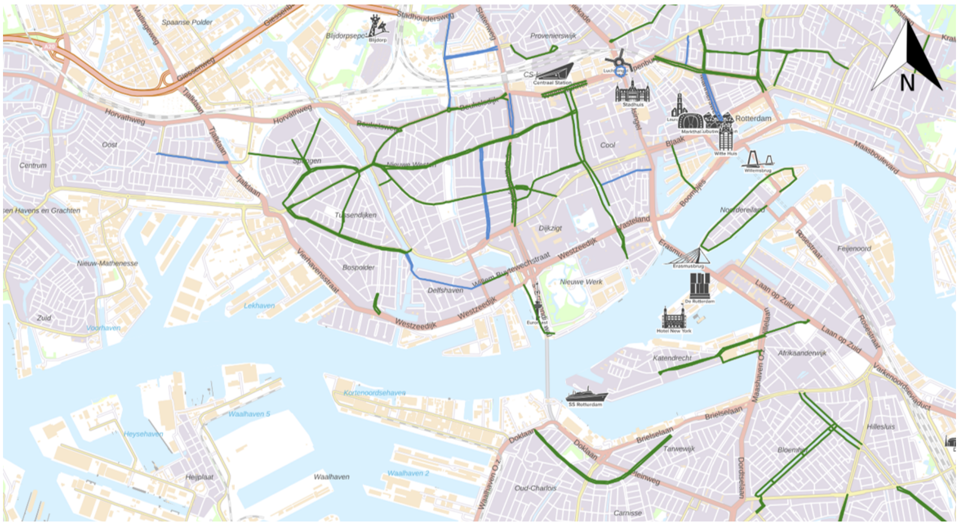


Figure 2.1: Streets where the speed limit changes from 50 km/h to 30 km/h. In blue, the streets where the speed limit is currently (2024) already being adjusted or has been adjusted, and in green, the streets where the speed limit will be adjusted in 2025. ((Gemeente Rotterdam, 2024))

automobiles in the infrastructure. Nonetheless, the municipality of Rotterdam is endeavoring to reallocate more space to alternative modes, such as cycling, walking, and public transportation. In 2023, the maximum speed limit on several streets in Rotterdam was reduced from 50 km/h to 30 km/h (Merkelbach, 2023), and by 2025, the municipality plans to extend this change to an additional 115 streets, see figure 2.1 also a list of the streets in the center of Rotterdam can be found in Appendix B. This initiative aims to decrease the likelihood of accidents, reduce traffic noise, and provide more space for cyclists and pedestrians in the redesigned urban layout (Gemeente Rotterdam, 2024).

2.4. Safe bicycle path

The objective of this report is to enhance cycling safety in Rotterdam and Schiedam. However, what does 'safe' actually mean? Van Dale, 2024 defines safe as 'protected from danger,' which is a fairly concise definition. A broader definition describes safety as the absence of potential causes of a hazardous situation. Safety can also encompass the presence of protective measures against these risks. Nonetheless, safety remains a subjective concept. Nothing is entirely without risk under all circumstances. There is no universal standard for safety. A situation may feel very safe to one individual, while the same situation may feel very unsafe to another. (Atlas Leefomgeving, 2024)

Hence, it is imperative to comprehend the primary reasons behind cyclists' sense of insecurity. The predominant factors contributing to a cyclist's feeling of insecurity within urban environments include non-adherence to traffic regulations by other road users, interaction with diverse traffic, high/variable speeds of other road users, and deficient infrastructure. (Blauw Research, 2022)
Foremost, the non-compliance with traffic regulations by other road users is a significant concern. The conduct of fellow cyclists profoundly influences the perception of safety. A considerable 21% of respondents report feeling constantly or frequently unsafe due to other road users, while 69% experience occasional unease. Factors such as mobile phone usage, cyclists riding abreast, and failure to signal direction significantly contribute to this phenomenon. (Blauw Research, 2022)
Interaction with diverse traffic leads 20% of cyclists to feel frequently or consistently unsafe, with 68% reporting occasional discomfort. This primarily pertains to motorized vehicles, such as cars, trucks, and buses, navigating the cycle lanes at high speeds. Interestingly, cyclists often feel more secure on a 30 km/h road devoid of dedicated cycle lanes or paths than on a 50 km/h road with such infrastructure (Blauw Research, 2022). Research indicates that increasing the separation between cyclists and other traffic results in fewer cycling casualties. Enhanced separation thus genuinely improves safety. Additionally, car journeys often take longer compared to the same trip by bicycle, which can further encourage cycling. (Schepers et al., 2013)
Additionally, the escalating utilization of cycle paths results in elevated and fluctuating velocities among cyclists. This circumstance engenders a sense of insecurity in a quarter of cyclists. Notably, sport cyclists present a greater concern in this regard compared to electric cyclists. (Blauw Research, 2022)
Lastly, substandard infrastructure emerges as a significant issue for cyclists. Approximately seven out of ten cyclists occasionally experience feelings of insecurity due to the condition of cycle paths. Predominantly, this concerns deteriorated road surfaces, tree roots, or uneven paving. Yet, other elements also pose hazards, including bollards, curbs, and the implementation of bidirectional paths (Baggerman, 2018). Sixteen percent of cyclists have encountered accidents in the past three years, with half of these incidents categorized as single-sided accidents. These involve collisions with objects or accidents attributable to poorly maintained cycle paths. (Blauw Research, 2022)

The solution to creating a safe cycling environment can thus be approached from various angles. A cyclist can take measures themselves to establish a safer situation, such as adhering to traffic regulations and utilizing aids like lights, mirrors, and/or a helmet.
This report primarily addresses the improvement of cycling safety in Rotterdam and Schiedam through infrastructural modifications. Nonetheless, aspects such as interaction with other traffic and measures to enhance adherence to traffic regulations can indeed be incorporated into this framework.
But what exactly does a safe design entail? Firstly, it is crucial that the road surface is flat, free from irregularities caused by tree roots, subsidence, or uneven tiles. Additionally, the friction of the road surface is crucial. A slippery surface can occur not only due to ice but also from substances on the roads, such as oil, wet leaves, sand, or from the material of the road surface itself or component incorporated into it, such as cobblestones, cattle grids, tram rails, zebra crossings, and plates used during roadworks (Baggerman, 2018).
Furthermore, bollards should be minimized in the design. They are often poorly visible, especially in the dark. Decisions regarding the placement of bollards should therefor be carefully considered. If

they are deemed necessary, careful consideration must be given to their design. For instance, bollard should be never positioned on the 'natural' trajectory of cyclists, it should be immediately clear which passage cyclists are expected to take, and it is preferable to maximize the distance between the bollards (CROW Kennisbank, 2023).

Additionally, bicycle paths should be wide enough. Often, bidirectional bicycle paths are implemented without adjusting the width of the path accordingly. This makes it difficult for cyclists traveling in opposite directions to pass each other. Therefore, the width of the bicycle path should be adjusted when it is a bidirectional path, and it should also be clearly indicated when two-way traffic is permitted, for instance through clear center line markings. This should be apparent not only to cyclists but also to motorists, so they expect cyclists from both directions. This can be achieved through warning symbols, such as a warning triangle with two arrows (see Figure 2.2 (Baggerman, 2018).

Even when bicycle paths are sufficiently wide, cyclists may still need to swerve off the path. Therefore, at the boundary between the bicycle path, and, for instance, the footpath, edges should be minimized. These are often misjudged. It is preferable to replace them with clear lines and color differences, making the edges and verges more forgiving and allowing for evasive maneuvers if necessary (Baggerman, 2018).

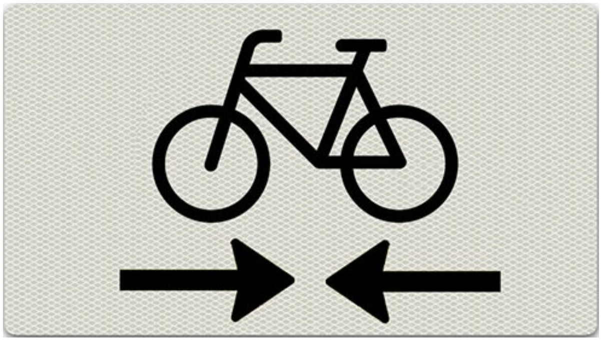


Figure 2.2: Warning sign to indicate bidirectional bicycle traffic (image from BARRERA, 2024)

3 Methodology

In this chapter, the methodology is described. Broadly, it consists of the following steps: doing a literature review, analysis, establishing requirements, design, and evaluation.

3.1. Literature review

Firstly, a literature review was conducted. This involved examining other reports to gain insight into how a design report can be conducted and what is most logical for this subject. Initially, searches were conducted on scientific websites, such as Google Scholar and Scopus. However, finding design reports proved to be quite challenging. Therefore, Y. Yuan eventually provided some reports from other students via his website (Yuan, 2024). This reports were searched with using the keyword 'network design'.

The literature review also delves into the history of Rotterdam, which has had a significant influence on its current infrastructure and developments. Additionally, it explores the precise meaning of safety and the criteria that a safe bike lane must meet. For both aspects, academic databases such as Google Scholar and Scopus are utilized. If these sources do not yield sufficient information, other sources such as Google may also be utilized. Searches are conducted in both English and Dutch. For history and current developments, search terms such as "Geschiedenis Rotterdam"/"History of Rotterdam", "Gemeente Rotterdam"/"Municipality Rotterdam", and "beleidsplannen gemeente Rotterdam"/"policy plans municipality Rotterdam" are used. For the definition of a safe bike lane, searches include "veiligheid"/"safety", "eisen fietspad"/"requirements bike lane", "veilig fietspad"/"safe bicycle lane", and "veilige fietsstrook"/"safe bicycle path".

