Designing a high level of service bus lane for Amersfoort

Development and evaluation of different design variants

Master thesis

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by

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Preface

This thesis could not have been written without the help of others. I am thankful to everyone who helped me during the process. I want to thank several people specifically, starting with my thesis committee. I want to thank Niels and Haneen for the guidance through the process and your sharp feedback, Anteneh for our weekly meetings, which helped me to create structure in the process and Vincent for the warm welcome at the Gemeente Amersfoort and the way you invited me to be part of the team there during my thesis.

I want to thank everybody that I met and cooperated with at the Gemeente Amersfoort. I felt very welcome during my stay. I really appreciated that people listened to what I had to say and valued my input. I want to thank Astrid and Elian from their feedback and input as public transport specialists, Maricke and Arno for the discussions on how to integrate bus infrastructure and the LES development, Falco and Kevin for their knowledge and input about the road layout and traffic loads in and surrounding my case area. I also want to thank Falco with his help with the Paramics model. Finally I want to thank Dennis and Gio for inviting me on the lunch walks providing the necessary structure to my days.

Next to the people from the Gemeente Amersfoort I also want to thank Roel from the Provincie Utrecht and Robin from Keolis for their input as representatives of important stakeholders of the project. Finally I want to thank Mark and Roemer from Sweco for providing me access to the Paramics software.

Beyond the people that were directly involved with the project I want to thank my parents, friends, housemates and girlfriend for supporting me. It was very helpful to be able to disconnect from my thesis work at times and I could not have done it without you.

As this thesis is the last project of my studies, this moment also marks the end of almost seven years at the TU Delft. I have enjoyed my stay here and am excited to move forward to a next step in my life.

Jorn
Delft, April 2026

Onze wandeling
is ten einde.

Daar komt reeds
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('s Anderendaags
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J. A. Deelder

Summary

In this project a design for a high level of service bus lane in the city of Amersfoort was made. The bus lane that was designed is located in an area that is currently undergoing a large urban redevelopment with 5000 new houses. The bus lane will be part of a larger BRT corridor that the municipality is developing. This corridor connects the main train station with the northern neighbourhoods of the city.

To determine what such a bus lane should look like a literature study was conducted. In the literature study two types of sources were referenced, academic publications and design guidelines. The academic publications gave insight into the different possibilities for designing dedicated bus lanes and the advantages and drawbacks of each design. In general median bus lanes were found to be the best for public transport operations. No specific BRT road design guideline was found, so general bus and tram road design guidelines were used to find base designs. These base design were then used in later stages to provide a starting point for the development of the designs.

The system analysis indicated the municipality as the most important stakeholder. Other important stakeholders are the province, the bus operator, the bus travellers and the bus drivers. The two principal functions of the design were found to be to provide fast, efficient and comfortable bus lanes and to provide high quality bus stops along the bus lanes.

The requirements that the municipality had for the project were defined in the basis of design. These requirements were slightly different for different sections of the design area, but in general they required a dedicated bus, one or two general traffic lanes, bicycle paths and sidewalks. There were also an underpass and a bridge could not be adapted due to costs and thus needed to be maintained. Finally the number of bus stops in the design area was defined at three after a short GIS analysis.

With the objective and requirements set, the development of the designs could start. First designs were made for street cross-sections for five different sections of the design area. For each section designs with bus lanes in the median, on the curb-side and side separated were considered. In consultation with the municipality the two most promising concepts were picked for each section.

The two most promising concepts were then developed into variants. For the development of these variants the number of design sections was reduced from five to two because of codependency between the sections. For both sections the two most promising concepts had median or curb-side bus lanes. These variants were thus developed in higher detail on a map using the AutoCAD software. For the second design section, the space available was not sufficient to provide separated bus lanes across the entire design section. Therefore in this section hybrid variants were developed, with dedicated bus lanes where possible and shared traffic where necessary.

The two design variants were evaluated using a set of evaluation criteria that was developed in cooperation with the stakeholders. There were three categories for evaluation criteria; traffic performance, passengers accessibility and urban integration and liveability. The category traffic performance consisted of the following criteria criteria; bus trip time, bus service reliability, general traffic travel time and bicycle traffic travel time. These criteria were evaluated using a traffic model for the design area that was constructed in the microsimulation software Paramics Discovery.

The second category, passenger accessibility, had the criteria; stop locations, stop quality, stop access routes and BRT appearance. These were evaluated using different criteria. Stop locations were evaluated using the number of inhabitants within 400 metres of a stop. Stop quality was evaluated using the total area of the stop. The stop access routes were evaluated using a grading system for road crossings from Dutch road design guidelines. Finally the BRT appearance was evaluated using expert opinion from public transport specialist from the municipality of Amersfoort.

The final category was urban integration and liveability. It included; road safety, space for pedestrians and bicycle traffic, road cross-ability, neighbourhood integration, public green space and long-term ro-

bustness. Road safety was evaluated using the number and type of conflict points. Space for pedestrians and bicycle traffic was evaluated using the total area dedicated to these modes. Road cross-ability was evaluated a grading system for road crossings from Dutch road design guidelines. The neighbourhood integration was evaluated using expert opinion from urban redevelopment specialists from the municipality of Amersfoort. Public green space was evaluated using the total area for green space. Finally long-term robustness was evaluated by checking the compliance with the most recent design guidelines.

For both designs sections, the variants that relied on median bus lanes were evaluated as the preferred designs. These variants performed better in all three evaluation categories. For the first design section where the entire section could be designed with dedicated bus lanes, the differences between the two designs was quite apparent. For the second design section where a significant portions had to be designed with shared traffic, the differences were less clear.

In general for the traffic performance, the trip time for buses and the reliability of the bus service was clearly better for the designs with median bus lanes. For the travel time for general traffic, the opposite was true and the designs curb-side bus lanes performed better.

For the passenger accessibility, the stop locations, stop access routes and especially the BRT appearance scored higher for the designs with median bus lanes. The stop quality scored better for the designs with curb-side bus lanes.

For the urban integration and liveability, the space for pedestrians and bicycle traffic, road cross-ability, neighbourhood integration, public green space and long-term robustness all were better for designs with median bus lanes, while only road safety was evaluated better for designs with curb-side bus lanes.

The designs that relied on median bus lanes were picked and the two design sections were integrated into one final design for the entire design area (see Figure 1 or Appendix F). Since this final design also includes the sections of the design area where no space was available for dedicated bus lanes the final design does not fully satisfy the aim of the project. The municipality is therefore advised to continue working on the design to find way to fully satisfy the aim of the project. This could be done by changing the requirements that were set for this project. The two most logical ways to do this are either reducing the number of required lanes for general traffic, or finding space to widen the street, which seems possible given that the entire area is undergoing urban redevelopment. If the municipality is able to find such space they are recommended to find a way to incorporate median bus lanes on these sections.

The main takeaways for other projects are that when dedicated bus lanes are created on an urban street median bus lanes provide the best public transport service and that set requirements for a project can have a big impact on the final design and even compromise the aim of the project.

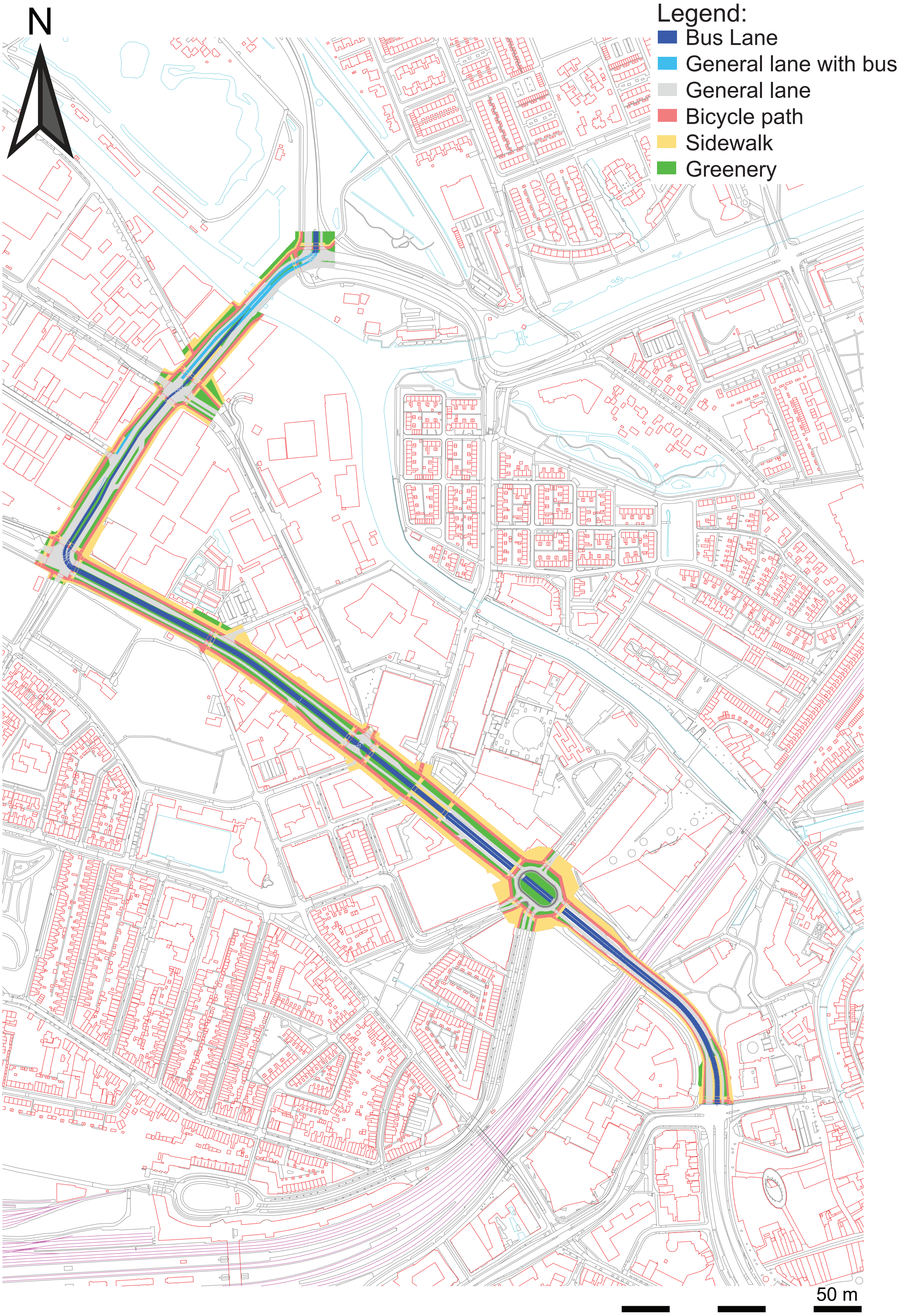


Figure 1: Final design

Contents

1 Introduction

1.1. Thesis motivation and relevancy

1.1.1. Motivation

Currently Europe is experienced a housing crisis (European Parliament, 2024). This crisis is also present in the Netherlands, where there is a significant shortage of housing. The national government has identified a gap of over 400 000 houses in the country (Ministerie van Volkshuisvesting en Ruimtelijke Ordening, 2024). To try to resolve this issue, a national long-term plan has been developed to build new housing. Within this plan seven regions in the country have been appointed for the accommodation of a significant part of these houses. Each of these regions is also subdivided into smaller areas on city scale. These are called the NOVEX-areas (Nationale Omgevingsvisie Extra; National Environment and Planning Vision Extra) and there are seventeen of them (Ministerie van Volkshuisvesting en Ruimtelijke Ordening, 2025).

The developments in the NOVEX-areas will bring new and more people to these cities. These people all have mobility needs. Since the NOVEX developments are of such a large scale, the current infrastructure cannot provide sufficient mobility. Therefore the national government has decided to also invest in the transportation infrastructure (Ministerie van Algemene Zaken, 2024). This new transportation infrastructure can then ensure that the NOVEX-areas have sufficient mobility options. Within these NOVEX-areas, space is scarce, therefore the amount of public space that mobility takes up in the public domain has become a point of attention. Space that is used for mobility cannot be used for other functions that enhance the liveability. A mobility system with a prominent place for public transportation can serve to both increase the capacity of the mobility while at the same time keeping space available for other functions (Gemeente Amersfoort, 2024).

1.1.2. Societal relevancy

Mobility is mentioned as a key factor for the NOVEX-areas. Without an adequate mobility solution for the NOVEX-areas, they will function below the desired level. If people have longer travel times, this means that less jobs, services and other opportunities will be available to them within reasonable travel time. This lowers the quality of life of the people living in the NOVEX-areas. This might cause the NOVEX-areas to become unpopular for living compared to other locations, which is the exact opposite of the goal of the project (Ministerie van Volkshuisvesting en Ruimtelijke Ordening, 2025).

1.2. Introduction to NOVEX-area Amersfoort

The Region Utrecht is one of the seven regions in the Netherlands that has been appointed for large scale growth. To organize this large scale growth in the Region Utrecht the programme U-Ned has been started; as a cooperation between all levels of government, as well as the private sector (U-Ned, n.d.). The U-Ned programme covers two NOVEX-areas; Utrecht Groot-Merwede and Amersfoort Spoor- en A1-zone. It also supports the development of housing and working locations in the wider area. Within the Region Utrecht between 2023 and 2040 165 000 houses and 110 000 working locations need to be realised. 40 000 houses and 32 000 working locations will be realised within the Amersfoort region. Around 14 000 houses and 24 000 working locations will be realised in the city of Amersfoort (U-Ned, 2023).

Within the city of Amersfoort, these houses and working locations will be built in different locations. There are three main development areas within the city; Langs Eem en Spoor (LES), Hoefkwartier and Bovenduist (see Figure 1.1). Furthermore some developments will also take place at a smaller scale all over the city. All the developments will have a relatively low number of parking spaces per house. Considering the high number of houses and low parking norms, other mobility options have to be provided. The municipality will invest into high quality walking and bicycle routes and bus public transportation. In previous stages the municipality also considered other modes of public transportation, but the decision for bus public transportation is now fixed. To improve the public transportation network within the city and towards the development locations, the municipality wants to create three 'bus rapid transport' (BRT) corridors, towards the north, east and south-west (see Figure 1.1). These improve and supplement the already existing bus network. The aim is to design the BRT corridors with a significant amount of dedicated infrastructure. (Gemeente Amersfoort, 2024).

This situation makes Amersfoort an interesting case, because it currently has very limited dedicated bus infrastructure. This means that with the addition of this infrastructure the public transport system in Amersfoort can make a leap forward. Therefore Amersfoort was chosen as a case study. The municipality of Amersfoort functions as the client for this project.

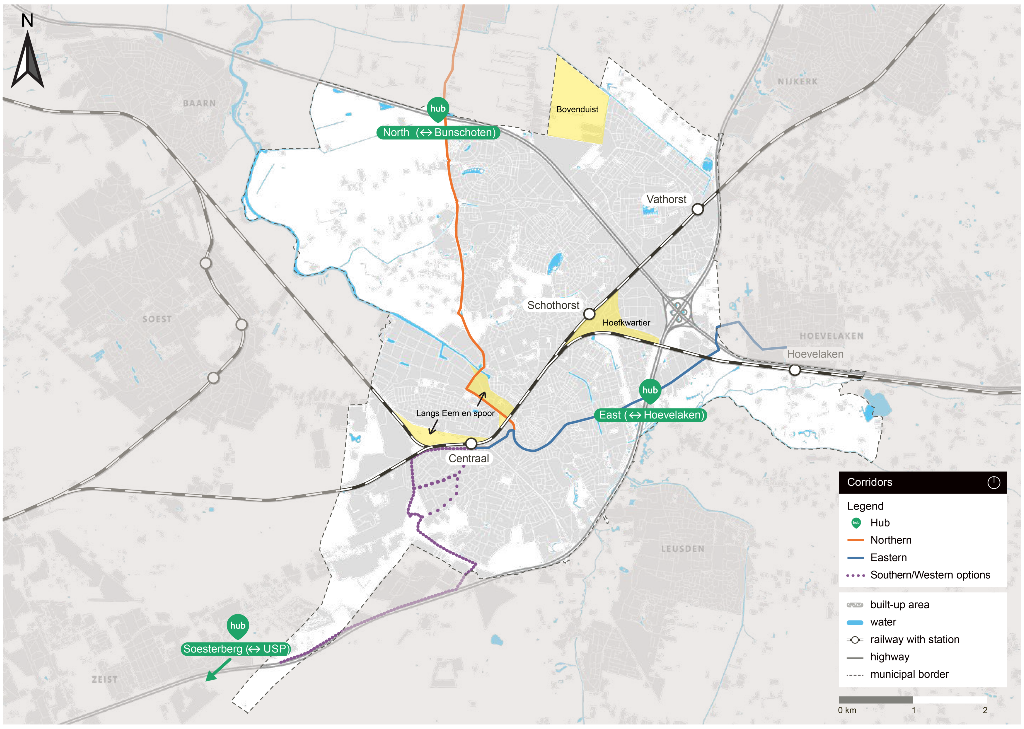


Figure 1.1: The targeted BRT network of Amersfoort and the three biggest development areas

2 Problem definition

2.1. Exploration of the problem

The NOVEX-areas will create new large scale housing developments in an already densely populated country. This will cause the mobility demands to go up. It is unlikely that the current transportation infrastructure can support these increased mobility demands. If the mobility demands cannot be met, capacity limits will be crossed. When capacity limits are crossed, travel times increase, leading to a reduced quality of life, as less locations are reachable within a reasonable travel time. This is undesirable and providing proper mobility infrastructure is therefore an integral part of the development of the NOVEX-areas.

Next to the issue of capacity and travel time, there is also a pressure on public space in general. Current transportation infrastructure takes up a significant portion of public space. This leaves less space for green areas, parks or other meeting places. This negatively affects the liveability of the neighbourhoods in which these streets are located.

2.2. Problem statement

In summary, the problem is:

- The transport infrastructure around many NOVEX-areas does not have the capacity to support the mobility demands that will exist after new housing has been built
- There is insufficient space to expand the current car-oriented transport infrastructure without unacceptable sacrifices of public space

2.3. Desired solution

To both increase the capacity of the transportation infrastructure and improve the liveability of the areas, the infrastructure needs to be redesigned. In such a redesign, it is key to aim for a mobility transition. This transition mainly encompasses the move from car-oriented mobility to public transportation and active modes. These modes are more space efficient, thus creating more transport capacity using less space. They are also perceived as less disturbing to the liveability. How a redesign can support this transition differs for each NOVEX-area. However, providing dedicated infrastructure for public transportation can be an effective way of improving the capacity, travel time and reliability of the transport network (Holve et al., 2022). Near each of the NOVEX-areas there already are public transport systems. To connect the NOVEX-areas to these systems most effectively it makes most sense to use the same form of public transportation (i.e. bus, tram, metro, etc.). The desired solution therefore uses the public transport mode that is already present.

2.4. Aim

Based on the problem statement and the desired solution, the aim of the project is to design infrastructure with increased transport capacity, while taking into account and making space for the liveability of the surrounding areas. More specifically this means that dedicated public transport infrastructure that can seamlessly connect to the already existing transport network needs to be designed.

3
Literature study

Because Amersfoort currently uses buses for their local public transport infrastructure, they are looking to expand and improve their bus network with new high quality infrastructure. To enable the design of such high quality bus public transport infrastructure, the current state-of-the-art was analysed. The current state-of-the-art will be a good starting point for the design process that will be conducted later on in the project. First a short history on high quality bus public transport is given. Then a systemic academic literature review is conducted and synthesised. This review is then expanded slightly, because the initial results were not entirely satisfactory. Afterwards a literature review of non-academic design guidelines was conducted. Finally the conclusions from the literature study were combined into a short design guideline that will be used as a starting point for the design process.

3.1. A history of high quality bus public transportation

The idea of using bus public transportation as a space efficient, yet high capacity form of transportation is not new. The first ideas date back to the 1930's. The concept was gradually developed throughout the 20th century and became known as 'bus rapid transit' or BRT. The system in Curitiba, Brazil from the 1960's and 1970's is seen as one of the first true BRT systems and was used as an example for BRT systems in the Americas and Asia (Bijl & Oort, 2024; Levinson et al., 2002). Especially since the early 2000's many new BRT systems have been built or are under construction (Hidalgo & Gutiérrez, 2013).

Many of the features that define a BRT system are not commonly implemented in Europe. A BRT system is similar in capacity and infrastructural scale to metro systems. In Europe, bus systems at this scale are not often necessary as metro systems are in place, where the demand is high enough. However, since the 1990's high quality bus lines have been developed. These have been at a smaller more 'tram-like' scale. These European systems are called 'buses with a higher level of service' or BHLS. It can thus be said that BHLS systems are mainly found in Europe and BRT systems are mainly found in the Americas and Asia (Bijl & Oort, 2024; COST, 2011; Heddebaut et al., 2010).

COST (2011) wrote extensively about examples of BHLS implementation and drew conclusions on the design elements that make BHLS successful. They noted that separated infrastructure and traffic priority are important design elements for the success of BHLS. The most successful projects included a significant amount of separated infrastructure and had priority at the crucial intersections. For the spacing of stops, they noted that every 400 meters was the minimum, because otherwise operational speed is too low for a BHLS compared to a regular bus. Finally they noted that the creation of BHLS lines often brings the opportunity to redesign an entire street, providing more space for liveability and a more welcoming streetscape. This was also noted by Bijl and Oort (2024).

In the Netherlands, the Dutch knowledge centre for road design; CROW, has a dedicated guideline for the design of bus lines and their infrastructure (CROW, 2020). This design guideline also has some sections dedicated to 'hoogwaardig openbaar vervoer' ('High quality public transport') or HOV. This term is often used in the Dutch context to describe BHLS. These sections are compact and feature bullet lists of what is important for HOV systems. They also stress that HOV systems often need to be adapted to the local situations.

3.1.1. Use of BRT, BHLS and other terminology

The analysis of the history of high quality bus public transportation showed that there are several different terms in use for high quality bus public transportation. To ensure continuity in this thesis high quality bus public transportation will either be referred to as high quality bus public transport or as BRT. The choice for the term BRT over the term BHLS was made because this is the term that the municipality uses in its publications. The only exception is during the literature analysis. Here the term that was used in the discussed publication will be used.

3.2. Systematic literature review

After researching the history of a high quality bus public transportation, the current state-of-the-art was next to be analysed. To find the current state-of-the-art, a systematic literature review was carried out based on the PRISMA guidelines (PRISMA Executive, 2024). The PRISMA guidelines aim to make literature review more systematic by explaining in the required detail what methods were used to review the literature. For this literature review that means that the database, search queries and paper selection criteria are clearly defined. This ensures that the literature should be reproducible by everyone and thus reduces possible bias from the author.

This literature review limits itself to the Scopus database. The Scopus database is a well-known and trusted database for scientific publications. Access was easily attained through the TU Delft.

3.2.1. Definition of the search query

The target of the literature review is to find literature about the spatial street design of streets incorporating dedicated bus lanes. To this end the following search query was used in the Scopus database:

> TITLE-ABS (”bus” AND ”design” AND (”brt” OR ”bhls” OR ”dedicated lane” OR ”bus lane”))
> AND (LIMIT-TO (LANGUAGE , ”English”))

As a side note, the use of double quotation marks instead of single quotation marks is important in this search query. The use of single quotation marks does not allow for multiple words within the quotation marks. Thus not allowing for ”dedicated lane” or ”bus lane” as compounds in the search query.

This search query consists of three terms; ”bus”, ”design” and ”brt”/”bhls”/”dedicated lane”/”bus lane”.

The term ’bus’ was added to ensure that the papers were about bus public transport. Without this specification for the ’b’ in the abbreviations of ’brt’ or ’bhls’, these abbreviations tended to yield medical results also.

The term ’design’ was added to ensure that the papers were about design of the infrastructure and not just about bus public transport themselves.

The term (”brt” OR ”bhls” OR ”dedicated lane” OR ”bus lane”) was used to find literature about bus infrastructure on dedicated lanes. This is often part of the concepts of ’brt’ or ’bhls’ and might thus be referred to as such.

The search query was limited to results in the English language, because the author only speaks Dutch and English at an adequate level to read academic literature and it was assumed no academic publications would exist in Dutch.

The search query was not limited in time, because the development of higher quality bus infrastructure is a relatively new concept. Out of all 399 results, only 10 were published before 2000.

3.2.2. Results from the search query

The search query was conducted on 27/05/2025 and yielded 399 results. All results were scanned based on their title and abstract to see if they matched the desired topics. For this manual scanning, the following criteria were used to decide whether a publication would be approved for further reading and analysis or discarded:

- Results must be about street level design, not network level design
- Results must be about spatial infrastructure design, not structural infrastructure design
- Results must be about permanent continuous bi-directional dedicated bus infrastructure
- Results must not be about metro-like BRT systems
- Results must be about urban roads/arterials and not about freeways or highways
- Results must not be limited to intersection or station design
- Results about specific case studies should not be translatable to the Dutch context

After manual scanning of the title and abstract 27 publications remained. 3 of these 27 were inaccessible and could therefore not be used. The final 24 publications were assessed on their full text using the same criteria as for the assessment based on the title and abstract. This resulted in a further narrowing down to 16 publications. These publications were all used in the literature synthesis.

The process is schematised in Figure 3.1.

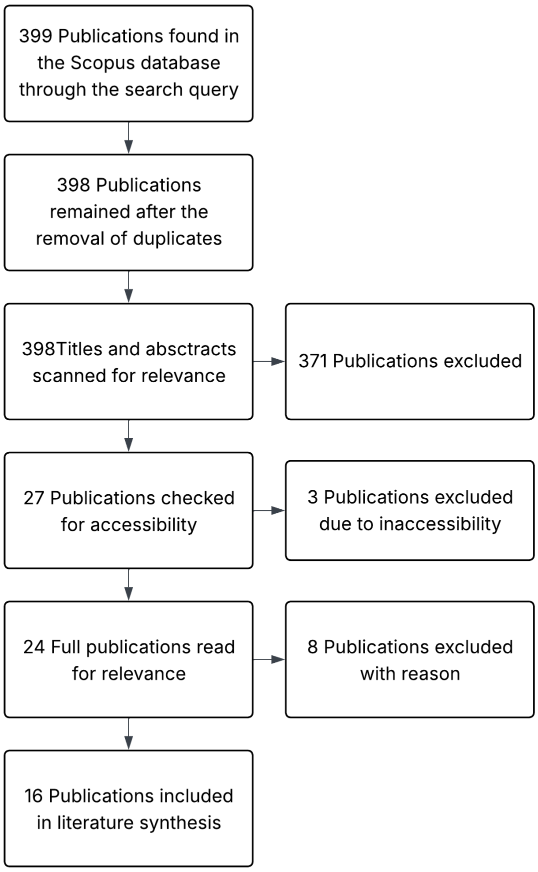


Figure 3.1: The PRISMA flowchart with the number of publications

3.3. Literature synthesis

In the literature results relating to the design of high quality dedicated bus infrastructure were found in three categories; road layout design, enforcement of bus lanes through design and safety impacts of bus priority infrastructure. There were also some publications with useful insights that did not fit into any of the three categories. These are discussed separately in a fourth category.

The first category consists of publications that describe the development of dedicated bus infrastructure in existing road layouts. These publications describe case studies were such projects were carried out, what alternatives were considered, how they compared to each other and which alternative was assessed to be the best fit and thus implemented.

The second category consists of publications that describe how the physical design of bus infrastructure can improve the adherence of road users to the dedicated bus infrastructure. It describes what measures are effective in preventing other road users from using the bus infrastructure illegally.

The third category consists of publications that describe the safety impacts of dedicated bus infrastructure. These describe case studies were dedicated bus infrastructure has been realised and compare the before and after situations in terms of traffic accidents. These studies also compare different types of dedicated bus infrastructure so conclusions may be drawn on which type of dedicated bus infrastructure is best for traffic safety.

The fourth category consists of other publications that did not fit any of the previous three categories, yet provided valuable insights.

The four categories are all elaborated on further below.

3.3.1. Road layout design

The redesign of streets to include dedicated space for buses has been documented in the literature several times (E. Beaton et al., 2013; E. B. Beaton et al., 2015; Bent et al., 2008; Shea & Turvey, 2006; Singh et al., 2016). The approach to finding the best solution at hand is fairly consistent across all of these publications. In all publications multiple different alternatives, for where on the street dedicated bus lanes can be created, are proposed. They then compare these alternatives qualitatively across different evaluation criteria.

In all of the scenarios the creation of dedicated bus lanes is considered within the context of an already existing city scape. All of the found publications consider cases in North America. Therefore the design of the street before the implementation of the dedicated bus infrastructure follows a somewhat standard design that is common in North America. This design includes 2 or more general traffic lanes in both directions and 1 curb side parking/access lane on both sides of the street. The proposed bus lanes then replace one of the existing lanes that is either used for general traffic or parking/curb access.

There are three general options (although per case slight variations do exist) for the inclusion of new dedicated bus lanes that are considered in these examples:

- Curb-side bus lanes
- Offset bus lanes
- Median bus lanes

The curb-side bus lanes replace the parking/curb access lane, that is directly adjacent to the sidewalk. The offset bus lanes replace the right (in the case of right hand travel) most general traffic lane, directly next to the parking/curb access lane. The median bus lanes replace the left (again in the case of right hand travel) most general traffic lane, thus creating two adjacent, but opposing bus lanes in the middle of the street. In Figure 3.2 illustrations of all three variants taken from E. Beaton et al. (2013) are shown.

(a) Curb-side bus lanes as illustrated by E. Beaton et al. (2013)

(b) Offset bus lanes as illustrated by E. Beaton et al. (2013)

(c) Median bus lanes as illustrated by E. Beaton et al. (2013)

Figure 3.2: The three possible locations for bus lanes as illustrated by E. Beaton et al. (2013)

In Table 3.1 the five different cases that were found in the literature are shown. For each case the alternatives that were considered and chosen are given. Interesting to note is that in 3 out of the 5 cases the publication is only informative and no formal conclusion about the best alternative is given.

Table 3.1: Considered and chosen bus lane locations found in the literature

Case	Curb-side	Offset	Median	Chosen
New York - Webster (E. Beaton et al., 2013)	yes	yes	yes	Offset
San Francisco - Geary (Bent et al., 2008)	yes	yes	yes [1]	No choice
San Francisco - Van Ness (Bent et al., 2008)	yes	no	yes [1]	No choice
Toronto (Shea & Turvey, 2006)	yes	no [2]	yes	No choice
New York - Woodhaven(Singh et al., 2016)	no	yes [3]	yes	Offset [3]

E. Beaton et al. (2013) find the offset bus lanes to be the best option. This option balances the demands of public transport users, pedestrians and motorists best. They acknowledge that the median bus lanes offer the best improvement for public transport operations, but this option negatively affects other traffic. The median bus lanes also received significant concern from the public. This is possibly due to the fact that the median bus lanes would only be used by express buses and not local buses. This makes transferring between the express and local bus relatively complicated. The curb-side bus lanes showed only minimal improvements for public transport operations, but sacrifices a lot of parking and curb access. Therefore this alternative was not recommended.

Bent et al. (2008) only describe to process of how they will compare their alternatives, but don't include the actual comparison in their publication. Therefore they do not draw any conclusion about which alternative is best in their publication.

Shea and Turvey (2006) seem to find no significant differences between their two alternatives for most evaluation criteria. They only note significant differences for traffic performance and costs. The median bus lanes score better in terms of traffic performance due to less interference from other traffic. On the other hand, they are also twice as expensive as the curb-side bus lanes.

Singh et al. (2016) conclude that their second variant[3] on offset bus lanes are the best option. Similar to E. Beaton et al. (2013) and Shea and Turvey (2006) they conclude that median bus lanes offer the best for public transport operations, they however find that their offset variant scores much higher on pedestrian safety. The median bus lanes show no improvement compared to the base scenario for this criteria, which is problematic as the street in the base scenario sees a large number of car-pedestrian accidents. This is likely related to the fact that the street on its widest sections has four travel lanes per direction in the base scenario. This creates a large number of conflict points for pedestrians as they cross the street to get to the median bus lanes.

Beyond trying to find an optimal spatial design based on different factors, Stewart et al. (2018) wrote about tools to engage the general public for the redesign of streets to incorporate dedicated space for public transportation. They showed that using modern open-data based tools, the general public can be informed and their understanding of BRT projects can be deepened. They also showed that using these methods their feedback and input for the project can be gathered. Such methods should be considered for similar projects. Especially because all the cases that were shown in Table 3.1 also considered some sort of public feedback for their decisions on which design was optimal.

Concluding, there are many different factors that need to be considered for the redesign of streets to accommodate dedicated infrastructure for public transportation. The best design is case specific and the arguments for different designs differ per case. The offset bus lanes were most often identified as the best option, even though the median lanes were seen as the best for public transport performance. Factors that give the offset lanes an edge over median lanes are costs, difficulty to integrate local

[1] Alternatives for both Geary Boulevard and Van Ness Avenue included multiple variations on the median design. The general concept stayed the same; using the two centre lanes for dedicated bus infrastructure. The differences lied in where the actual green medians were and thus how the bus lanes were separated from the other traffic.

[2] The street considered by Shea and Turvey (2006) does not feature a parking/access lane. Therefore the offset option does not make sense. In this case it might be more realistic to consider the curb-side option as a combination of curb-side and offset options in the other case studies.

[3] Singh et al. (2016) included two variants on the offset option. The first was a regular offset option similar to the option in the other cases. The second was an offset option were between the bus lanes and the sidewalk a local lane was implemented for traffic that needed to park/access the curb. This means that this offset option jumps over two lanes; a parking/access lane and a local lane. This second variant of the offset lanes was the one chosen as the best option.

and express buses on median lanes and, arguably most importantly, road safety. For future projects it might be interesting to see if these factors can be mitigated for median lanes. Thus combining the best alternative for public transport performance with the best alternative for the other street functions. Curb-side lanes were found to be the least effective option in all cases where they were considered. This is due to the fact that they create little public transport performance improvement, but do sacrifice a lot in terms of parking and curb access.

Finally, it must be noted that all cases found in the literature were situated in North America. The general challenges of street redesign for better integration of public transport and the different interests of different road users are global. However the base scenario that most streets have are very different across the globe. Therefore the method that was applied to compare different alternatives translates quite well across the world, but the considered alternatives might not be relevant everywhere. Especially in Europe many streets in urban centres look very different to those in North America. This is a gap in the literature, as a case study of such a project in Europe currently cannot be found.

3.3.2. Enforcement of bus lanes through design

Dedicated bus lanes are prone to violation of their exclusivity by other road users. This hampers the bus service and limits the function of the lane to service as a piece of high quality public transport infrastructure. The enforcement of bus lanes can be done in multiple ways. Police can be dispatched to the locations to actively enforce the bus lane. Also Cameras, either roadside or onboard of bus vehicles, can be used. However the design can also play a part. A well designed bus lane can make it harder or less appealing to violate the exclusivity of the bus lane by other road users (Cesme et al., 2018; Kiesling & Ridgway, 2006).

The design aspects that influence the enforcement of the bus lanes have been studied by Cesme et al. (2018), Kiesling and Ridgway (2006), and Safran et al. (2014). The two most common methods to enforce bus lanes are; using painted lines to delineate the bus lanes from general traffic lanes and complete painting of the bus lane in a contrasting colour (in all examples found red is used, but theoretically other colours could be used as well) to the black/gray of the asphalt. All three publications show that the complete painting of the bus lane in a contrasting colour is a more effective method than using painted line to delineate the bus lanes. However this is also more expensive as it requires more paint. Despite this extra cost, Cesme et al. (2018) showed that the complete painting of the lanes is the most cost effective option, if no or low police enforcement is used. However, if either moderate police enforcement or camera based enforcement is used this no longer holds true and the extra cost of the complete painting of the lanes makes it less cost effective than using painted lines.