3.2. Analysis

The analysis begins with an examination of the current situation through a morphological analysis. In a morphological analysis, an infrastructure network is essentially deconstructed into its individual components. This can be performed in various ways, each with specific objectives, such as a the layer approach or methods of Geurtsen, Lynch, or Cullen. This report uses the layer analysis method. In this approach, the network is subdivided into sub-networks, such as primary infrastructure, secondary infrastructure, buildings, public facilities, and surrounding landscape. (van den Brug, 2024) For this project, it is particularly useful to identify the locations of bicycle paths and lanes, their surroundings and other road users. This is achieved by categorizing into three different bicycle paths (shared with cars, separated unidirectional and separated bidirectional), different roads (30 km/h and 50 km/h), and tram lines, using the Visio software for clear representation. In Visio, a screenshot of a map is used as a base layer, over which other layers are drawn to provide clarity. Subsequently the weaknesses in the network are identified. This primarily involves using the Verkeersveiligheidsprikker and the 'black spot' identification from the municipality of Rotterdam. 'Black spots' are locations where six or more injury accidents have occurred annually for three consecutive years. A brief review of the Smart Traffic Accident Reporting (STAR) data will also be conducted. STAR is a program that records the locations of all registered accidents. It is important to note that only reported accidents are included here, with

serious traffic accidents reported thought the police and non-serious ones through insurers. The STAR data can be further filtered by vulnerable and non-vulnerable road users, severity of the accident (property damage only, at least one injury, or at least one fatality), and age (0 to 24, 25 to 64, and 65+) (STAR, 2024). In this report, the filter for vulnerable or non-vulnerable users looks particularly relevant. However, caution is advised in using this source, as vulnerable road users may include a wide range of vehicles such as mobility scooters, speed pedelecs, mopeds, motor scooters, quadricycles, motorcycles, and quads, which are not specifically relevant to bicycle safety. Therefore, STAR data will primarily be used to identify locations with few to no accidents involving vulnerable road users and cyclist.
After the morphological analysis and identification of hazardous points are completed, the locations identified as unsafe are examined to determine any correlations. Additionally, these locations are visited to gain a better understanding of the design flaws that need to be addressed in a redesign.
Subsequently, a stakeholder analysis is conducted to identify the project's stakeholders and understand their requirements and wishes. Due to time constraints, assumptions will be made regarding the requirements and wishes of stakeholders. This is based on their perspectives as outlined in policy documents, typically accessible online via Google. A program of requirements and preferences can be formulated based on the stakeholders' perspectives.

Finally, a forecast is made regarding the development of the current situation if no action is taken. A SWOT analysis is applied to identify the strengths, weaknesses, opportunities, and threats. The strengths and weaknesses are more focused on the current situation. These points will primarily be determined based on the preceding analysis in this chapter, and effectively serving as a summary of this chapter. The opportunities and threats are more future-oriented and may also correlate with the strengths and weaknesses.

3.3. Requirements

In terms of requirements, the initial consideration is the requirements derived from the CROW guidelines. The CROW guidelines are the Dutch standards for road design and the final design must comply with these standards (CROW Kennisbank, 2023). For this report, the Chapter Fietsverkeer (bicycle traffic) is particularly pertinent. This chapter primarily addresses the application of various design approaches. The design is significantly influenced by the type of road (through road, distributor road, or access road), the speed limit, and traffic intensity (CROW, 2016). During the design phase, the CROW guidelines will be further consulted for specific requirements and dimensions.
After summarizing the requirements from the CROW guidelines, the report further elaborates on the requirements and wishes set by the client and other stakeholders (Werken aan projecten, 2024a). These have already been partially identified in chapters 2 and 4 and are summarized here into a comprehensive list. This list is an essential tool for avoiding ambiguity and will serve as a guide during the design process (Kraan, 2023). The requirements are standards that the final design must meet. They must be clearly defined, with no room for assumptions. Furthermore, requirements can be both functional and qualitative (Bosgra, 2019). In addition to the requirements, there are also wishes, which the design does not necessarily need to fulfill. Wishes are functional benefits or user preferences, and although they are not mandatory incorporating them into the design can be advantageous (Bosgra, 2019).

3.4. Design

Once the requirements and wishes for the redesign have been determined, a new design can be made. In this process, designs from CROW are initially examined. The guidelines provided by CROW will be used as guiding principles during the design phase. The CROW Kennisbank is an online resource on infrastructure, traffic and transportation, and public space. CROW also frequently uses examples in its explanations. For this project, the chapter on 'Fietsverkeer' will be primarily used. (CROW Kennisbank, 2023) Additionally, inspiration can be drawn from similar projects. Priority is given to improving safety at the "black spots". If time permits, the rest of the network will also be evaluated and adjusted if necessary. The Double Diamond method is employed during the design process. This is an iterative process focusing on the questions: "Are we designing the right thing?" and "Are we designing it well?" (van 't Veer et al., 2021).

3.5. Evaluation

During the evaluation phase, the diverse designs are subjected to a Multi Criteria Analysis, with the program of requirements and wishes as a guideline. This approach identifies the best designs. Ultimately, the conclusions and recommendations are formulated based on the outcomes of this analysis. The initial step involves defining the evaluation criteria. These criteria are determined based on the requirements and preferences of stakeholders, as well as factors such as sustainability and comfort. In this study, there is chosen for the following criteria:

- **Safety:** In this context, safety concerns the traffic safety of cyclists. This is assessed bases on the following factors: protection from other traffic, the width of the bike lane, the quality of the road surface, and the edges of the bike path (CROW, 2016). The design with the highest score will ultimately lead to the fewest accidents.
- **Accessibility:** The main concern is whether the design is usable for all road users. Can someone in a wheelchair or using a walker, who generally requires more space, also utilize the route? (Bartiméus, 2024) Additionally, the route should be logical and should not, for example, necessitate significant detours for cyclists due to the selection of a unidirectional bike lane where a bidirectional bike lane would be more appropriate. (CROW, 2016)
- **Sustainability:** Sustainability refers to products or resources obtained in a manner that minimally impacts the environment and nature. Additionally, a design intended to have a long lifespan is also highly sustainable. (Onze Taal, 2024)
- **Social impacts:** The environment, including local residents, must also be satisfied with the design. If this is not the case, they may protest, potentially causing delays. Key aspects here include: promotion of health and well-being (considering noise pollution and air quality) and social safety (visibility and social control).
- **Aesthetics:** The new design should be visually appealing. This can be achieved in various ways, and innovation is acceptable, but it must align with the current surroundings (FlexiSpot, 2022). Rotterdam must maintain its identity.
- **Future-proof:** When significant modifications are made, it is crucial that the design also meets future requirements. The bike lane should be prepared to accommodate changes in usage over time. An important factor in this is the increasing diversity of bike lane users, including variations in vehicle speed and size, as well as the age of the cyclists. (CROW, 2021)
- **Costs:** Lastly, it is crucial to consider the costs as well. Clients, such as the municipality, prioritize innovation, yet they also place significant emphasis on fiscal responsibility. (Werken aan projecten, 2024b)

Subsequently, the criteria are measured and standardized, enabling a comparable assessment of the different criteria. It is most practical if all criteria are measured on a uniform scale, such as percentages or a 5-point scale, where 5 is the best score and 1 is the worst. Then, weighting can be applied to the different criteria. This is done using a 10-point scale. Safety receives the highest score (10), as it is the main objective of the project and therefore the most important criterion. Next come accessibility and social impact, it is important that everyone can use the new design, and residents who heavily utilize the design must also be satisfied. If the disagree with the design, it will be difficult to implement it. Subsequently it is also important that the design is future-proof. There is no point in implementing a design now if it proves ineffective in a year. Sustainability is reasonably high on the agenda nowadays, including in the making of this design. It is crucial that the Earth is not depleted and that future generations can also enjoy it (Nottelman et al., 2024). Criteria that are less important, but still influential, include aesthetics and costs. If a design scores very high on the rest of the criteria but is costly, it is highly that it will not be chosen, sometimes simply because the client cannot afford the project (Werken aan projecten, 2024b). The same goes for aesthetics, it must look attractive and fit into the surroundings, but this is not the primary goal of the design. All of this ultimately translates into the weighting factors as shown in Table 3.1.

Finally, after determining the weighting factors, the different designs are ranked based on the results. The total score of the design is the score per criterion multiplied by the weighting factors, and then the

Table 3.1: Multi Criteria Analysis weighting factors

Criteria	**Weight factor**
Safety	10
Accessibility	8
Sustainability	6
Social impact	8
Aesthetics	2
Future-proof	7
Costs	3

sum of all criteria. Ultimately, the best variant will emerge from this process. (Zijlstra & Rooij, 2020)

4

Analysis

This chapter performs an analysis of the environment. This is accomplished through an analysis of the current situation, a stakeholder analysis, and a SWOT analysis.

4.1. Analysis of the current situation

In this section, an analysis of the current situation is conducted. Initially, a morphological analysis is performed on the bicycle route and the surrounding area. Subsequently, the public transport network is assessed. Weak points within the network are then identified and subsequently visited and further analyzed based on these inspections.

4.1.1. Morphological analysis

In figure 4.1, the morphological analysis is presented of the three different types of bicycle paths (shared with cars, separated unidirectional, and separated bidirectional), different roads (30 km/h and 50 km/h), and tram lines. It is noteworthy that a relatively high number of roads now have a speed limit of 50 km/h, particularly in the vicinity of city centers. This contributes to a situation where many roads are used by both cyclists and cars.
Additionally, this setup does not appear to favor bicycles over cars. This trend is also reflected in the results of the mobility strategy employed by the municipality of Rotterdam. Most car trips within the city cover less than 5 kilometers, a distance at which travel by bicycle, scooter, or public transport is often faster. (Gemeente Rotterdam, 2020)

When examining the selected bicycle route in more detail, it becomes apparent that it predominantly traverses 50 km/h roads. Along these routes, separated bicycle paths are primarily present, with the exception of a segment near the center of Rotterdam on West-Kruiskade. Furthermore, the majority of these paths are unidirectional, except for sections on Rotterdamsedijk and Schiedamseweg, where a bidirectional bicycle path is located.

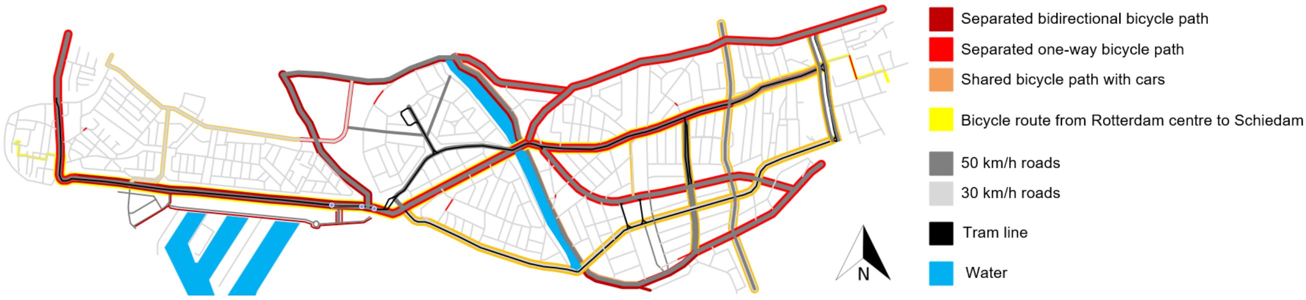
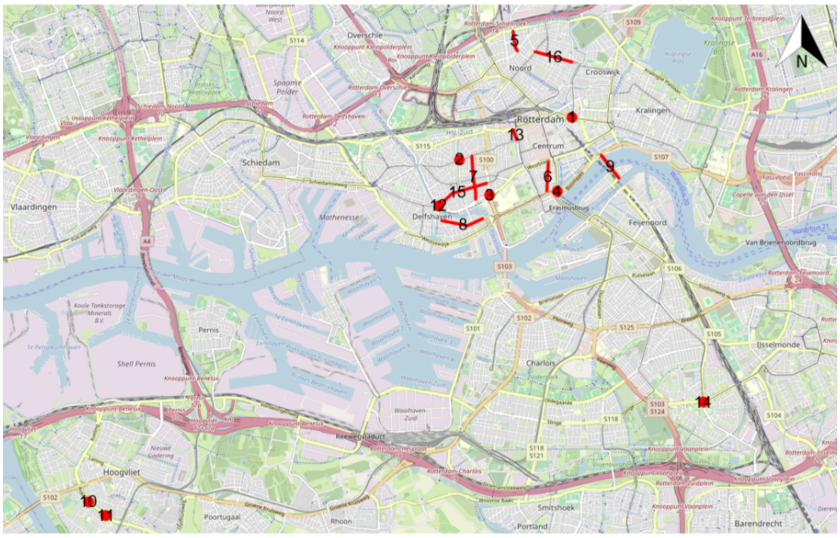


Figure 4.1: Morphological analysis of the area around the bicyle route from the centre of Rotterdam to Schiedam

4.1.2. Unsafe locations

In addition to the locations identified using the Verkeersveiligheidsprikker (shown in Figure 4.2), there are also seven 'black spots' (Gemeente Rotterdam, 2023a). One of these 'black spots' is located on the bicycle route from the center of Rotterdam to Schiedam, specifically at the intersection of 1e Middellandstraat, Henegouwerlaan, and 's Gravendijkwal. Similar to the locations identified by the Verkeersveiligheidsprikker, the municipality of Rotterdam already plans to address these 'black spots' in 2024.



1. Intersection Goudsesingel – Meent – Jonker Fransstraat
2. Intersection Heemraadssingel – 2e Middellandstraat
3. Rochussenstraat – 's Gravendijkwal
4. Erasmusbrug – Vasteland
5. Rodenrijsestraat
6. Schiedamse Vest
7. Cleas de Vrieselaan
8. Willem Buytewechstraat
9. Willemsbrug
10. Aveling – Baarsweg – Holwinde
11. Aveling – Lengweg
12. Lage Erfbrug – Nieuwe Binnenweg
13. Kruisplein
14. Spinozaweg – Molenvliet – Pascalweg
15. Nieuwe Binnenweg (Delfshaven part)
16. Zaagmolenstraat

Figure 4.2: Sixteen 'black spots' in Rotterdam according to residents (Verkeersveiligheidsvergelijker, 2021) (Original map from Open Street Map, 2024)

When examining the STAR data on accidents involving vulnerable road users between 2019 and May 2024 (see Figure 4.3, it appears that significantly more accidents occur on the streets of Rotterdam. However, as noted in Chapter 3, it is uncertain whether these accidents involve cyclists or other vulnerable road users. What can be inferred is that in the center of Schiedam, no accidents occur, as no accidents are reported on the map for this area.

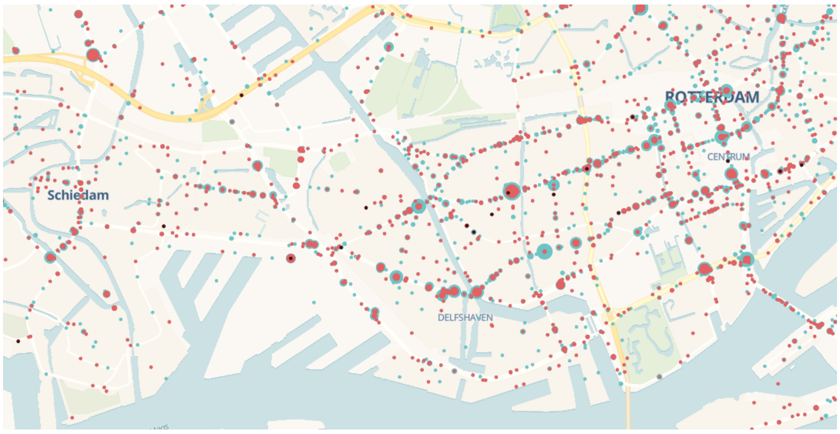


Figure 4.3: Map from Smart Traffic Accident Reporting, 2024, where blue represents accidents involving only property damage, red represents accidents involving at least one injury, and black represents accidents involving at least one fatality.

4.1.3. At location

During a visit to the area, it becomes apparent that there is a relatively large amount of space allocated for cars, both for moving vehicles and for parking. This is also evident in Figure 4.4(b) which shows the Mathenesserlaan. Here, there is no bike path, but there is extensive space for car parking, both on either side of the main road and along the parallel road that runs alongside it. Additionally, the presence of numerous roadside trees is notable. While enhancing the area aesthetically, these trees contribute to potentially hazard road conditions in autumn due to fallen leaves, posing a significant risk, particularly for cyclists.

I experienced crossing from Heemraadsingel over the 2e Middellandstraat, see Figure 4.4(a), as quite daunting. This intersection is also listed in the locations of the Verkeersveiligheidsprikker. The primary reason for the perceived dangers is the absence of traffic signals at this intersection, with cars currently traveling at a speed of 50 km/h along the 2e Middellandstraat. Furthermore, Heemraadsingel sees a relatively high volume of traffic without a designated bike lane for cyclists. Finally, there is also a tram line at this intersection, which further complicates the situation.

Additional images depicting the current situation in Rotterdam can be found in Appendix D.

(a)

(b)

Figure 4.4: Photos on location: (a) Mathenesserlaan; (b) intersection Heemraadssingel - 2e Middelandsstraat

4.2. Stakeholder analysis

As previously mentioned in the introduction, there are various stakeholders involved in the project, all of whom have a say in the new design. This paragraph discusses the different stakeholders and their requirements and wishes.

4.2.1. Municipality of Rotterdam

The municipality of Rotterdam is a key stakeholder. They will ultimately have to finance the project and make the final decision.

The Municipality of Rotterdam prepares a Mobility Plan with an accompanying Implementation Plan every few years. In the current plans from 2020, the emphasis is on, the three V's in Dutch: Volume, Change, and Cleanliness. Volume refers to reducing short car trips within the city and decreasing traffic in the city center. Change involves transitioning from cars to other modes of transportation, such as public transport or active and healthy mobility. And Cleanliness focuses on reducing CO_2 emissions and noise pollution by using cleaner modes of transportation. (Gemeente Rotterdam, 2020)

4.2.2. Municipality of Schiedam

The bike route also passes through the municipality of Schiedam, so they will also have to make a decisive decision in the end. When looking at the Mobility Plan of the municipality of Schiedam, it can be seen that Schiedam focuses mainly on: traffic flows, public transport, shared mobility, neighborhood parking, cyclists and pedestrians, electric transport, traffic safety, and inclusive mobility.