Safran et al. (2014) looked extensively at the bus lanes in New York and considered several factors that influence the obstruction of bus lanes. In terms of design they considered two factors; the location of the lane in the street; curb-side or offset (see subsection 3.3.1) as well as the use of painted lines or completely painted lanes. They found that offset bus lanes are less likely to be obstructed than curb-side lanes and that completely painted lanes are less likely to be obstructed than lanes delineated with painted lines. In both of these scenarios the number of buses that encountered obstruction was 1.5 times higher in the curb-side/painted line delineated lanes than in the offset/completely painted lanes. However, they do also find that these bus lanes do still face an unacceptable amount of obstructions, with 30% of buses encountering obstruction in the offset lanes and 35% of buses encountering obstruction in the completely painted lanes.

Therefore it might be necessary to look towards other options to further improve the enforcement of lanes through design. Where possible Kiesling and Ridgway (2006) proposes the use of physical separation of the bus lanes using medians. Such a physical separation makes it significantly harder for other road users to use the bus lanes as they can only access them in specific locations (such as intersections). This does however come with extra costs as this requires a significant redesign of the street, instead of a simple lane conversion from general traffic lane to dedicated bus lane.

In conclusion, it is useful to apply design elements to enforce bus lanes. The complete painting of bus lanes was found to be more effective than delineating bus lanes with painted lines. However if the space and budget allows for it, it is preferred to opt for complete physical separation between the bus lanes and the general traffic lanes.

3.3.3. Safety impacts of bus priority infrastructure

When a street is redesigned in a way that changes the traffic make-up on the street, this has an effect on the safety of the street. Duduta et al. (2012), García M. et al. (2024), and Goh et al. (2013) all find that the addition of dedicated bus infrastructure to a street can improve the road safety on that street. However there are some caveats and some types of dedicated bus infrastructure are more effective at improving the road safety than others.

Duduta et al. (2012) studied a total of nine different BRT systems in cities in Latin America and India. They found that over 90% of accidents on BRT corridors occurred outside of the BRT lanes, leading to the conclusion that the design of the general traffic lanes remains more important for road safety than the design of the BRT lanes. Pedestrians involved were part of only 9% of all accidents, but involved in 54% of fatal accidents. For the BRT lanes, road safety thus mainly concerns pedestrians. For accidents on the BRT lanes, there were three main types of BRT lanes that were applied; curb-side BRT lanes, median BRT lanes and counterflow BRT lanes. Curb-side and median lanes were explained earlier in subsection 3.3.1. Counterflow lanes are similar to median lanes, in that they are located in the middle of the street. However they are different as buses travel in the opposite direction compared to the general traffic. This type of lanes is usually applied to make it possible to have only one platform at BRT stations while still having buses with the doors on the right side (in the case of right hand traffic). They found that this type of BRT lane is the most dangerous. They also found that curb-side lanes may be dangerous as pedestrians might enter them from the curb to walk on when the side walk is overcrowded. Therefore median lanes were found to be the safest option. Median lanes also often replace a general traffic lane in the middle of the street and create a crossing refuge. This makes it safer for pedestrians to cross the street as they have to cross less far and can cross in stages. They also note that most accidents involving BRT buses occur at stations and intersections. It is therefore important to design intersections in such a way that the number of points of conflict is reduced, for example by restricting left-turns across the BRT lanes. Conflict points at BRT stations mainly occur when there are multiple BRT lanes at the station. In this case pedestrians wanting to cross the station may be hit by a bus passing the station, which they could not see because another bus was stopped at the station.

García M. et al. (2024) studied the safety on streets with different types of bus service in Bogotá, Colombia. They studied arterials with BRT service (completely separated median bus lanes), BHLS service (curb-side bus lanes, that are not always present) and regular arterials with bus service (with no dedicated bus lanes). They found that arterials with BRT service have better road safety than regular arterials, while arterials with BHLS service have worse road safety than regular arterials. The higher rate of accidents on the arterials with BHLS service is likely due to the fact that these arterials see a high number of different types of road users using the same space. High percentage of motorbikes, trucks and buses increase the likelihood of accidents. It was also noted that although arterials with BRT have the least amount of accidents, they do have a high number of accidents involving pedestrians. These accidents have a high likelihood of being fatal and were linked to jaywalking and fare evasion around the BRT stations.

Goh et al. (2013) studied the addition of curb-side bus lanes to streets in Melbourne, Australia. They found that the addition of curb-side bus lanes to the street results in a significant decrease in the number of accidents. It seems as if the curb-side bus lanes act as a kind of buffer between general traffic lanes and roadside obstacles, reducing the risk for accidents. Important to note is that the reduction in accidents was true for all types of accidents, except for those involving pedestrians, for which a slight increase in accidents was noted.

In conclusion, dedicated bus infrastructure in general improves road safety, but different types of dedicated bus infrastructure can have very different effects on the road safety. Physically separated median bus lanes have the best effects on road safety. However median bus lanes do tend to have accidents occurring with pedestrians trying to reach the stations in the middle of the street. Therefore special attention must be paid to pedestrian access routes when such stations are designed. Similarly accidents are more likely to happen at intersections, so special attention should be given to intersection design. Finally, most accidents on streets with dedicated bus lanes occur outside of the dedicated bus lanes. It is therefore important to consider the entire street when designed dedicated bus infrastructure, so that road safety can be ensured on the entire street.

3.3.4. Other insights

Besides the publications that have been discussed by in the three categories, several publications were found that had some insights that are useful, but do not fit any of the three previously discussed categories.

Cordera et al. (2024) conducted interviews with bus drivers in seven medium sized Spanish cities. The bus drivers perspective can be very insightful, but has not often been highlighted in the literature before. Among other topics, the bus drivers were asked about the importance of dedicated bus lanes. The bus drivers identified dedicated bus lanes as very important for the bus service. They saw the the use of bus lanes as beneficial, for driver comfort, passenger comfort, operating speeds, reliability and pedestrian safety. The bus drivers also noted that for pedestrian safety it is important that bus stops and walking routes around bus stops are visible and clearly defined.

Coni et al. (2020) conducted surveys about passenger comfort on buses in Cagliari, Italy and also found that the presence of dedicated bus lanes has a positive influence on passenger comfort. This was linked to the more consistent speed that buses can drive over dedicated bus lanes. Limited acceleration and deceleration increases passenger comfort.

Imam and Tarawneh (2012) analysed a multitude of BHLS systems all across Europe and also looked at the influence of dedicated bus lanes on operations. They found a moderate correlation between dedicated bus lanes and operational speed and a strong correlation between stop spacing and operational speed. The use of dedicated bus lanes is thus important to improve the speed, but minimising the number of stops is even more relevant.

Losa et al. (2014) described the creation of a BHLS system in Pisa, Italy, where limited to no space was available for dedicated bus lanes. They showed that if no space for dedicated bus lanes is available, an adequate service can still be achieved using public transport signal priority at intersections and roundabouts.

3.4. Beyond the systematic literature review

The results stemming from the systematic literature review, while insightful, were not satisfactory. The absence of examples for dedicated bus lane design in Europe especially was deemed problematic. Therefore it was decided to look for other publications that were not yet found during the initial systematic literature review. The first was through a new search query in the Scopus database. The second was through looking for design guidelines that are not published in academic databases and could thus not be found through Scopus.

3.4.1. New search query to find European results

The publications pertaining to dedicated bus lane design that were found in the systematic literature review were all from North America. This was seen as problematic, because the case at hand is in Europe and there are real and significant differences between European and North American street design. Therefore a new search query was created to look specifically for results about European cases. Projects relating to the improvement of bus services in Europe are often classified as BHLS and not BRT, partially because of the different street designs found in Europe, when compared to North America, Latin America and Asia. Therefore it was decided to look for publications discussing BHLS. The search query used in the Scopus database was:

TITLE-ABS (”bus” AND ”bhls”) AND (LIMIT-TO (LANGUAGE , ”English”))

The same rule set as described in subsection 3.2.1 was applied for this search query.

This search query yielded only 15 results, of which 2 were duplicates and three were already found using the first search query. This left 10 papers for assessment based on the title and abstract. The same rule set as described in subsection 3.2.2 was used to see if papers were relevant or not. 5 papers were discarded and 5 papers were left to be analysed based on their full text.

3.4.2. Synthesis of European BHLS publications

The publications that were found using the new search query also acknowledge a difference between street and urban structures between Europe and North America. They identify that this difference also leads to differences the way high quality bus systems are designed and implemented (Heddebaut et al., 2010; Hidalgo & Gutiérrez, 2013; López-Lambas & Valdés, 2013). However none of them give concrete examples of how to design high quality bus infrastructure within the European context. They explain the concept and describe of dedicated bus infrastructure is an important part of improving the bus service and that examples have shown that improving infrastructure can make a real difference (Disperati et al., 2011; Hidalgo & Gutiérrez, 2013). They also note the differences between the tram and higher quality buses and explain that each holds its place in a functioning public transport system (Heddebaut et al., 2010; López-Lambas & Valdés, 2013; Novales et al., 2012). These publications are useful for understanding the concepts that underlie the buses with a high level of service, but they don't provide any real guidance in how to design such systems at the street level. Therefore it can be concluded that there is a gap here in the academic literature. For street level design cases for infrastructure to support buses with a higher level service in the European context no academic literature could be found.

3.5. Review of design guidelines

Beyond academic literature there are also guidelines for road design available. These guidelines are written for direct use in the field and are often published by government agencies or international co-operatives. For any project concerning road design, it is valuable to conduct these design guidelines. The following eight design guidelines were considered for review.

- BHNS Concept et recommandations (Certu, 2005) (in French)
- BHNS Du choix du système à mise en oeuvre (Certu, 2009) (in French)
- BRT Planning guide (Insitute for Transportation and Development Policy, 2017)
- **Buses with High Level of Service (COST, 2011)**
- **Global Street Design Guide (Global Designing Cities Initiative, 2016)**
- **Richtlijn inpassing tram in stedelijk gebied (CROW, 2022b) (in Dutch)**
- Transit Capacity and Quality of Service Manual (Transit Cooperative Research Program, 2013)
- **Wegontwerp voor openbaar vervoer (CROW, 2020) (in Dutch)**

The guidelines in **bold** were deemed useful based on a scan of their contents, whereas the other 4 were discarded for further review. The two French publications by Certu were discarded, because they discuss the design, planning and implementation of a complete BHLS system and not specifically the street design part of these systems. The publications from ITDP and TCRP were discarded, because they feature limited information about street design specifically and all the information that they do feature was also available in the publications by COST, CROW and GDCI, so they provided no meaningful new information for street design for public transport.

The four publications that were selected for further review are synthesised in the following two subsections. First the using the publications from GDCI and COST for a global/European view and then the two publications from CROW for a Dutch view.

3.5.1. Global and European design guidelines

The Global Street Design Guide (Global Designing Cities Initiative, 2016) is a guideline specifically written for street level design. It does not specifically focus on public transportation, but does discuss how to implement it effectively into the street. Like most street design guides it does not provide a clear-cut process of how to design any street, but rather shows a wide range of ways that can be adapted to local circumstances. The guide thus relies more on general principles than direct design advice. The most important design principle for public transport is the usage of dedicated space on multimodal streets. Multimodal streets have clear distinctions between the space provided for different transport modes. This increases the capacity of the street as all modes can operate at their highest efficiency with limited obstructions from other modes. At the same time, clear demarcations of what space is used for also make it easier to allocate space to non-mobility functions.

The guide discusses each element of the multimodal street individually and therefore has a section specifically for the design of public transportation. This section shows examples of how to integrate public transportation into a multimodal street. The guide identifies five general ways in which this can be done (they can also be seen in Figure 3.3):

- Side-running dedicated transit lanes
- Side-running transitways
- Centre-running transitways with centre boarding
- Centre-running transitways with passenger-side boarding
- Shared transit streets

The difference between a dedicated transit lane and a transitway is a physical separation between the transitway and general traffic lanes, which is not present for a dedicated transit lane (see Figure 3.3). The shared transit streets are shared with pedestrians.

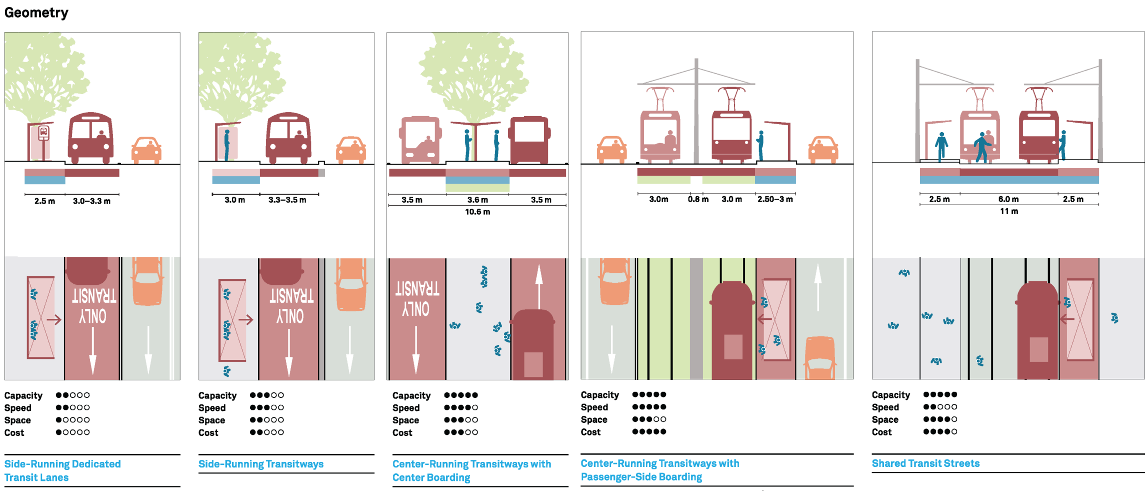


Figure 3.3: The possible bus lane locations as per the Global Street Design Guide (Global Designing Cities Initiative, 2016) (pp. 114-115) (edited)

The GDCI scores all five of the ways to implement dedicated space for public transport in four categories; capacity, speed, space and cost. In general it holds that designs that score high in capacity and speed also take up a larger amount of space and cost more. When compared to the bus lane locations discussed in subsection 3.3.1 it can be seen that the side-running and centre-running options are analogous to the curb-side and median options. Both here and in subsection 3.3.1 the centre-running transitways/median bus lanes score higher in capacity and speed/public transport performance than the side-running transitways/curb-side bus lanes. Interestingly there is no analogous option to the offset bus lanes here. The shared transit streets are new, however it could be argued that this is not true dedicated public transport space as it is shared with pedestrians. It is therefore also not relevant for this project.

The guide also discusses pedestrians crossings and how they can be applied around public transport stops. Pedestrians often choose the shortest route to cross streets. Therefore it is safest to facilitate pedestrian crossings at all logical locations. At these locations the crossings must designed in such a way that their length across both general traffic and bicycle lanes is minimised.

As part of the European Cooperation in Science and Technology programme, a guide on BHLS, based on 35 European case studies, was published (COST, 2011). This guide identifies the main characteristics of BHLS and makes recommendations on how to implement BHLS systems as effective as possible. It notes that having dedicated space for the BHLS service is the most strategic, visible and expensive component of the system. This shows that while having dedicated space for BHLS service is important, it comes at a cost. Therefore creating this dedicated space is not always easy, especially when demands from other road users, for the same space comes into play. Therefore there is no single solution that will be effective everywhere.

For bus lane design they identify two main locations in which dedicated bus lanes can be placed; median or curb-side (similar to what was found in subsection 3.3.1 and the publication by GDCI). They identify that in general systems seem to function better with the median bus lanes than with the curb-side bus lanes. For bus lanes they also have a recommended lane width included. This value can be seen in Table 3.2. Finally for the design of bus lanes they note that the using a coloured surface increases the visibility and enforcement of the bus lane, which is in accordance with what was found in subsection 3.3.2.

Table 3.2: Recommended lane widths for BHLS lanes according to COST (2011)

	One-way	Two-ways
30 km/h	3.25 m	6.00 m
50 km/h	3.50 m	6.50 m

For the stop design they note that the safety of pedestrians is of high importance. Therefore all logical pedestrian crossings should be facilitated and precautions for safety should be taken around these crossings. The platforms should be large enough for the demand and the stop should meet all the requirements for accessibility. On accessibility they add that more is better. Taking extra accessibility measures beyond the minimum requirements improves the system for all users, not just the bottom few that need it the most. Therefore investing in accessibility can be worthwhile as it increases the attractiveness for all users.

Finally this guide notes that the use of examples from other projects in Europe can be a very useful way to expand knowledge and learn what works and what doesn't.

3.5.2. Dutch design guidelines

The Dutch design guidelines published by the CROW (2020, 2022b) are more extensive and describe in detail, what options are available to in the design of a street.

The 'Wegontwerp voor openbaar vervoer' ('Road design for public transport') by CROW (2020) is a guideline for the design of bus systems, including some of the street level design. The guideline was written for bus systems in general and therefore does not specifically focus on higher level bus systems. However, the guide still provides useful information and examples that can be translated to higher level bus systems as well.

The 'Richtlijn inpassing tram in stedelijk gebied' ('Guideline for the integration of a tram in urban areas') by CROW (2022b) is a guideline for the design of urban tram networks, including the street level design. Although separated bus lanes are not necessarily designed in the same way as tram lanes, there are many similarities. Which allow the information and examples to be translated for dedicated bus lanes fairly easily. The guide is therefore a useful addition to the 'Wegontwerp voor openbaar vervoer', because it does focus on higher level public transport systems, which trams in most cases are.

Both guidelines give a description of what a higher level bus system is. In both cases to differentiate it from the main topic of the guideline (i.e. regular bus or tram systems). The guidelines both agree that a higher level bus system (called BRT (CROW, 2022b) or HOV (CROW, 2020)) features separated infrastructure that has been fitted into the street without compromise. Proper design of this separated infrastructure, especially at intersections with other streets, creates an infrastructural network in which travel times are predictable. This means that all buses have a similar travel time, which can decrease the need for buffer, which in turn increases the efficiency and reduces the operation costs (CROW, 2020). The presence of level-boarding (CROW, 2022b) and a comfortable road surface (CROW, 2020) are also mentioned as features.

The creation of separated bus lanes often takes place in the context of urban redesign. This gives the possibility to not just improve the bus infrastructure, but also make a general redistribution of street space among different modes. This allows for a higher emphasis to be given to pedestrians. This will also allow for bus stop locations, including their access routes for pedestrians, to be optimised. Thus connection between the bus system and the most important origins and destinations in an area can be improved. The bus stop can even be used to achieve urban goals beyond providing access to a bus system. A bus stop can be used to; create stronger pedestrians, provide a natural connection between two neighbourhoods and serve as a landmark (CROW, 2020).

The width of a dedicated bus lane should lie between 3.25 en 4.00 m (CROW, 2020). Around stops the width of a lane should be at least 3.50 m, to ensure that traffic in the opposite direction has enough space to pass (CROW, 2022b). For the curve radii on bus lanes minimal values are provided in Table 3.3 at 30 km/h or 50 km/h. If there is not enough space for a 50 km/h curve, then a tighter curve can be applied, but then the curve should be taken at a lower speed.

Table 3.3: Minimal curve radii for bus lanes according to CROW (2020)

	BRT	Minimum
30 km/h	60 m	25 m
50 km/h	150 m	110 m

Dedicated or separated bus lanes have no specific design guidelines. Therefore CROW (2020) advices to use the same design methods for bus lanes as for general traffic lanes. This is important to maintain a homogeneity across the road network. This homogeneity and recognisability is one of the main principles of 'Duurzaam veilig' ('Sustainable safety') that lies at the base of Dutch road design.

For pedestrian/bicycle crossings of separated bus lanes there should be a priority regulation. In principle the buses should have priority of the crossing traffic. If there is a high volume of traffic on either the bus lane or the crossing, the installation bus warning lights or traffic lights should be considered (CROW, 2020).

Stop Design

In general a stop should be safe, recognisable, accessible and approachable. To this end the integration with the surrounding area is a priority (CROW, 2020).

Access routes

A stop should be reachable without unnecessary street crossings. In homogenous areas this means that there should be an access route from all directions to the stop. In locations with large origins/destinations, a high quality direct access route to the origin/destination can suffice. Access routes should be as straight as possible. When the routes have large detour, pedestrians and bicycle traffic will take short cuts that are not accommodated in the road design. This causes unpredictable and unsafe situations (CROW, 2020). Access routes should logically connect onto the pedestrian and bicycle network in the surrounding area. Height differences in the access route should be minimised to increase accessibility for wheelchairs users, strollers and less-mobile pedestrians (CROW, 2022b). When choosing between median bus lanes or curb-side bus lanes, it should be considered that to reach a stop on a median bus lane, passengers will always have to cross half of the general traffic lanes. For curb-side bus lanes on the other hand, some passengers will have to cross all the general traffic lanes (CROW, 2020).

Platform design

The dimensions of the platform depend on multiple factors. The length of the platform is mainly decided by the length of the buses that will use the platform. The platform should be at least the same length as the longest bus that will use it (CROW, 2020). If the stop is busy the capacity for waiting passengers can also be increased by making a longer platform. However increasing the width is much more effective than increasing the length to increase capacity (CROW, 2020, 2022b). The minimum width for a bus platform is 2.50 m and the optimal width is 3.20 m. In both cases at least 1.20 m should be free from obstacles, including the shelter (CROW, 2020). To achieve level boarding with a low-floor kneeling bus, the platform height should be between 180 and 200 mm. The bus approach should make it easy for bus drivers to stop with a minimised gap between the bus and the platform (CROW, 2020).

Cover and seating

The stop should have at least one shelter (Dutch: Abri) to protect against wind and rain. The shelter should have a comfortable bench to sit and wait on. If the stop is busy it should be considered to place a second shelter (CROW, 2020, 2022b). Adding lean benches can also increase the number of people that can comfortably wait at the stop. Fences can also be used instead of lean benches. This should also be considered when using fences at the back of the platform. There should be enough free space for someone to lean on the bench with a backpack (CROW, 2022b).

Social Safety

To increase both the social safety and visibility of a bus stop, there should be lighting present. In many cases the street lighting will suffice, but if not, the stop should have its own lighting. For social safety it is also worth considering that lone travellers are more prone to harassment than travellers surrounded by others and that people also feel safer with more people around. Therefore designing the stop such that it is visible by people in the surrounding area will increase the social safety (CROW, 2022b).

Accessibility

Stops should be supplied with route guidance for the less-abled. The accessibility of the stop for the less-abled also deserves special attention within a 100 m radius of the stop (CROW, 2020).

Parking facilities

A stop should have parking facilities for bikes and scooters. The number is dependent on the number of passengers that use a bike or scooter for their first-/last mile. They should be on the approach route for bikes and scooters. In some locations it is useful to install charging for e-bikes and/or bike lockers at the stop (CROW, 2022b).

Fencing

Fencing can be applied at the back edge of the platform, to protect passengers from general traffic lanes behind the stop. Fencing can also be applied between bus lanes to prevent passengers walking from one platform to the other across the bus lanes. This should be avoided when the bus lanes are also used by emergency services as such fences make it harder for an emergency vehicle to pass a stopped bus (CROW, 2022b).

Traffic signals

Traffic signals should be made to prioritise the public transport services that pass them. Special attention should be paid to the way priority is given when the traffic signal is just after a stop. The easiest way is to give a standard amount of time for the loading and unloading of passengers at the stop upon arrival at the stop, after which the priority is given at the traffic light. If necessary the amount of time can be changed depending on the time of the day (CROW, 2022b).

Design examples from the Dutch design guidelines

Both of the Dutch design guidelines also provide plenty of base designs that can be used as a starting point for a redesign. The relevant base designs from both design guidelines were selected and included here. To be relevant to the case at hand, base design had to be for distributor roads within urban areas. This means that designs for roads outside urban areas, designs for access roads, designs for stand-alone bus lanes and designs for shared space were excluded. Furthermore designs with roundabouts were deemed irrelevant as the area for the case does not feature roundabouts.

Designs for buses and trams were deemed equally relevant, because the base designs are not strict and must be adapted to the case at hand. Therefore designs for trams can be just as helpful as designs for buses, when adapted to work well for buses.

The base designs are included in Appendix A. In total twelve base designs from CROW (2020) have been included. These come with an informative table as well as an image displaying the base design. Eleven base designs from CROW (2022b) have been included. These come short description and an image displaying the base design.

3.6. Conclusion of the literature study

Based on the literature study several conclusions can be drawn for the best ways to design dedicated bus lanes. These conclusions can be used as a short design guideline and will form the basis for the design process.

3.6.1. Design of bus lanes

The first part of the design of a bus lane is determining where in the street profile the bus lane will be located. Through the literature study four options were identified:

- Median bus lanes
- Curb-side bus lanes
- Offset bus lanes
- Side separated bus lanes

Both the academic literature and the design guidelines that were found identified median bus lanes as the most effective for public transport operations (E. Beaton et al., 2013; COST, 2011; Global Designing Cities Initiative, 2016; Shea & Turvey, 2006; Singh et al., 2016). The location in the middle of the street allows buses to operate smoothly with limited interference from other traffic. Curb-side and offset bus lanes have more interference from other traffic, which makes buses more susceptible to being hindered. Therefore median bus lanes are the preferred option. However, they also have downsides. They usually require a complete redesign of the street, which is expensive, and it might be hard to fit them in at intersections, especially when there are left-turning lanes for the general traffic.

Curb-side and offset bus lanes were mentioned as cheaper measures that are easier to fit into existing infrastructure. They are somewhat similar, offset bus lanes only differ from curb-side bus lanes when there is a parking lane present. The offset bus lanes then jump over the parking lane and allow the parking lane to stay present. Curb-side lanes are always located directly next to the sidewalk. In scenarios where there never was a parking lane, they are essentially the same. This is quite common in the European context. In this case they are called curb-side parking lanes in this report. Both score lower for transit operations than median bus lanes (E. Beaton et al., 2013; COST, 2011; Global Designing Cities Initiative, 2016; Shea & Turvey, 2006; Singh et al., 2016), because interaction with other traffic is more common, which causes buses to slow down.

The side-separated bus lanes were not mentioned in any academic literature, but they are mentioned in the guidelines from CROW (2020). There are examples of their implementation in the Netherlands, but they are not very common. A major downside of this design is that it creates an asymmetric street. This is undesirable as it is inconsistent with standard design, which makes it less predictable for road users. This design is therefore best applied on streets where the street sides are already asymmetric (e.g. housing on one side and a forest on the other), which can be common on the edge of urban areas.

Based on the literature study, the advice therefore is to apply median bus lanes in urban contexts, when the required space is available and the street is completely redesigned. In such a scenario they are not necessarily more expensive than curb-side bus lanes. Curb-side bus lanes are advised when a 'quick and dirty' implementation is used and therefore should be a temporary solution until integral maintenance of the street is scheduled. Side-separated bus lanes should preferably only be implemented in semi-urban and rural contexts, where street symmetry is less relevant and there is plenty of space to provide considerable buffers between the bus lanes, general traffic lanes and active modes.

Beyond the location of the bus lane, there are also the dimensions to which they should be designed. A combination of the guidelines from COST (2011) and CROW (2020) gives a complete picture. Together they provide values for both the width and the curve radius that a bus should have at design speed of 30 or 50 km/h. They can be seen in Table 3.4.

Table 3.4: Recommended lane widths and curve radii for BRT systems

	Lane widths One-way	Two-ways	Curve radii BRT systems	Minimum for a bus system
30 km/h	3.25 m	6.00 m	60 m	25 m
50 km/h	3.50 m	6.50 m	150 m	110 m

Finally the colouring of bus lanes to enforce them as dedicated public transport lanes can be a useful tool. This is mainly relevant when the bus lanes are not physically separated from general traffic lanes. When the lanes are physically separated it is likely not worth the extra cost to also colour them. It is therefore advised to determine the necessity of the colouring of bus lanes based on local circumstances, with higher priority when the bus lanes are not physically separated from general traffic lanes.

3.6.2. Design of bus stops

After the bus lanes themselves have been designed, the bus stops should be designed. Bus stops have a mainly physical aspect in the platform design, but also aspects that don't necessarily increase the stops footprint. Such as the its facilities and its integration into the surrounding area. All of these are elaborated on below. The most important aspects of a stop are always that it is safe, recognisable, accessible and approachable (CROW, 2020).

Platform design

The length of the platform is decided by the length of the buses that will use it. The platform should be at least the length of the longest bus that will use it (CROW, 2020). If a stop is located on a busy route, it should be considered to lengthen the stop, so that it can be used by two or more buses at the same time, in such a case at least a metre of buffer should be applied between the two stopping locations for the buses. The width of a bus platform should be between 2.50 and 3.20 metres. There should also be at least 1.20 m of obstacle free space (CROW, 2020). The platform height should be between 180 and 200 mm. At this height a kneeling low-floor bus can provide level boarding (CROW, 2020).

Physical facilities at the stop

Each stop should have cover and seating. There should be at least one shelter with a bench to sit on. In case of frequent use of the bus stop, adding additional shelter and/or seating should be considered (CROW, 2020, 2022b). Next to shelter stops should also have parking facilities for bicycles. It is important to place the bicycle parking facilities on a logical route for bicycle traffic, so that parking a bicycle does not require taking a detour (CROW, 2022b). Finally a stop should have sufficient lighting. If the stop is well lit from regular street lighting, this suffices, but otherwise dedicated lighting must be installed. Creating open vision lines from the surrounding area can help spread light as well as provide a greater social control area around the stop, increasing the social safety (CROW, 2022b).

Integration into the surrounding area

A stop should be reachable without unnecessary street crossings. This means that there should be direct walking routes to all origins and destinations surrounding the stop. These walking routes should connect to the pedestrians network in the surrounding area. Similarly, there should be direct connections to the bicycle network in the surrounding area. Special attention must be given to the accessibility of the area for the less-abled. The stop and walking routes should be supplied with route guidance, also height differences should be kept to a minimum (CROW, 2020). It should be considered that such accessibility measures are required for the less-abled, but make the use of the stop easier and more comfortable for all passengers. From this perspective investments in accessibility have higher benefits than when only the less-abled are considered (COST, 2011).

4

System analysis

After the literature study has been completed, the system in which the project will take place must be analysed. To analyse this system, the area in which it is located is first introduced in more detail. After this area is introduced, the specific scope for the project can be defined and this area can be analysed. Afterwards, all the stakeholders for the project are defined. Finally the functions of the system that the design must fulfil are given.

4.1. Introduction to the case of Amersfoort

Within the city of Amersfoort, new houses and working locations will be built in different locations. A number will be built at smaller scale all over the city, but most will be built in specific dedicated locations. The three biggest locations for larger scale development are: Bovenduist (around 3000 houses), Hoefkwartier (up to 4000 houses) and Langs Eem en Spoor (LES, over 5000 houses). LES and Hoefkwartier, are urban densification projects. These take place entirely within already built up areas. Bovenduist is an urban expansion project.

All of these developments will have a relatively low number of parking spaces per house (starting with 0.2 in the lowest case for LES, up to 1 for Bovenduist). These low parking norms are used, because there simply is not space for more, as well as to support the mobility transition that the municipality wants to achieve. Considering the high number of houses and low parking norms, other mobility options have to be provided. The municipality will invest into high quality walking and bicycle routes and public transportation. To improve the public transportation network within the city and towards the development locations, the municipality wants to create three high level bus corridors (see Figure 4.1), with a significant amount of dedicated infrastructure. At earlier stages also rail based public transport options were discussed. These were however discarded due to the fact that not enough travellers were expected to justify the investment.

The northern corridor is one of the three desired bus corridors. This corridor is a connection between the northern and northwestern parts of Amersfoort as well as Bunschoten-Spakenburg on one side and the city centre and main station of Amersfoort on the other side. To a certain extend the northern corridor already exists, as the route is already served by a multitude of bus routes. However in the current situation, there is no dedicated bus infrastructure, so all bus services are operated in mixed traffic with general traffic. To improve the bus service, the municipality wants to create a true bus corridor that also features significant sections with dedicated bus infrastructure. This corridor will service both the LES and Bovenduist developments. It will feature around 8 different bus lines that use its infrastructure and then service different neighbourhoods. It should be able to handle around 1000 buses per day (Gemeente Amersfoort, 2024).

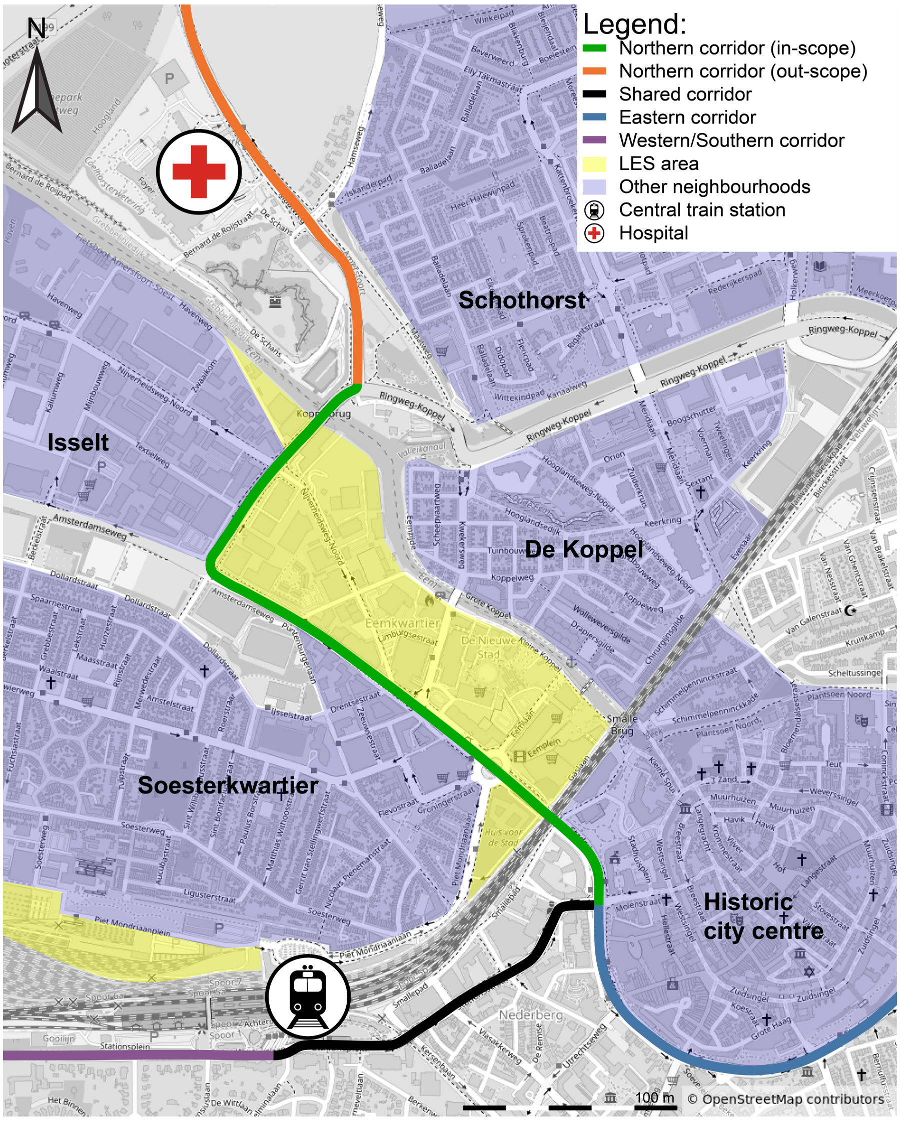


Figure 4.1: The design area of the northern corridor through the LES-area

4.2. Design area analysis and scope

4.2.1. Scope of the design area

The bus lane that will be designed through the LES-area is part of a larger ‘northern bus corridor’. This bus corridor will connect the northern parts of Amersfoort, as well as Bunschoten-Spakenburg, to the central station and city centre. It will also connect to the south-western bus corridor at the central station and create a connection beyond Amersfoort towards the Utrecht Science Park (see Figure 1.1). This project however focusses only on the section through the LES-area, the rest of the northern corridor is out of scope. The design area starts at the intersection between the Stadsring and the Molenstraat, just south-east of the railway underpass on the street. It continues in the north-west direction, under the railway and towards ‘De Nieuwe Poort’, a roundabout with an underpass. The design of the roundabout itself is not part of the scope, as the municipality already has a redesign project ongoing for this roundabout. The underpass under the roundabout and the entry and exit roads for the roundabout are in scope. After the ’De Nieuwe Poort’ the design area continues along the ‘Amsterdamseweg’. At the intersection with the ‘Industrieweg’ it turns onto this road in the Northeast direction. It follows this road over the river Eem and ends at the intersection of the ‘Maatweg’ and the ‘Ringweg Koppel’ (see Figure 4.1).