Schiedam aims to be a livable, green, and attractive city. They want to achieve this by giving more space to pedestrians and cyclists and directing through traffic onto roads with a maximum speed of 50 km/h. Additionally, the city center must be more accessible and faster for local traffic. Despite the fact that slow-moving traffic is prioritized in the city center and on certain roads, where the speed limit will decrease from 50 km/h to 30 km/h. (Gemeente Schiedam, 2020b)

4.2.3. Fietsersbond

The Fietsersbond represents the interests of cyclists in the Netherlands. Many of the Fietsersbond's positions primarily focus on bicycle safety. They believe that bike paths should be well-maintained for both comfort and safety. According to them, the current bike paths are not designed for an aging society. Older people need more time and space to correct steering mistakes. Furthermore, posts on bike paths are not recommended.

The Fietsersbond is also not very enthusiastic about two-way bike paths. These paths see a lot of overtaking, which leads to dangerous situations. Additionally, motorists from side streets are not prepared for this. Two-way bike paths are only advisable if cyclists would otherwise ride against traffic because the alternative route is too cumbersome or it is dangerous to cross.

Conversely, the Fietsersbond is highly supportive of bicycle streets. These are streets where cyclists have priority and cars are considered guests. The design of bicycle streets, featuring a cobblestone strip in the center, ensures that cars cannot drive at high speeds and that cyclists have the right of way. When bicycle streets are properly constructed, they enhance traffic safety. Furthermore, bicycle streets provide safe primary routes for cyclists. (Fietsersbond, 2024)

4.2.4. ANWB

The ANWB, Algemene Nederlandsche Wielrijders Bond, is an organization that focuses on promoting mobility, traffic safety, leisure activities, and holidays for everyone. The mission of the ANWB is to make it possible for everyone to travel carefree and with pleasure, within a sustainable society. They achieve this, among other things, by mediating to serve societal or individual interests, eliminating barriers, preventing and resolving issues, urging governments, businesses, and other organizations to take action or abstain from it, and taking initiative when other agencies or companies fail to fulfill their duties. (ANWB, 2024a)

When considering the viewpoints of the ANWB regarding 30 km/h roads, they generally argue that the layout of these streets rarely necessitates driving at 30 km/h anywhere. Nonetheless, they support the implementation of a 30 km/h speed limit due to the significantly lower probability of a fatal accident (at 30 km/h, the chance of a fatal accident is less than 10%, compared to approximately 50% at 50 km/h). Furthermore, they observe that there is currently a diverse range of 'slow' road users on the cycle path, resulting in hazardous situations. They advocate for a maximum speed limit on the cycle path of 20 or 25 km/h. Most accidents occur on urban roads with speeds of 50 and 70 km/h. In this context, it is crucial that the maximum speed limit aligns logically with the road design. Additionally, the visibility of the maximum speed limit on these roads needs improvement.(ANWB, 2024b)

4.2.5. Government

In the plans for the new coalition agreement, PVV, VVD, NSC and BBB, 2024, little is known about plans for (bike) infrastructure. Therefore, for now, we're sticking with the 'old' coalition agreement from Rijksoverheid, 2021.

In this agreement, traffic safety is one of the focal points. This is to be achieved by reducing the maximum speed within built-up areas to 30 km/h wherever possible.

The government also aims to invest in the expansion and improvement of infrastructure for public transport, cycling, cars, and water, with the aim of creating a good and faster connection between the city and the region.

Lastly, the government is committed to promoting social safety and improving the accessibility of public transport for people with disabilities. This includes investments in bike parking facilities at public transport hubs and bike highways.

4.2.6. RET

The RET is the company responsible for regional public transportation in the Rotterdam area (RET, 2023). Several metro and bus lines also run along the routes undergoing redesign.The expectation is that they primarily aim to minimize disruptions to public transportation. Additionally, it's important that the redesign provides ample space for the existing lines.

4.2.7. Local residents

Local residents prioritize safety and thus place high importance on addressing dangerous locations. Additionally, they find it essential that their homes remain accessible by foot, bicycle, and car. A green living environment also significantly contributes to their overall satisfaction. During the implementation of plans, it is crucial for them to be involved in the process and have their opinions taken into account.

4.3. SWOT-analysis

After conducting the above analysis, several findings have emerged. Specifically, the current situation reveals a relatively generous allocation of space for traffic. While this space is predominantly occupied by cars at present, there exists potential to repurposed it for alternative mode of transportation such as bicycles or pedestrians. However, a significant challenge arises form residents' strong preference for convenient car accessibility. They are accustomed to this accessibility, and any proposed changes would necessitate behavioral adjustments among residents. Otherwise, a reduction in car capacity would directly result in increased traffic congestion and a considerable decrease in accessibility, which is a concern for the municipality as well.
These findings, along with others previously mentioned, have been categorized in Table 4.1 into strengths, weaknesses, opportunities, and threats. The strengths and opportunities will be maximized as much as possible in the new design. Weaknesses and threats need to be mitigated or addressed effectively.

Table 4.1: SWOT-analysis

Strengths - There is relatively a lot of space - The municipality wants more space for cyclists and pedestrians - There are many separated bicycle paths	**Weaknesses** - The current design is primarily focused on cars - Residents are attached to the good accessibility by car - There are many trees along the road
Opportunities - There is enough space to create more room for cyclists and pedestrians - Promoting bicycle use and other sustainable modes of transportation, such as public transport and walking	**Threats** - When the number of cars remains this high, it affects the health of residents (noise and air pollution) - The municipality of Rotterdam aims to maintain good accessibility by car for local traffic

5 Requirements

In this chapter, the requirements that the design must meet will be established. First, the CROW guidelines will be reviewed. Subsequently, the remaining requirements and wishes for the design will be formulated based on chapters 2 and 4.

5.1. CROW guidelines

To limit the diversity of types of applications for bicycle lanes, CROW proposes various designs. These designs primarily adhere to the following principles:

- Wider bicycle lanes contributes more significantly to objective and subjective traffic safety.
- Bicycle lanes should always accommodate two cyclists riding abreast.
- The width of the travel lane should provide motorists with clarity regarding desired behavior.

These three principles culminate in three distinct designs for bicycle lanes: separated bicycle lanes with dedicated domains for cyclists and motor vehicles, bicycle lanes featuring a wide central travel lane for bidirectional automobile traffic, and bicycle lanes incorporating a narrow central travel lane for bidirectional automobile traffic.

In separated bicycle lanes with a dedicated domains for cyclists and motor vehicles, cyclists and motor vehicles are segregated. This profile is suitable urban distributor roads with a maximum speed limit of 50 km/h and a high volume of motorized traffic. A buffer zone, which can incorporate continuous markings and/or distinct surfacing, is implemented between the bicycle lane and the travel lane. While a segregated bicycle path is preferred on urban distributor roads, it should only be employed where sufficient space is available. The design featuring separated bicycle lanes is recommended for effective pavement widths ranging from 1030 to 1180 centimeters.

The profile featuring bicycle lanes with a wide central travel lane for car traffic is particularly suitable for urban ”grey roads”. Grey roads are characterized by a 50 km/h speed limit, but lower speeds are desirable due to frequent interactions among motorists, cyclists, and oncoming traffic. If achieving a maximum speed limit of 30 km/h is unfeasible, a design speed of up to 40 km/h should be pursued. Ideally, these roads, which according to the principles of SWOV, 2018b, should be avoided, are still heavily used due to spatial constraints. In this design, the central travel lane accommodates to passenger cars traveling in opposite directions to pass each other at moderate speeds without encroaching on the bike lanes. However, if a bus or truck approaches from the opposite direction, at least one driver must yield by using a bike lane. Additionally, the bike lanes are wide enough for two cyclists riding side by side, although the clearance between the leftmost cyclists and motorists is limited. In such situations, most motorists will adjust their position slightly leftward during overtaking to ensure a safer passing distance.

Lastly, the bike lanes with a narrow central travel lane profile. In this design, the central travel lane is clearly insufficient for two passenger cars, narrower than 380 centimeters. Consequently, motorists must consciously deviate into the bike lane when encountering oncoming traffic. If cyclists are using the bike lane at the same time, the motorist must wait behind the cyclists until the oncoming vehicle has passed. This profile features minimal separation between cyclists and motor vehicles. The bike lane primarily serves to highlight the presence of cyclists. This design is particularly suited for busy access roads within urban areas that form part of a network of primary cycling routes. The speed limit is 30 km/h, with a maximum motor vehicle intensity of 6,000 vehicles per day.

In addition to these three designs, a bicycle street or a mixed-use profile can also be applied. These design are typically reserved for roads with a pavement width of less than 580 centimeters, where separating traffic becomes impractical. It is important to note that these applications are limited to access roads with a speed limit of 30 km/h. Speed reduction measures are often recommended, and the optimal motor vehicle intensity should not exceed 4,000 vehicles per day. (CROW, 2016)

5.2. Requirements

The requirements that the design must meet are:

- The redesign should result in fewer accidents than the current design.
- The design should adhere to the CROW guidelines. (CROW Kennisbank, 2023)
- On the route, the design speed for cars on Broersvest, Rotterdamsedijk, Schiedamsedijk, Mathenesserweg, Mathenesserbrug, and Mathenesserplein is 50 km/h. For all other streets, the design speed is 30 km/h. (Gemeente Rotterdam, 2024)
- The bicycle path should consist of a flat and non-slip surface. Elements that can negatively affect the friction of the road surface should be avoided. (Baggerman, 2018)
- The pedestrian pathways have a minimum clear width of 1.80 meters. Only a reduction of 1.20 meters is permissible for a maximum length of 10 meters. And after this narrowing, a minimum length of 2.00 meters is necessary to facilitate passing. (CROW Kennisbank, 2023)
- Cyclists should be able to ride two abreast.

5.3. Wishes

The wishes that the new design can potentially meet are:

- Active and healthy modes of transportation need to be made attractive.
- The design includes space for a green environment, possibly with water features. (Gemeente Rotterdam, 2020)
- Cyclists should feel safe on the bike path.