4.2.2. Analysis of the surroundings of the design area

The section of the northern corridor that will be designed passes through the LES-area. This area will see over 5 000 new houses being built in the coming years at a rate of 1 000 per year. There will also be a lot of new space for offices and services. The LES-area is surrounded by different other neighbourhoods. To the east lies the railway line, beyond which the historic city centre is located. To the south is the residential area 'Soesterkwartier', which was built during the 1920's and 30's. To the west lies the Isselt industrial area. The LES-area currently has a similar industrial function. To the north is the Koppel residential area and one of the previous large scale developments of the city 'Schothorst', which was built during the 1970's and 80's. Further North lie the village of Hoogland, that was agglomerated into Amersfoort and other newer residential neighbourhoods 'Kattenbroek' and 'Nieuwland'. All of these neighbourhoods that lie north of the LES-area will be served by the northern bus corridor. The design of the bus corridor thus has an effect that goes beyond the LES-area. This is important to keep in mind during the design, because it means that both the local residents' interest and the interest of residents further along the northern bus corridor need to kept in mind. A map of the area is shown in Figure 4.1.

4.3. Stakeholder analysis

After the scope of the project is defined, the stakeholder for the project can be assessed. This is necessary to the project to ensure that the interests of all stakeholders are considered, even if the stakeholder does not have the power to influence the project directly. Also when the most important stakeholders are known, they can be contacted during the project to contribute. The stakeholders that are involved are divided into four categories; public service providers, private service providers, core stakeholders and periphery stakeholders. They are all explained below.

4.3.1. Public service providers

The public service providers are the different levels of government, starting with municipal, then provincial and finally national.

Gemeente Amersfoort

The Gemeente Amersfoort is the main stakeholder in the project. They are the owner of the streets and roads within the municipality. They are therefore responsible for designing, building and maintaining the roads, including bus lanes. They have a high interest in the project because providing proper transportation infrastructure to its inhabitants is crucial for its new housing projects to succeed. They also have a high level of influence as they can make the final decisions on the design and construction of the infrastructure.

Provincie Utrecht

The Provincie Utrecht is the responsible public transport authority in the city of Amersfoort and the region around it. They make the final decisions on how public transport service is provided within the city. Therefore they have a high interest in how the public transport infrastructure in the city is designed and built. They also have more financial means for such construction projects than the municipality so they might be able to support the project financially. They have less influence than the municipality, but stay in close contact with them and can thus still have a significant influence on the project.

Dutch national government

The Dutch national government is involved in the project, because of the development of the NOVEX-areas is of national importance. Since the project is of national importance and also quite large in scale for the city of Amersfoort, the national government will need to provide financial support, which gives them influence. Through the U-Ned programme different parts of the national government are involved in all development projects within the province of Utrecht, which includes this project. They have less influence than the municipality or the province, but also less interest as the national government needs to consider all 17 NOVEX-areas and the municipality of Amersfoort only one.

4.3.2. Private service providers

The private service providers are private companies that will perform one or more tasks in the project commissioned by a public service provider.

Private construction company

Since the municipality does not have its own construction company, the construction will be subcontracted to a private construction company. They are responsible for the construction. They have small influence as they only contribute to the civil part of the design, not to the functional part. They only have a small interest as they are mainly there to construct and do not much care for the function.

4.3.3. Core stakeholders

Keolis and/or other (future) bus operators

Keolis is the bus operator in city of Amersfoort and the surrounding areas (until 2035). Some other bus operators also operate buses through Amersfoort. The bus operators are responsible for daily operation of buses. They will use the future bus lanes on a day-to-day basis. They thus have a high interest in the design and construction, as a good bus lane will allow smoother operations for them. Their influence on the project is limited as they don't have any real power in the matter and can only ask things from the municipality, but not demand anything.

Emergency services

It is common for emergency services to also use dedicated bus lanes to pass traffic. Since the bus lanes through the LES-area provide a connection between the hospital and the city centre (see Figure 4.1), it is likely that emergency services will use the bus lanes as one of the main access routes to the hospital. They therefore have a medium interest in the design as a well-designed bus lane will allow them shorter travel times and thus faster care for patients in case of emergency. They have limited direct influence, but can use their wide public support to exert influence over the project if needed.

Bus travellers

The group of people that will travel on the bus is large and very diverse. It includes both people that are already reliant on bus travel and new travellers who are currently reliant on other modes of transport. However as bus travellers they have fairly similar interests. They have high interest in a comfortable and efficient design of the bus lane. Their influence on the project itself is fairly low, as they are such a large and diverse group that does not have a clear spokesperson or leader. They do have a large influence on the success of the project as they will decide how much they will actually use the project and with that determine its success.

4.3.4. Periphery stakeholders

Inhabitants of the LES-area

The inhabitants of the LES-area will live next to the bus lane. They will see and hear the buses drive by on a daily basis. They will also be disturbed by the construction of the project. Their interest is medium as they want a liveable area around their houses. This includes the streets that the bus lanes will go over, but also streets that are out of scope for this project. They have limited influence, because they are a diverse group that does not have a clear leader or spokesperson and their interests might differ. Some value a good quality bus service, while others value silence and tranquillity more. Having misaligned interests makes it harder to exert influence.

Other inhabitants of Amersfoort

The other inhabitants of Amersfoort will be affected by the project in different ways. Some might live in another location along the northern bus corridor and thus be interested in a proper design for an optimal bus corridor. Others might feel the opposite as they are not benefitted directly, which leads them to feel left out of the development of the city. Their interest varies, but in general is quite low. Their influence also varies, some locals can be quite effective in voicing their opinions to the municipality. However their opinions are often contrasting, which makes it hard for them to be adopted.

Bus drivers

The bus drivers will use the new infrastructure the most as they will drive over it on a daily basis. They thus have a high interest in a good and functional design so that they can do their job in a comfortable and safe environment. They have limited influence as they can only influence the project through their employer, the bus operator.

Other road users

Other road users will have to interact with the traffic on the bus lane on a daily basis. They have limited influence on the project as they are not directly involved with the project itself and also do not have a clear leader or spokesperson. Their interest is medium as for the most part they will not encounter the bus lane and only have interest in the locations where other transport infrastructure crosses the bus lane.

4.3.5. Conclusions

A total of five stakeholders is identified to have a high interest in the project. The municipality, the province, the bus operator, the future travellers and the bus drivers. It will therefore be considered to contact these stakeholders for input during the project. This way their interest can be taken into consideration during the project.

4.4. Functions

The function analysis shows which functions the design needs to provide. The functions of the design are given by the municipality. The most important functions are the principal functions that the design is made for specifically. The preserving functions are currently provided within the design area and thus must be preserved as functions also in the new design. The supporting functions are functions that are not a focus or reason for the design. They can however support the design, by making improvements beyond the principal functions. This makes it easier for the design to be accepted by stakeholders who are less interested in the principal functions.

Principal functions:

- Provide a fast, efficient and comfortable bus lane for an intensity of 1000 buses per day
- Create high quality bus stops along the bus lanes

Preserving functions:

- Provide a strong surface to support the weight of the traffic that uses the street
- Provide separated road spaces for general traffic, bicycle traffic and pedestrians to promote traffic safety
- Maintaining the ability for general traffic, bicycle traffic, pedestrians and other users to use the streets safely
- Provide drainage for rainwater to prevent standing water

Supporting functions:

- Provide additional green space
- Provide additional space for liveability

4.5. Conclusion

Based on the system analysis it can be concluded that the design area is a highly urban area within the densifying city of Amersfoort. To provide suitable mobility options in the future the infrastructure needs to be adapted. The most important stakeholder in the project is the municipality itself, but the province, the bus operator, the bus travellers and bus drivers also take a significant interest in the project. The surrounding area should be considered and the stakeholders consulted during the project. This ensures that the result not only fulfils its principal function to create high quality bus public transport infrastructure but also fits in the environment and is supported by its users

5
Basis of design

This chapter builds on the system analysis in the previous chapter. It further specifies the functions with the design objective and requirements. Afterwards, the design area is divided into different sections to simplify the design process. Finally the boundary conditions of the design area are defined.

5.1. Design objective

The objective of this thesis is to design the a part of the northern bus corridor, which is to be developed in the municipality of Amersfoort. The part of the corridor that is to be designed passes along the development area ‘Langs Eem en Spoor’ (LES). It starts at the Stadsring, where the northern bus corridor branches off from the eastern bus corridor and it ends at the Maatweg, just before the hospital. The total length of this segment is around 1.75 kilometres. The bus corridor should be designed with dedicated bus infrastructure and several bus stops. It should be able to handle over 1000 buses per day. To show that such dedicated bus infrastructure can fit well into the urban landscape the entire streets along the corridor will be redesigned to make the bus corridor merge well with the other street functions and the surrounding neighbourhoods.

5.2. Design requirements

In this section the design requirements from the municipality are given. These scope the project down to its core focusses. There are three types of design requirements; bus specific, other modalities and other.

The bus specific design requirements are related directly to the bus service and its users. They relate directly to the principal functions of the design (section 4.4). They are:

- Fully dedicated bus infrastructure where possible[1]
- Tram-grade geometric design for both ride comfort and possible conversion of the right of way
- Design speed of 50 km/h
- 1 bus stop on the section ’Stadsring’
- 2 or 3 bus stops on the sections ’De Nieuwe Poort’, ’Amsterdamseweg’ and ’Industrieweg’ (see subsection 5.2.1)
- Preservation of the roundabout with underpass structure at De Nieuwe Poort
- Preservation of the Koppelbrug with the same width

The requirements for other modalities describe the minimum and/or maximum road space that needs to be provided for modalities other than the bus (pedestrian, bicycle and general traffic). They relate directly to the preserving functions of the design (section 4.4). They were defined in municipal vision for design relating to mobility for the period 2025-2035 (Gemeente Amersfoort, 2024). They are:

- Minimum width of sidewalks is 2.00 m as per the most recent guidelines from the CROW
- Bi-directional ’Doorfietsroute’ on south side of the Amsterdamseweg with a minimum width 4.00 m
- Uni-directional ’Hoofdfietsroute’ cycle path on the north side of the Amsterdamseweg with a minimum width 2.70 m
- Uni-directional ’Hoofdfietsroute’ cycle paths on both sides of the Industrieweg with minimum width 2.70 m
- Amsterdamseweg will be designed at 2x1 for general traffic at 30 km/h
- Industrieweg will be designed at 2x2 for general traffic at 50 km/h

The other requirements are requirements that do not influence or affect the traffic directly, but the general atmosphere and liveability of the street. They relate directly to the supporting functions of the design (section 4.4). They are:

- Inclusion green buffers wide enough for trees to create a ‘lane style’ street profile for the Amsterdamseweg

5.2.1. The number of bus stops

The requirement for the number of bus stops on the sections will be either three or four. The first will be located in the section ’Stadsring’. The location of this bus stop if fixed at the same location where this bus stop is already located. For the other bus stops the location is not yet fixed. There will be either two or three bus stops next to the ’Stadsring’ bus stop and they will be located in the sections ’De Nieuwe Poort’, ’Amsterdamseweg’ and ’Industrieweg’. In the case of three more bus stops, each of these sections will feature one bus stop and in the case of two more bus stops, two sections will have a bus stop and the other will not. The reason that the municipality is unsure whether they want two or three more bus stops is because they want to minimise the number of bus stops, but at the same time retain good coverage of the area. The idea is thus that there will be two more bus stops if possible and three if necessary.

To determine whether two bus stops is sufficient to cover the area a quick GIS study is conducted. Using this GIS study it is determined how much coverage the bus stops provide. Thus enabling the municipality to see how many bus stops are needed. Since the bus stops will be newly developed and serve a new development area, they only need to cover the new development area. The other areas surrounding the development area are already sufficiently served by public transport service that will also continue to exist after the development of the new BRT services.

Within the municipality 400 metres of walking distance to reach a bus stop is used as a maximum. This means that the municipality strives to give all their inhabitants access to a bus stop within 400 metres of walking distance. This value is usually used for bus services to ensure that everyone has access to public transport within a reasonable walking distance. This value is also applied to the LES-area and thus the entire area must be within 400 metres of a bus stop.

To check the coverage of the possible bus stops for each of the sections ’De Nieuwe Poort’, ’Amsterdamseweg’ and ’Industrieweg’ a logical location for a bus stop was found. For all sections this was an area of around 100 metres long, so that the exact location of the bus stop could be optimised later, also based on the spatial fitting. At all the locations there is an intersecting road. Since bus stops are commonly named after intersecting roads this will also be done for the bus stops here. For the section ’De Nieuwe Poort’ this was the area immediately west of the roundabout, where the bus stop ’Eemplein’ is currently located. This stop will thus be called ’Eemplein’. For the ’Amsterdamseweg’ this was around the intersection with the ’Geldersestraat’ where an important street crossing for pedestrians and bicycle traffic is planned. This stop will be called ’Geldersestraat’. And finally for the section ’Industrieweg’ this is around the intersection with the ’Nijverheidsweg-Noord’. This stop will be called ’Nijverheidsweg-Noord’ These possible locations for bus stops can be seen in Figure 5.1

[1] At De Nieuwe Poort and the Koppelbrug, there are spatial constraints, that make dedicated bus infrastructure harder to fit in. In these locations designs both with dedicated bus lanes and mixed traffic solutions should be considered.

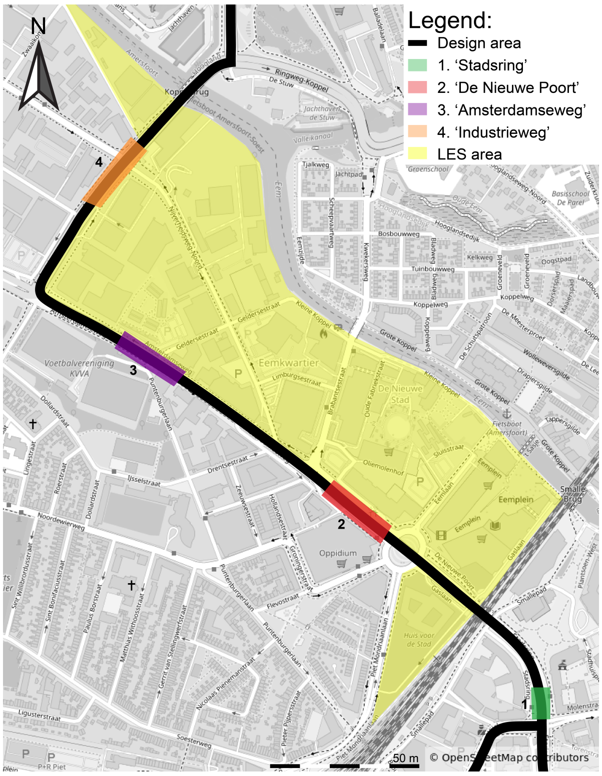
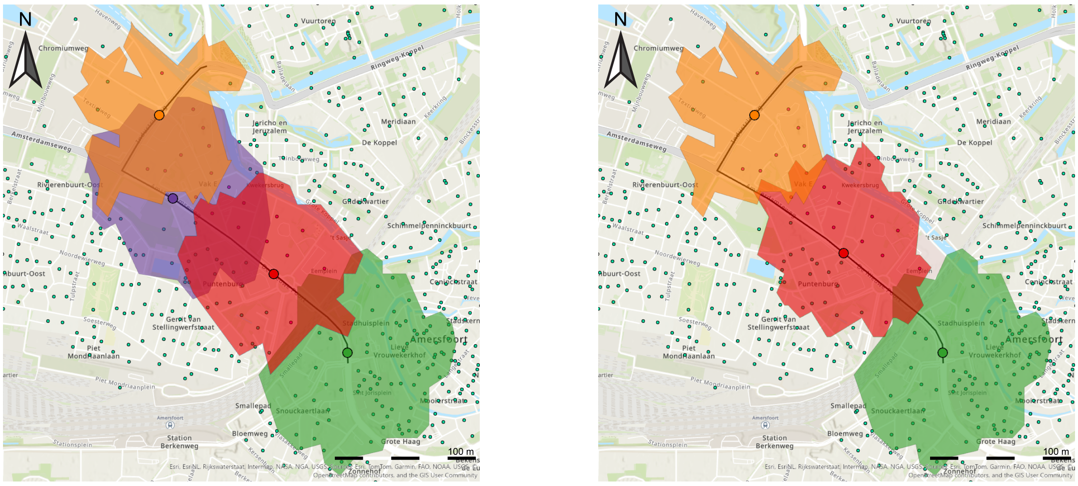


Figure 5.1: The possible locations for bus stops



(a) All three potential bus stops and the fixed stop at the 'Stadsring' with their catchment area

(b) Only the 'Eemplein', 'Nijverheidsweg-Noord' and fixed 'Stadsring' stops with their catchment area

Figure 5.2: Two possible bus stop arrangements

With these possible locations for the bus stops, their coverage of the LES-area is analysed. In ArcGIS first the underlaying pedestrian network is laid out. Using this network the walking distances from the possible bus stop locations can be calculated. In Figure 5.2a all three possible bus stops are shown with their respective catchment areas, or the areas that are within 400 metres of walking distance to the stop. As can be seen in the figure, the middle of the three stops shares a large part of its coverage with the other two stops. Especially of the area that will be newly developed. In this scenario the stop in the stop 'Eemplein' is located just west of the roundabout, where the bus stop is currently located. When this stop is moved about 100 metres more to the west, further away from the roundabout, its catchment area reaches that of the stop 'Nijverheidsweg-Noord'. This is shown in Figure 5.2b. Here it can be seen that the stop 'Geldersestraat' is not strictly necessary because if smartly placed, the 'Eemplein' and 'Nijverheidsweg-Noord' stops can together cover the entire LES-area.

Based on this short GIS analysis it was decided that two stops would be sufficient. The municipality thus only requires the bus stops 'Eemplein' and 'Nijverheidsweg-Noord' and not the stop 'Geldersestraat'.

5.3. Design sections

The design area is heterogeneous and and has several distinct features. To help the design process, the area is divided into sections. This allows design concepts for sections to be developed separately of each other, which makes it possible to create more creative and locally relevant concepts. The sections that are identified are:

- 1. Stadsring
- 2. De Nieuwe Poort
- 3. Amsterdamseweg
- 4. Industrieweg
- 5. Ringweg Koppel

The sections are shown on a map in Figure 5.3. The sections are described in further detail in chapter 7, where street profile cross-sections are also shown. Street profile cross-sections for the current situation can also be found in Appendix B, where they are numbered with a '0'.

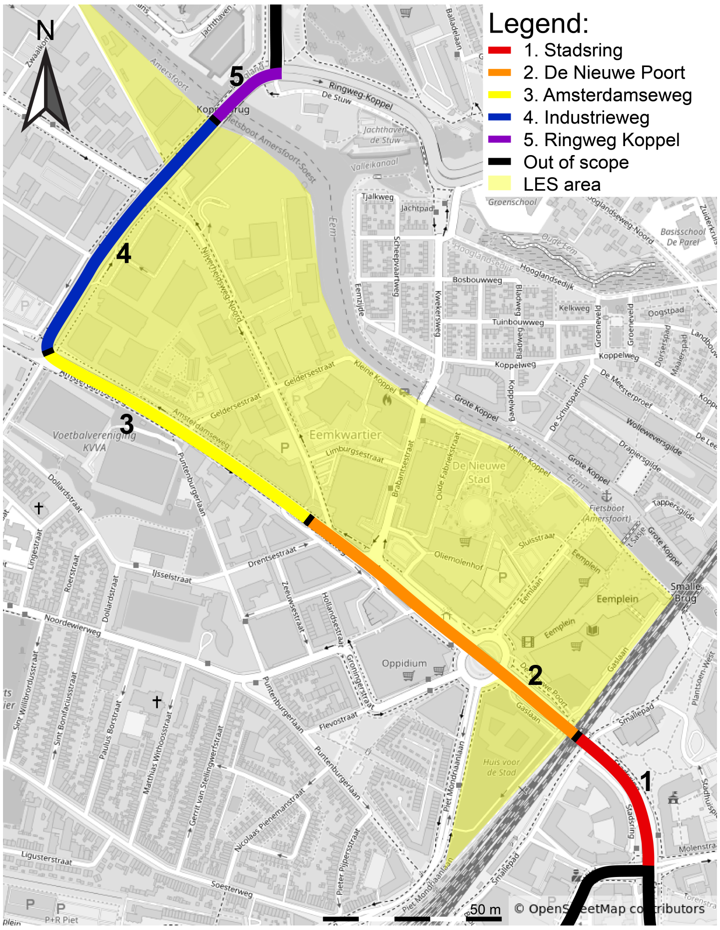


Figure 5.3: The five different design sections

5.3.1. Stadsring

The first section is the Stadsring. It starts at the intersection between the Molenstraat, Van Asch van Wijckstraat and the Stadsring. It then follows the Stadsring north-west to the railway underpass. It is included as a section because it bridges the gap between the railway underpass and the intersection where the northern bus corridor branches off from the eastern bus corridor. It was not added to the 'De Nieuwe Poort' section, because the infrastructural layouts on the either side of the railway underpass are quite different. The intersection with the Molenstraat and the Van Asch van Wijckstraat is not in scope for this section or the entire project.

5.3.2. De Nieuwe Poort

The second section, De Nieuwe Poort section, starts right north-west of the railway underpass. Currently there is a roundabout at ground level and a underpass to bypass the roundabout in the dominant general traffic direction. The section ends at the current intersection with the Brabantsestraat, where the two levels of the roundabout and underpass rejoin. Because of its unique design and function in the current situation, De Nieuwe Poort is considered as one section.

5.3.3. Amsterdamseweg

The third section is the Amsterdamseweg, which is straight section of road between two intersections. The first is the intersection Amsterdamseweg - Brabantsestraat and the second in the intersection Amsterdamseweg - Brabantsestraat. For this definition the current layout of the roads is considered. The Brabantsestraat (including its connection to the Amsterdamseweg) will be moved further west due to the development of the LES-area. This is further explained in section 5.4. The Amsterdamseweg is considered as one section, because it is a relatively homogenous straight section of road.

5.3.4. Industrieweg

The fourth section encompasses the intersection between the Amsterdamseweg and the Industrieweg and the Industrieweg until the Koppelbrug over the river Eem. The intersection is considered part of the section with the Industrieweg and not the Amsterdamseweg, because it is assumed that in the new design the general traffic from the Industrieweg is of bigger influence on the design of this intersection than the traffic from the Amsterdamseweg. The Industrieweg itself is a relatively straight and homogenous section of road. It does however feature a four-way intersection with the Nijverheidsweg-Noord.

5.3.5. Ringweg Koppel

The last section includes two elements; the Koppelbrug over the Eem and the intersection between the Ringweg Koppel and the Maatweg. This is the least homogeneous section of all five, because it includes both an intersection and a bridge. It is considered as one section, because the intersection is so close to the bridge that it influence the road design on the bridge; there is a turning lane on the bridge, because of the intersection. They are therefore so knit together that they cannot be considered separately of each other. The width of the bridge is also an important bottleneck in the design.

5.4. Boundary conditions

The boundary conditions describe what the assumed conditions of the area beyond the design area are. For this design project the relevant areas beyond the design area are the connecting streets. There are two types of connecting streets to the design area. First, those that are on the same level in the road structure, being distributor road designed at 50 km/h (In Dutch; 'gebiedsontsluitingsweg 50 km/h', shortened as GOW50). Second, those that are on a lower level in the road structure, being distributor road or access road at 30 km/h(In Dutch; 'gebiedsontsluitingsweg 30 km/h' or 'erftoegangsweg 30 km/h', shortened as GOW30 and ETW30) or bicycle only streets. The locations where the boundary conditions meet the design area are shown in Figure 5.4. The street profile cross-sections are available for all boundary conditions in Appendix C.

There are four roads that connect to the design area that are of similar level in the road structure (GOW50). These are:

- 1. Stadsring (at the intersection Stadsring - Molenstraat - Van Asch van Wijckstraat)
- 2. Amsterdamseweg (continuation at the Amsterdamseweg - Industrieweg intersection)
- 3. Maatweg (at the Ringweg Koppel - Maatweg intersection)
- 4. Ringweg Koppel (at the Ringweg Koppel - Maatweg intersection)

For the Stadsring, an open boundary condition is assumed. The intersection Stadsring - Molenstraat - Van Asch van Wijckstraat will likely be redesigned in the near future, but there is no knowledge yet about what it will look like. The municipality therefore would like this boundary condition to be considered completely open with no requirement to connect to current road layouts.

For the Maatweg it is assumed that there will be dedicated bus lanes in the future when this project is realised. These are not located in any fixed location as they will need to connect logically onto the designs chosen in this project. Besides these new bus lanes that are in a non-fixed location, the same number of general traffic lanes must be present on the Maatweg. The designs must thus connect onto a Maatweg that looks similar to the current layout, but with dedicated bus lanes in a location where they fit best onto the designs of this project.

For the Amsterdamseweg and the Ringweg Koppel it is assumed that they do not change their layout in terms of number of general traffic lanes, bicycle path and sidewalk presence and location. The connections will be designed to fit onto the current design of these roads.

There are currently fifteen roads connecting to the design area that are on a lower level in the road structure (GOW30, ETW30 and bicycle only streets).

Five of these connect into the LES-area:

- 5. Eemlaan (at De Nieuwe Poort) (ETW30)
- 6. Brabantsestraat - Old (at De Nieuwe Poort) (bicycle only)
- 7. Brabantsestraat - New (at the Amsterdamseweg) (GOW30)
- 8. Geldersestraat (at the Amsterdamseweg) (ETW30)
- 9. Nijverheidsweg-Noord - 2 (at the Industrieweg) (GOW30)

These streets will be completely redesigned as part of the development of the LES-area. The new Brabantsestraat will even connect onto the design area in a different location. It will be moved westward by about 100 metres compared to the old Brabantsestraat. To ensure that the design will fit onto the future road layout for these roads, the roads as they are in the redesigned LES-area will be assumed as the boundary conditions.

Six connect into the 'Soesterkwartier':

- 10. Piet Mondriaanlaan (at De Nieuwe Poort) (GOW30)
- 11. Groningerstraat (at De Nieuwe Poort) (GOW30)
- 12. Friesestraat (at De Nieuwe Poort) (ETW30)
- 13. Drentsestraat (at the Amsterdamseweg) (ETW30)
- 14. Puntenburgerlaan (at the Amsterdamseweg) (bicycle only)
- 15. Merwedestraat (at the intersection Amsterdamseweg - Industrieweg) (ETW30)

The 'Soesterkwartier' is the neighbourhood south of the Amsterdamseweg. This neighbourhood is not part of any large scale development, so the streets their will remain in their current location and also maintain their current layout. The connections will therefore be designed to fit onto the current street layouts.

Three connect to the industrial area 'Isselt'.

- 16. Textielweg (at the Industrieweg) (ETW30)
- 17. Nijverheidsweg-Noord - 1 (at the Industrieweg) (GOW30)
- 18. Havenweg (bicycle only)

The 'Isselt' is the industrial area west of the Industrieweg. This area will not be redeveloped and thus the street layouts are taken as boundary conditions in their current design.

And the last street connects north of the river Eem:

- 19. De Stuw (at the intersection Ringweg Koppel - Maatweg) (ETW30)

This street merely provides access to a couple of building along the river. This street will not be re-designed and is thus taken as a boundary condition in its current design.

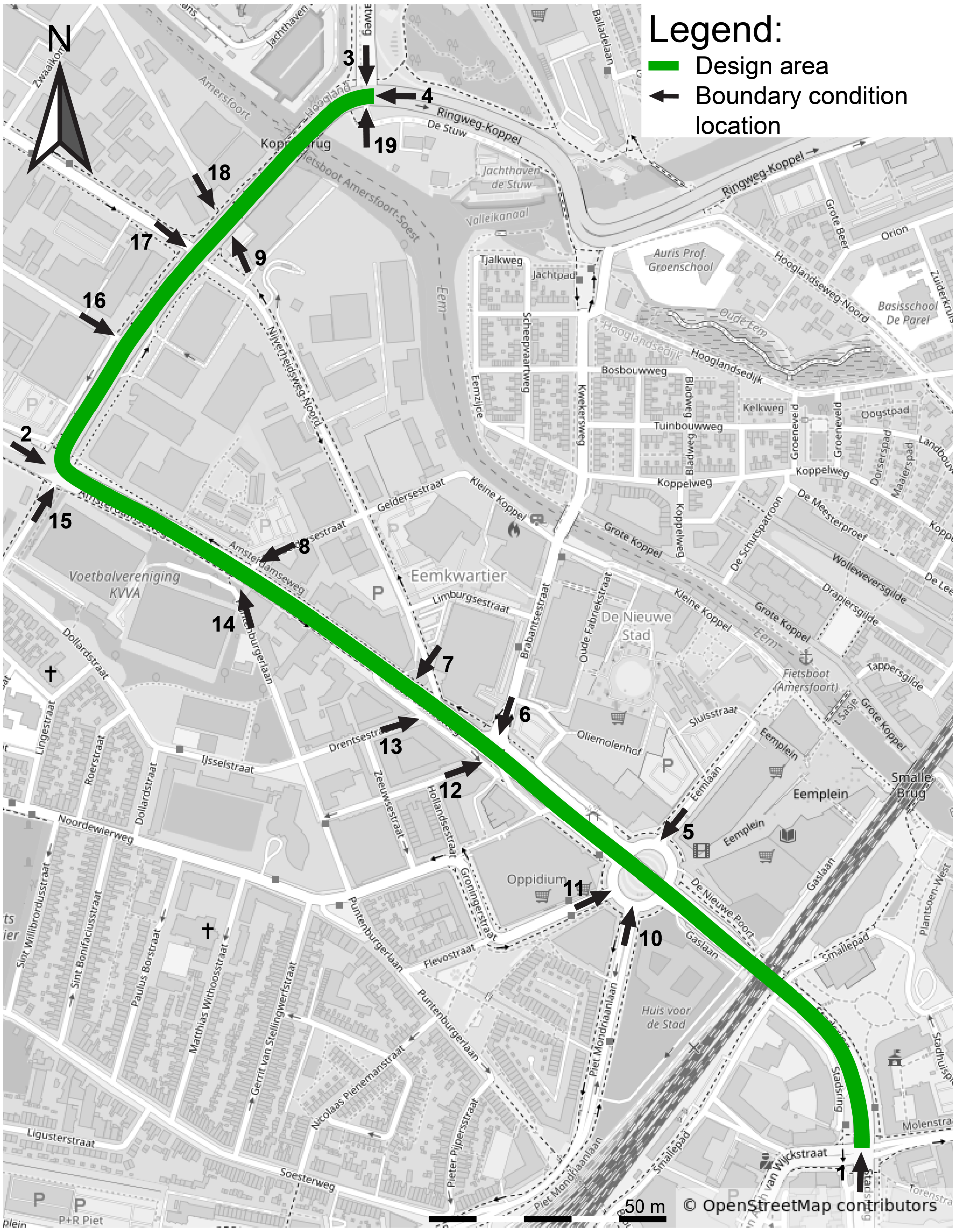


Figure 5.4: The locations where the boundary conditions meet the design area

6 Design methodology

After the establishment of the basis of design, the design process can be started. To start the design process first the design methodology will be written. The design methodology is based on general design principles. Specifically the 'civil engineering design method' by Molenaar and Voorendt (2025) was used. This design approach includes 8 steps:

- Step 1: Problem definition
- Step 2: System analysis
- Step 3: Basis of the design
- Step 4: Development of concepts
- Step 5: Verification of concepts
- Step 6: Evaluation of concepts
- Step 7: Integration of subsystems
- Step 8: Validation of the result

For this project two alterations were made to the steps to fit the specific circumstances better. The first alteration is the addition of a development of variants step. This step is included after the verification of concepts. This step allows the concepts to be adapted into variants based on the results from the verification. The evaluation of concepts is thus also renamed to evaluation of variants. The second alteration is the exclusion of the validation of the result. The validation of the result takes place after the design has been implemented. Due to time limitations of this project as well as uncertainty of implementation, this step cannot be taking during this project.

Therefore the steps that were taking during the design process are as follows.

- Step 1: Problem definition
- Step 2: System analysis
- Step 3: Basis of the design
- Step 4: Development of concepts
- Step 5: Verification of concepts
- Step 6: Development of variants
- Step 7: Evaluation of variants
- Step 8: Integration of subsystems

They are divided into two groups; the preparatory steps and the designing steps. The preparatory steps aim to gather all the information required to start the design process. These steps have already been taken to provide sufficient context for the designing steps, as the designing steps are specific to this project. They describe how the designing process for this project will take shape. All steps are explained in further detail below.

6.1. Preparatory steps

6.1.1. Step 1: Problem definition

To start the process of the design, first there has to be a clear problem definition. To clearly define the problem, documents from the owner or developer of the design area are required. In the case of a national or international problem, these documents can be obtained from the government. Using these documents the problem can be explained and the desired solution space can be introduced. Using the problem definition and the desired solution space the aim of the project can be defined. The goal of the project is then to fulfil this aim. This step was already performed in chapter 2 to provide direction for the literature study.

6.1.2. Step 2: System analysis

Once the problem has been defined, the system in which the problem lies needs to be analysed. To properly analyse a system, three main components of the system have to be defined and described. These three components are the physical space, the stakeholders and the functions of the system. The analysis must include a clear demarcation of the design space. It must mention all the relevant stakeholders and it must identify all the functions of the system, in its current and future state. It should also explain all of these components. This step was be performed in chapter 4.

6.1.3. Step 3: Basis of the design

The basis of the design provides all the necessary information actually to start designing. It provides the starting position of the design. In the basis of design, the design area will be divided into several different design sections, which will be developed separately. This makes the design task more manageable. The basis of design also states the functional requirements and the boundary conditions. These serve to guide the design in the right direction and make sure that the project stays within its scope. The functional requirements are hard demands that the design must feature. They are based on the system functions that were established in subsection 6.1.2. The boundary conditions determine how the area around the design area influences the design area. They must be taken into consideration for a seamless transition between the design area and its surrounding area. These follow from the demarcation of the physical space that was done in subsection 6.1.2. This step was be performed in chapter 5.

6.2. Designing steps

6.2.1. Step 4: Development of concepts

With both the system analysis and the basis of design, the actual designing part can start. For each design section different concepts will be developed. The concepts will be developed at the street cross-section level to see what is possible to fit within the given width of the street. The elements that are considered for each cross-section are:

- The location and width of bus lanes in the street profile
- The location and width of general traffic lanes in the street profile
- The location and width of the bicycle paths in the street profile
- The width of the sidewalks in the street profile
- The width and location of green space as buffers in the street profile
- The location and width of bus stops in the street profile (if relevant at that location)
- The location of different road functions in the street profile

The differences between concepts will mainly lie in the location of the bus and the general traffic lanes, because the fitting in of bus lanes is the focus of this project. The location and width of the sidewalk, bicycle paths and green space is based on the requirements from subsection 6.1.3, although this will also be influenced by the location of the bus and general traffic lanes.

The different types of concepts that will be developed are based on the conclusions from the literature review (see section 3.6).

The number of concepts that are developed will differ for different subsections. The number depends on how many concepts can be conceived within the constraints and requirements for each design section. This step will be conducted in chapter 7.

6.2.2. Step 5: Verification of concepts

The verification of concepts serves as step between the development and the development of variants. All the concepts that were developed will be verified in discussion with the municipality. Some concepts will be dropped because they are deemed to be unrealistic, will others will be kept because they are seen as promising. The idea is to reduce the number of concepts down to two for all design sections. The reduction to two is done because of time constraints. The two concepts that remain after the verification can then be further developed in the next step. This step is done for each design section at the end of the description of that section in chapter 7.

6.2.3. Step 6: Development of variants

In the development of variants the two most promising alternatives from the development of concepts are worked out further. The variants will now be developed as a map of the street, thus making a complete design of each design section, rather than a design at the cross-section level. This means that while the same elements that were present in the development of concepts remain, also some new elements come into play.

For the design of the bus lanes the following elements are considered:

- The location of the bus lanes in the street profile
- The geometric design of the bus lanes, including; the width of the lanes and the curve radius at turns
- The location of bus stops along the bus lanes
- The design of bus stops along the bus lanes, including; length of the platform, width of the platform, access routes for passengers

For the design of the rest of the street, similar elements are considered, namely:

- The location of general traffic and bicycle lanes as well as sidewalks
- The geometric design of the general traffic and bicycle lanes, including; width and curve radii at turns
- The geometric design of intersections, including; facilitated directions, presence and length of turning lanes
- The location and design of street crossings, including; waiting areas to cross the street.
- The location of buffers between different modes, to be used as green space where possible

The design of a map requires a different approach than the design of a cross-section. The base designs from the CROW (see Appendix A) for public transport infrastructure will be as a starting point. These will then be adapted to fit the local circumstances best as possible.

For situations where these base designs are not applicable, inspiration will be taken from the other sources that were found, like the designs as shown in Figure 3.2. Besides these, the design process will also require plenty of creativity from the designer to come up with possibilities. These ideas can then be discussed with several people at the municipality to ensure that these ideas are workable.

The combination of base designs from the CROW, other sources and creativity from the designer in co-operation with the municipality should be able to provide sufficient inspiration to create valid designs.

This step is done in chapter 8

6.2.4. Step 7: Evaluation of alternatives

Once the two design variants for each design section have been finalised, these need to be evaluated. The evaluation of the alternatives will be done through a multi criteria analysis. The evaluation criteria were established with input from three different stakeholders with a high interest (see section 4.3). These are the municipality, the province and the current public transport operator. From the municipality a public transport specialist, a public space specialist, and an urban development specialist were involved. From the province a public transport specialist was involved and from the current public transport operator Keolis a public transport operations specialist was involved.

The criteria that were established have been divided into three categories: Traffic performance, Passenger accessibility and liveability. The criteria and their categories can be seen in Table 6.1.

The category traffic performance concerns the performance and efficiency of the bus lane in the wider traffic system. It concerns both the buses and all other traffic modes.

The category passenger accessibility concerns all aspects of the bus lanes from passenger perspective. This includes for example; walking distance to stops, easy of access to the bus stop and comfort of the road alignment while on the bus.

The final category is liveability and urban integration. This includes all ways in which the bus lane influences the area around it for people that are not taking the bus, or otherwise partaking in general traffic.

Beyond the established criteria several other criteria could have been considered as well. The two most important ones are costs and emission.

Costs were not included, because the idea of the project is that the entire street will be redesigned from façade to façade. This means that the costs will likely not differ much between different designs. The designs don't determine what kind of aspects are included in the street, but rather where the aspects are located. This means that the amount of asphalt or tiling needed for each design is similar and thus costs will also be similar and therefore not likely a deciding factor.

Emissions were not included for similar reasons. The designs won't directly influence the amount of traffic that is expected to use the streets. Therefore designs won't differ from one another on how many emissions the traffic is expected to produce.

This step is taken in chapter 9.

Table 6.1: The evaluation criteria methods for each criteria

Evaluation criterium	Evaluation method	Evaluation type
Traffic performance		
Trip time for buses	Average trip time in morning peak using a traffic model in Paramics	Quantitative
Reliability of the bus service	The standard deviation in trip time in the morning peak using a traffic model in Paramics	Quantitative
Travel time for bicycle traffic	Average travel time in morning peak using a traffic model in Paramics	Quantitative
Travel time for general traffic	Average travel time in morning peak using a traffic model in Paramics	Quantitative
Passenger accessibility		
Stop locations	Number of inhabitants reachable within 400 m of walking using an ArcGIS study	Quantitative
Stop quality	The total area dedicated to the bus stops	Quantitative
Stop access routes	The number and quality of all the stop access routes	Quantitative
BRT appearance [1]	The extent to which the street design signifies the presence of high quality bus service	Qualitative
Urban integration and liveability		
Road safety	The number of conflict points	Quantitative
Space for pedestrians and bicycle traffic	Total area dedicated to active modes in final drawing	Quantitative
Road cross-ability	The number and quality of all the road crossings	Quantitative
Neighbourhood integration [2]	The level to which there is a natural transition between the street and the neighbourhood	Qualitative
Public green space	Total area dedicated to public green space in final drawing	Quantitative
Long-term robustness	To what extend does the design meet the highest standards of current guidelines	Qualitative

[1] The BRT appearance describes to what extend the infrastructure indicates towards the passenger that this is a high quality bus system, it includes dedicated lanes, comfort of the bus lane alignment, etc.

[2] The neighbourhood integration describes to what extend the mobility infrastructure integrates into and adds to the neighbourhood instead of creating a hard barrier between mobility functions and local neighbourhood functions.

6.2.5. Traffic performance

All the criteria that are part of the category traffic performance will be analysed using a traffic microsimulation model. The software that will be used is Paramics Discovery 28. The traffic model will be designed to predict the handling of traffic in the peak hour in 2035. The year 2035 was chosen because that is the municipality expects the road to be redesigned and the bus lanes to be added. The peak hour was chosen, because it is the normative hour of the day and a full day model was not possible with the educational licence of the software.

To make this prediction two main elements are needed. The designed road networks for 2035 and the expected traffic loads that will use this network.

For each design variant the designed road network within the design area will be constructed in Paramics. The road network will have general traffic lanes, bus lanes and bicycle lanes. Intersections between different streets and modes will also be modelled. Intersections will be modelled with a priority regulation or a traffic light regulation. When an intersection is designed with a traffic light regulation, the traffic light also needs to be designed. This is explained further in Appendix D. Due to limitations of the software pedestrians will not be modelled. However, the number of pedestrian only street crossings will be limited, so in most situations they will cross the street at a location where bicycle traffic will be modelled.

The constructed road layout and programmed traffic lights together form the model road network. They depict a plausible future situation of the road infrastructure in the design area. The next step is to load traffic onto the network. To load traffic onto the network the traffic demand at the boundary conditions of the design area must be known. The demand can then be loaded onto the network and traffic can be simulated. The design area has a total of 19 boundary conditions (see section 5.4). For all of these the predicted general and bicycle traffic intensities in 2035 are needed. Bus traffic will be loaded onto the network separately based on the targeted public transport schedule in 2035.

The municipality has recently conducted a city-wide traffic model for a predication for 2035. This model includes only general traffic. The traffic intensities from this city-wide model will be used as the input for the model of the redesigned design area. At each boundary condition the calculated traffic intensity in the city-wide model is taken. This traffic intensity value can then be used as the input for the design area models. This data can then be converted into a OD-matrix using a gravity model. How this was done is explained in more detail in Appendix D.

Since the city-wide traffic model for 2035 only has data for general traffic, a different data source has to be found for bicycle traffic. For bicycle traffic measured data from the period 2022 to 2024 will be used. This data has been collected by the municipality. This data will not be adjusted to reflect the future situation of 2035, because no reliable estimation can be made for the future demand in bicycle traffic. This is a limiting factor of the data as it is unlikely that the demand in bicycle traffic is the same in 2022 as in 2035. The measured bicycle traffic is converted into an origin-destination-matrix in the same way as the general traffic (see Appendix D).

Whereas general and bicycle traffic is loaded onto the network based on an origin-destination matrix with general demand, bus traffic is loaded onto the network using public transport schedules. The municipality does not have public transport schedules available for 2035, because these are not made that far in advance. They do however have an aim for the number of bus lines, their routes and frequency that they want to operate within the city in 2035. With this information it can be determined how many buses will travel through the design area in 2035. This is shown in Appendix D.

When the demand that the network needs to handle has been determined, the microsimulation software can be run. The simulation software loads the traffic onto the network and records the travel time of each vehicle that has been loaded onto the network. The data that is collected during the microsimulation can subsequently be used to draw conclusions about the performance of the network and how well it is able to handle the traffic load. This information can thus be used to compare different designs for the design area.

Trip time for buses

For the trip time of the buses, the average trip time from, one end of the model to the other, of all the buses that are modelled will be taken. The lower the average trip time for buses, the better the model scores for trip time for buses.

Reliability of the bus service

For the reliability of the bus service, the standard deviation of the bus trip time from, one end of the model to the other, of all the buses that are modelled will be taken. The lower the standard deviation in trip time for buses, the better the model scores for the reliability of the bus service.

Travel time for general traffic

For the travel time of the general traffic, the average travel time from, one access point of the model to another, of all the general traffic that is modelled will be taken. The lower the average travel time for general traffic, the better the model scores for travel time for general traffic.

Travel time for bicycle traffic

For the travel time of the bicycle traffic, the average travel time from, one access point of the model to another, of all the bicycle traffic that is modelled will be taken. The lower the average travel time for the bicycle traffic, the better the model scores for travel time for bicycle traffic.

6.2.6. Passenger accessibility

The category passenger accessibility concerns how easy the system is to use for passengers. The criteria set to judge this are all based on different metric and thus also unrelated to each other. Therefore they are explained in better detail individually.

Stop locations

The locations of the stops will be judged based on how many inhabitants can reach the stops within 400 metres of walking distance. The value of 400 metres is based on an internal value from the municipality. The municipality strives to have all inhabitants be able to reach a bus stop within walking distance. Therefore it was assumed that only within 400 metres people would use a bus stop, because otherwise there would be another bus stop closer to them. To find the number of inhabitants within 400 metres of a bus stop, two data sources will be used. The first is the data of the inhabitants in already existing housing. For these the postal code data in 2024, accurate to 6-figure postal codes, from the Centraal Bureau voor de Statistiek (2024) will be used. The second is the data for the inhabitants that will live in the LES-area in the future. The municipality has data for this development. These numbers do not specify the number of inhabitants, but rather the number of housing units. To get to the number of inhabitants, the number of housing units is multiplied by the national average of 2.1 inhabitants per housing unit in the Netherlands (Centraal Bureau voor de Statistiek, 2025).

The software ArcGIS Pro will be used to combine the different types of geographical data into a simple value per bus stop.

Stop access routes

For each stop, the number and quality of the access routes will be determined. The access to the stop will be considered from both sides of the street. The number of access routes is simply the number of street crossings that connect a stop to both sides of the street. This number can be zero, when there is no dedicated street crossing. It is most often one, and sometimes it is two, when a stop can be reached at both ends of the platform. The street crossings to reach the stop will be graded using evaluation criteria for road cross-ability of road crossings provided by the CROW (2019). The evaluation criteria are different for three different types of street crossings; traffic light regulated, unregulated and zebra. The evaluation criteria for all three types are included in Appendix E.

Stop quality

The stop quality will be based solely on the total area of the bus stop. The idea behind this is that the higher the area, the more space there is that can be used for amenities. The more amenities that can be placed at a stop, the higher its quality.

BRT appearance

This criterium describes to what extend the street design indicates that this street is being served by a high quality public transport service. This is done through the presence and quality of dedicated bus infrastructure and the comfort of this infrastructure. This is a qualitative criterium and it is judged using the expert opinion of the public transport specialists from the municipality of Amersfoort.

6.2.7. Urban integration and liveability

The urban integration and liveability contains all aspects that do not relate to the traffic or bus service. The different criteria that are used to judge it are unrelated and therefore explained individually in more detail.

Road safety

To determine the road safety of a design, it was decided to look at the number of conflict points. Specifically the number of conflict points between general and active modes. Conflict points between general modes were not considered because they were deemed less relevant to the case at hand. In general collisions involving only general modes lead to much less severe accidents than those involving general and active modes. Especially in the urban setting in the Netherlands, were speed limits generally do not exceed 50 km/h (Jurewicz et al., 2016).

The conflict points are categorised using two properties, leading to a total of four categories. First they are divided by the speed limit for general traffic, which can either be 30 km/h or 50 km/h. Obviously a conflict point at a lower speed weighs less, because the consequences of a collision are less severe. Secondly they are divided by the type of intersection that the conflict point occurred at. The intersection can either be signal regulated or not. In general signal regulated intersections tend to be less safe than unregulated intersections. This is because signals are only placed at the busy intersections that require them (SWOV, 2022). The designs will then be graded based on the number and type of different conflict that are present.

Space for pedestrians and bicycle traffic

The total space for pedestrians and bicycle traffic as an evaluation criterium is as straightforward as it sounds. The total area for these modes will simply be measured using the available tools for this in the design software AutoCAD. This will then be converted to a percentage of the total design area. The higher the percentage of the total area that is dedicated to pedestrians and bicycle traffic, the higher the design scores in this metric.

Road cross-ability

The road cross-ability will be judged based on the number of crossings between both sides of the street as well as the quality of each of these crossings. To determine the quality of a crossing the same evaluation criteria from the CROW (2019) are used as for the stop access routes. The higher the number and quality of street crossings the higher a design scores in road cross-ability.

Neighbourhood integration

This criterium describes to what extend the street naturally and logically connects to its surrounding neighbourhoods. It is a qualitative criterium. It will be judged using the expert opinion of the urban development specialists from the municipality. They have been working on the LES-area urban development for several years.

Public green space

Similarly to the space dedicated to pedestrian and bicycle traffic, the criterium public green space is simply calculated by taking the percentage of the total design area that is dedicated to public green space. The higher the total percentage, the better a design scores in this metric. The area is measured using built in features in the design software AutoCAD.

Long-term robustness

The long term robustness of a design will be judged on how close a design follows the state-of-the-art in design guidelines and practices as described in section 3.6. This is seen as a valid indicator as the closer a design is to the state-of-the-art, the likelier it is that it will last as a valid and recommended design. This decreases the chance that the design will have to be altered in the short- or medium-term, thus making the design robust for the long-term.

6.2.8. Step 8: Integration of the final design

After the evaluation has established all the preferred alternatives for each design section, these preferred alternatives need to be integrated into a complete final design. This final design will be a drawing made in AutoCAD of the entire design area. It will feature the preferred design alternatives for all sections. This step will be taken in section 9.4.

7 Development of concepts

For the development of concepts each of the five design sections (see Figure 5.3) was considered separately. For each design section a normative street cross-section was found. This street cross-section includes all elements of the street from façade to façade. This normative cross-section was then used to create alternatives for the design of the street at the cross-section level. This is a relatively straight forward task, that nonetheless gives quite some insight to the design possibilities. For each design section several key points were identified where it might make sense to create a normative cross-section. The chosen normative cross-section is simply the narrowest cross-section. The narrowest cross-section was chosen, because at the narrowest point of the design section, it is hardest to find space for all street functions.

After the normative cross-section was established, design alternatives could be developed. To develop design alternatives, demands and wishes from the municipality were used. These were based on the general demands as described in section 5.2 as well as specific demands and wishes that were constructed in cooperation with the municipality for each design section. Design alternatives were then developed. Each design alternative had to meet at minimum all of the posted requirements and where possible fulfil the wishes. The differences in the design alternatives is found mainly in the way the bus infrastructure is fitted into the street.

After the design alternatives were created they were discussed with the municipality. With input from the municipality, the most promising alternatives were picked for further development the development of variants.

7.1. Stadsring

The Stadsring is the first design section. It is relatively short at a length of 200 metres. It ends right at intersection with the Van Asch van Wijckstraat and Molenstraat. From this intersection the Van Asch van Wijckstraat goes to the main station. While the continuation of the Stadsring itself provides access to the eastern part of Amersfoort. The Molenstraat connects into the historic city centre. Currently there is a bus stop on the Stadsring just after this intersection. This stop is called 'Stadhuis' for the nearby city hall. This stop will be retained in the new designs, although it will be redesigned.

7.1.1. Normative cross-section

Due to the short length of the design section, there are only two locations that were considered for the normative cross-section. They lie at both ends on the design area. They are:

- 1 Just after the intersection with the Van Asch van Wijckstraat and the Molenstraat (48.0 m)
- **2 The railway underpass (26.0 m)**

The second option, the railway underpass, is chosen as the normative. This is because it is significantly narrower than the first option and thus likely will be a tighter fit, even though the bus stop will need to be fitted in around the location of the first cross-section. The railway underpass consists of 4 separate tunnels, as well as some buffers between the tunnels that cannot be moved. There are 2 narrower tunnels on the outsides, the northern one is 4.6 metres wide and the southern one is 3.7 metres wide. The two middle tunnels are wider and both have a width of 7.0 metres.

7.1.2. Current situation

In the current situation (see Figure 7.1) the northern tunnel is shared between pedestrians and bicycle traffic with a 2.8 metres wide bi-directional bicycle path and a 1.8 metres wide sidewalk. It is important to note that this tunnel lies around two metres higher than the other tunnels, which is not reflected in Figure 7.1 due to limitations of the drawing tool. This elevation difference is because bicycle traffic and pedestrians don't need a tunnel as deep as general traffic. The middle tunnel both have 2 lanes (3.5 metres wides) for general traffic. One tunnel westbound and the other eastbound. The final southern tunnel has a single eastbound bus lane with a width of 3.7 metres. Between the tunnels there are buffers of differing width between 1 and 1.5 metres. As said before the buffer between the active modes and the general traffic is also an elevation difference.

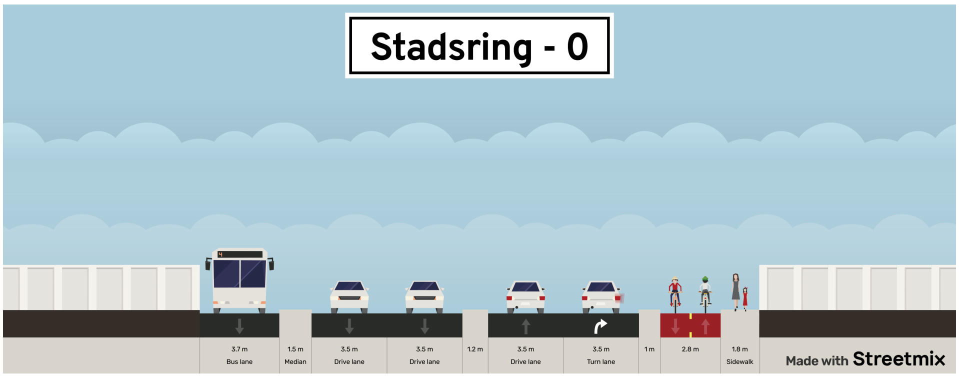


Figure 7.1: The current situation on the normative cross-section of the Stadsring

7.1.3. Requirements and wishes

For the redesign the municipality has certain requirements and wishes. The requirements for this section are based on the general requirements as defined in section 5.2. With extra input from the municipality, specifically for the Stadsring, the following requirements have been established for a redesign of this section:

- 1 bus lane (3.5 m per lane or 6.5 m for 2 lanes) per direction for 50 km/h
- 1 general traffic lane (3.25 m) per direction for 30 km/h
- retaining of a pedestrian and bicycle connection on the northern side
- buffers (min 1.0 m) between the different tunnels
- buffers (min 0.5 m) between lanes with a different speed limit
- buffers (min 0.5 m) and elevation difference between active modes and general traffic

The wishes from the municipality are as follows:

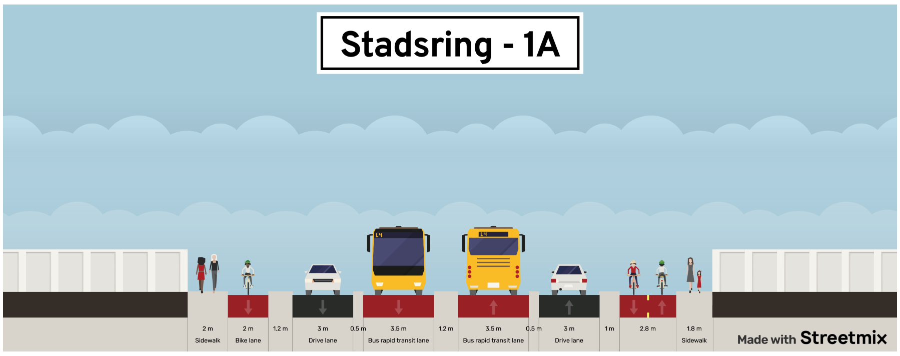
- introduction of a pedestrian and bicycle connection on the southern side, similar to the current situation on the northern side.
- widening of the pedestrian and bicycle connection on the northern side

7.1.4. Design alternatives

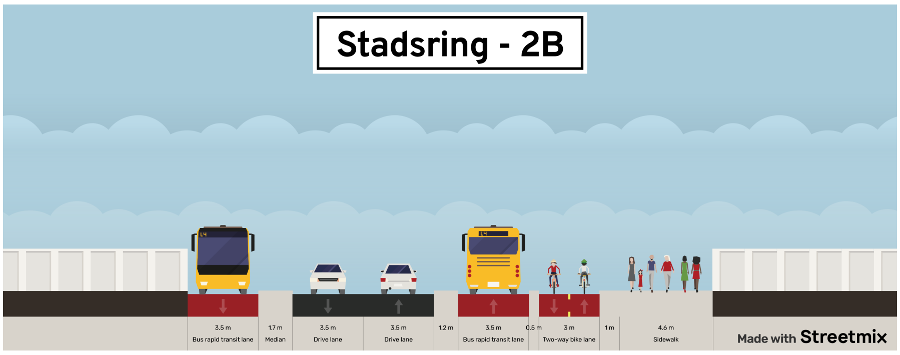
Based on the conclusion of the literature review as written in section 3.6 there are there are four easily conceivable locations for the bus and general traffic lanes. These are alternatives 1 through 4 in Table 7.1. All these alternatives meet the requirements for the street. They can all be realised in two different flavours, the alternatives A and B (see Table 7.1). Option A is to create a new shared pedestrian/bicycle tunnel on the southern side which complements the one on the northern side. Option B is to widen the already existing pedestrian/bicycle connection on the northern side, so that the active modes are better accommodated on one side. In Figure 7.2 alternative 1A and 2B are given to illustrate the alternatives. All eight design alternatives can be found in Figure B.1 and Figure B.2.

Table 7.1: The design alternatives for the Stadsring

	A: New pedestrian and bicycle connection on the southern side	B: Widened pedestrian and bicycle connection on the northern side
1: Separated median bus lanes	1A	1B
2: Curb-side bus lanes	2A	2B
3: Side separated bus lanes on the northern side	3A	3B
4: Side separated bus lanes on the southern side	4A	4B



(a) The design alternative 1A for the normative cross-section of the Stadsring



(b) The design alternative 2B for the normative cross-section of the Stadsring

Figure 7.2: Design alternative 1A and 2B for the normative cross-section of the Stadsring

7.1.5. Conclusions based on discussion

Both the option with median bus lanes and the option with curb-side bus lanes can be connected onto the roundabout with underpass design that is currently present on the northern side of the railway underpass. For the both of the side separated bus lanes options (alternatives 3 and 4), this is harder to imagine as providing access for general traffic to the roundabout would practically be impossible. Alternatives 3A, 3B, 4A and 4B are therefore not taken into consideration for the development of variants.

To widen the pedestrian/bicycle connection on the northern side, half of the northern middle tunnel would have to be converted to a cycle path. There would need to be a buffer and elevation difference between the cycle path and the general traffic. This would likely take at least 1 metre of space. Leaving only 6 metres for a general traffic lane and a bidirectional cycle path. This could be fitted in, but would not allow for a wider cycle path than in the current situation.

The municipality also expressed that they would prefer to see a new pedestrian and bicycle connection on the southern side, because the southern most tunnel was originally designed for this when the underpass was constructed. The bus lane that is currently there was a later addition. This tunnel is slightly narrower than the one on the northern side at 3.7 metres currently. It is conceivable that by taking away some buffer space this section could be widened to 4.0 metres, but this is still quite narrow. It would consist of a 2.0 metre wide sidewalk and 2.0 metre wide unidirectional eastbound cycle path.

The municipality chose to continue with option A, therefore alternatives 1B and 2B were discarded. Leaving only 1A and 2A for the development of variants.

7.2. De Nieuwe Poort

De Nieuwe Poort is the second design section and it is around 500 metres long. It is the most complex of the 5 sections. This is because it has a roundabout with an underpass in the middle of the section. This roundabout and underpass need to be maintained in a redesign. It currently features the bus stop 'Eemplein' just after the roundabout, which is the second busiest bus stop in Amersfoort after the main station. This bus stop will be retained as it as determined in subsection 5.2.1 that there should be a bus stop around here. The exact location of the stop is not fixed, so it might be relocated slightly compared to its current location.

7.2.1. Normative cross-section

There are three locations that were considered for the normative cross-section of De Nieuwe Poort, these are:

- 1 Just before De Nieuwe Poort tunnel exit (51.0 m)
- 2 Just after De Nieuwe Poort tunnel exit (52.5 m)
- **3 Just before intersection with new Brabantsestraat (45.5 m)**

The third cross-section was chosen because it is the narrowest. In the current situation the width of the street at the normative cross-section is 36.0 metres, but this will be widened to 45.5 metres due to a setback of buildings on the northern side. It lies at the western most point of the design section, just before the new intersection with the new Brabantsestraat. In the current situation there is no intersection here. However in the new design there will. This intersection will provide access to the LES-area. No cross-sections were considered where the roundabout is. This was done, because it was deemed impossible to correctly reflect the roundabout with a cross-section. The design of the roundabout will be more extensively covered in the development of variants (see section 8.1), where a 2D top view drawing will be made for all the alternatives.

7.2.2. Current situation

The current street profile at the normative cross-section features two general traffic lanes per direction in the middle. One of these general traffic lanes comes down from the roundabout, where the other comes up from the underpass. On the northern side there is a right turn lane, a unidirectional cycle lane and a quite minimal sidewalk. On the southern side, there is a parallel expedition road for eastbound general traffic and bidirectional bicycle traffic, as well as a minimal sidewalk. The entire street profile is characterised by limited pedestrian and green space. The current street profile can be seen in Figure 7.3.

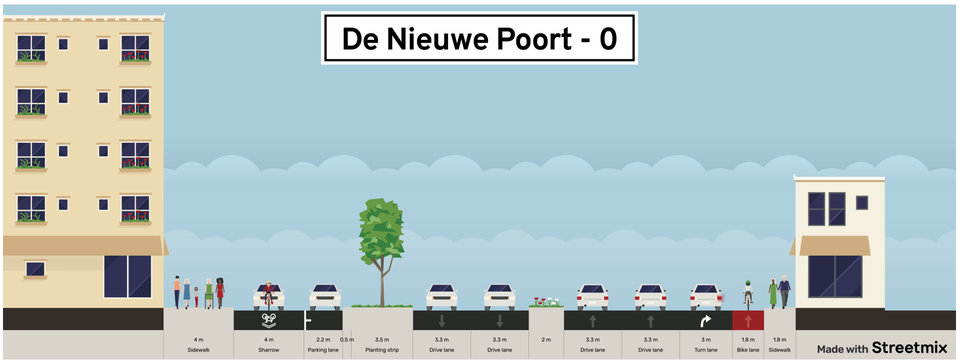


Figure 7.3: The current situation on the normative cross-section of De Nieuwe Poort

7.2.3. Requirements and wishes

For the redesign the municipality has certain requirements and wishes. The requirements for this section are based on the general requirements defined in section 5.2. With extra input from the municipality, specifically for De Nieuwe Poort, the following requirements have been established for a redesign of this section:

- retaining of the roundabout with underpass design
- 1 general traffic lane connecting to the roundabout (3.25 m) per direction for 30 km/h
- improved infrastructure for the bus service
- a bus stop
- a bidirectional bicycle street (5.0 m) on the southern side
- a unidirectional cycle path (2.7 m) on the northern side
- a wide sidewalk (min 5.0 m) on both sides
- buffers (min 2.0 m) between active modes and general traffic
- a median buffer (min 2.5 m)

The wishes from the municipality are as follows:

- 1 bus lane (3.5 m per lane or 6.5 m for 2 lanes) per direction for 50 km/h
- a bidirectional cycle path (4.0 m) on the northern side instead of a unidirectional one
- general traffic access through the underpass
- wider buffers with green space

7.2.4. Design alternatives

The possible design alternatives are severely limited by the roundabout with underpass, as it is quite a defining constraint. The creation of separated bus lanes is only possible if they are placed in the middle of the street and make use of the underpass. Curb-side bus lanes or side separated bus lanes are not possible as they make the roundabout inaccessible to general traffic at one or more locations. The use of the underpass for dedicated bus lanes is alternative 1A. The bus stop would be place immediately after the underpass in this alternative.

Next to dedicated bus lanes, there are also options with shared traffic. Currently buses drive over the roundabout and share the road space with general traffic. This is alternative 2. In this alternative the stop would have to be located after the roundabout as a bus stop cannot be fitted onto a roundabout. Finally there is the option, alternative 3, to implement shared traffic through the underpass. In this case both buses and general traffic would be able to use the underpass. The stop would have to be located beyond the underpass just like in alternative 1A.

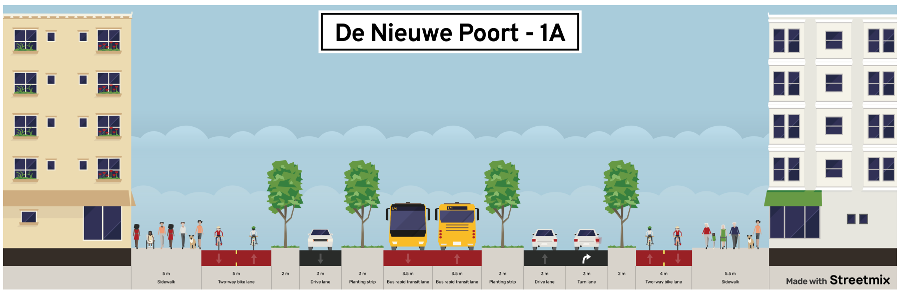
The alternatives 1A, 2 and 3 all assume that the current design for the underpass is maintained. It is however also discussed within the municipality to create a new underpass design with a bus stop in the middle of the underpass. The benefit of this design is that it places the bus stop in the most central location of the area. The biggest origins and destinations (including a new city hall that is currently under construction) in the area directly surround the roundabout. Such a redesign with dedicated bus lanes through the underpass is given as alternative 1B. It is theoretically possible to also create an alternative 3B, in which the stop is located in the underpass, but the underpass is still shared between buses and general traffic. This is however not a desirable option as it would require an expensive redesign, while not providing a true a high quality public transport service. Therefore it would not be worth the investment.

Since the alternatives do not vary much in their implementation at the normative cross-section and take up a similar amount of space, they meet the wishes to a similar extend. All of the alternatives have a bidirectional cycle path on the northern side instead of a unidirectional one. They also all use excess space to provide wider green buffers. The design alternatives 1A and 2 are given in Figure 7.4, all of the design alternatives can be found in Figure B.3.

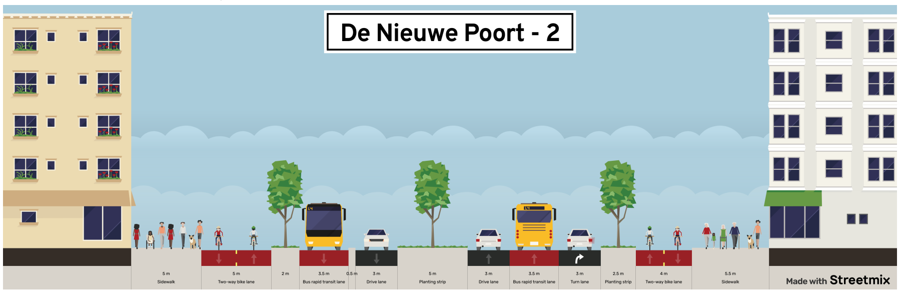
The alternatives are:

Table 7.2: The design alternatives for De Nieuwe Poort

	A: Current underpass design (no bus stop in the underpass)	B: New underpass design (bus stop in the underpass)
1: Bus lanes through the underpass	1A	1B
2: Shared traffic over the roundabout	2	-
3: Shared traffic through the underpass	3	-



(a) The design alternative 1A for the normative cross-section of De Nieuwe Poort



(b) The design alternative 2 for the normative cross-section of De Nieuwe Poort

Figure 7.4: Design alternative 1A and 2 for the normative cross-section of De Nieuwe Poort

7.2.5. Conclusions based on discussion

Alternative 1A feels the most intuitive for the creation of a high quality bus service, however the bus stop would have to be moved westward 100 metres from its current location, which could be maintained in alternative 2. The moving of the bus stop westward is undesirable as this moves it further away from the roundabout, where the most important origins and destinations are.

Alternative 2 provides no real improvement for the bus service over the current situation, but does allow for the maintaining of the bus stop close to the roundabout, therefore this alternative is kept.

Alternative 3 combines the worst of alternative 1A and 2, namely a bus stop that has to be moved and sharing of infrastructure with general traffic. This alternative is therefore not considered promising and is discarded for the development of variants.

While the municipality is interested in a redesign of the underpass, it will not be further analysed in this thesis. This is due to time constraints as looking into this option further would take a significant amount of extra time, due to its differences to the current design and complex implications for the structural design of the underpass. The municipality is also already doing their own research into this option. Alternative 1B is thus discarded for the development of variants. This leaves alternatives 1A and 2 for the development of variants.

7.3. Amsterdamseweg

The Amsterdamseweg is the third design section. This section is 450 metres long and is a fairly straight section of road. Currently it is only used by one bus line, so the introduction of the high quality bus service will be a new addition to connect the LES-area using high quality public transport. In the development plans for the LES-area there is a green corridor. This corridor crosses the Amsterdamseweg around the Geldersestraat. There will also be an important bicycle traffic and pedestrian crossing here.