6
Design

In this Chapter, three different designs are developed: minimal & functional, space for cyclists and pedestrians, and green environment. For each design, layouts are created for four different categories: streets with a speed limit of 30 km/h without a tram, streets with a speed limit of 30 km/h with a tram, streets with a speed limit of 50 km/h without a tram, and streets with a speed limit of 50 km/h with a tram.

6.1. Design 1: Minimal & Functional

This design investigates how the current design can be modified to meet the requirements, outlined in Chapter 5. The aim is to implement minimal changes to the existing design while enhancing the safety of the new design. Only the weaknesses in the design will be addressed, with the remainder left unchanged to maintain relatively low costs. First, the focus will be on the 30 km/h roads, followed by the assessment of the 50 km/h roads.

30 km/h roads

The 30 km/h roads without tram tracks are mainly located in the center of Rotterdam and Schiedam. Cyclists share the roadway with motor vehicles on these routes. An important difference between these roads in Rotterdam and Schiedam is that roads in Rotterdam have a red color, which making motorist more aware of cyclists' presence and driving more attentively. (Merkelback et al., 2023)
Analysis of STAR data in Chapter 4 reveals that no traffic accidents involving vulnerable road users, including cyclists, have occurred in the center of Schiedam since 2019. Consequently, adjustments in Schiedam seem unnecessary.
In the center of Rotterdam, numerous trees flank the roads, simultaneously impeding visibility and contributing to slick road surfaces during autumn, leading to hazardous situations. the recommendation is to remove these trees, and potentially replacing them with lower vegetation that does not obstruct sight lines.
The roads have a pavement width of less than 580 centimeters, which is too narrow for full-fledged bicycle lanes. The standard solution is a basic mixed-use profile without a central axis. This approach has been uniformly applies and will remain unchanged in the new design. The same applies to sidewalks and parking spaces, which currently meet the requirements. This yields the standardized design depicted in figure 6.1.

The 30 km/h roads with tram lines are primarily arterial roads. On many of these roads, the current speed limit is still 50 km/h. To ensure that road users adhere to the new 30 km/h speed limit, physical measures must be implemented, such as speed bumps, raised platforms, road narrowing, or chicanes (SWOV, 2018a). Particularly, speed bumps and road narrowing are relatively easy to apply to existing roads.
In the spatial integration of tramways in an urban environment, there are three options: street-level integration (mixed with other traffic), segregated tramways (only intersecting with other traffic), and

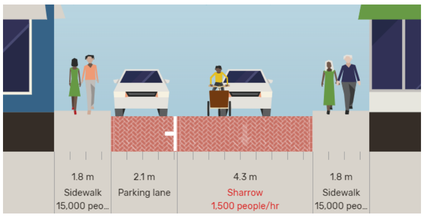


Figure 6.1: Design 30 km/h roads without tram: Minimal & Functional

completely conflict-free tramways (no interaction with other traffic). The preferred option is segregated tramways. If street-level integration is unavoidable due to space constraints, it should be kept as short as possible (CROW Kennisbank, 2023).
For a road with a pavement width of 24 meters, there is sufficient space to install a segregated tramway. The tramway will separate the lanes for motor vehicles in both directions. Consequently, a bike lane with a narrow median is not feasible. The preferred design is a lane with an adjacent bike lane, which clearly indicates to motorists that it is a 30 km/h road. Attention must be given to the width and color of the bike lane to clearly indicate that it is intended for cyclists. Additionally, tall trees will be replaces by low greenery to prevent a slippery road surface. The design is depicted in Figure 6.2. It is not visible in the illustration, but the edges between the bicycle path and the green areas will be sloped upwards. This will be implemented to eliminate hard edges that could pose hazards when swerving to avoid dangerous situations (Baggerman, 2018).
On the roads that currently have a speed limit of 50 km/h, there are often separate bike paths. The roadway can be widened by replacing parking spaces with bike paths. The space from the separate bike paths can the be used for parking spaces or additional space for sidewalks. When parking spaces are created here, sufficient space must be maintained between the bike path and the parking spaces. This can be achieved by implementing a buffer zone, with a minimum width of 50 centimeters, between the bike path and the parking spaces (CROW Kennisbank, 2023).

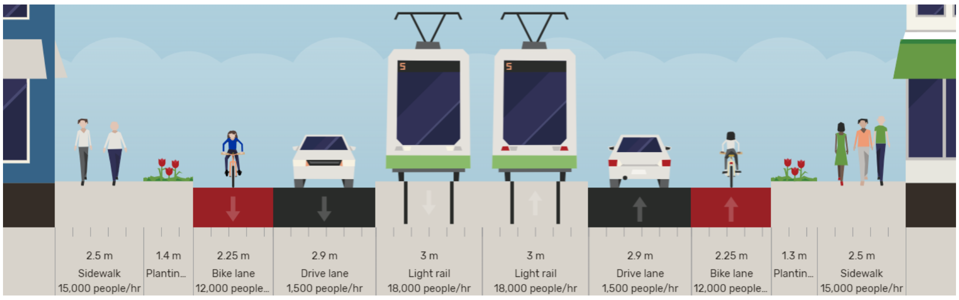


Figure 6.2: Design 30 km/h roads with tram: Minimal & Functional

50 km/h roads
The Mathenesserweg is the only 50 km/h road without a tram line. The current design already incorporates a separated bike lane. Measurements conducted using Google Maps, 2024 indicate a width of 2.25 meters, which is sufficiently spacious. Additionally, there are parking spaces along the main road. The space between these parking spaces and the bike path offers ample protection against the hazard of swinging car doors. The only hazard in the design remains the trees, which can create slippery road conditions with their leaves during autumn. These could be replaces with lower vegetation, such as a hedge. The hedges will be alternated with the bicycle racks, as depicted in the design in Figure 6.3.

Alongside the 50 km/h roads with tram lines, predominantly segregated bike lanes are present. However, it is noteworthy that these bike lanes are generally substantially narrower than the stands outline by the CROW Kennisbank, 2023 and in comparison to other bike lanes. Alongside the Schiedamseweg and the Rotterdamsedijk, there currently exists a bidirectional bike lane. Such infrastructure poses heightened risks compared to unidirectional lanes, particularly at intersections. However, the replacement of these lanes with unidirectional counterparts would necessitate significant detours for cyclists, likely resulting in continued utilization of the bidirectional lane. Therefore, unidirectional bicycle lanes

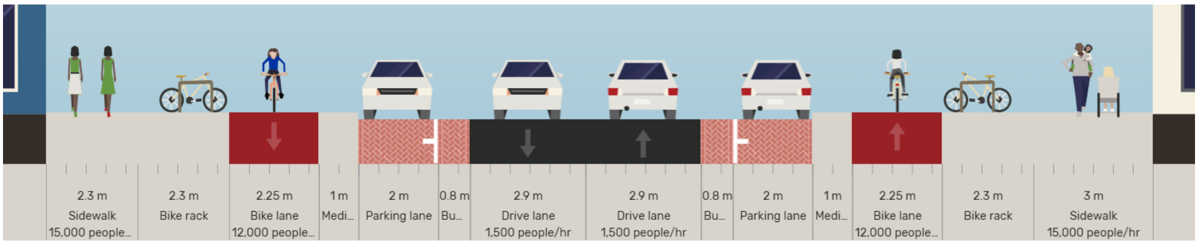


Figure 6.3: Design 50 km/h roads without tram: Minimal & Functional

are not deemed feasible. Nonetheless, it is recommend to widen the existing bicycle lanes to 4.5 meters from the current 2.4 meters to mitigate potential hazards during overtaking maneuvers. This expansion, however, may entail the loss of some green spaces. The same principles applies to narrow unidirectional bike lanes, which should also undergo widening measures, ideally to 2.25 meters where feasible (see Figure 6.4).
In addition to the widening of bidirectional bicycle lanes, it is imperative to ensure clear communication to motorists at intersections. Where lacking, supplementary measures such as the installation of signage indicating bidirectional bicycle traffic should be implemented.

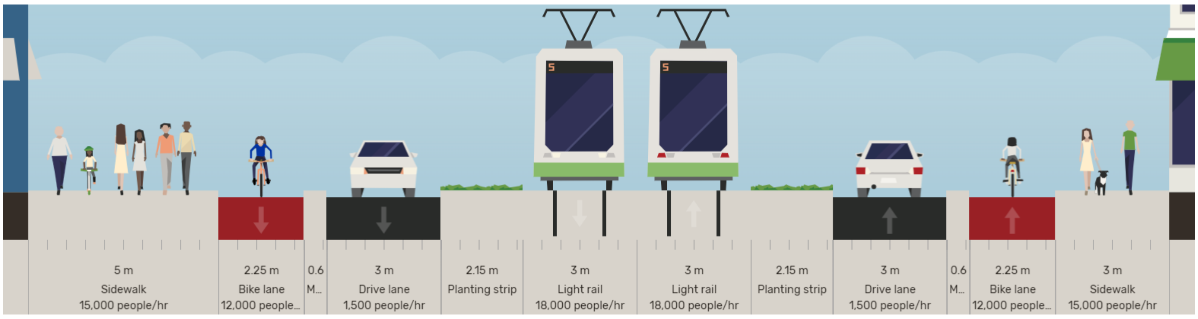


Figure 6.4: Design 50 km/h roads with tram: Minimal & Functional

6.2. Design 2: Space for cyclists and pedestrians

In this design, priority is given to cyclists and pedestrians. This is accomplished by implementing ample bicycle and pedestrian paths, while also emphasizing the visibility of cyclists and pedestrians.