7.3.1. Normative cross-section

There were three locations considered for the normative cross-sections. They lie at both ends of the section and in the middle. They are:

- 1 Just after intersection with new Brabantsestraat (43.5 m)
- **2 Just after intersection with Geldersestraat (37.5 m)**
- 3 Just before intersection with Industrieweg (41.0 m)

The second cross-section just after the intersection with the Geldersestraat is the narrowest and was thus chosen as normative. In the current situation it has a width of 28.0 metres, but the redevelopment of the LES-area on the northern side of the street allows for a setback of buildings. This means that the street will be widened significantly to a new width of 37.5 metres at this location. This setback is applied over the entire length of the street so, this remains the most critical location. The space that is created by the setback is mainly intended for wider sidewalks and extra green space.

7.3.2. Current situation

The current street profile of the Amsterdamseweg (see Figure 7.5) features 2 general traffic lanes in both directions in the middle. On the northern side there is a narrow unidirectional bicycle path as well as a narrow sidewalk. On the southern side there is a decent bidirectional cycle path and another minimal sidewalk. Similarly to De Nieuwe Poort, the current design is quite dominated by asphalt and has very minimal space for pedestrians and greenery.

Figure 7.5: The current situation on the normative cross-section of the Amsterdamseweg

7.3.3. Requirements and wishes

For the redesign the municipality has certain requirements and wishes. The requirements for this section are based on the general requirements defined in section 5.2. With extra input from the municipality, specifically for the Amsterdamseweg, the following requirements have been established for a redesign of this section:

- 1 bus lane (3.5 m per lane or 6.5 m for 2 lanes) per direction for 50 km/h
- 1 general traffic lane (3.25 m) per direction for 30 km/h
- a bidirectional cycle path (4.0 m) on the south side
- a unidirectional cycle path (2.7 m) on the north side
- a wide sidewalk (min 5.0 m) on the northern side
- a sidewalk (min 2.0 m) on the southern side
- buffers (min 2.0 m) between active modes and general traffic
- a median buffer (min 2.5 m)
- buffers (min 0.5 m) between lanes with a different speed limit

The wishes from the municipality are as follows:

- a bidirectional cycle path (4.0 m) on the north side instead of a unidirectional one
- a wider sidewalk on the southern side
- wider buffers with green space

7.3.4. Design alternatives

Due to the wide profile of the street and the relatively small number of functions that need to be fitted into the street, all requirements and wishes can be fulfilled. The only question is where the bus lanes will be located. The design alternatives therefore only differ from each other on the location of the bus lanes and some associated details in the buffers. The four standard alternatives as defined in section 3.6 are all possible. These alternatives are:

- 1: Separated median bus lanes
- 2: Curb-side bus lanes
- 3: Side-separated bus lanes on the northern side
- 4: Side-separated bus lanes on the southern side

Alternative 1 and 2 are shown in Figure 7.6. All four alternatives can be found in Figure B.4

(a) The design alternative 1A for the normative cross-section of the Amsterdamseweg

(b) The design alternative 2 for the normative cross-section of the Amsterdamseweg

Figure 7.6: Design alternative 1 and 2 for the normative cross-section of the Amsterdamseweg

7.3.5. Conclusions based on discussion

Alternatives 3 and 4 with side separated bus lanes do not have a corresponding design alternative in the section 'De Nieuwe Poort' and would thus require significant weaving at the intersection with the new Brabantsestraat where the design sections connect. This is undesirable and makes this intersection unnecessarily complex. Alternatives 3 and 4 are therefore not seen as promising and will not be considered in the development of variants. The municipality thus wants to continue with alternative 1 and 2 in the development of variants.

7.4. Industrieweg

The Industrieweg is the fourth design section at a length of just over 400 metres. It is a busy connector road in the road structure of Amersfoort. Currently it is only used partially by one bus line, so the introduction of high level bus service is completely new here. In subsection 5.2.1 it was determined that in the redesign there will have to a bus stop here. This bus stop will provide access to high quality public transport for a large part of the LES-area.

7.4.1. Normative cross-section

There are four locations that were considered for the normative cross-section. At both ends of the design section and on both side of the major intersection with the Nijverheidsweg-Noord. In order they are:

- 1 Just after intersection with Amsterdamseweg (55.0 m)
- **2 South of the intersection with the Nijverheidsweg-Noord (38.0 m)**
- 3 North of the intersection with Nijverheidsweg-Noord (41.5 m)
- 4 Just before the Koppelbrug (44.0 m)

The second cross-section south of the intersection with the Nijverheidsweg-Noord is the narrowest at 38 metres in the redesign and is thus chosen as the normative cross-section. However in the current situation the cross-section north of this intersection is narrower. This is because in the redesign a setback is only applied north of the intersection and not south of the intersection. This is because the

Pon car dealership south of the intersection is the only current function in the LES-area that will not be removed and redeveloped, making introducing a setback here impossible. The cross-section south of the intersection will thus remain 38.0 metres like in the current situation, while the cross-section north of the intersection will be widened from 32.0 to 41.5 metres.

7.4.2. Current situation

The Industrieweg has a width of 38.0 metres at its most critical position south of the intersection with Nijverheidsweg-Noord (see Figure 7.7). The street profile is quite dominated by asphalt. There are 4 northbound general traffic lanes, of which 1 a left turn and 1 a right turn lane. In the southbound direction, there are 2 southbound general traffic lanes. Furthermore there is a minimal sidewalk on both sides of the street. There is a decent bidirectional cycle path on the western side of the street and a minimal unidirectional cycle path on the eastern side of the street.

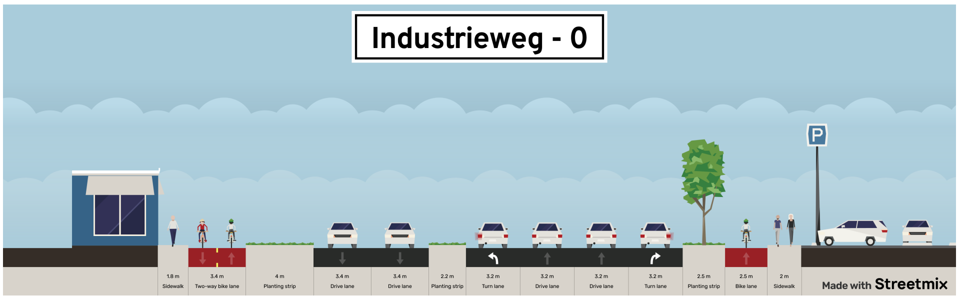


Figure 7.7: The current situation on the normative cross-section of the Industrieweg

7.4.3. Requirements and wishes

For the redesign the municipality has certain requirements and wishes. The requirements for this section are based on the general requirements defined in section 5.2. With extra input from the municipality, specifically for the Industrieweg, the following requirements have been established for a redesign of this section:

- 2 general traffic lanes (3.25 m) per direction for 50 km/h
- 1 bus lane (3.5 m per lane or 6.5 m for 2 lanes) per direction for 50 km/h
- a bus stop
- a unidirectional cycle path (2.7 m) on both sides
- a sidewalk (min 2.0 m) on both side side
- buffers (min 2.0 m) between active modes and general traffic
- a median buffer (min 2.5 m)

The wishes from the municipality are as follows:

- a bidirectional cycle path (4.0 m) on both sides instead of unidirectional ones
- a wider sidewalk on the eastern side
- wider buffers with green space

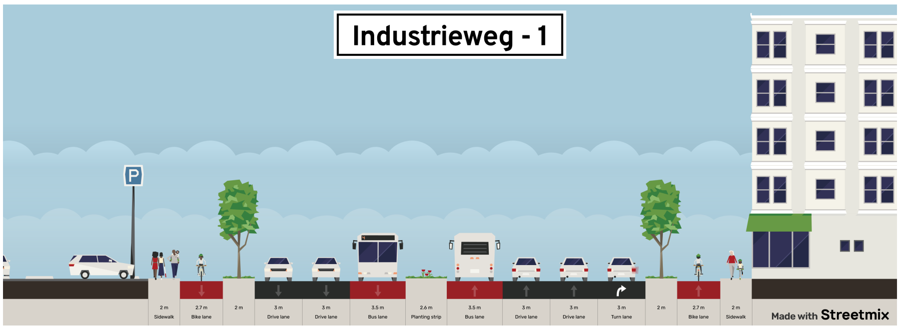
7.4.4. Design alternatives

Due to the fact that the street profile is not widened along the entire Industrieweg and the design must retain 2 general traffic lanes per direction, the Industrieweg is the hardest section to fit all functions in. The intersection with the Nijverheidsweg-Noord had to be made incomplete to meet all requirements. The western part of the Nijverheidsweg-Noord will become unidirectional in the eastbound direction for general traffic. This means the western part of the Nijverheidsweg-Noord is no longer accessible from the Industrieweg for general traffic. This area thus has to be accessed from another street. Such possibilities do exist outside of the scope of this project.

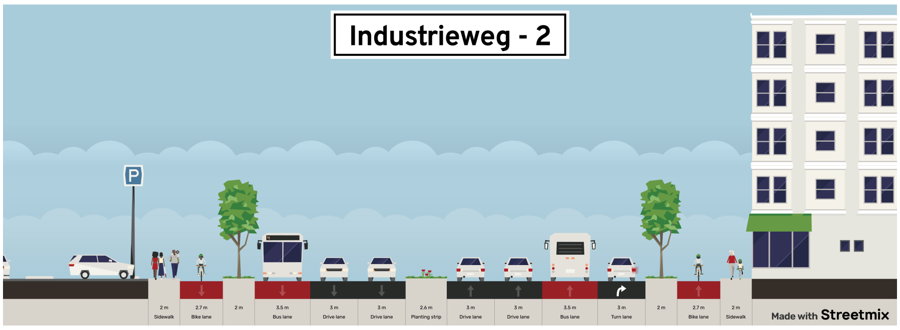
Since it was already quite difficult to meet the requirements, no wishes are met in any of the alternatives. In the end only two alternatives were developed. These alternatives are:

- 1 Median bus lanes
- 2 Curb-side bus lanes

Both alternatives are shown in Figure 7.8 and Figure B.5.



(a) The design alternative 1A for the normative cross-section of the Industrieweg



(b) The design alternative 2 for the normative cross-section of the Industrieweg

Figure 7.8: Design alternative 1 and 2 for the normative cross-section of the Industrieweg

7.4.5. Conclusions based on discussion

The municipality was quite surprised to learn that the Industrieweg was the hardest section to find sufficient design alternatives for. Also the fact that none of the wishes were met was not received positively. The minimum requirements set for pedestrians and bicycle traffic were already low and the municipality wants there to be more space for these modes. It was therefore decided to change the requirements for this design section. The hard requirement for dedicated bus lanes was dropped in favour of creating more space for pedestrians and bicycle traffic. For the development of variants it was therefore decided to develop two new alternatives. These alternatives are based on the two alternatives that were developed here, but use bus lanes only where possible and sometimes only in one direction. What this will actually look like will be defined in the development of variants.

7.5. Ringweg Koppel

The final design section is the Ringweg Koppel. This section is the shortest at just over a 100 metres. It features the Koppelbrug (Koppelbridge) over the river Eem. This is also the most defining element of this section as it gives a significant constraint to the street profile.

7.5.1. Normative Cross-section

As the section is so short, there are only two locations that are considered for the normative cross-section. At both ends of the section.

- **1 The Koppelbrug (25.0 m)**
- 2 Just before intersection with Maatweg (29.0 m)

The Koppelbrug is the narrowest of the two and as a bridge it also logically is the most constraining element of the section. The cross-section of the bridge is thus taken as the normative cross-section for the design section. The bridge has three sections separated by medians. The western section is 5.5 metres wide. The middle section is 6.5 metres wide and the western section is 9.0 metres wide. The sections are separated by medians that also feature arm barriers to block the bridge when it opens.

7.5.2. Current situation

In the current design (see Figure 7.9) the western section is shared between a 2.0 metre wide sidewalk and a 3.5 metre wide bidirectional cycle path. The middle section is used for two southbound general traffic lanes, both 3.0 metres wide. The eastern section is used for 3 northbound general traffic lanes, of which one is a left turning lane.

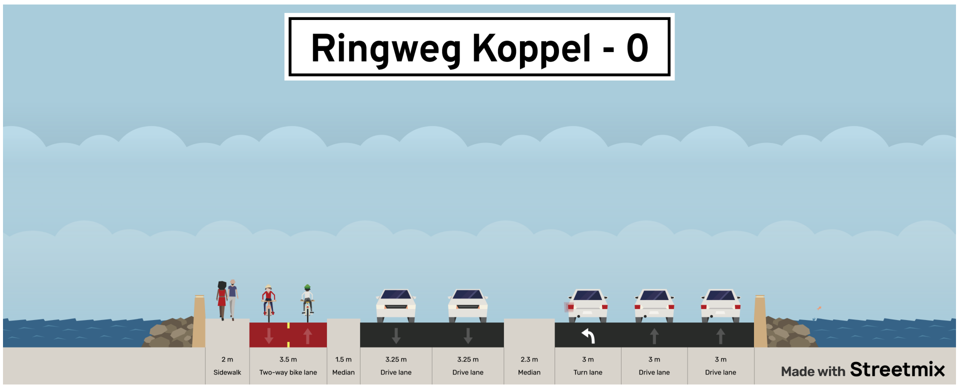


Figure 7.9: The current situation on the normative cross-section of the Ringweg Koppel

7.5.3. Requirements and wishes

For the redesign the municipality has certain requirements and wishes. The requirements for this section are based on the general requirements defined in section 5.2. With extra input from the municipality, specifically for the Ringweg Koppel, the following requirements have been established for a redesign of this section:

- 2 general traffic lanes (3.25 m) per direction for 50 km/h
- retaining of the pedestrian/bicycle section of the bridge
- improved infrastructure for the bus service

The wishes from the municipality are as follows:

- 1 general traffic turning lane northbound (3.25 m) for 50 km/h
- 1 bus lane (3.5 m per lane or 6.5 m for 2 lanes) per direction for 50 km/h

7.5.4. Design alternatives

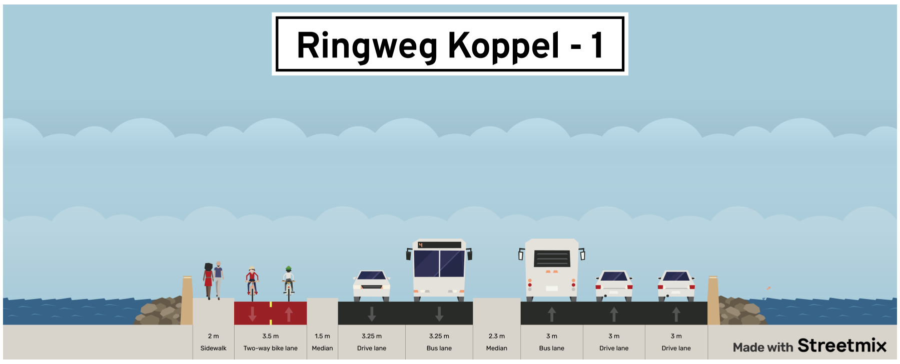
The first two alternatives use the bridge as is and provide no dedicated bus infrastructure. In the first alternative buses would drive on the median lane and in the second alternative they would drive on the curb-side lane. This makes it possible to logically connect onto either median or curb-side bus lanes on the Industrieweg. In both of these alternatives the traffic-light controlled intersections at the intersection between the Ringweg Koppel and the Maatweg, can be optimised so that buses traffic always has priority over general traffic, providing a service level near to that of a bus lane, without the expensive cost of a new bridge. This is called smart sharing. In the third alternative this approach is supplemented with a northbound bus lane at the cost of a general traffic turning lane. This is considered, because providing effective traffic-light priority is harder to realise in the northbound direction than in the southbound direction. This is harder because northbound buses can only be given a green (or white) light very quickly, but they cannot easily skip the queue. Southbound buses can skip the queue, assuming that the Maatweg will have dedicated bus lanes (bus lanes on the Maatweg are out of scope for this thesis, but they are part of the same higher level of service bus corridor that is under study at the municipality).

The last three alternatives all take a much different approach, in that they assume the construction of a new bridge. This bridge could then be made wide enough to fit all the current functions, as well as a dedicated bus lane in both directions. Alternative 4 places the bus lanes in the median. Alternative 5 has them side-separated on the eastern side and alternative 6 has them side-separated on the western side.

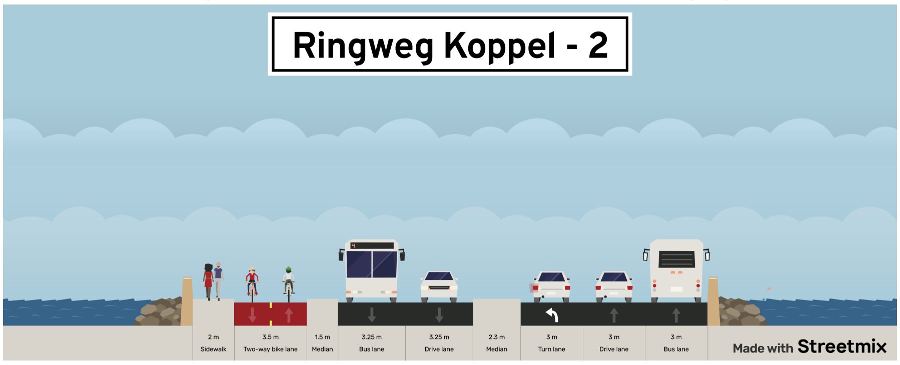
The listed alternatives are:

- 1 Current number of lanes with smart sharing on the median lanes
- 2 Current number of lanes with smart sharing on the curb-side lanes
- 3 Current number of lanes with smart sharing southbound and a median bus lane northbound
- 4 Widened bridge with median bus lanes
- 5 Widened bridge with side-separated bus lanes on the eastern side
- 6 Widened bridge with side-separated bus lanes on the western side

Alternatives 1 and 2 are given in Figure 7.10, while all six alternatives are available in Figure B.6 and Figure B.7.



(a) The design alternative 1A for the normative cross-section of the Ringweg Koppel



(b) The design alternative 2 for the normative cross-section of the Ringweg Koppel

Figure 7.10: Design alternative 1 and 2 for the normative cross-section of the Ringweg Koppel

The municipality is currently also working on an additional pedestrian/bicycle bridge that will be placed next to the current bridge on the eastern side. This would significantly improve the pedestrian and bicycle traffic connectivity between the LES-area and the northern side of the river Eem. This additional bridge is left out of scope for this thesis.

7.5.5. Conclusions based on discussion

The municipality was interested in the options with a new widened bridge, but considering that on the Industrieweg the requirements were softened, they deemed that it would not make sense to include a new bridge in the scope for this thesis. Alternatives 4, 5 and 6 were thus discarded.

Similarly the municipality decided that alternative 3 with a dedicated bus lane on the bridge did not make sense in combination with the softened requirements on the Industrieweg. Therefore they decided that this alternative would also be dropped. Alternatives 1 and 2 are thus considered for the development of variants.

8

Development of variants

After discussing the first design concepts that were developed during the development of concepts with the municipality, two main decisions were taken to continue with the development of variants.

The first is to reduce the number of design sections from five to two. This decision was rooted in the fact that several of the design sections are so intertwined that it is not realistic that they have a different design. It was therefore decided to combine the intertwined design sections. The first set of intertwined design sections includes the Stadsring, De Nieuwe Poort and the Amsterdamseweg. It will be called design section Amsterdamseweg. The second will be called design section Industrieweg and include the Industrieweg and the Ringweg Koppel. The new design sections can be seen in Figure 8.1.

The second decision was to reduce the of the number of design alternatives. For each new section only the promising alternatives from the development of concepts were taken. These alternatives were developed further into variants as fully designed maps for the sections. This reduction allows for the alternatives that remain to be properly analysed in the given time frame, rather than providing a rushed analysis for all the alternatives.

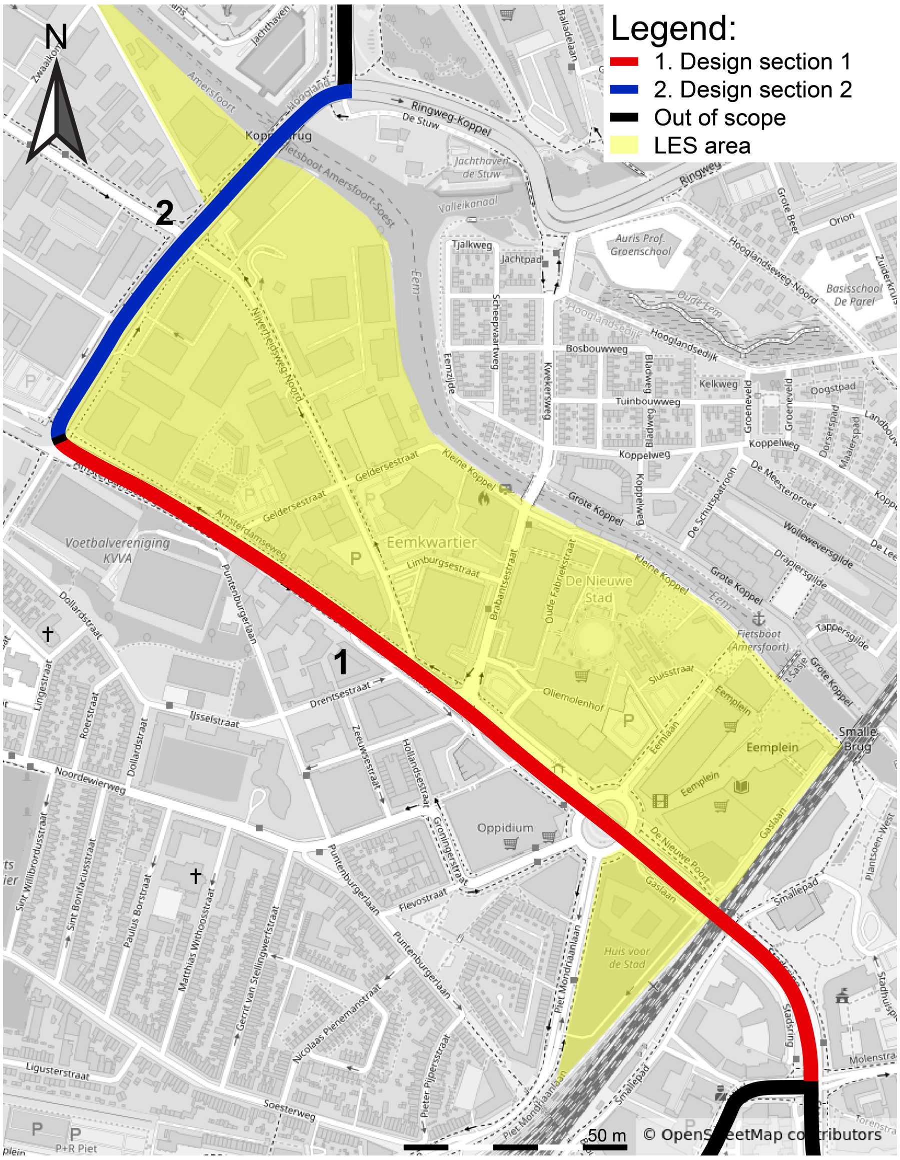


Figure 8.1: The new design sections

8.1. Design section Amsterdamseweg

The first new design section contains the Stadsring, De Nieuwe Poort and the Amsterdamseweg. Together they have a length of around 1200 metres. This section connects the Stadsring all the way to the Industrieweg. The section forms the main street for the LES-area. This street will connect the area to the rest of Amersfoort. It includes two bus stops. One directly at the start of the design section, where the bus stop 'Stadhuis' currently is. The location of this bus stop is fixed here. The second is located in the middle of the section around where the bus stop 'Eemplein' currently is. The location of this stop is not fixed and will be different in the two design variants that are developed.

8.1.1. Current situation

In the current situation the street has 2 general traffic lanes per direction. At the railway underpass there is an additional bus lane in the eastern direction. At De Nieuwe Poort there is a roundabout with an underpass. 1 of the 2 general traffic lanes connects to the roundabout and the other goes through the underpass. After the roundabout there is an intersection with the old Brabantsestraat and further along there is a smaller, incomplete intersection with the Geldersestraat. Towards the end of the section there is the intersection with the Industrieweg for which there are two additional turning lanes.

At the railway underpass there is a sidewalk and bicycle path on the northern side only. The rest of the section has sidewalks and bicycle paths on both sides of the street. Between the Geldersestraat and De Nieuwe Poort roundabout the southern cycle path is a shared street with expedition traffic. Many of the sidewalks are quite minimal in their width and also the bicycle paths are quite narrow. In general the current design is quite dominated by asphalt and has very minimal space for pedestrians and greenery.

8.1.2. Requirements and wishes

The requirements from the municipality are as follows:

- 1 bus lane (3.5 m per lane or 6.5 m for 2 lanes) per direction for 50 km/h
- 1 general traffic lane (3.25 m) per direction for 30 km/h
- a bus stop directly at the start of the design section at the Stadsring
- a bus stop somewhere between the roundabout and the new Brabantsestraat
- retaining of a pedestrian and bicycle connection on the northern side of the railway underpass
- retaining of the roundabout with underpass design at De Nieuwe Poort
- a unidirectional cycle path (2.7 m) on the northern side between the roundabout and the Industrieweg
- a bidirectional bicycle street (5.0 m) on the southern side between the roundabout and the Geldersestraat
- a bidirectional cycle path (4.0 m) on the south side between the Geldersestraat and the Industrieweg
- a wide sidewalk (min 5.0 m) where there are building that enter onto the sidewalk
- a sidewalk (min 2.0 m) where there are no building that enter onto the sidewalk
- buffers (min 1.0 m) between the different tunnels of the railway underpass
- buffers (min 0.5 m) between lanes with a different speed limit
- buffers (min 2.0 m) between active modes and general traffic
- a median buffer (min 2.5 m)

And their wishes are as follows:

- a bidirectional cycle path (4.0 m) on the northern side instead of a unidirectional one
- the creation of a pedestrian and bicycle connection on the southern side of the railway underpass
- general traffic access through the underpass under the roundabout
- wider buffers with green space
- wider sidewalks (up to 5.0 m), where the minimum is lower

8.1.3. Design variant median: Median bus lanes

Starting point and considerations

As mentioned in section 7.1, section 7.2 and section 7.3 the first of the two design variants is based on the cross sections with median bus lanes from the development of concepts. The cross-section of this design variant for the Amsterdamseweg can be seen in Figure 8.2. This variant is slightly improved from the development of concepts. This cross-section provides a starting position for the map design that is developed in the the development of variants.

Figure 8.2: The design variant of the Amsterdamseweg on which the design variant median for the design section Amsterdamseweg is based

To develop the map designs, the base designs from the CROW (see Appendix A) were used. Because the road profile was often wider than in the base designs, there was space for additional greenery or buffers. For the street design with median bus lanes the base design in Figure A.1 was used. Furthermore Figure A.6, Figure A.7, Figure A.10, Figure A.11 and Figure A.21 were used to design the road crossings and access routes to the bus stops. Also Figure A.14 was used for the crossing and intersection around the Geldersestraat. For the larger intersection Figure A.13 was used. Finally Figure A.18 could be used for the intersection that connects the two design sections.

Because design section Amsterdamseweg is quite wide, all of the requirements from the municipality could easily be met in this design variant. The wishes were also mostly possible to realise. Bidirectional bicycle paths are realised on both side of the street almost everywhere. This was only not possible on the southern side of the railway underpass, where a new pedestrian and bicycle connection was realised although quite narrow. The buffers between different modes are also often wider than the minimum with more space for greenery. The sidewalks are also 5 metres wide almost everywhere. In this variant the general traffic access through the underpass under the De Nieuwe Poort roundabout could not be realised.

Walk-through

Starting from the Stadsring in the south-east. The median bus lanes are immediately flanked by a bus stop. The bus stop is quite long at 54 metres, this length allows the bus stop to be used by a maximum of three buses simultaneously, in each direction. Next to the bus stop, there are three general traffic lanes in the southbound direction. All three for a different direction at the upcoming intersection. Also on both sides of the street there is a sidewalk and a bicycle path. The sidewalk and bicycle path on the southwestern side are quite narrow and thus the bicycle path is also unidirectional here. The buffers are relatively wide and can be used for green space.

Towards the railway underpass the buffers between the different modalities shrink and they become too narrow to be used as green space. As the underpass is entered the general traffic and the active modes diverge in elevation as the general traffic needs a larger clearance under the railway underpass. In both directions there is now only 1 general traffic lane, which is designed for 30 km/h.

After the railway underpass the general traffic lanes go up towards the roundabout at De Nieuwe Poort and connect onto this roundabout. The bus lanes in the middle of the street continue on the lower level and enter the underpass under the roundabout. The sidewalks and cycle paths also go up and connect onto the roundabout and the space surrounding the roundabout.

The roundabout itself was not designed in this thesis as the municipality is currently working on a redesign of the roundabout, which will be retained even if the bus lanes are implemented in the future. The design for the roundabout will thus also be the same for both design variants.

The design up to this point can be seen in Figure 8.3.

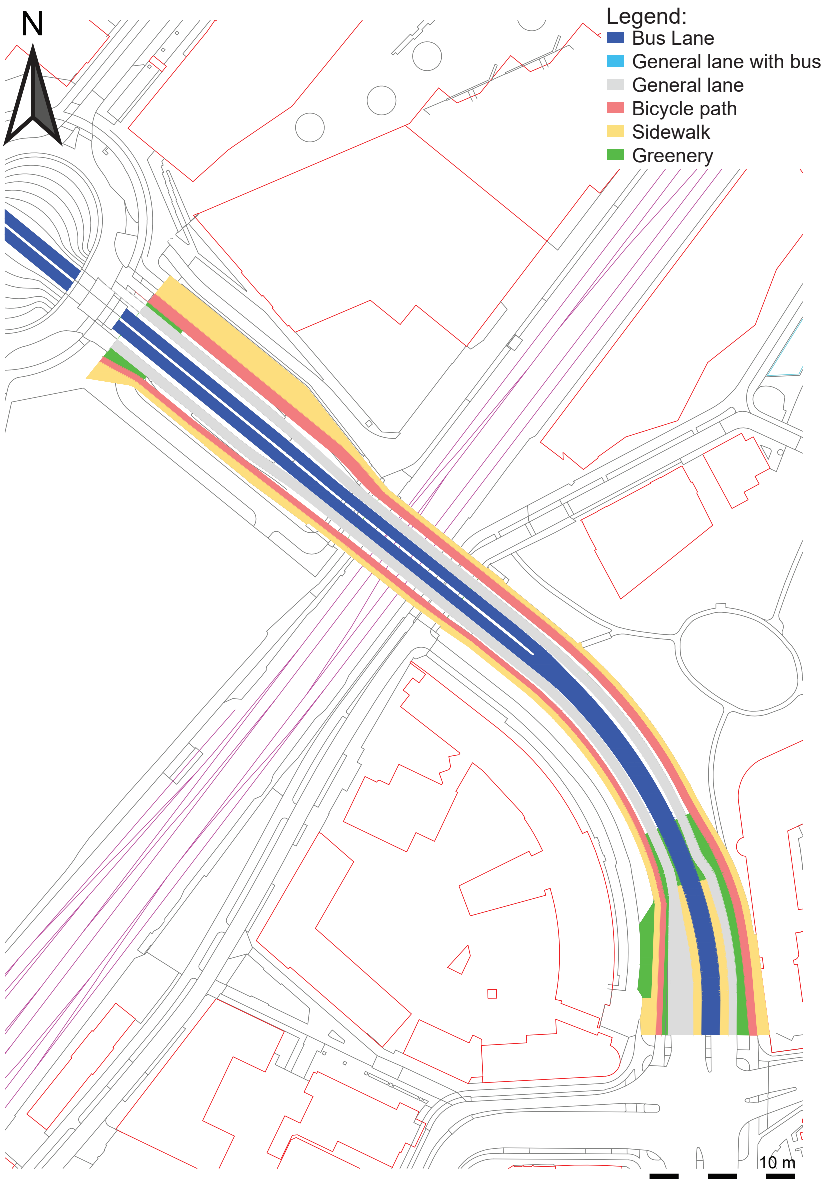


Figure 8.3: Design variant median between the start at the Stadsring and the roundabout at De Nieuwe Poort

After the roundabout the street continues in a similar configuration, however as it has become wider now, the sidewalks on both sides are 5 metres wide and there is space for a 4 metre wide bidirectional bicycle path on both sides as well. Shortly after the roundabout the bicycle path on the southern side becomes a bicycle street, where eastbound expedition traffic is also allowed. At the end of this street there is a connection to the general traffic lanes for the general traffic from the bicycle street.

As soon as the underpass under the roundabout arrives at street level there is a bus stop. The bus stop is thus located as close to the roundabout as it can be with the buses using the underpass. This bus stop is again long enough to allow three buses to stop simultaneously, in each direction. Pedestrian access routes to the bus stop are available from all four directions.

On the southern side of the street the Friesestraat and the Drentsestraat connect on the bicycle street, but not directly onto the general traffic lane. On the northern side the old Brabantsestraat connects as a bicycle path onto the bicycle path on the northern side.

Shortly thereafter the new Brabantsestraat connects to the street through a traffic light regulated intersection. In both directions there is a additional general traffic turning lane towards this intersection.

On all sides, there is also a crossing for bicycle traffic and pedestrians. After this intersection further westward, there is the entry point onto the bicycle street for general traffic. West of this point the bicycle street becomes a bicycle path again.

The design up to this point can be seen in Figure 8.4.

Figure 8.4: Design variant median between the roundabout at De Nieuwe Poort and the Geldersestraat

Finally, there is the intersection with the Geldersestraat. For general traffic, this crossing is incomplete. Only the westbound general traffic lane can be entered or exited via the Geldersestraat. Other traffic will have to use the previously discussed intersection with the new Brabantsestraat. There is also a traffic light regulated bicycle and pedestrian crossing here.

Towards the intersection with the Industrieweg, there is an additional turning lane.

The final section of this design can be seen in Figure 8.5.

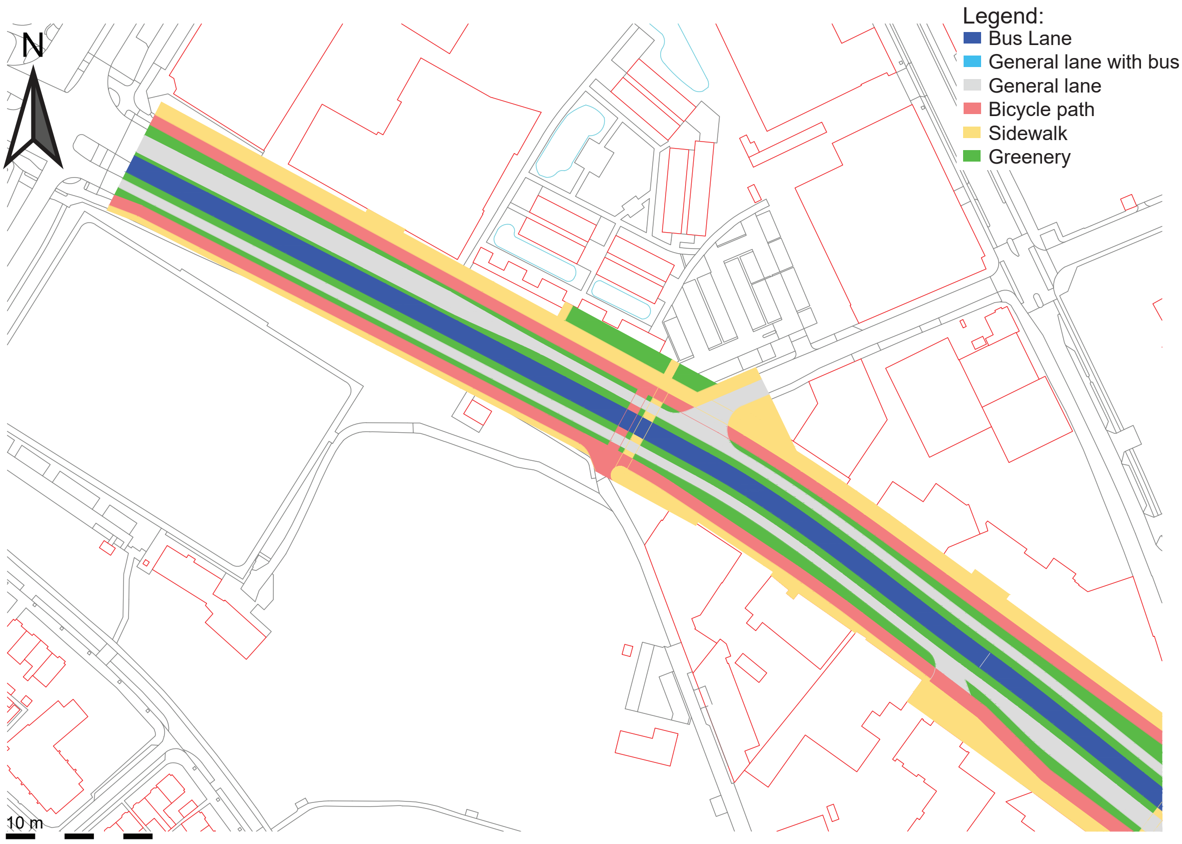


Figure 8.5: Design variant median between the Geldersestraat and the intersection with the Industrieweg

8.1.4. Design variant curb-side: Curb-side bus lanes

Starting point and considerations

Design variant curb-side is based on curb-side bus lanes. This was mentioned earlier in the conclusions of the development of concepts in section 7.1, section 7.2 and section 7.3. The slightly improved cross-section for the Amsterdamseweg that this variant is based on can be seen in Figure 8.6. This cross-section provides the main starting position for the map design that is developed in the development of variants.

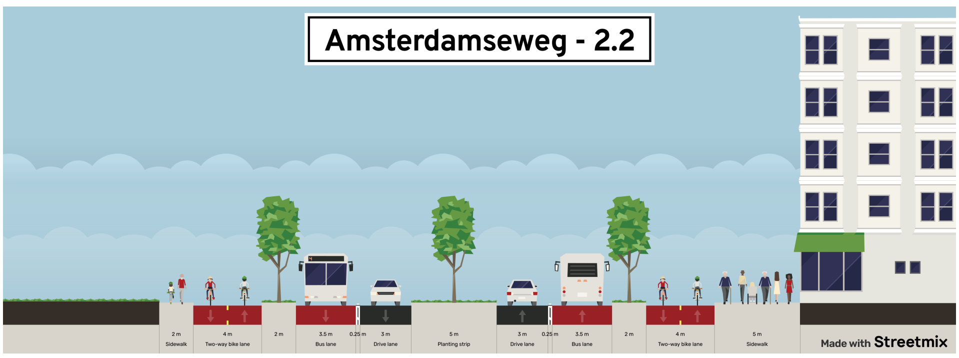


Figure 8.6: Design variant of the Amsterdamseweg on which design variant curb-side for design section Amsterdamseweg is based

For curb-side bus lanes, there are less base designs available then for the median bus lanes. For the street sections the design is therefore based on the examples for curb-side bus lanes in the literature (see Figure 3.2a) and the example from the GDCI in Figure 3.3. For the beginning and end of bus lanes Figure A.3, Figure A.2 and Figure A.4 were used. For the intersections themselves, no base designs were available, but for the bus lanes at intersections Figure A.5 was used as a reference. Finally, for the street crossings and bus stop access routes Figure A.8 and Figure A.9 were used.

As mentioned for the previous design variant, design section Amsterdamseweg is quite wide. This meant that also for this design variant most of the requirements from the municipality could be met quite easily. The only requirement that could not fulfilled is the requirement for bus lanes throughout the entire design. As the curb-side bus lanes enter onto the roundabout at De Nieuwe Poort they have to mix with the general traffic on this roundabout. Everywhere else separated bus lanes are present. Furthermore the requirement for physical buffers between lanes with a different speed limit leads to the design where between the general traffic lane and the curb-side bus lane there is a 0.5 metre wide buffer. This is because the speed limit is 30 km/h for general traffic and 50 km/h for buses. The requirement for this buffer is a legal requirement as there must be a physical separation between two lanes for them to have different speed limits.

The idea was to make the 'Eemplein' bus stop as close to the roundabout as possible, because there it is closest to some primary functions, especially the new city hall and the college.

Most wishes of the municipality are also realised in this design. Bidirectional bicycle paths are realised on both side of the street almost everywhere. The sidewalks are also 5 metres wide almost everywhere. General traffic access through the underpass of the De Nieuwe Poort roundabout is maintained. The buffers between different modes are also often wider than the minimum with more space for greenery. The only wish that was not realised is the creation of a new connection for pedestrians and bicycle traffic on the southern side of the railway underpass. This was done to create more space for buses, which was required to prevent buses from having to yield to other traffic. This is further explained in the walk-through of the design.

Walk-through

For the second of the two design variants, the starting point is that the bus lanes will be located on the curb-side. Again, starting from the Stadsring in the south-east, there is a bus stop. This bus stop has a length of 54 metres, so that it can be used by three buses simultaneously. In the southbound direction, there are three general traffic lanes, each for a different direction at the upcoming intersection. In this design there is only space for a bicycle path and a sidewalk on the northeastern side. This is because of the railway underpass needs more space for general traffic in this design. The buffers are relatively wide and can be used for green space.

Towards the railway underpass the buffers between the different modalities shrink and they become too narrow to be used as green space. As the underpass is entered the general traffic and the active modes diverge in elevation as the general traffic needs a larger clearance under the railway underpass. In the southbound direction, there are two general traffic lanes and in the northbound direction, there is only one. This is also the case in the railway underpass itself. They are designed for 30 km/h.

After the railway underpass, in the northbound direction, the bus lane ends and becomes a shared lane with general traffic. This shared lanes goes up to and connects to the roundabout. The other general traffic lane stays at the lower level and goes into the underpass under the roundabout. In the southbound direction, immediately after the roundabout, where buses share the road with general traffic, the buses go onto their dedicated bus lane. This leaves two general traffic lanes. One coming from the roundabout, and one coming from the roundabout underpass. They then continue under the railway underpass next to each other. This design was chosen because without this extra general traffic lane, the general traffic and buses coming down from the roundabout, would have to yield to the traffic coming from the roundabout underpass. This is an undesirable situation as buses having to yield to general traffic is not a high quality public transport solution. This does however also make it impossible to create a new connection for pedestrians and bicycle traffic on the southern side of the railway underpass.

The sidewalk and bicycle path on the northern side of the street also goes up and connects onto the roundabout and the space surrounding the roundabout.

As mentioned before for design variant median, the roundabout itself was not designed in this thesis.

The design up to this point can be seen in Figure 8.7.

Figure 8.7: Design variant curb-side between the start at the Stadsring and the roundabout at De Nieuwe Poort

After the roundabout, the shared lanes between buses and general traffic come off off the roundabout and have a bus stop immediately. The bus stop, again, is 54 metres long so that it can be used by three buses as the same time. The sidewalks on both sides are 5 metres wide and there is space for a 4 metre wide bidirectional bicycle path on both sides as well. Shortly after the roundabout the bicycle path on the southern side becomes a bicycle street, where eastbound expedition traffic is also allowed. At the end of this street there is a connection to the general traffic lanes for the general traffic from the bicycle street.

After the underpass under the roundabout comes to street level, the general traffic lanes move towards each other. There is a short section where general traffic can weave between these two lanes and then the outer of the two lanes, becomes a dedicated bus lane again. In the northbound direction, the dedicated bus lane only appears shortly before the intersection with the new Brabantsestraat so that the right-turning lane for general traffic can still be reached here.

On the southern side of the street the Friesestraat and the Drentsestraat connect on the bicycle street, but not directly onto the general traffic lane. On the northern side the old Brabantsestraat connects as a bicycle path onto the bicycle path on the northern side. Here there is also a pedestrian crossing across the entire street.

Shortly thereafter the new Brabantsestraat connects to the street through a traffic light regulated intersection. In both directions there is a additional general traffic turning lane towards this intersection. On all sides, there is also a crossing for bicycle traffic and pedestrians. After this intersection further westward, there is the entry point onto the bicycle street for general traffic. West of this point the bicycle street becomes a bicycle path again.

The design up to this point can be seen in Figure 8.8.

Figure 8.8: Design variant curb-side between the roundabout at De Nieuwe Poort and the Geldersestraat

Finally, there is the intersection with the Geldersestraat. For general traffic, this crossing is incomplete. Only the westbound general traffic lane can be entered or exited via the Geldersestraat. Other traffic will have to use the previously discussed intersection with the new Brabantsestraat. There is also a traffic light regulated bicycle and pedestrian crossing here.

Towards the intersection with the Industrieweg, there is an additional turning lane.

The final part of this design can be seen in Figure 8.9.

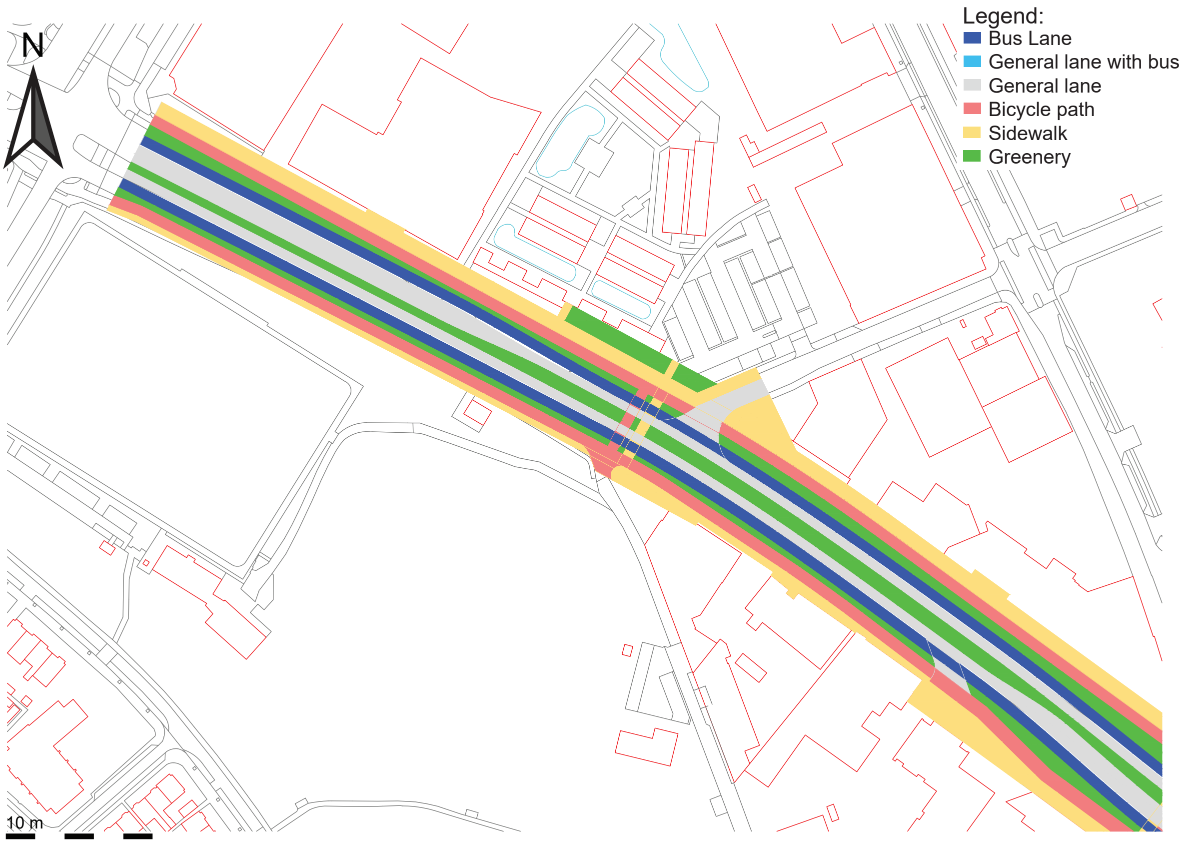


Figure 8.9: Design variant curb-side between the Geldersestraat and the intersection with the Industrieweg

8.2. Design section Industrieweg

The second new design section contains the Industrieweg and the Ringweg Koppel. With these two sections combined the total length is around 550 metres. This section connects the Amsterdamseweg to the Maatweg. There will be one bus stop. This bus stop will be located around the intersection with the Nijverheidsweg-Noord. Its exact location will be decided in the design.

8.2.1. Current situation

Currently the street has 2 general traffic lanes per direction, but because it has a high number of intersections in a short length, quite a lot of turning lanes are needed. This means that on average there approximately 3 general traffic lanes per direction, instead of 2. The street profile is therefore quite dominated by asphalt and there is limited space for pedestrians, bicycle traffic and public greenery. This also makes fitting in dedicated bus lanes quite a challenge as mentioned in section 7.4. On the Koppelbridge, which functions a bottleneck for the width of the street, there are 2 southbound general traffic lanes and 3 northbound general traffic lanes.

There is a minimal sidewalk and a decent bidirectional cycle path on the western side of the street. Between the Amsterdamseweg and the Nijverheidsweg-Noord there is a sidewalk and bicycle path on both sides of the street. Between the Nijverheidsweg-Noord and the Maatweg, these are only present on the western side. All of the sidewalks and bicycle paths are quite narrow.

There is a project from the municipality to build a new pedestrian and bicycle bridge on the eastern side of the Koppelbridge, so that pedestrians and bicycle traffic can cross the river on both sides of the general traffic. This project is out of scope for this thesis.

8.2.2. Requirements and wishes

The requirements from the municipality for design section Industrieweg are as follows:

- 2 general traffic lanes (3.25 m) per direction for 50 km/h
- a bus stop around the intersection with the Nijverheidsweg-Noord
- a unidirectional cycle path (2.7 m) on both sides
- a sidewalk (min 2.0 m) on both side sides
- buffers (min 2.0 m) between active modes and general traffic
- a median buffer (min 2.5 m)
- retaining of the pedestrian/bicycle section of the bridge

The municipality also has the following wishes:

- a bidirectional cycle path (4.0 m) on both sides instead of unidirectional ones
- 1 bus lane (3.5 m per lane or 6.5 m for 2 lanes) per direction for 50 km/h
- wider sidewalks (up to 5.0 m)
- wider buffers with green space

8.2.3. Design variant mostly median: Mostly median bus lanes

Starting point and considerations

Because neither of the designs for the Industrieweg that were developed in section 7.4 were sufficient, a new cross-section was designed to base the development of variants on. This cross-section has a bus lane only in the northbound direction and not in the southbound direction. In the southbound direction the buses share the street with general traffic. It was chosen to create the bus lane in the northbound direction, because in the southbound direction it is easier to make sure that the bus is always at the front of the traffic flow and thus not very limited by other traffic. The cross-section is shown in Figure 8.10.

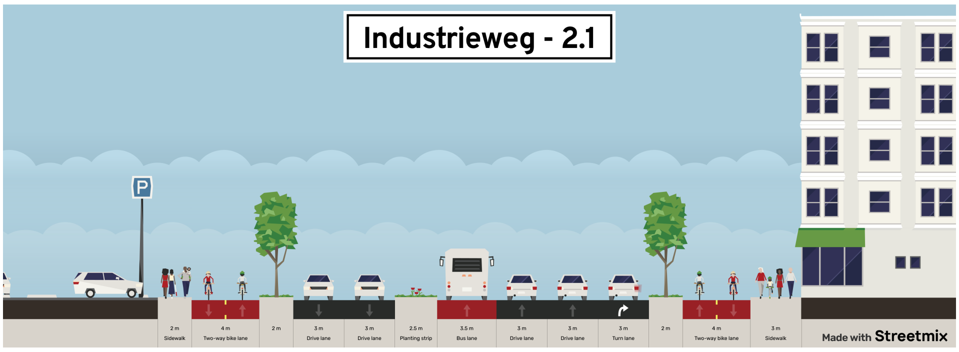


Figure 8.10: The design variant of the Industrieweg on which design variant mostly median for design section Industrieweg is based

The map design was based slightly on the base design from the CROW that design variant mostly median for design section Amsterdamseweg was also based on, but since the bus lane is only present in one direction, the base design was harder to translate to this specific situation. Additionally because the bus lane appears and ends within this section, Figure A.2 and Figure A.4 were also used.

Because design section Industrieweg needs to fit more functions and is often narrower than design section Amsterdamseweg, meeting the requirements for this section was relatively hard. However, because the dedicated bus lanes are no longer a hard requirement, the other requirements were possible to fit. Also the wishes for bicycle traffic could be met. The municipality also stressed that this was important for them, so this wish was given priority for the wish for more green space. It was also possible to create sidewalks somewhat wider than the absolute minimum in quite a few locations.

Walk-through

Starting at the intersection with the Amsterdamseweg, in the northbound direction there is a median bus lane, next to two general traffic lanes. In the southbound direction there are two right turn lanes, one left turning lane and one bus turning lane. The north- and southbound directions are separated by a median. On both sides of the street there is space for a 4 metres wide bicycle path. On the eastern side, there is space for quite a large sidewalk, on the western side it is more minimal.

Towards the north the side of the street moves around somewhat, causing some changes in the location and width of the sidewalks. The number of lanes in the southbound direction reduces to two general traffic lanes, which are also used by the buses.

On the eastern side there is a short expedition road which provides access to the Pon location located here. On the western side there is an incomplete intersection with the Textielweg. This street can only be entered or exited from the southbound direction. Leading up to this intersection there is a short right turning lane. This lane also doubles as a bus stop. The bus stop was placed here because there is not enough space elsewhere in the design section to place a bus stop. This bus stop is only long enough for one bus to use at a time.

Towards the intersection with the Nijverheidsweg-Noord the northbound direction gets a right turning lane. The intersection with the Nijverheidsweg-Noord itself is incomplete. The western part of the Nijverheidsweg-Noord is turned into a one-way street coming onto the intersection. This means that traffic on the Industrieweg cannot enter this western part of the Nijverheidsweg-Noord. This intersection was designed this way to create enough space for a dedicated bus lane. If the intersection was complete, there would need to be extra turning lanes at the cost of the dedicated bus lane.

North of the intersection, there is a bus stop in the northbound direction. This bus stop is located in the median and there is sufficient space for it. It can therefore be 54 metres long again and thus serve three buses simultaneously. In the southbound direction, there is a left turning lane, to reach the eastern section of the Nijverheidsweg-Noord.

The design up to this point can be seen in Figure 8.11.

Figure 8.11: Design variant mostly median between the intersection with the Amsterdamseweg and the Koppelbridge

On the bridge, the northbound dedicated bus lane also disappears to facilitate three general traffic lanes, one of which is a left turning lane. The northbound buses can continue directly from their dedicated bus lane onto the general traffic left turning lane. In the southbound direction there are two general traffic lanes, which are also used by the buses.

After the intersection with the Maatweg, it is assumed the Maatweg has a similar design as the Industrieweg with dedicated median bus lanes. In the southbound direction there is only one general traffic right turning lane. This is done so that the leftmost lane on the bridge effectively becomes a bus lane. All general traffic will go onto the rightmost lane on the bridge and the buses thus get free access to the rightmost lane.

The final part of this design be seen in Figure 8.12.

Figure 8.12: Design variant mostly median between the Textielweg and the Maatweg

8.2.4. Design variant mostly curb-side: Mostly curb-side bus lanes

Starting point and considerations

For design variant mostly curb-side the starting point was creating curb-side bus lanes wherever possible. Similarly to design variant mostly median it was chosen to facilitate a dedicated bus lane in the northbound direction, because this bus lane was seen as more important than the southbound direction (see subsection 8.2.3). In the southbound direction the buses thus share the lanes with general traffic. The cross-section is shown in Figure 8.13.

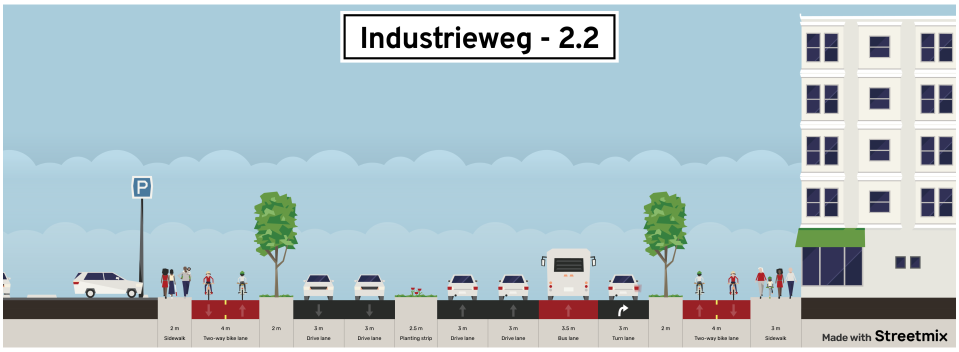


Figure 8.13: The design variant of the Industrieweg on which design variant mostly curb-side for design section Industrieweg is based

The map design for the mostly curb-side bus lanes was on the same base designs as the curb-side bus lanes for the first section.

Because the removal of the bus lanes as hard requirements for this design section, all the requirement were able to be met. As for design variant mostly median, also in design variant mostly curb-side the wishes for bicycle traffic could be met. Similarly it was also possible to create sidewalks somewhat wider than the absolute minimum in quite a few locations. There was not much space for additional green buffers.

Walk-through

Starting at the intersection with the Amsterdamseweg, in the northbound direction there is a curb-side bus lane, next to two general traffic lanes. In the southbound direction there are two right turn lanes, one bus turning lane and one left turn lane. The north- and southbound directions are separated by a median. On both sides of the street there is space for a 4 metres wide bicycle path. On the eastern side, there is space for quite a large sidewalk, on the western side it is more minimal.

Towards the north the side of the street moves around somewhat, causing some changes in the location and width of the sidewalks. The number of lanes in the southbound direction reduces to two general traffic lanes, which are also used by the buses.

On the eastern side there is a short expedition road which provides access to the Pon location located here. On the western side there is an incomplete intersection with the Textielweg. This street can only be entered or exited from the southbound direction. Leading up to this intersection there is a short right turning lane. This lane also doubles as a bus stop. The bus stop was placed here because there is not enough space elsewhere in the design section to place a bus stop. This bus stop is only long enough for one bus to use at a time.

Towards the intersection with the Nijverheidsweg-Noord the northbound direction gets a right turning lane. The intersection with the Nijverheidsweg-Noord itself is incomplete. The western part of the Nijverheidsweg-Noord is turned into a one-way street coming onto the intersection. This means that traffic on the Industrieweg cannot enter this western part of the Nijverheidsweg-Noord. This intersection was designed this way to create enough space for a dedicated bus lane. If the intersection was complete, there would need to be extra turning lanes at the cost of the dedicated bus lane.

North of the intersection, there is a bus stop in the Northern direction. For this bus stop there is sufficient space. It can therefore be 54 metres long again and thus serve three buses simultaneously. In the southbound direction, there is a left turning lane, to reach the eastern section of the Nijverheidsweg-Noord.

The design up to this point can be seen in Figure 8.11.

Figure 8.14: Design variant mostly curb-side between the intersection with the Amsterdamseweg and the Koppelbridge

On the bridge, the northbound dedicated bus lane also disappears to facilitate three general traffic lanes, one of which is a left turning lane. The northbound buses thus must also merge across form the rightmost lane to the leftmost lane to turn left with the general traffic. In the southbound direction there are two general traffic lanes, which are also used by the buses.

After the intersection with the Maatweg, it is assumed the Maatweg has a similar design as the Industrieweg with dedicated curb-side bus lanes. In the southbound direction there is only one general traffic right turning lane. This is done so that the rightmost lane on the bridge effectively becomes a bus lane. All general traffic will go onto the leftmost lane on the bridge and the buses thus get free access to the rightmost lane.

The final part of this design be seen in Figure 8.15.

Figure 8.15: Design variant mostly curb-side between the Textielweg and the Maatweg

9 Evaluation of variants

After the final alternatives have been established in the development of the variants, they needed to be evaluated. The framework of evaluation was established and explained in subsection 6.2.4. For each evaluation criterium a design variant can score on a scale with five grades. The highest is 'excellent' or '++'. The worst is 'very poor' or '- -'. In between the options 'good' ('+'), 'medium' ('+/-') and 'poor' ('-') are also available.

The evaluation of the variants is discussed following the categories of evaluation criteria: traffic performance, passenger accessibility and urban integration and liveability.

9.1. Traffic Performance

The traffic model was made for the entire design area and not the separate design sections. This was done because this would be less time consuming and because it would provide a better picture of the area functioning as a whole system. This decision does mean that not all design variants can be properly assessed using the model. Therefore a decision had to be made on how to connect the design sections. For the first model, design variant (mostly) median from both design sections was taken together. For the second model, design variant (mostly) curb-side was taken from both design sections. The road networks in the Paramics microsimulation software were copied from the design variants that were developed in chapter 8.

For all of the vehicles that is simulated during a run of the model, the vehicle type as well as the total time spent within the network is recorded and saved. This dataset forms the result of a run of the model. For all vehicles types the average travel time in the network was calculated, as well as the standard deviation of the travel time for buses. These results are shown in Table 9.1.

Table 9.1: Traffic performance of the design variants for design section Amsterdamseweg, times are in seconds

Demand	100%		75%		50%	
Design variant	1	2	1	2	1	2
Average trip time of the bus [s]	389	508	303	368	242	256
Standard deviation of the bus trip time [s]	204	326	136	201	55	53
Average travel time for general traffic [s]	1830	1547	964	808	280	247
Average travel time for bicycle traffic [s]	298	325	288	295	254	270

As can be seen from the difference in travel time for general traffic and the trip time for buses, the traffic intensities that are predicted for 2035 caused a heavily congested situation. This is problematic for using the model as assessment, as neither of the design variants would be approved with this level of predicted congestion. This means that the traffic model cannot be used to prove that the design variants will provide a viable solution for the traffic volumes that are predicted for 2035. However, since the model does show significant and consistent differences between the two design variants, the model can be used to compare the two design variants. The traffic model will thus only be used to compare the two design variants, not to validate either of the two variants.

Because the runs with 100% of the predicted demand showed such high level of congestions, the model was rerun with lowered demand for general traffic and bicycle traffic. This was done to ensure that the differences between the two design variants were not anomalies due to the high congestion. The bus demand was not changed. As expected, the difference in travel time for buses and general traffic reduced for both design variants, suggesting lower congestion. However at 75% of the predicted demand, congestion was still a large issue and travel times are very high for general traffic. The demand was further reduced to 50% of the predicted demand. In this scenario both design variants showed comparable values for the bus trip time and the general traffic travel time, indicating no detrimental congestion in this scenario. The differences between the two design variants remained throughout all demand scenarios, indicating that the model can indeed be used to compare the two design variants.

Trip time for buses

The trip time for buses varies between the design variants and demand scenarios. In all three demand scenarios the design variant with (mostly) median bus lanes has a lower bus trip time than design variant with (mostly) curb-side bus lanes (see Table 9.1). The difference is most pronounced when the traffic volumes are highest and becomes smaller as the traffic volumes lower. This is an expected result. The design with median bus lanes has more dedicated bus infrastructure than the design with curb-side bus lanes. The design with median bus lanes thus encounters less congestion as it uses the general traffic lanes for less distance. The advantage that this provides is larger when the congestion on the general traffic lanes is larger.

It was decided to look primarily at the 50% demand scenario to compare the two design variants as this scenario is the closest to a scenario in which the design variants will actually be implemented. In this scenario design variant (mostly) median performs better than design variant (mostly) curb-side. Especially when the bus trip times are compared to the general traffic travel times. Design variant (mostly) median has a lower bus trip time than a general traffic travel time, while for design variant (mostly) curb-side the bus trip time is slightly higher than the general traffic travel time. However neither of the design variants is scored highly because they do cause significant delays under the higher demand scenarios. It was therefore decided to score design variant (mostly) median as 'medium' and design variant (mostly) curb-side as 'poor' (see Table 9.2).

Reliability of the bus service

The reliability of the bus service follows a similar pattern to the trip time for buses. Under the higher demand scenarios the variability of the bus trip time was higher and the bus service thus less reliable. For the congested demand scenarios with 100% and 75% of the demand, the design variant (mostly) median showed a lower variability than design variant (mostly) curb-side. Interestingly this difference was completely gone for the 50% demand scenario. This indicates that in an uncongested situation the variability in bus trip time is consistent over the two different design variants. It must be noted that even in this scenario the standard deviation in bus trip time is still quite high at around 20% of the average travel time. There is no clear indicator as to why this is the case. It is possible that some congestion does occur at certain moments during the run, which is not seen back clearly in the average trip times, but does show up in the standard deviation of the trip time.

Because the reliability of the bus service is a factor that is especially important in a congested situation, it was decided to take the results from the 100% and 75% demand scenarios into account. This means that design variant (mostly) median is scored better than design variant (mostly) curb-side, because it has a lower variability in the bus trip time. However the variability of the bus trip time remains quite high for both design variants (20% - 60% of the total trip time). Neither of them can therefore be scored positively. Design variant (mostly) median is thus scored as 'poor' and design variant (mostly) curb-side as 'very poor' (see Table 9.2).

Travel time for general traffic

The travel time for general traffic shows the most extreme differences between the different demand scenarios. It is more than six times higher in the 100% demand scenario than in the 50% demand scenario for both design variants (see Table 9.1). This indicates very high congestion on the general traffic lanes in the 100% demand scenario for both design variants. Next to the high level of congestion the travel time for general traffic shows an opposite pattern to the trip time for buses between the two design variants. Across all three demand scenarios design variant (mostly) curb-side had lower travel time for general traffic than design variant (mostly) median. This can be explained by the fact that in design variant (mostly) curb-side the underpass under the shared traffic roundabout at De Nieuwe Poort can be used by general traffic, whereas in design variant (mostly) median it is reserved for buses. This gives more road capacity to general traffic in design variant (mostly) curb-side, leading to lower travel times. As expected, the difference in general traffic travel time between the two design variants decreases as the demand decreases, because there is less congestion to highlight the differences between the two design variants.

Because of the high values for general traffic travel time in the 100% and 75% demand scenarios, both design variants have to be scored negatively. It is not conceivable that the found travel time will be accepted. Design variant (mostly) curb-side is rated higher than design variant (mostly) median, because it consistently had lower travel times for general traffic. Design variant (mostly) median is thus scored as 'very poor' and design variant (mostly) curb-side is scored as 'poor' (see Table 9.2).

Travel time for bicycle traffic

Out of the three modes, the travel time for bicycle traffic was most comparable over all three different demand scenarios. The congestion in general traffic does still influence the bicycle traffic as the higher the demand, the higher the bicycle traffic travel time (see Table 9.1). However, when compared to the general traffic travel time or bus trip time, the influence on the bicycle traffic travel time remains limited. This can be explained by the fact that the bicycle infrastructure is completely separated from the infrastructure for general traffic and buses. This means that bicycle traffic is not influenced by any congestion experienced by the general traffic. The small increases in bicycle traffic travel time as the demand increases can be explained by the fact that when there is more general traffic, it needs more green time at traffic signals. This means there is a smaller percentage of time available for bicycle traffic, however it will always get its minimum green time each cycle. Thus it is impossible for the bicycle traffic travel time to spiral out of control (see Appendix D for more explanation on the traffic lights).

Because the travel time for bicycle traffic is not very sensitive to the demand, the design variants score better for bicycle traffic than for the other modes. Both design variants give reasonable travel times for bicycle traffic in all demand scenarios. The small difference in travel time between the two design variants is consistently in favour of design variant (mostly) median. Design variant (mostly) median is therefore rated higher than design variant (mostly) curb-side. Design variant (mostly) median is scored as 'good' and design variant (mostly) curb-side is scored as 'medium' (see Table 9.2).

Table 9.2: Traffic performance of the design variants for both design sections

Design variant	(Mostly) median	(Mostly) curb-side
Trip time for buses	+/-	-
Reliability of the bus service	-	- -
Travel time for general traffic	- -	-
Travel time for bicycle traffic	+	+/-

9.2. Passenger accessibility

The evaluation criteria for the passenger accessibility are not related to the functioning of the entire design area. Therefore they could be applied independently for each design section.

9.2.1. Design section Amsterdamseweg

Stop locations

The bus stop ’Stadhuis’ directly at the Stadsring is in the same location in both design variants and thus does not have a difference in the number of inhabitants that live within 400 metres of walking distance of it. It currently has 2735 inhabitants within 400 metres of walking distance. All of these live in current housing and none of the new housing in the LES-area is within 400 metres of the bus stop, so it will not reach any new inhabitants. The second bus stop ’Eemplein’ between De Nieuwe Poort and the new Brabantsestraat has a different location in the two design variants. The location in design variant median is around 100 metres more westward than the location in design variant curb-side. The stop in design variant median reaches 7065 inhabitants within 100 metres walking distance, of which 1630 in existing housing and 5435 in the LES-area. The stop in design variant curb-side reaches 6287 inhabitants of which 2205 in existing housing and 4082 in the LES-area. Because the ’Eemplein’ stop reaches such a high number of inhabitants in both design variants, both design variants are rated highly. Because design variant median reaches more inhabitants than design variant curb-side, design variant median is rated ’excellent’ and design variant curb-side is rated ’good’ (see Table 9.3).

Stop quality

In design section Amsterdamseweg there are two bus stops. The quality of these stop does not differ much between the two design variants. Design variant median has a total area of 316 m^2 for the ’Stadhuis’ stop and 340 m^2 for the ’Eemplein’ stop. Design variant curb-side has slightly bigger stops with 343 m^2 for the ’Stadhuis’ stop and 362 for the ’Eemplein stop’. All of the stops in both design variants are long enough to facilitate three buses stopping simultaneously. Both design variants can thus be rated positively. Because of the slightly higher stop area, design variant curb-side scores ’excellent’, whereas design variant median scores ’good’ (see Table 9.3).

Stop access routes

For the bus stop ’Stadhuis’ directly at the Stadsring the access route to the stop is the same in both design variants. The stop can be reached from both sides of the street with the same traffic light regulated crossing. This crossing is part of the larger intersection between the Stadsring, Van Asch van Wijckstraat and the Molenstraat. This crossing can be rated A using the rating guidelines from the CROW (2019) (see Appendix E). So there is no difference between the two design variants for the accessibility of this stop.

For the bus stop ’Eemplein’ between De Nieuwe Poort and the new Brabantsestraat, there is a difference. The stop in design variant median can be reached from both sides of the street using unregulated crossings at both ends of the bus platform. In design variant curb-side the stop can only be reached using an unregulated crossing at the east side of the bus platforms. All unregulated crossings in both design variants can be rated A using the previously mentioned guidelines from the CROW (see Appendix E).

Because all access routes in both design variants to the bus stops have a grading of A both design variants can be rated positively. Because the stop ’Eemplein’ has more access routes in design variant median, it is rated higher than design variant curb-side. Design variant median is rated ’excellent’. Design variant curb-side is rated ’good’ (see Table 9.3).

BRT appearance

The public transport specialists from the municipality thought that design variant median has a higher BRT appearance that design variant curb-side. They argued that location of the bus lanes in the middle of the street is reminiscent of bigger Dutch cities, especially those with tram networks, where tram tracks are located in the middle of the street. This design signifies a higher priority fort the bus than for general traffic. The location in the middle of the street also is more logical as the middle of the street has the highest speed limit and the speed limit is reduced outwards. Another advantage of the median bus lanes over the curb-side bus lanes, is that it is much harder for road users to temporarily park on the bus lane and block the bus traffic. Finally they did note that design variant curb-side does provide more flexibility in case of road works, but they did not think this outweighed the other benefits of design variant median. They graded design variant median as ’excellent’ and design variant curb-side as ’medium’ (see Table 9.3).