30 km/h roads

The 30 km/h roads without tram tracks are primarily used for residential purposes and are relatively narrow (10 meters). The main objective is to foster a sense of belonging for cyclists and pedestrians while encouraging motorists to adopt a guest mindset. This is achieved through the implementation of a bicycle street and wide footpaths, as depicted in Figure 6.5(a). The bicycle lane accommodates sufficient width in both directions, allowing cyclists to ride side by side comfortably. Positioned in the middle is a cobblestone pavement featuring rounded stones, exemplified in Figure 6.5(b). This surface is less conductive to smooth driving for cars, compelling them to maintain a slower pace behind cyclists and exercise caution when overtaking, consequently resulting in reduced overall speeds. (CROW Kennisbank, 2023)

For the 30 km/h roads with tram tracks, implementing a bicycle street is not feasible due to the high traffic intensity of cars. These roads are also used by through traffic. The solution to reduce speed, as outlined in Paragraph 6.1, primarily involves the application of speed bumps, raised platforms, road narrowing, or zigzag shifts of the road axis. Particularly at intersections, raised platforms can be used, and zigzag shifts of the road axis can be implemented before the intersection, provided that visibility of other traffic is maintained.
In the design, we propose the installation of a bicycle lane, providing cyclists with additional space by creating wide bicycle lanes on one side. These lanes will be designed to be just wide enough to allow

Figure 6.5: (a) Design 30 km/h roads without tram: Space for cyclists and pedestrians; (b) Example of a bicycle street: Ezelsveldlaan in Delft

cars to pass cyclists calmly. The tram tracks will be elevated relative to the car lanes, creating the illusion of a narrower road. Additionally, the bicycle lane will be marked with a distinct red color, clearly indicating its intended use for cyclists.
Furthermore, space will be allocated for cyclists to park their bicycles along the bike lane (see Figure 6.6). Pathways will be incorporated between the plantings to provide access to the sidewalk.

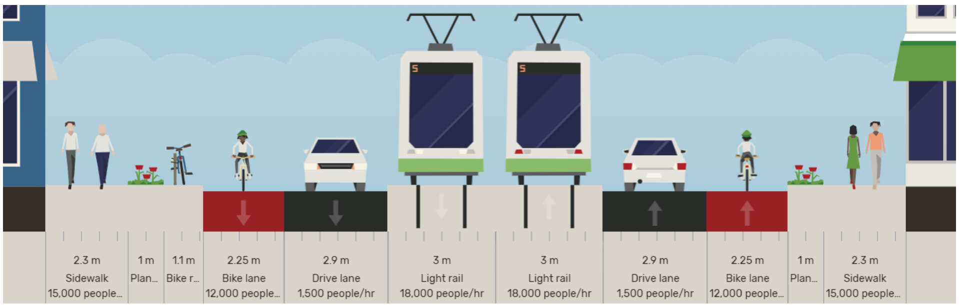


Figure 6.6: Design 30 km/h roads with tram: Space for cyclists and pedestrians

50 km/h roads
Along the 50 km/h roads, segregated bicycle paths are endeavored to be implemented wherever feasible, with a target width of 2.25 meters. Additionally, strategically positioned bike racks will facilitate orderly bicycle parking along these pathways. Presently, numerous parking spaces line the 50 km/h road without tram tracks. Complete removal of these spaces is deemed impractical. Instead, emphasis is placed on mitigating any inconvenience or heightened risk to cyclists. This is achieved through the selective placement of parking spaces solely along the carriageway, thus preventing potential encroachment on cyclists pathways by vehicles.
Despite the classification as a 50 km/h road, significance is attributed to instilling awareness among motorists that they are traversing through an urban setting inhabited by other road users. This awareness is engendered through design interventions such as the placement of hedgerows between lanes (see Figure 6.7). This creates a perceptual narrowing of the road, prompting heightened mindfulness among motorists regarding the presence of cyclists and pedestrians within this milieu.

In the design for the 50 km/h roads with tram tracks, the space between the tram tracks and the roadway is reduced. This modification allows the segregated bike lanes to be widened to 2.25 meters and creates additional space that can be utilized for bicycle parking and a bench for pedestrians, providing them with the opportunity to rest if needed. Additionally, the elevated buffer strip between the roadway and the bike lane is slightly widened to enhance the perceived safety for cyclists.
The design is depicted in Figure 6.8, which suggests that the bike lane is lower than the sidewalk and the buffer strip. However, in practice, these will be at the same height.

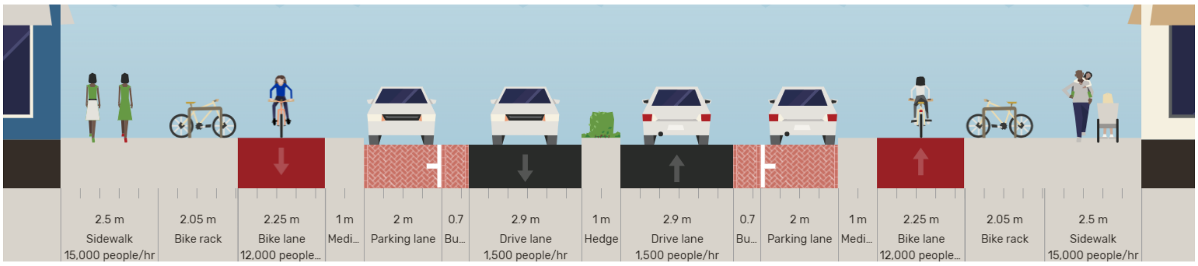


Figure 6.7: Design 50 km/h roads without tram: Space for cyclists and pedestrians

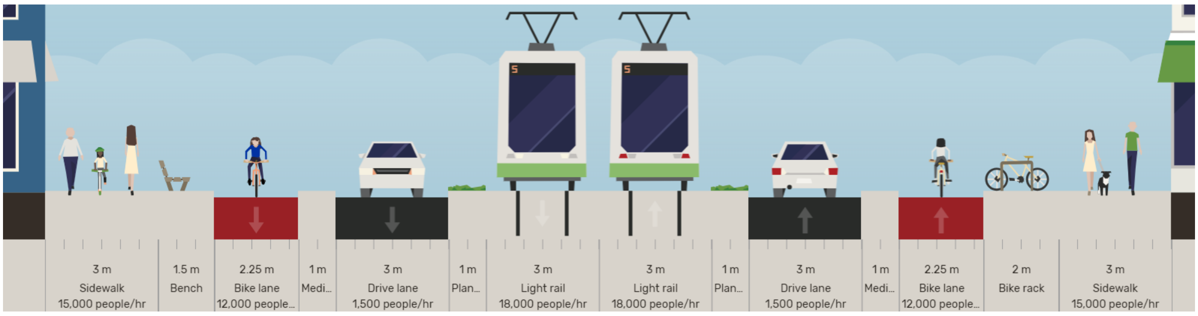


Figure 6.8: Design 50 km/h roads with tram: Space for cyclists and pedestrians

6.3. Design 3: Green environment

In this design, substantial space is allocated for greenery, primarily through the incorporation of hedges, shrubs, and flowers. The inclusion of trees is minimized as much as possible, as overhanging branches can deposit significant amounts of leaves on the roadway, resulting in hazardous conditions.

30 km/h roads

The design for the 30 km/h streets without tram lines closely resembles that of 6.2 Design 2: Space for cyclists and pedestrians. Similarly, the concept of a bicycle street is employed to emphasize that cars are guests. The pavement width is insufficient to accommodate separate bike lanes, prioritizing bicycle safety above all. Hence, it is imperative for motorists to acknowledge the shared road usage by cyclists, with a bicycle street presenting an effective solution.
Within this design, both sidewalks and bike paths have been marginally narrowed to allow to the integration of green spaces. Pathways will be interspersed every 10 meters between the hedgerows, facilitating pedestrian crossings and maintaining accessibility for cyclists to residences.

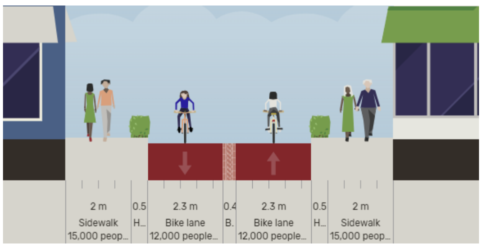


Figure 6.9: Design 30 km/h roads without tram: Green environment

Along the 30 km/h roads with tram tracks, the rials are integrated into a green surface. In this design, cyclists share the roadway with cars, with the presence of cyclist clearly demarcated by the red color of the bike lane. Additionally, extra space is allocated for vegetation. Cyclists are provided with designated areas for parking their bicycles on one side. Pathways are created between the planted areas, allowing cyclists to continue their journey on foot without traversing through the vegetation.