Table 9.3: Passenger accessibility of the design variants for design section Amsterdamseweg

Design variant	Median	Curb-side
Stop locations	++	+
Stop quality	+	++
Stop access routes	++	+
BRT appearance	++	+/-

9.2.2. Design section Industrieweg

Stop locations

Because of the limited space in design section Industrieweg, the bus stop is located in the same location in both design variants. Therefore both variants are rated the same. The stop reaches 4069 inhabitants within 400 metres of walking distance. Of these only 10 live in current housing and the remaining 4059 will live in the LES-area. This stresses the importance of this stop for the development. Both design variants are rated 'medium' (see Table 9.4), because they reach significantly less inhabitants than the 'Eemplein' stop in design section Amsterdamseweg.

Stop quality

For design section Industrieweg both design variants have a total stop area of 226 m^2. This area is used by 1 bus stop, with platforms in two directions. Both variants score the same as the total area is the same in both design variants. They score 'medium' (see Table 9.4), because the quality of the stops in both directions is quite different. The stop in the northern direction is quite wide and long enough for three buses to use the stop simultaneously. However the stop in the southern direction is only the minimum width and too short for even two buses to use the stop simultaneously.

Stop access routes

There is only one bus stop in the design section Industrieweg. In both design variants the two bus platforms are located quite far away from each other because there is very limited space available to place them closer together. In both design variants the northbound bus platform can be accessed by one traffic light regulated street crossing. This crossing can be graded B. Also in both design variants the southbound bus platform does not have any street crossing close to it. The other side of the street must be reached using an intersection a bit further along. This might lead to detours when accessing the stop. Since the accessibility of the stop is the same in both design variants and both have limited accessibility to the southbound bus platform, both are rated 'poor' in terms of stop access routes (see Table 9.4).

BRT appearance

The public transport specialists from the municipality immediately noted that both of these design variants have significantly less BRT appearance than the design variants for design section Amsterdamseweg. They thought that in design variant mostly median having the one dedicated bus lane in the middle feels quite forced. They saw the design variant with the curb-side bus lane as more practical in daily use. This variant does have the disadvantage that it comes with quite a tight turn from design section Amsterdamseweg onto the design section Industrieweg (although this turn can be somewhat optimised from the current design). This does not signify high quality public transport. In conclusion, they had a slight preference for design variant mostly curb-side, although they mainly thought that neither of these design variants have a real BRT appearance. They rated design variant mostly median as 'very poor' and design variant mostly curb-side as 'poor' (see Table 9.4).

Table 9.4: Passenger accessibility of the design variants for design section Industrieweg

Design variant	Mostly median	Mostly curb-side
Stop locations	+/-	+/-
Stop quality	+/-	+/-
Stop access routes	-	-
BRT appearance	-	- -

9.3. Urban integration and liveability

Similar to the evaluation criteria for passenger accessibility, the evaluation criteria for urban integration and liveability are not related to the functioning of the entire design area. Therefore they could also be applied independently for both design sections.

9.3.1. Design section Amsterdamseweg

Road safety

The number of conflict points in the two design variants is almost the same. The bigger intersections around the new Brabantsestraat and the Geldersestraat give both design variants a total of 12 signalised conflict points at 50 km/h and 22 signalised conflict points at 30 km/h. The difference between the two design variants lies in the number of non-signalised conflict points. In design variant median there are 4 of these at 50 km/h and 20 at 30 km/h. In design variant curb-side there are none of these at 50 km/h and 19 at 30 km/h. Design variant curb-side has less of these conflict points because this variant has one less street crossing. In terms of road safety both design variants score quite well because of their limited conflict points at 50 km/h. They could therefore both be graded positively. Design variant curb-side scores 'excellent' (see Table 9.5), because there are no non-signalised conflict points at 50 km/h. Design variant median scores 'good' (see Table 9.5), because it does have a few non-signalised conflict points at 50 km/h.

Space for pedestrians and bicycle traffic

There is a significant difference in the amount of space for pedestrians and bicycle traffic between the two variants. This is mainly due to the fact that design variant median has a second connection for pedestrians and bicycle traffic on the southern side of the railway underpass. Design variant curb-side does not include this new connection, which reduces the amount of space for pedestrians and bicycle traffic. Design variant median has 9332 m^2 in total that is dedicated to pedestrians and 8034 m^2 that is dedicated to bicycle traffic. For design variant curb-side these values are 8687 m^2 and 7352 m^2 respectively. The total area of the design section is 45161 m^2. Design variant median thus has 20.7% of the total area for pedestrians and 17.8% for bicycle traffic. Design variant curb-side has 19.2% for pedestrians and 16.3% for bicycle traffic. These percentages are quite high so both design variants are scored positively. Because design variant median has higher percentages it is scored higher than design variant curb-side. Design variant median scores 'excellent', while design variant curb-side scores 'good' (see Table 9.5).

Road cross-ability

The two design variants have almost the same number of street crossings. Design variant median has nine, while the design variant curb-side has eight. This difference is found in the street crossings around the bus stop 'Eemplein'. There is one more crossing here in design variant median than in design variant curb-side. The other eight crossings are the same in both design variants. Five of these are traffic light regulated and all can be graded A. The other three/four crossings are unregulated and can also all be graded A. The number of crossings is quite high in both design variants, however because over half of the crossings are traffic light regulated neither of the design variants can be graded 'excellent' for street cross-ability. Because of the additional crossing, design variant median is rated 'good', while design variant curb-side is graded 'medium' (see Table 9.5).

Neighbourhood integration

The LES development specialists from the municipality thought that design variant median shows a higher neighbourhood integration than design variant curb-side. Their main argument for this is that with the bus lanes in the middle of the street, there are real choices being made and the priorities in the street design become apparent. Design variant curb-side with the curb-side bus lanes feels more like a compromise between different wishes. They argue that having the bus lanes in the middle of the street gives a better structuring effect to the street, where it is clear that the buses have the highest priority for high traffic flow as they are located furthest from the sidewalks with a dwelling function. This structure also appears in the clarity when crossing the street. Since the buses have the highest maximum speed, having them in the middle makes crossing the street the clearest and safest. Finally they noted that the design with curb-side bus lanes does provide wider buffers between the general traffic and bicycle traffic, which is especially useful as a queueing area for bicycle traffic at street crossings. However, this does not weigh strong enough against the other factors, to make them prefer this design. They graded design variant median as 'excellent' and design variant curb-side as 'medium' (see Table 9.5).

Public green space

The total area dedicated to public green space is 8740 m^2 in design variant median and 8225 m^2 in design variant curb-side. This represents 19.4% and 18.2% of the total design area respectively. The difference is likely due to the fact that in design variant median the bus lanes can be slightly narrower as they are next to each other. Also design variant curb-side requires and extra buffer between the bus and general traffic lanes because of their different speed limits. These two factors mean that the general traffic takes up more space in design variant curb-side. This results in less space remaining for greenery. Since both design variants have a high percentage of public green space they can both be scored positively. Because of the higher percentage design variant median is scored better than design variant curb-side. Design variant median is graded 'excellent' and design variant curb-side is graded 'good' (see Table 9.5).

Long-term robustness

Design variant median scores 'excellent' on the long-term robustness (see Table 9.5). The design is almost fully in line with the design guidelines established in subsection 3.6.1. Only at the intersection between the Amsterdamseweg and the Industrieweg the curve radius of the turn is not up to BRT standards. However, the curve radius is still as wide as it can be for this location so this is not a very significant downside.

Design variant curb-side scores 'medium' on the long-term robustness (see Table 9.5). The design does feature separated bus lanes for the most part, but still shares a section with general traffic and this is also across a roundabout, which does not allow for BRT standard curve radii. The bus lanes are also not located in the best location according to the design guidelines in subsection 3.6.1. If the municipality decides to adopt this design and want to further improve it in the future this would require a second large reconstruction of the road to put the bus lanes in the middle of the street. This makes the design not very robust for the long term.

Table 9.5: Urban integration and liveability of the design variants for design section Amsterdamseweg

Design variant	**Median**	**Curb-side**
Road safety	+	++
Space for pedestrians and bicycle traffic	++	+
Road cross-ability	+	+/-
Neighbourhood integration	++	+/-
Public green space	++	+
Long-term robustness	++	+/-

9.3.2. Design section Industrieweg

Road safety

For design section Industrieweg, this number of conflict points is exactly the same for both design variants. In both design variants there are; 0 non-signalised conflict points at 50 km/h, 4 non-signalised conflict points at 30 km/h, 46 signalised conflict points at 50 km/h and 12 signalised conflict points at 30 km/h. Because of the high number of signalised conflict points at 50 km/h, both design variants score a 'medium' for road safety (see Table 9.6).

Space for pedestrians and bicycle traffic

Because the two design variants don't differ much outside of the location of the lanes for general traffic the amount of space dedicated to pedestrians and bicycle traffic does not significantly differ between the two design variants. Design variant mostly median has 3104 m^2 for pedestrians and 3951 m^2 for bicycle traffic. Design variant mostly curb-side has 3138 m^2 for pedestrians and 3966 m^2 for bicycle traffic. The total area of the design section is 25070 m^2, which means that the design variants have 12.4% and 12.5% of the total area dedicated to pedestrians respectively. Both design variants have 15.8% of the total area dedicated to bicycle traffic. Because the percentages are so similar, both design variants are graded the same. The percentages are quite a bit lower than those for design section Amsterdamseweg, especially those for the pedestrians. Therefore these design variants score 'medium' in terms of space for pedestrians and bicycle traffic (see Table 9.6).

Road cross-ability

The two design variants both have the same number and quality of street crossings in design section Industrieweg. Both can be crossed using a total of five crossing spread out over three intersections. All three of these intersections are traffic light regulated. Using the evaluation criteria from the CROW (see Appendix E) all of the crossings at these intersections can be graded B in both design variants. Because all the street crossings are confined to intersections and the quality of the crossings is B, the road cross-ability is not considered adequate for a highly urbanised area. Both design variants are thus graded as 'poor' (see Table 9.6).

Neighbourhood integration

For design section Industrieweg, the LES development specialists from the municipality had no specific preference for either of the two design variants. They had two main reasons for this choice. The first reason is that the design variants are quite similar in their appearance. This is due to the fact that compromises had to be made in this design section, which left limited space for dedicated bus lanes. Therefore the bus lanes are unable to truly define the look and feel of the street. Therefore the look and feel of both design variants is similar. There is no meaningful differences in the neighbourhood integration between the two design variants. The second reason is that this street is simply less important for the LES-area, than the street in design section Amsterdamseweg. This street is further away from both the core of the development and the city centre. Its integration into the development is thus also less important than for design section Amsterdamseweg, making the already minor differences between the two design variants also less relevant. Due to the high number of general traffic lanes in both design variants they rated both design variants as 'poor' (see Table 9.6).

Public green space

As stated in the section about space for pedestrians and bicycle traffic, the two design variants do not differ much from each other apart from the location of the lanes for general traffic. This means that the difference of space that can be used for greenery does not differ much between the two design variants either. Design variant mostly median has 4740 m^2 dedicated to greenery and design variant mostly curb-side has 4795 m^2. This represents 18.9% and 19.1% of the total design section respectively. These percentages are relatively high when compared to the space dedicated to pedestrians and bicycle traffic so both design variants score well in this metric. Since the percentages are so close to each other, this metric cannot be used to differentiate between the two design variants and both design variants are graded 'good' (see Table 9.6).

Long-term robustness

Design variant mostly median scores 'medium' for the long term robustness (see Table 9.6). This is because the northbound bus lane is completely in line with the guidelines from subsection 3.6.1. The southbound section is not, because it does not feature a dedicated bus lane. However due to the fact that the northbound section is in line with the guidelines a possible improvement of the system in the future would only require a reconstruction in the southbound direction, making this design somewhat robust for the long-term.

For design variant mostly curb-side, the northbound direction does follow some of the guidelines from subsection 3.6.1, but the design with the bus lane at the curb-side is not preferred. Also the southbound section does not have a dedicated bus lane. This means that if the design is even upgraded both directions need to be constructed to get middle bus lanes. Therefore the long-term robustness of this design is scored ’poor’ (see Table 9.6).

Table 9.6: Urban integration and liveability of the design variants for design section Amsterdamseweg

Design variant	Mostly median	Mostly curb-side
Road safety	+/-	+/-
Space for pedestrians and bicycle traffic	+/-	+/-
Road cross-ability	-	-
Neighbourhood integration	-	-
Public green space	+	+
Long-term robustness	+/-	-

9.4. Conclusion and integration

For each design section both design variants have been evaluated. Based on this evaluation the preferred design variant can be chosen for each design section. The chosen design variants can the be integrated and connected to create the final design for the entire design area.

9.4.1. Conclusion

For design section Amsterdamseweg the choice for the preferred variant seems quite clear. As can be seen in Table 9.7 design variant median scores better than design variant curb-side in 11 out of 14 evaluation criteria. The only criteria where design variant curb-side scores better are; ’travel time for general traffic’, ’stop quality’ and ’road safety’. For ’travel time for general traffic’ the difference was significant and design variant curb-side is a better design for this criterium. However as this criterium concerns general traffic is it not the primary focus of this project. For the criterium ’stop quality’ the difference between the two design variants was small and both design variants were well beyond the minimum requirements for a high quality bus stop. For ’road safety’ the difference was significant, design variant curb-side has less conflict points at 50 km/h, which makes it a safer design. Together the score on these three criteria give a clear view of the downsides of design variant median. However the combined weight of these three criteria and their scores is not enough to tip the balance in favour of design variant curb-side. Therefore it was concluded that design variant median is the preferred design variant for design section Amsterdamseweg. Design variant median will thus be included in the final design for the entire design area.

For design section Industrieweg the choice is less clear at first glance. For 8 out of 14 evaluation criteria both design variants score equal (see Table 9.7). However in 5 out of 14 evaluation criteria design variant mostly median scores higher than design variant mostly curb-side. This leaves only the criterium ’travel time for general traffic’ for which design variant mostly curb-side scores better than design variant mostly median. The difference between the two design variants for this criterium was significant. However as this criterium concerns general traffic is it not the primary focus of this project. Therefore this criterium alone is not enough to shift the favour to design variant mostly curb-side. It was thus concluded that design variant mostly median is the preferred design variant for design section Industrieweg. Design variant mostly median will therefore be included in the final design for the entire design area.

Table 9.7: The evaluation methods for each criteria

Design section	**Amsterdamseweg**		**Industrieweg**	
Design variant	**Median**	**Curb-side**	**Mostly median**	**Mostly curb-side**
Traffic performance				
Trip time for buses	+/-	-	+/-	-
Reliability of the bus service	-	- -	-	- -
Travel time for general traffic	- -	-	- -	-
Travel time for bicycle traffic	+	+/-	+	+/-
Passenger accessibility				
Stop locations	++	+	+/-	+/-
Stop quality	+	++	+/-	+/-
Stop access routes	++	+	-	-
BRT appearance	++	+/-	-	- -
Urban integration and liveability				
Road safety	+	++	+/-	+/-
Space for pedestrians and bicycle traffic	++	+	+/-	+/-
Road cross-ability	+	+/-	-	-
Neighbourhood integration	++	+/-	-	-
Public green space	++	+	+	+
Long-term robustness	++	+/-	+/-	-

9.4.2. Integration of the final design

The integration into a final design of the is relatively straightforward. Since the design sections were considered separately from each other the designs for each section do not influence each other beyond the intersection where the two design sections meet. This intersection is the intersection between the Amsterdamseweg and the Industrieweg. A design for this intersection has not been made in chapter 8. It is thus the only missing piece for the final design. To develop the intersection the starting position was the requirement to fit onto the designs for the design sections. The base designs Figure A.5 and Figure A.18 from the CROW (2020, 2022b) were used as examples for an intersection with high quality public transport.

For the final design the roundabout at 'De Nieuwe Poort' was also included. The design of the roundabout was not part of this project, because there is an ongoing project within the municipality to redesign this roundabout. The design for the roundabout that was included in the final design, is the current preferred design in this project within the municipality. It is not yet the definitive design for the roundabout.

Finally at the southern end of the design area at the bus stop 'Stadsring', a street crossing was also included in the final design. In earlier stages this crossing was not included, because it is part of the larger intersection between the Stadsring, Van Asch van Wijckstraat and Molenstraat. This intersection is out of scope for this project. The street crossing was included to show that the bus stop at the Stadsring will be accessible from the sidewalks on both sides of the street.

9.5. The final design

The final design is given in Figure 9.1 and in Appendix F, which is available as a separate document. As the design section is relatively large, it is hard to get a clear overview of the biggest design decision from the total overview. Therefore the design is explained in sections. First general design decisions that are visible throughout the entire design area are discussed. Afterwards detailed images from specific locations along the design area are show and the design choices that are visible in that image are discussed. are discussed from south to north. This is the route that a bus would take coming from the central station and going towards the northern neighbourhoods of Amersfoort.

The most defining design choice that is visible throughout the entire design area is the choice for median bus lanes. Where space was available for dedicated bus lanes they were placed in the median. This option was found to be the preferred option in both design sections. This is in line with the results from the literature study, where median bus lanes were also found to be the preferred option for BRT systems (see section 3.6).

Another design choice that is visible throughout the whole design is the amount of space dedicated to bicycle traffic and pedestrians. Overall the quality of the infrastructure for active modes is high. This design choice can be attributed to the design requirements posed by the municipality (see section 5.2). Active modes are important for the municipality and are therefore prioritised in redesign projects. This is clearly visible in the final design.

Finally the amount of green space that was included in the final design is increased compared to the current situation. This was possible because the municipality has decided to widen the longest streets in the design area (i.e. the Amsterdamseweg and the Industrieweg) as part of the redevelopment of the LES-area (see section 7.3 and section 7.4). This added space gives the possibility to also include greenery in the street profile and not just traffic functions.

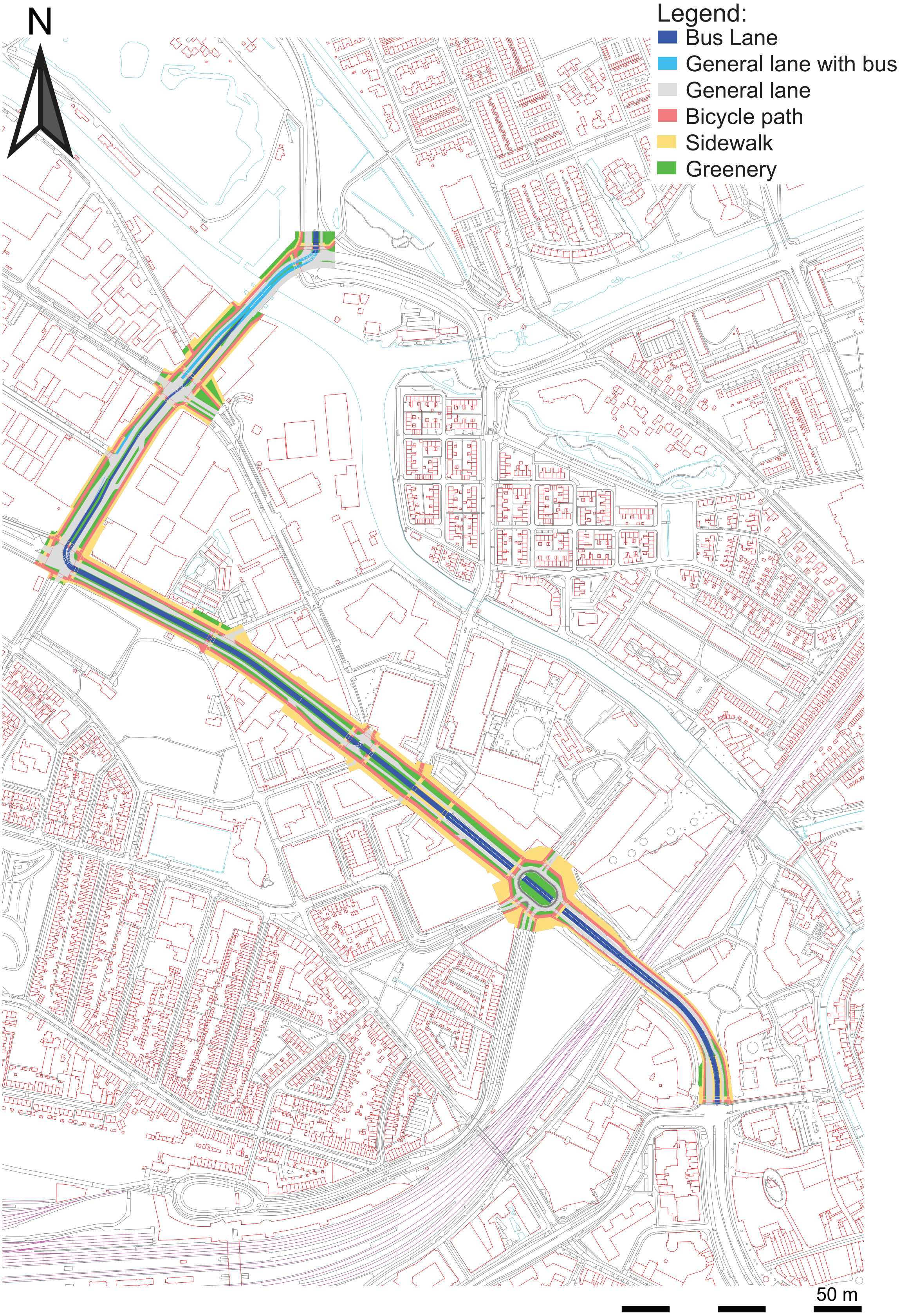


Figure 9.1: Final design

The first detail (see Figure 9.2) is right at the southern end of the design area. Here the design area connects to the rest of the road network of Amersfoort with an intersection. The design of intersection was not part of the scope of this project. The municipality is planning on redesigning this intersection, therefore the an open boundary condition was considered here (see section 5.4). Meaning that the street profile had to be within the given width, but not necessarily connect logically to the current road layout. The bus stop 'Stadsring' visible in the design. The bus stop is place right at the intersection. The location of this bus stop was fixed at this location as a requirement from the municipality (see subsection 5.2.1). The location of the bus stop also allows for the access routes to be included as part of the intersection, which reduces the need for road crossings. The bus stop is relatively long. At this length is should be able to have three buses halt at the same time, which will be necessary for smooth operation with the number of buses that will stop here (see subsection 8.1.3).

Figure 9.2: Detailed image of the area around the bus stop 'Stadsring'

The next detail (see Figure 9.3) shows street passing under the main railway line in Amersfoort. Because the underpass itself could not be widened as part of the redesign (see section 7.1), the design choices here are limited. Besides the introduction of bus lanes, there is only one major change, the addition of a new bicycle and pedestrian crossing. The bicycle and pedestrian crossing on the southern side is currently does not exist. It could be realised because the number of lanes for general traffic was reduced from two to one. The wish from the municipality to use this space for pedestrians and bicycles could thus be realised.

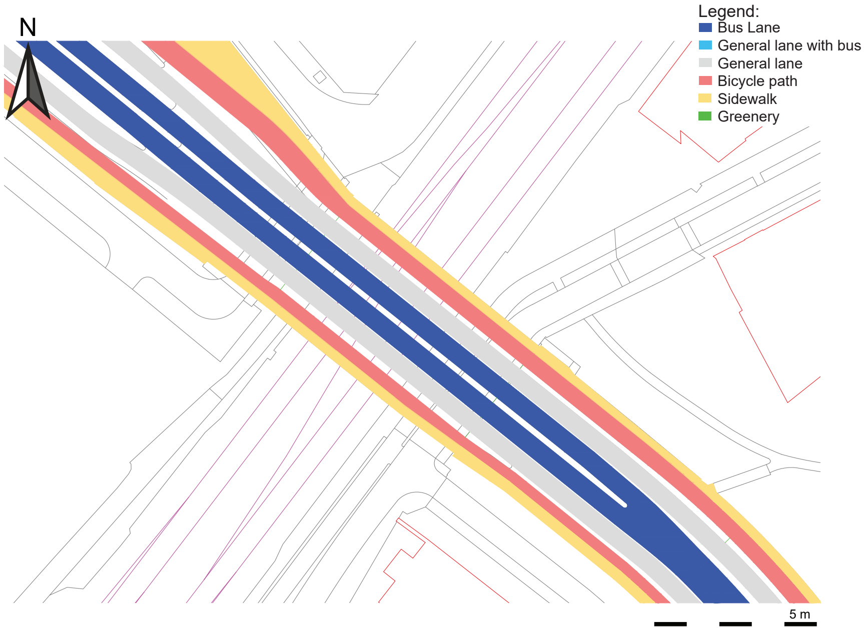


Figure 9.3: Detailed image of the railway underpass

The detail in Figure 9.4 show the roundabout with an underpass at 'De Nieuwe Poort'. The design of the roundabout itself was not in scope for this project as the municipality has an ongoing project to redesign the roundabout (see section 4.2). The design for the roundabout itself is thus simply the most recent version of the redesign that the municipality is working on .

The main decision that was in scope for this project was whether the buses should go over or under the roundabout. Because the buses use median bus lanes on the rest of the street, using the underpass was most logical and does not cause extra weaving movements. Because the aim was to create high quality bus infrastructure, it was decided that the underpass would be reserved for bus traffic. This means that all general traffic has to use the roundabout.

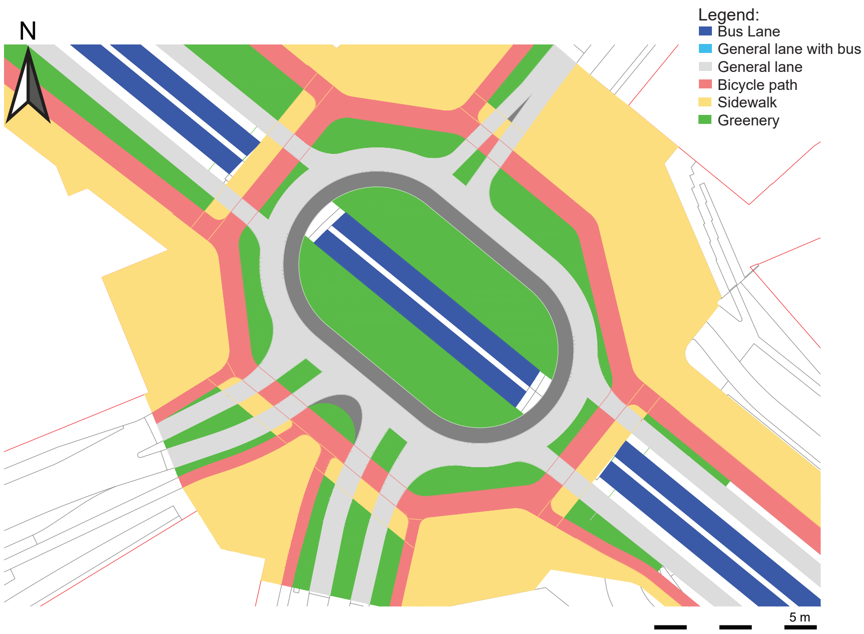


Figure 9.4: Detailed image of the roundabout at 'De Nieuwe Poort'

The next detail (see Figure 9.5) shows the location of the second bus stop in the design area, 'Eemplein'. This bus stop was moved about 100 metres west from its current location. There were two reasons for this. The first is that since the buses use the underpass they need to be at street level before a stop can be placed. This means that the stop could not be at the current location as that is directly on the roundabout, where the underpass is still underground. The second reason is to increase catchment area of the bus stop so that the total number of bus stops could be minimised (see subsection 5.2.1). It will thus be closer to the centre of the redeveloped LES-area. It will also be closer to most inhabitants of the LES-area. It does however also mean that the bus stop is further away from the important facilities near the current stop, e.g. the large college, the main city library and the new city hall. The maintain the access to these facilities as best as possible the bus stop is accessible by a pedestrian crossing on the east side of the bus platforms. The bus stop is also accessible by a pedestrian crossing on the west side of the platforms. This pedestrian crossing lines up with the side streets the old 'Brabantsestraat' and the 'Friesestraat' (see section 5.4).

Figure 9.5: Detailed image of the area around the 'Eemplein' bus stop

The detail in Figure 9.6 shows the intersection between the design area and the new Brabantsestraat. This intersection is designed with traffic lights to regulate the traffic. The intersection does currently not exist as the new Brabantsestraat does not exist. This street will be built as part of the redevelopment of the LES-area (see section 5.4). It will replace the old Brabantsestraat which will turn into a bicycle only street and is visible in Figure 9.5.

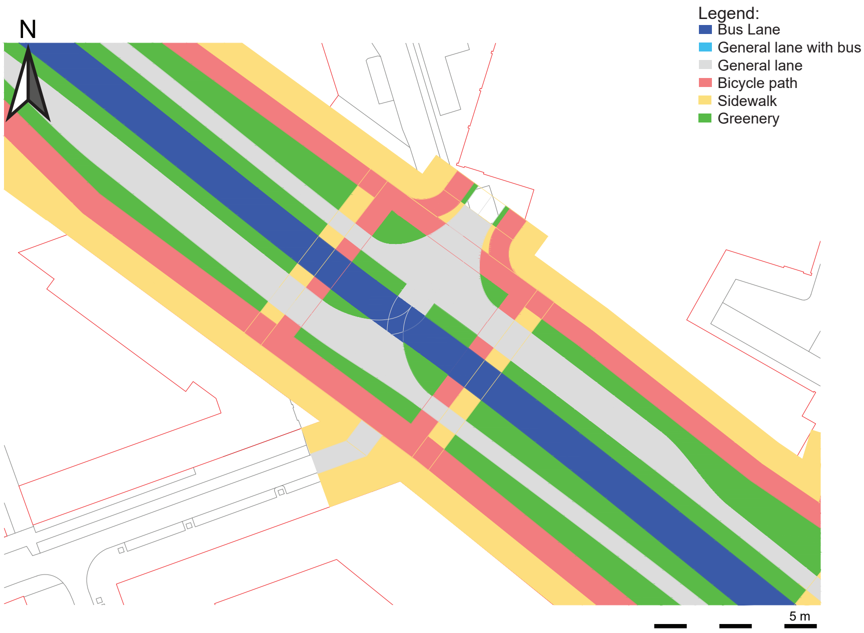


Figure 9.6: Detailed image of the intersection with the new Brabantsestraat

The detail in Figure 9.7 shows the connection of the Geldersestraat to the design area as well as the bicycle and pedestrian crossing next to this connection. The connection is incomplete. Traffic on the eastbound part of the Amsterdamseweg cannot reach the Geldersestraat and vice versa. This is the same as in the current situation and not a big problem because the LES-area can be reached from both directions from the previous intersection with the new Brabantsestraat (see Figure 9.6). The crossing for pedestrians and bicycle traffic is an important connection between the redeveloped LES-area and the Soesterkwartier neighbourhood south of the design area.

Figure 9.7: Detailed image of the connection and street crossing at the Geldersestraat

In Figure 9.8 the detail of the intersection between the Amsterdamseweg and the Industrieweg is shown. This is biggest intersection in the design area. It is regulated with traffic lights. The continuation of the

Amsterdamseweg towards the west provides access to the industrial area of the 'Isselt' and towns west of Amersfoort (see Figure 4.1). The Merwedestraat that connects to the design area here is a one-way street, which it currently already is (see section 5.4).

Figure 9.8: Detailed image of the intersection between the Amsterdamseweg and the Industrieweg

The next detail (see Figure 9.9) shows the narrowest part of the Industrieweg. The biggest compromises in the entire design area were made here. This was due to the fact that the municipality required to have both two general traffic lanes and a dedicated bus lane per direction. There simply was not enough space to accommodate all these requirements. The municipality thus decided to drop their requirements for dedicated bus lanes. Within the available space one dedicated bus lane was still possible. It was decided to have the bus lane in the northbound direction, because it would be easier to ensure that the southbound bus was at the front of traffic using traffic lights (see section 7.5).

Next to the limited space available for the bus lanes, there is also limited space available for a bus stop (see also the next detail Figure 9.10). Especially in the southbound direction there simply was not enough space to create a high quality bus stop. Therefore the southbound bus stop is placed on the turning lane into the Textielweg that connects onto the design area here. The bus stop here is only long enough to accommodate one full bus. This cannot reasonably be called a high quality bus stop and it will likely cause problems in operation, but not other solution was found.

Finally the Textielweg which connects to the design area here does not have access to the northbound general traffic lanes. This is a reduction of access compared to the current situation. This should not pose significant problems, because access to the Isselt from the south is possible from the western section Amsterdamseweg (the part that leaves the design area in Figure 9.8) and egress from the Isselt is possible from the Nijverheidsweg-Noord that enter the design area in Figure 9.10.

Figure 9.9: Detailed image of the area around the southbound 'Nijverheidsweg-Noord' bus stop

The detail in Figure 9.10 shows the intersection between the Industrieweg in the design area and the Nijverheidsweg-Noord. Also at this intersection is the northbound bus stop 'Nijverheidsweg-Noord'. The intersection is traffic light regulated. Because of the tight space around this intersection and the wish to include a dedicated bus lane, turning lanes towards the western part of the Nijverheidsweg-Noord could not be included. The intersection was thus made incomplete. The western part of the Nijverheidsweg-Noord was turned into a one-way street coming onto the intersection. Traffic that wants to reach the Isselt will have to go via intersection with the Amsterdamseweg (see Figure 9.8) to the western part of Amsterdamseweg to enter the Isselt.

The bus stop is placed directly at the intersection so that the access route can be integrated into the traffic lights at the intersection. The bus stop is long enough to have three buses stop at it simultaneously. It is thus long enough to be considered high quality for the bus operations.

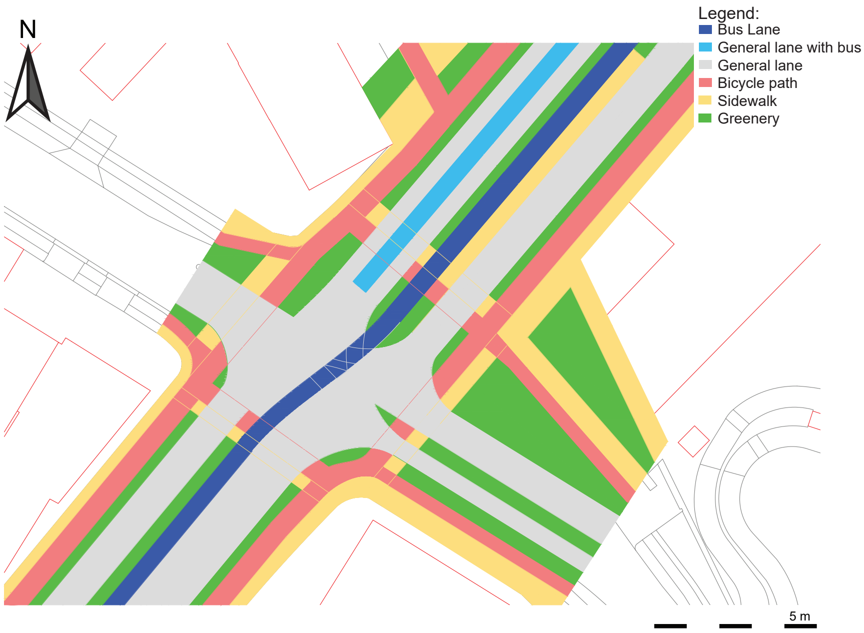


Figure 9.10: Detailed image of the intersection with the Nijverheidsweg-Noord

In Figure 9.11 the Koppelbrug is shown. During the project it was decided not to consider widening this bridge for this project (see section 7.5). Therefore the width of the bridge became a bottleneck for the design. Again the municipality decided that they would drop their wish for dedicated bus lanes here and thus buses in both directions have to travel with general traffic over the Koppelbrug. In the northbound direction this is facilitated through the dedicated bus lane turning into a left turning lane for the upcoming intersection with the Maatweg (see Figure 9.12). This works well for the bus service because all buses make this left turn at the intersection. In the southbound direction bus traffic is given priority at the intersection with the Maatweg, thus ensuring that it is at the front of traffic. The bus then continues on the general traffic lanes over the bridge towards the intersection with the Nijverheidsweg-Noord (see Figure 9.10).