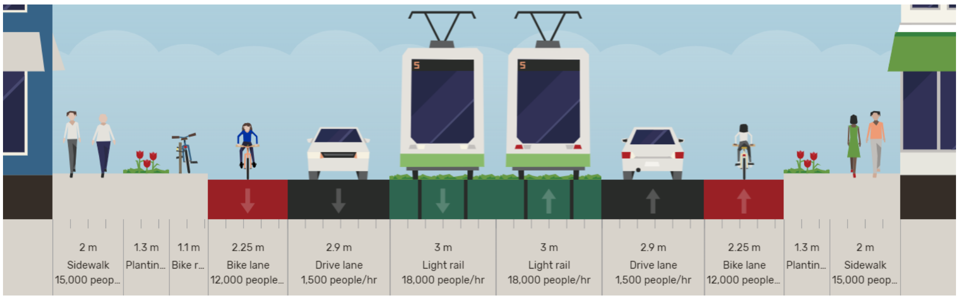


Figure 6.10: Design 30 km/h roads with tram: Green environment

50 km/h roads

The design of the 50 km/h roads without tram tracks, see Figure 6.11, closely resembles that of Design 2: Space for Cyclists and Pedestrians. Here, a hedge will also be planted between the two lanes to create a narrower road profile, enhancing motorists' attentiveness while preserving parking spaces. Space for greenery will be incorporated within the buffer strip between the bike lane and the parking spaces. Additionally, the sidewalks will be slightly narrowed, providing space for planting greenery in front of the houses. Projects such as 'Jouw groene straat' can facilitate this initiative, encouraging residents to enhance the greenery in their street by replacing pavement tiles with vegetation. Residents undertake the responsibility for maintaining the plants, while the municipality assists with financing the facade gardens. (Doelen et al., 2022)

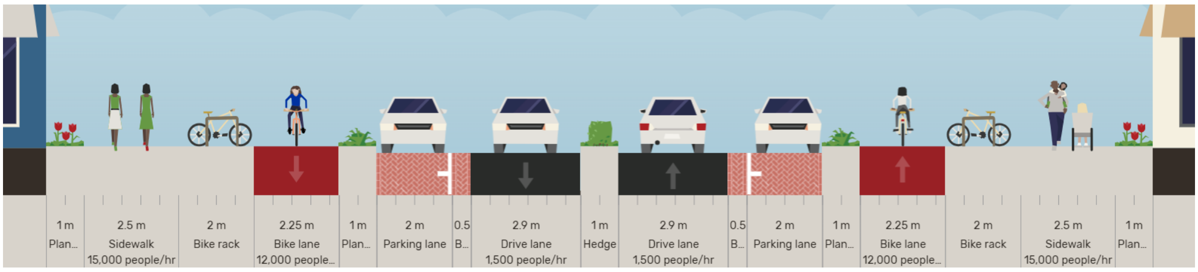


Figure 6.11: Design 50 km/h roads without tram: Green environment

Along the 50 km/h roads with tram tracks, the tram will once again be integrated into the grass verge. Furthermore, the bench for Design 2: Space for cyclists and pedestrians will be replaced with hedges. Space will also be allocated for planting alongside the buffer strip. Similar to Design 2, a bicycle parking facility will be installed, with space in the hedge reserved to access the bicycle parking for the bike line. In addition to enhancing greenery, the hedge will provide a clear separation between the bike lane and the sidewalk. Cyclists will thus be aware of the need to dismount when passing the hedge.

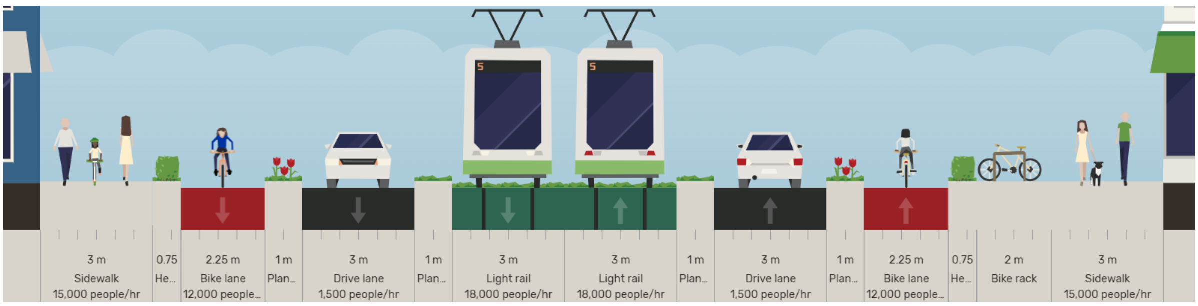


Figure 6.12: Design 50 km/h roads with tram: Green environment

7 Evaluation

In this Chapter, the best design from Chapter 6 is determined using a multi-criteria analysis. The designs are evaluated with a score between 0 and 5 on the following criteria: safety, accessibility, sustainability, social impact, aesthetics, future-proof, and costs. Subsequently, the total score for each design is calculated, incorporating the weighting factors established in Section 3.5.

7.1. Score per criteria

The design have been evaluated based on the following criteria: safety, accessibility, sustainability, social impact, aesthetics, future-proofing, and costs. Table 7.1 presents the scores for each criterion, where design 1 is Minimal & functional, design 2 is Space for cyclists and pedestrians, and design 3 is Green environment. This paragraph further elaborates on the scores for each criterion.

Table 7.1: Multi Criteria Analysis

Criteria	Weight factor	Design 1	Design 2	Design 3
Safety	10	3	5	4
Accessibility	8	3	5	3
Sustainability	6	4	3	4
Social impact	8	4	3	4
Aesthetics	2	2	3	5
Future-proof	7	2	3	4
Costs	3	5	3	2

7.1.1. Safety

All designs are, in any case, safer than the initial ones. They are all intended to reduce bicycle accidents. However, design 1 does not implement significant changes, as it focuses on minor adjustments without extensive roadwork. Design 2 provides the most space for cyclists and pedestrians, which, according to predictions, will result in the greatest safety.

7.1.2. Accessibility

The wide cycling and walking paths in design 3 ensure excellent accessibility, including for people with disabilities. In general, large detours are avoided as much as possible in all designs, and bidirectional bike paths are only implemented where they are truly useful.

7.1.3. Sustainability

These designs exhibit two distinct types of sustainability. Firstly, design 1 is relatively sustainable due to its lower material requirements for implementation. Secondly, design 3 has a better environmental impact compared to design 2, attributed to its reduced use of paved surfaces and increased incorporation of green elements.

7.1.4. Social impact

Regarding social impact, there are two different aspects that must be considered. First, the level of social surveillance that can be maintained is approximately equal across all designs. However, the implementation of design 1 will cause less disruption to residents compared to designs 2 and 3, due to the reduced scope of work required. Additionally, design 3 can enhance air quality through the incorporation of extensive greenery, particularly if plants capable of absorbing pollutants are utilized (Viridi Air, 2023).

7.1.5. Aesthetics

In design 1, only minimal changes are implemented, with less focus on visual aesthetics. In design 2, more attention is given to visual appeal, resulting in a more refined appearance, albeit with considerable use of paving. Design 3 incorporates extensive greenery, enhancing its visual appeal and creating a welcoming atmosphere. Additionally, all designs are well-suited to the Rotterdam environment.

7.1.6. Future-proof

Design 1 is primarily beneficial in the short term. However, larger adjustments will eventually be necessary, making this design less future-proof. Designs 2 and 3 are more resilient for the future, although design 2 lacks significant greenery. With the prospect of global warming, it is advantageous to integrate more green spaces in urban areas. Vegetation converts sunlight into evaporative energy, reducing the warming effect of surfaces and the atmosphere. This is particularly critical in urban environments, which already experience higher temperatures compared to rural areas (Heusinkveld, 2017). Therefore, design 3 is more future-proof than design 2.

7.1.7. Costs

In terms of costs, design 1 is the most cost-efficient. This design is expected to be the least expensive in the long run because it requires fewer actions to be implemented, thus reducing material and labor costs. Designs 2 and 3 require more extensive interventions. However, design 2 will likely be cheaper than design 3, as the latter involves a greater amount of planting. Plants generally incur higher costs compared to paving materials.

7.2. Conclusion

The scores for each criterion from Table 7.1 were multiplied by their respective weighting factors and summed. This calculation resulted in the scores presented in Table 7.2, which shows that design 3, Green Environment, achieved the highest overall score.

Table 7.2: Total scores of the three different designs

Design	**Total score**
Design 1: Minimal & Functional	143
Design 2: Space for cyclists and pedestrians	168
Design 3: Green environment	169

8
Conclusions and Recommendations

In this chapter, the main research question is initially addressed using the sub-questions. Based on the conclusions, further recommendations are provided.

8.1. Conclusions

This study aimed to answer the following research question: *What type of (re)design can improve safety on the bicycle route between the centre of Rotterdam and Schiedam?* This question was addressed through four sub-questions.

It can be concluded that there are different approaches to developing a design solution. For this report, conducting a literature review, analyzing the current situation, and performing a stakeholder analysis were initially crucial. Subsequently, a set of design requirements had to be established, and the designs were evaluated using a multi-criteria analysis.

Based on the literature review and analyses, it is evident that the history of Rotterdam has had a profound impact on its current infrastructure. The infrastructure is primarily oriented towards automobiles, a consequence of Rotterdam's extensive reconstruction after World War II, coinciding with the rise of the automobile era. The Rotterdam municipality is actively engaged in efforts to address this issue by aiming to allocate more space for pedestrians and cyclists. They are already planning significant reductions in speed limits on many roads, from 50 to 30 km/h.

The project involves various stakeholders, including the municipalities of Rotterdam and Schiedam, the Fietsersbond, the ANWB, government authorities, RET, and local residents. All these stakeholders have distinct requirements and preferences.
The municipalities of Rotterdam and Schiedam aim to increase space for cyclists and pedestrians and promote these modes of transport. The Fietsersbond and ANWB focus primarily on bicycle safety. Government authorities prioritize traffic safety, infrastructure investments, and public transport accessibility. RET focuses on minimizing disruptions in public transport. Local residents advocate primarily for safety and seek involvement in decision-making processes, as well as maintaining access to their homes by foot, bicycle, and car.

There are various designs for bicycle paths tailored to different scenarios. The safest option for cyclists is a segregated one-way bike path, contingent upon adequate space, which must also meet a minimum width of 1.90 meters (CROW Kennisbank, 2023).

Ultimately, three distinct designs were developed: Minimal & Functional, Space for cyclists and pedestrians, and Green environment. According to the multi-criteria analysis, design 3, Green Environment, emerged as the most suitable for Rotterdam. This design allocates significant space for greenery, including grass-covered tram tracks and extensive green areas along the road.

The primary objective of redesigning the bicycle route is safety. This aspect is carefully considered, with cyclists provided ample room on paths or lanes that maximize width to accommodate side-by-side cycling. Adequate space is also allocated for pedestrians, with footpaths being a minimum of 2 meters wide. Moreover, clear demarcation using a distinct red color for bike lanes ensures motorists are aware when sharing the road with cyclists.

8.2. Recommendations

This report concludes that design 3, Green Environment, is the best option. Therefore, it is recommended to implement this design to improve cyclist safety in Rotterdam.
However, this report has focused only on one route in Rotterdam. It would be beneficial to address other routes, including those mentioned in the introduction, and develop new designs for them using the methodology outlined in this report as a guide.
Future research could also explore redesigning intersections as part of further investigations.

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A

Planning

Week	Deadline	Time	Activity
1	Mon 22-4-2024	10:00-12:00	Kick-off
	Mon 22-4-2024	13:00-17:00	Research
	Tue 23-4-2024	9:00-17:00	Complete Civil Engineering Information Literacy 2
	Wed 24-4-2024	13:00-17:00	Formulate research questions and sub-questions
	Thu 25-4-2024	13:00-17:00	Working on workplan
	Fri 26-4-2024	11:00-16:00	Finishing workplan
	Fri 26-4-2024	**16:00**	**Submission: Work plan**
2	Mon 29-4-2024	13:00-16:00	Reviewing other students
	Mon 29-4-2024	**16:00**	**Submission: Review of other students**
	Mon 29-4-2024	17:00-18:00	Reading feedback
	Tue 30-4-2024	10:00-11:30	Discussion: workplan
	Tue 30-4-2024	12:00-14:00	Processing feedback
	Tue 30-4-2024	14:00-17:00	Beginning on table of contents and proposed methodology
	Wed 1-5-2024	9:00-17:00	Working on proposed methodology and design approach
	Thu 2-5-2024	13:00-17:00	Working on proposed methodology and design approach
	Fri 3-5-2024	11:00-16:00	Finishing Table of contents, proposed methodology and design approach
	Fri 3-5-2023	**16:00**	**Submission: Table of contents, proposed methodology and design approach**
3	Mon 6-5-2024	13:00-16:00	Reviewing 2 other students
	Mon 6-5-2024	**16:00**	**Submission: Review of 2 other students**
	Mon 6-5-2024	17:00-18:00	Reading feedback
	Tue 7-5-2024	10:00-11:30	Discussion: Methodology & design approach
	Tue 7-5-2024	12:00-17:00	Processing feedback and finishing Methodology & design approach
	Wed 8-5-2024	9:00-15:00	Preparing presentation Methodology & design approach and design proposals
	Thu 9-5-2024		*Ascension day*
	Fri 10-5-2024		*Ascension day*
	Fri 10-5-2023	**16:00**	**Submission: Methodology and/or design approach**

4	Mon 13-5-2024 **Mon 13-5-2024** Mon 13-5-2024 Tue 14-5-2024 Tue 14-5-2024 Wed 15-5-2024 Thu 16-5-2024 Fri 17-5-2024 **Fri 17-5-2023**	13:00-16:00 **16:00** 17:00-18:00 10:00-11:30 12:00-17:00 9:00-17:00 13:00-17:00 11:00-16:00 **16:00**	Review of 2 other students **Submission: Review of 2 other students** Reading feedback Presentation on: Methodology & design approach and design proposals Processing feedback and beginning on analyses Working on analyses Working on analyses Working on analyses **Submission: Preliminary results for report**
5	*Mon 20-5-2024* Mon 20-5-2024 Mon 20-5-2024 **Mon 20-5-2024** Tue 20-5-2024 Tue 21-5-2024 Wed 22-5-2024 Wed 22-5-2024 Thu 23-5-2024 Fri 24-5-2024 **Fri 24-5-2023**	 9:00-13:00 13:00-16:00 **16:00** 10:00-11:30 12:00-17:00 9:00-17:00 13:00-17:00 11:00-17:00 **16:00**	*Pentecost* Working on analyses Reviewing 2 other students **Submission: Review of 2 other students** Discussion: Preliminary results Processing feedback and working on (re)designs go/no-go decision Working on (re)designs Working on (re)designs Beginning on evaluation **Submission: Preliminary results**
6	Mon 27-5-2024 **Mon 27-5-2024** Tue 27-5-2024 Tue 28-5-2024 Wed 29-5-2024 Thu 30-5-2024 Fri 31-5-2024 **Fri 31-5-2023**	13:00-16:00 **16:00** 10:00-11:30 12:00-17:00 13:00-17:00 13:00-17:00 12:00-17:00 **16:00**	Reviewing 2 other students **Submission: Review of 2 other students** Discussion: Results for report Processing feedback and working on evaluation Finishing evaluation Working on conclusion and recommendations Working on summary **Submission: Preliminary summary, conclusions and recommendations**
7	Mon 3-6-2024 **Mon 3-6-2024** Tue 4-6-2024 Tue 4-6-2024 Wed 5-6-2024 Thu 6-6-2024 Fri 7-6-2024	13:00-16:00 **16:00** 10:00-11:30 12:00-17:00	Reviewing 2 other students **Submission: Review of 2 other students** Elevator pitch: conclusions; subsequent discussion Processing feedback and working on conclusions and recommendations
8	Mon 10-6-2024 Tue 11-6-2024 Wed 12-6-2024 Thu 13-6-2024 Fri 14-6-2024		
9	**Mon 17-6-2024** Tue 18-6-2024 Wed 19-6-2024 Thu 20-6-2024 Thu 20-6-2024 Fri 21-6-2024	**16:00** 9:00-17:00 9:00-17:00 9:00-12:00 12:00-17:00 9:00-17:00	**Submission: Final report (digital) with plagiarism scan** Beginning on presentation Working on presentation Finishing presentation Learning presentation text Learning presentation text
10	Mon 24-6-2024 Tue 25-6-2024 Wed 26-6-2024 Thu 27-6-2024 Fri 28-6-2024	9:00-17:00 10:00-12:30 13:00-17:00	Final preparations for presentation Final presentation Working on self-evaluation
11	**Mon 1-7-2024** *Mon 1-7-2024*	**16:00** *16:00*	**Submission: Self-evaluation (digital version), presentation** *(if relevant) Addition*

B

Streets where the speed limit changes from 50 km/h to 30 km/h

In 2024, the municipality of Rotterdam has decided to decrease the speed limit from 50 km/h to 30 km/h on an additional 115 streets by 2025 (Gemeente Rotterdam, 2024). The list of these streets in the center of Rotterdam is provided below:

- Eendrachtsplein
- Eendrachtsweg (South of Witte de Withstraat)
- Eendrachtsweg (between Witte de Withstraat and Eendrachtsplein)
- Gedempte Zalmhaven
- Glashaven
- Goudsesingel
- Henegouwerlaan parallel
- Hofplein
- Maasstraat
- Mariniersweg
- Mathenesserlaan (between Nieuwe Binnenweg and Rochussenstraat)
- Mauritsweg
- Nieuwe Binnenweg (between Eendrachtsplein and ’s-Gravendijkwal)
- Oostplein
- Parkhaven
- Posthoornstraat
- Regentessebrug
- Scheepstimmermanlaan
- Weena (parallel lane)
- West Kruiskade
- Westersingel north (between Weena and Eendrachtsplein)
- Westersingel south (between Eendrachtsplein and Westzeedijk)
- Westerstraat
- Willemskade

C

Results Verkeersveiligheidsprikker and black spots

Locations identified by the Verkeersveiligheidsprikker: (Gemeente Rotterdam, 2023c)

- Kruispunt Goudsesingel - Meent - Jonker Fransstraat
- Kruispunt Heemraadssingel - 2e Middelandstraat
- Rochussenstraat - ’s Gravendijkwal
- Erasmusbrug - Vasteland
- Rodenrijsestraat
- Schiedamse Vest
- Claes de Vrieselaan
- Willem Buytewechstraat
- Willemsbrug
- Aveling - Baarsweg - Holwinde
- Aveling - Lengweg
- Lage Erfbrug - Nieuwe Binnenweg
- Kruisplein
- Spinozaweg - Molenvliet - Pascalweg
- Nieuwe Binnenweg (Delfshavense deel)
- Zaagmolenstraat

Black spots: (Gemeente Rotterdam, 2023a)

- 1e Middellandstraat - Henegouwerlaan - ’s Gravendijkwal
- Goudsesingel - Mariniersweg - Vondelweg
- Koningslaan - Duikerstraat
- Bergweg - between Voorburgstaat and Insulindestraat
- Oudedijk - Rozenburglaan - Voorschoterlaan
- Pleinweg - Mijnsherenlaan
- Mercatorweg

D

Photographs of Rotterdam

Figure D.1: Current situation: Heemraadssingel - 2e Middelandsstraat

Figure D.2: Current situation: Heemraadssingel - 2e Middelandsstraat

Figure D.3: Current situation: Heemraadssingel - 2e Middelandsstraat

Figure D.4: Current situation: Mathenesserlaan

Figure D.5: Current situation: Schiedamseweg

Figure D.6: Current situation: Broersvest - Rotterdamsedijk