Furthermore there is an oddity shown here were the bicycle path on the southeastern side of the river seemingly ends into the river. This bicycle path will in the future connect onto a separate bicycle and pedestrian bridge on the east side of the Koppelbrug that the municipality is working on. The design and exact location of this bridge were left out of scope for this project (see section 7.5).

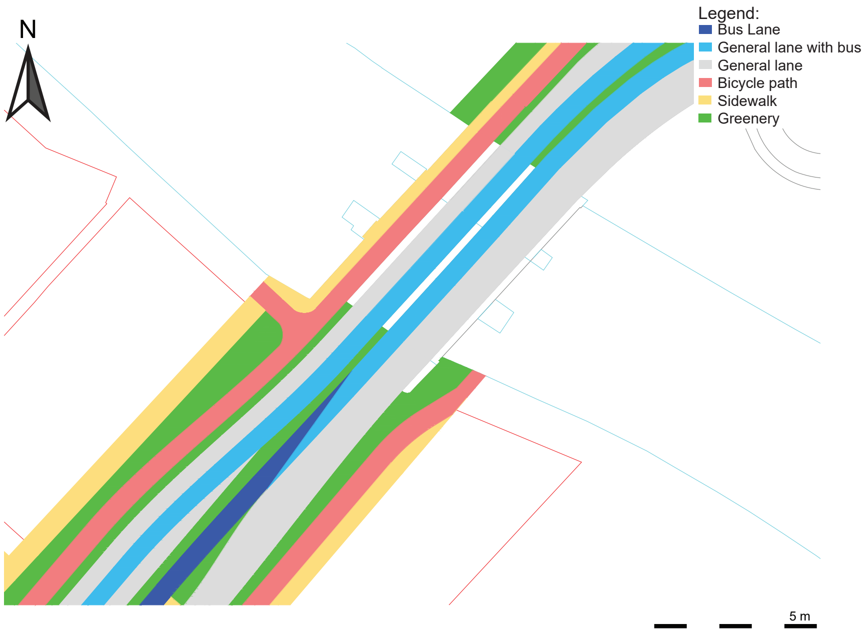


Figure 9.11: Detailed image of the Koppelbrug

In the final detail (see Figure 9.12) the northern end of the design section is shown. Here the BRT corridor continues north along the Maatweg towards the northern neighbourhoods of the city. For this intersection it was assumed that the Maatweg would have dedicated bus infrastructure in a similar way as the design area (see section 5.4), so for the final design median bus lanes on the Maatweg were assumed. Currently these are not here. They were assumed to be there as they are part of the same BRT corridor and thus would be implemented in an integral project. This intersection also connects the design area to the Ringweg Koppel and the De Stuw roads. The intersection is traffic light regulated.

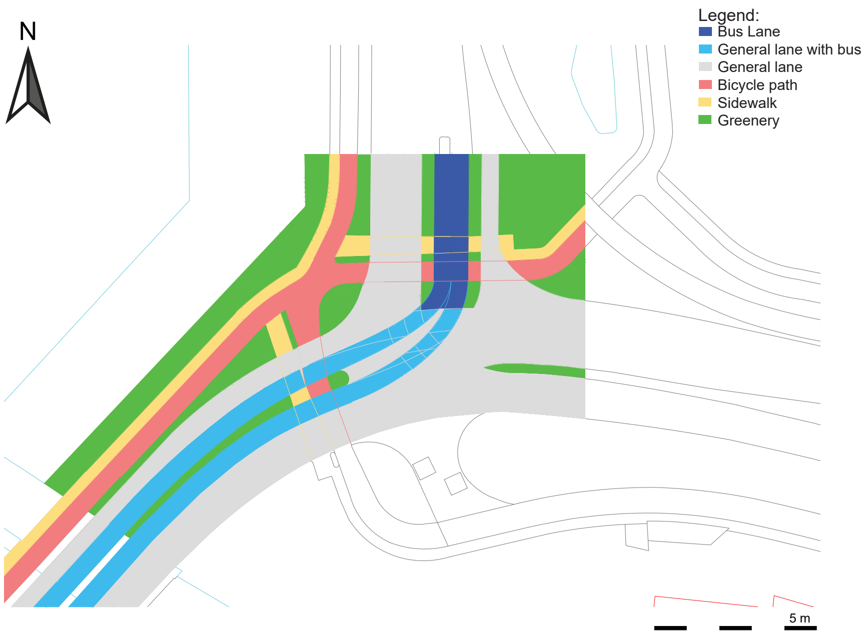


Figure 9.12: Detailed image of the intersection with the Maatweg

10 Conclusion, discussion and recommendations

10.1. Conclusion

The aim of this project was to design dedicated public transport infrastructure that can seamlessly connect to an already existing public transport network. For the specific case of this project this meant to design high quality bus infrastructure for the northern bus corridor through the LES-area in Amersfoort (see section 2.4).

During this project it was concluded that the best way to create high quality bus infrastructure is by using median bus lanes on the streets along which the bus corridor will run. This is true from a traffic performance point of view, but also holds true for passenger accessibility and neighbourhood integration and liveability. This result for traffic performance is backed up by both the literature study and the evaluation of variants. In the literature review this is shown by several different publications that all found that median bus lanes yield the best results for public transport operations. In the evaluation of variants the traffic performance was found using a traffic model which compared the two variants with (mostly) median bus lanes and (mostly) curb-side bus lanes. The traffic model showed that the median bus lanes had a better performance for bus public transport services. The result for passenger accessibility and neighbourhood integration is supported only by the evaluation of variants. Using a varied set of evaluation criteria the median bus lanes were also found to be preferred over curb-side bus lanes from these two perspectives. Median bus lanes are thus the best way to implement dedicated bus lanes into an urban street.

Next to the findings about the type of dedicated bus lanes, it was also found that the desire to fit too many functions into limited space will ultimately result in one or more functions not being able to achieve the desired level of functionality. In this project this showed through some of sections of the design area being too narrow to fit all desired transportation modes. The municipality chose to prioritise the requirements for other modes over the need for high quality bus infrastructure on these sections. This meant that on these sections the buses will have to operate in mixed traffic. This compromised the aim of the project as such mixed traffic does not qualify as high quality bus infrastructure. The aim of the project was thus not completely fulfilled.

10.2. Discussion and Recommendations

This section discusses the different aspects of the project, identifies their shortcomings and gives recommendations how the given shortcomings might be overcome in future studies or projects. The aspects that will be discussed are the literature study, the design requirements, the design methodology, the evaluation methods and the final design.

10.2.1. Literature study

Systematic approach

The literature study was the first major component of this project. In the literature study two different types of sources were looked for and analysed; academic publications and design guidelines. These are two different types of sources and therefore required a different method to acquire them. The academic sources were found and scanned using the PRISMA guidelines. These ensure a systematic approach and reproducible results. This was made possible by the use of a database for academic publications. Because such a database does not exist for design guidelines, at least not on a global scale, this method could not be applied to the design guidelines. Therefore the design guidelines that were found are somewhat arbitrary. This makes it likely to some potentially useful design guidelines were missed. This is a shortcoming of the approach towards the literature study. Since it is unlikely that the limited systematic approach caused important guidelines to be missed, the effect of this limitation on the project is low. In future research a systematic approach of looking for design guidelines could be used, for example by going through all government publications on road design from a selected set of countries.

European projects

During the literature study it was concluded that there were no publications about European case studies where a street was redesigned to include dedicated bus infrastructure. These projects are however not uncommon in Europe and the European context is different enough from the North American context that different conclusions can be drawn. Also there could be design variants that are relevant for the European context that were not considered at all in the North American context. There is a real gap in the literature here, so it should be interesting to conduct more research into such European projects and expand the scientific literature on them. It would be a shame if such knowledge is only kept within the field and not spread wider on scientific platforms.

Side separated bus lanes

In the studies that were found of cases in North America, there were several options for where the bus lanes could be located in the street; curb-side, offset or median, but side separated bus lanes were not mentioned. The Dutch CROW did however have several base design for how to design such bus lanes. This type of bus lanes is also not uncommon to be implemented within the Netherlands. Further research could help to investigate how this design variant stacks up against the other variants that were found in the literature. This should give a better insight to the benefits and drawbacks of this design and thus identify the best use cases for it.

Dedicated BRT design guideline

It was surprising to find that no dedicated design guideline for BRT from the Dutch CROW exists. The CROW has a multitude of design guidelines for road design within the Netherlands. This includes a design guideline for general bus infrastructure and a design guideline for tram infrastructure. Both of these design guidelines were useful for this project. However the design of BRT is different from the design of both regular bus infrastructure as well as tram infrastructure. BRT is also becoming more and more common as an element of public transport networks, therefore it is worthy of its own dedicated design guideline. Writing and publishing such a guideline would be a valuable addition to the set of guidelines that are available for road design within the Netherlands.

10.2.2. Design requirements

Unclear municipal priorities

The design requirements were given by the client of this project, the municipality of Amersfoort. The requirements that were given were reasonable and largely understandable. However at certain points the municipality seemed to want more than was possible. Different departments within the municipality had different priorities and no clear overarching decision on what modes of transportation were most important in this location seemed to be made. This lead to watered down requirements for the BRT corridor, where the other requirements were too restricting. This had an undeniable impact on the quality of the final design that was created. The municipality would benefit from making clear overarching decisions on what transportation modes will get priority in this location in the future and sticking to these decision after them have been made.

Ways to deal with tight requirements

The biggest problem with the design requirements were found at the Industrieweg in design section 2 (see section 7.4 and section 8.2). Here the requirements for dedicated bus lanes were dropped by the municipality because they could not be fit into the street next to the required number of general traffic lanes and bicycle paths. The result of this was seen in the evaluation of concepts. The final designs that were evaluated for the design section 2 were not rated very high. Compared to design section 1, the design variants for design section 2 are rated significantly worse. This is likely a direct result of the loosening of this goal. Another option that could have been considered here was to widen the street to make dedicated space for all modalities instead. This option was not explored because it would have taken too much time and taken this project out of scope. However it is interesting. The design area is part of an area that will be redeveloped and at other locations it has already been decided to widen the streets, mainly to make them feel less cramped and allow space for greenery. The section were the street was too small to fit all requirement is not very long. Within the larger redevelopment project for the LES-area including such a street widening would not be a major change, but it could provide real extra quality to the planned BRT corridor. It is thus strongly recommended to consider this possibility for this project.

10.2.3. Design process

Iterative process

During the design process there were two moments for an evaluation of the designs. The first was done to reduce the number of design variants when moving from street-level based designs to map based design (see chapter 7). The second moment of evaluation was the final evaluation of the design variants to decide which to include in the final design (see chapter 9). This also meant that the development of ideas was constricted to two phases. This made it harder to implement new ideas for problems that were identified during the evaluation. This was part of the reason that both design variants for design section 2 do not score very well. It is reasonable to assume that if a more frequent evaluation was used during the project that would have lead to at least a slightly better final design than the one that was made. It is therefore recommended for a continuation of this project or similar future projects to do intermediate evaluation more frequently. This allows the design process to become more iterative. This would probably lead to a higher work load for the project. It would thus be important to either scope the project down to only a fixed number of stages in the iterative process or increase the amount of work hours that are assigned to the project, either by lengthening the project duration or increasing the number of people that work on the project.

Use of reference projects

The inspiration for the designs that were developed came mainly from examples that were found in the design guidelines. The examples that were found in the design guidelines were mainly based on standard situations in road design and not location specific. This made them adaptable to the specific situations of this case, but since the examples of how to do such adaptation were limited, the adaptation itself remained difficult. It would have been useful to also take inspiration from reference projects to see how generic design examples are adapted to local circumstances. Using such projects as references would have been beneficial to the design process and likely increased the number of different design alternatives that were developed. This was not done during this project, because the design processes for reference projects are not often published. This makes it difficult to learn of the decisions that were made during a design process and only trying to interpret the final design is harder and less insightful. To increase knowledge about the decisions that are made during a design process it would be valuable to publish the design process of more road design projects.

10.2.4. Evaluation methods

Determining the evaluation criteria

The evaluation methods had a large impact on the results of the project. They were the deciding factor in which design variants were chosen as the preferred design variant and thus included in the final design. How to choose and weigh evaluation criteria is always an important point of discussion. For this project the evaluation criteria were established based on what the stakeholders with high interest deemed important. This inevitably left some voices unheard. Especially individual stakeholders like inhabitants and travellers that do not have a clear spokesperson to represent them will not be heard. These people could be better heard using surveying to find out what they value. This would have taken too much time for this project, but would have increased the validity of the results. It is therefore interesting to consider for future projects.

The traffic model

All four evaluation criteria of the category traffic performance were based on the results from the traffic model that was developed in Paramics Discovery 28. The traffic model was not perfect due to time constraints and thus still had room for optimisation. For example, the traffic light cycles were kept as simple as possible, where more complex designs can optimise the performance and increase the throughput for both design variants. Besides the traffic lights at the intersections the exact length of turning lanes can greatly influence the capacity of an intersection. If for example all directions are blocked by a single vehicle that wants to turn in a direction with a red light, while the other directions have green light but are unable to reach the intersection due to the blocking vehicle. The Paramics software has functionalities to see exactly how each vehicle travels through the modelled network. This function can be used to identify such bottlenecks and see whether traffic lights have an adequate throughput. This functionality was not used in this project due to time constraints. This functionally could be used to optimise the model and increase its throughput for both design variants. The model could then be used not only to compare the two design variants, but also be used to see if one of the design variants can actually handle the predicted traffic load.

General traffic data input for the traffic model

The input data for general traffic that was used for the model came from the results of the city-wide model that the municipality has recently conducted. It would have been better to use the underlaying demand that was used for the city-wide model for the traffic model in the project as well. This was not possible due to the fact that city-wide traffic model is not made by the municipality itself, but by a separate engineering consultancy firm, which was unable to share this underlaying data in a useable form within the time frame of this project. The results from the model would likely be more representative of the predicted situation if this underlaying data had been used instead. Although the influence of using the results from this model instead of the underlaying data on the outcome of the constructed traffic model is likely low. If the municipality wants to continue with the project it is recommended to work with the underlaying data and include the design variants in a city-wide model in cooperation with the separate engineering consultancy firm to ensure the best results.

Bicycle traffic data input for the traffic model

For the bicycle traffic no predicted traffic loads for 2035 were available. Thus measured data from the years 2022 to 2024 was used instead. This data is not representative for the year 2035, because the LES-area will be redeveloped by then and the municipality targets high bicycle use in this area. The traffic load will thus increase compared to now. It is hard to make an accurate prediction for the increase in bicycle traffic, but an increase between 50 to 100% should not be a surprise. This means that the used input is very far off from realistic numbers. The travel times for cyclists are thus likely underestimated. However, since the bicycle network is completely separated from the other traffic modes and only influenced the other modes at traffic lights, the influence of this inaccurate data on the full traffic model is low. To better include the bicycle traffic in the model, the municipality should make predictions for the bicycle traffic similar to how this was done for general traffic and then use this data to model the bicycle traffic.

Pedestrians in the traffic model

Pedestrians were not taken into account in the traffic model, because the Paramics software is not capable of modelling pedestrians. The design area will be quite urbanised once the LES-area is redeveloped, so there will be a significant amount of pedestrians in the design area. To consider the influence these pedestrians will have on traffic flow it should be considered to look for a way to try to model pedestrians within the Paramics software or to consider making a traffic model in different software that can model pedestrians.

Results from the traffic model

The results from the traffic model (see section 9.1) showed that both of the design variants were unable to handle the predicted demand for 2035. This caused extremely long travel times. This means that either the traffic model in its current state is not good enough to accurately model the predicted traffic in 2035 or that both design variants cannot handle the predicted traffic in 2035. This meant that in this project the traffic model could not be used to validate either of the two designs. The model was thus only used to compare the two designs. This was possible because under different demand scenarios the model consistently showed the same differences in performance between the two designs. The comparison of the designs would thus also be valid for a scenario without severe congestion.

It is also worth mentioning that if the traffic performance is completely disregarded because the model results are deemed unreliable, then the chosen design variants still remain the preferred design variants as they also outscore the other variants in the other two evaluation categories.

To figure out whether the model is insufficiently mature or both designs simply cannot handle the amount of predicted traffic, the traffic model should be developed further. Using the functionalities that the software has to see individual vehicles move throughout the network, the traffic model can be optimised. This approach also allows for an iterative process in the design, where the model is used to evaluate different designs. Traffic bottlenecks in the model can often be resolved by minor alterations in the design, like lengthening a turning lane slightly. With an iterative process the design can continuously be improved until a design variant is found that satisfies both the spatial constraints of the design and the traffic demand that the design must be able to handle.

Services within bus stop catchment areas

The stop locations were evaluated using an GIS study to determine the number of people that live within 400 metres of a stop. However, the number of people that live within such an area is not the only factor that contributes to a stops usage. The presence of jobs, stores, schools, etc. also plays a role. It was not possible to include this information in the evaluation, because the number and location of these functionalities in the LES-area is not yet known. If the locations of the bus stops is chosen, it might be a good idea to then use the location of the bus stops to determine where these functionalities should go so that they are located closely to a bus stop.

Size of bus stop catchment areas

The size of the catchment area of the bus stop was defined at 400 metres, because this value is used within the municipality of Amersfoort. However using 400 metres as a clear cut for a bus stop catchment area does not represent the full reach of a bus stop. People travel further to bus stops, especially if they travel by bicycle. To better simulate the real catchment area of a bus stop, a gradation could be used instead, where the value of each service within predefined range (e.g. 2000 metres) is weighed based on its exact distance to the bus stop.

Stop quality

To evaluate the stop quality, the total area of the stop was used. The area of a stop is a large factor in enabling a stop to be of high quality, but it is not the only factor. Other factors such as the shelter facilities or the sight lines from the neighbourhood to provide social safety were not considered. These aspects were not included in the design and could therefore not be evaluated. To ensure that these aspects of the stops also are of high enough quality sufficient attention should be given to these details when they are worked out before the design is implemented.

Stop access routes and road cross-ability

The stop access routes and road cross-ability were judged using evaluation criteria provided by CROW (2019). These criteria provide an objective way to grade the quality of road crossings. However the criteria focus on the safety and accessibility of the road crossings. The time a crossing is available is not an element, but this is very relevant for the experience of how cross-able a street or accessible a stop is. If the traffic on the street is dominant and waiting times are long to cross a street. This reduces the cross-ability in the experience of the pedestrian. It would thus be valuable to also consider this element in the evaluation of the stop access routes and road cross-ability. Grading this element is difficult as it very dependent on the volume of traffic. Perhaps the best way to evaluate this element would be by adding pedestrians in the traffic model and see how long they have to wait to cross the street. This would need to be done in a traffic simulation software that includes pedestrians.

BRT appearance and neighbourhood integration

Both BRT appearance and neighbourhood integration were evaluated using expert opinion. For both criteria two specialists from the municipality were consulted. For BRT appearance these were public transport specialists and for neighbourhood integration they were urban development specialist. Due to the use of expert opinion as the evaluation method, the results for these criteria are subjective. Defining both these evaluation criteria in an objective manner was difficult and thus it was decided to use expert opinion. However using only two experts for both evaluation criteria made the results more subjective than they could have been. To reduce the subjectivity of the criteria more specialists could have been consulted. Especially consulting specialists that are not affiliated with the municipality might be valuable as they do not know the ins and outs of the case. This means they can evaluate the case from a distance and with less prejudice and predefined wishes for the outcome.

Road safety

The road safety was evaluated based on the number of conflict points between general traffic and active modes. The number of conflict points does provide a good initial insight to how safe a road section is and is relatively straightforward to indicate. However there are more factors that influence the road safety than the number of conflict points. The sight lines around a conflict point greatly influence how dangerous a conflict point actually is. Also the intensity of traffic is very relevant, as it indicates how often a conflict can actually occur at a conflict point. To better assess the road safety these factors should also be taken into account. This may be done by consulting road safety experts on by looking at statistics on what type of intersections generally perform better in terms of road safety compared to others.

Space for pedestrians and bicycle traffic

The amount of space for pedestrians and bicycle traffic was evaluated based on the total area for pedestrians and bicycle traffic. The quality of this space was not considered. Specific elements like meeting points for pedestrians and bicycle parking spaces for bicycle traffic, improve the quality of the space for pedestrians and bicycle traffic. Both of these elements were not part of this design and could therefore not be evaluated. For a continuation of this project and a further detailing of the design these elements should be considered and enough space should be made available for them.

Green space

The amount green space was evaluated simply based on the total area within a design that is dedicated to green space. However to enable biodiversity, the quality of the green space is also relevant. One large green area usually has a higher quality than several smaller green areas. To better evaluate the quality of the green space next to simply the total area of green space it could thus be considered to also look at the average size of the individual green spaces.

Long-term robustness

Long-term robustness is evaluated by comparing the design against the newest design guidelines, the better it follows these design guidelines, the longer the design should hold up in the future. The design guidelines are however subject to change. If they change quickly in the near future a design that is currently up-to-date might be outdated soon. However it remains difficult to grade the long-term robustness, as a proper evaluation requires knowledge of the future. Therefore using the current guidelines is the best option that is available.

10.2.5. The final design

The final design was put together from the preferred design variants for both design sections. The final design makes use of median bus lanes where space was available for dedicated bus lanes. As mentioned in the discussion (see section 10.1) the final design only partially fulfils the aim of the project. Therefore it cannot be recommended to implement the final design from this project. Before the municipality implements the design it needs to be developed further. The three most important recommendations to further develop the design are:

- Choose a design with median bus lanes
- Develop the model, but consider it remains only a model
- Find creative solutions when the requirements compromise the aim

Median bus lanes

The median was found to be the best location for bus lanes both in the literature study and the evaluation of the design variants of this design project. This shows that both in general and in this specific case median lanes would create the best public transport service. It is therefore strongly recommended to the municipality to continue with a design with median bus lanes. Choosing any other variant would lead to a suboptimal public transport performance.

Traffic modelling

The traffic modelling done in this project proved that the predicted traffic loads in the design area are high. So high in fact that both designs that were developed in this project lead to problematic traffic congestion. However, the model that was developed in this project was not perfect and likely underestimates the traffic capacity because of this. It is therefore recommended to improve the model further so that it more accurately represents a real traffic situation. The municipality is also advised to not blindly trust the outcomes of the model. They are in the end based on predicted traffic volumes in 2035. It should be taken into account that the design that is eventually implemented also influences the traffic demand. Thus implementing a design that does not prioritise general traffic may also cause the travel demand for general traffic to be lower, as people prefer the travel options with the prioritised modes, like public transport or bicycle.

Creative solutions

Finally the municipality is recommended to look for creative solutions when the set requirements become too restricting. In the final design, the section where no space was found for dedicated bus lanes was restricted by both the width of the street and requirements for other traffic modes. Because of these restrictions the aim of the project was compromised. When the aim of the project becomes compromised due to other requirements it should be considered to see how strict the requirements actually are. If buying extra land to widen the street is considered and compared with the aim of the project, it might be the case that such an approach is worth it to achieve the aim of the project. The same can be said for reducing the road space for other traffic modalities. If the municipality wants to prioritise public transport over general traffic, this will mean that sometimes road space for general traffic has to be sacrificed to improve the public transport system.

AI Statement

No generative AI based chat programs were consulted during this thesis. Any and all text was written by the author, including any potential mistakes. The author bears full responsibility for the publication.

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A

Appendix A

In this appendix design examples from the Dutch design guidelines (CROW, 2020, 2022b) are included. In total twelve base designs from CROW (2020) have been included. These come with an informative table as well as an image displaying the base design. Eleven base designs from CROW (2022b) have been included. These come short description and an image displaying the base design.

The first is a design for median bus lanes on distributor roads that can be used in- and outside of urban areas (see Figure A.1 and Table A.1).

Table A.1: Median bus lanes on distributor roads in- and outside urban areas CROW (2020) (§ 9.1.9)

Function	Connection between (several) access roads and stream roads Facilitates both the stream of traffic (on road sections) as well as the exchange of traffic (at intersections)
Application	Distributor road with a 50 km/h speed limit No bicycle traffic on the general traffic lanes No parking lanes or spots
Implementation	Bus lane elevated compared to other traffic Increase space between bus lane and general traffic lanes at stops
Sizing	Bus lane width 3.25 m
Considerations	No obstacles in obstacle-free zone of 0.50 m Stops only accessible after crossing general traffic lanes Chance of crossing pedestrians
Combination possibilities	Construction of cycle paths and sidewalks
Alternatives	Implement bus lanes physically separated

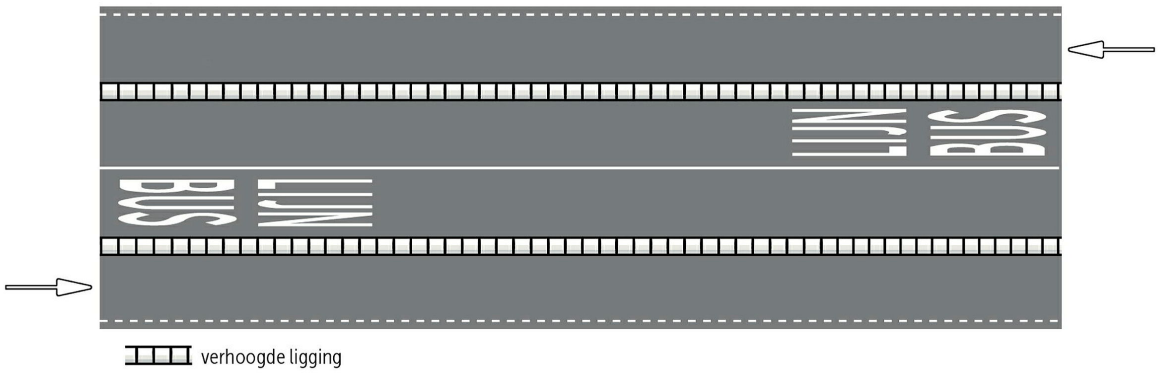


Figure A.1: Median bus lanes on distributor roads in- and outside urban areas CROW (2020) (§ 9.1.9)

This is a design for the addition of a dedicated bus lane on distributor roads that can be used in- and outside of urban areas (see Figure A.2 and Table A.2).

Table A.2: Addition of dedicated bus lane on distributor roads in- and outside urban areas CROW (2020) (§ 10.2)

Function	Safe and swift exit of bus traffic to a dedicated bus lane
Application	Distributor road in- or outside urban areas On the right or left side of the road
Implementation	No special indications with signs Continuous line between bus lane and lanes for other traffic Apply text 'LIJNBUS' at the start of the bus lane Before start of bus lane, apply 50 m of double side line
Sizing	entry angle to bus lane 1 : 10
Considerations	continuous line emphasises that other traffic may not enter the bus lane other traffic does not enter the bus lane on accident
Combination possibilities	Bus stops

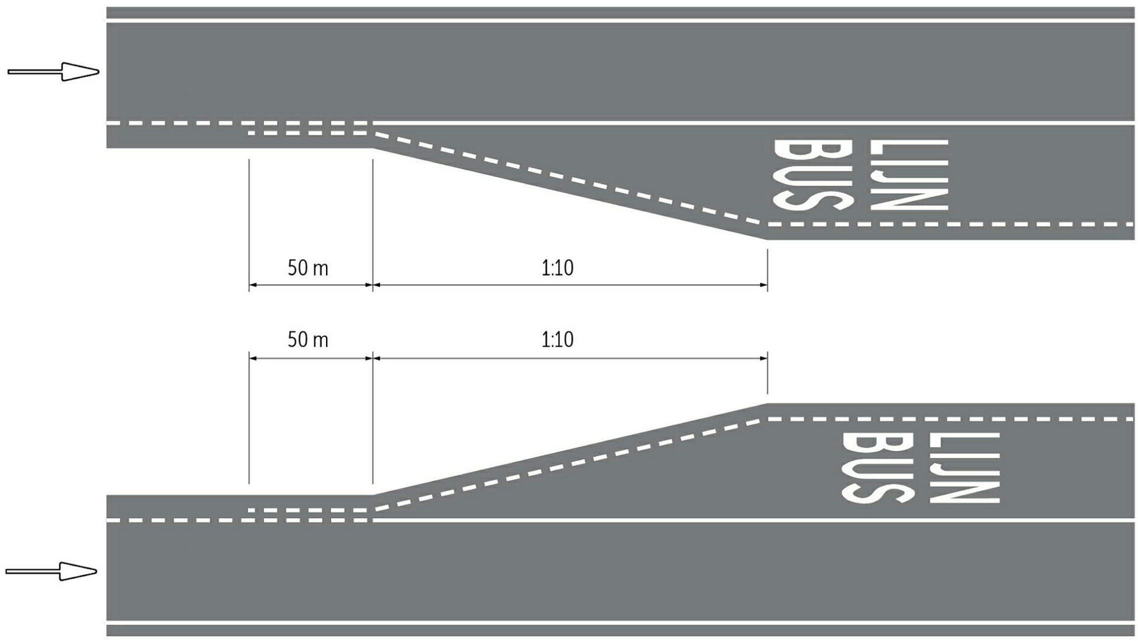


Figure A.2: Addition of a dedicated bus lane on distributor roads in- and outside urban areas CROW (2020) (§ 10.2)

This is a design for the beginning of a dedicated bus lane on distributor roads that can be used in- and outside of urban areas (see Figure A.3 and Table A.3).

Table A.3: Beginning of a dedicated bus lane on distributor roads in- and outside urban areas CROW (2020) (§ 10.3)

Function	Safe and swift exit of bus traffic to a dedicated bus lane
Application	Distributor road in- or outside urban areas On the right or left side of the road
Implementation	No special indications with signs Continuous line between bus lane and lanes for other traffic Apply text 'LIJNBUS' at the start of the bus lane Before start of bus lane, apply 50 m of double side line
Considerations	continuous line emphasises that other traffic may not enter the bus lane
Combination possibilities	Bus stops

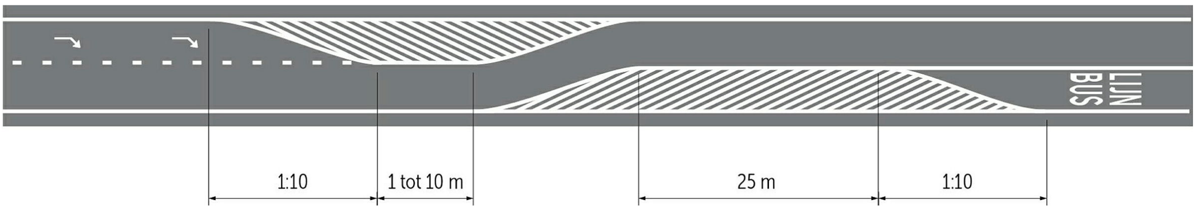


Figure A.3: Beginning of a dedicated bus lane on distributor roads in- and outside urban areas CROW (2020) (§ 10.3)

This is a design for the end of a dedicated bus lane on distributor roads that can be used in- and outside of urban areas (see Figure A.4 and Table A.4).

Table A.4: End of a dedicated bus lane on distributor roads in- and outside urban areas CROW (2020) (§ 10.5)

Function	Turn bus lane into a general traffic lane
Application	Distributor road in- or outside urban areas
Considerations	Bus does not have to change its lane increased traffic capacity Apply final textmarking 'LIJNBUS' at least 10 m before the end of the bus lane
Combination possibilities	Bus lane can also turn into a turning lane at a priority intersection, if the bus goes in this direction At transition to a turning lane at a intersection with traffic lights, the bus can also go in another direction

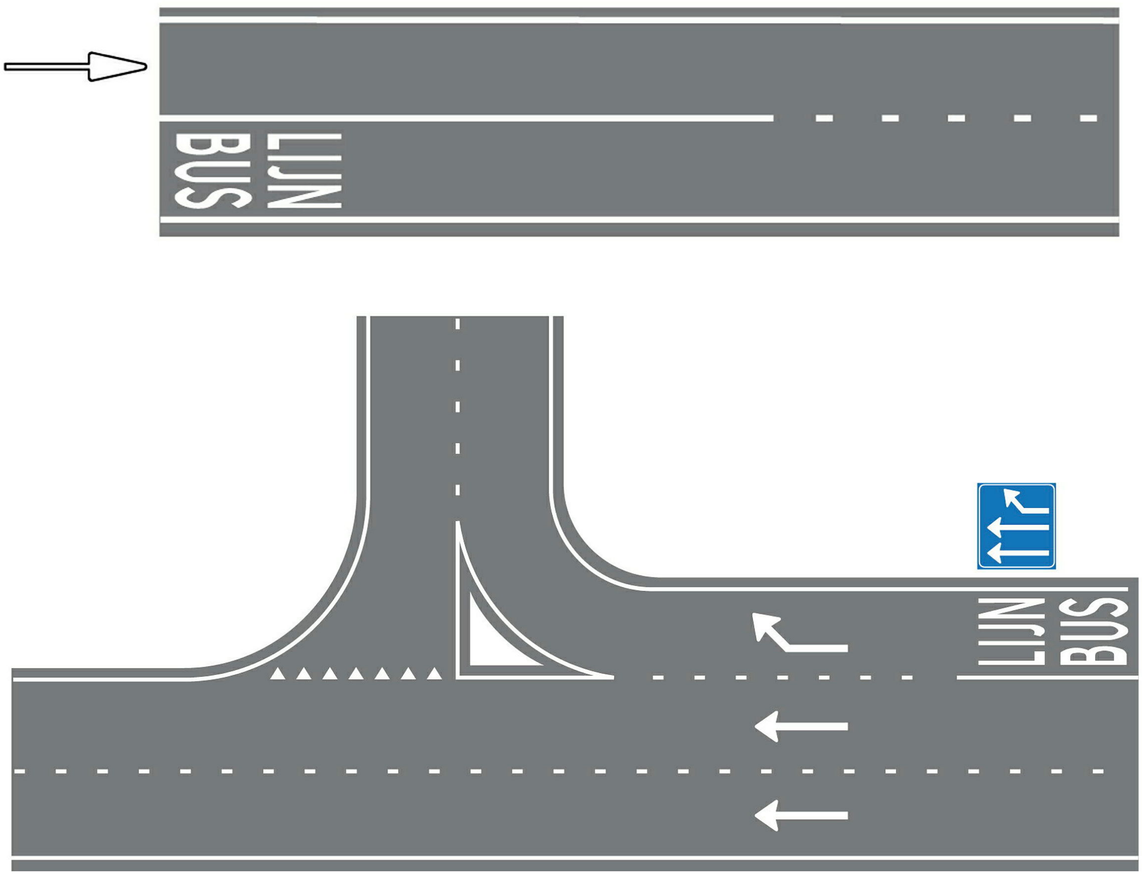


Figure A.4: End of a dedicated bus lane on distributor roads in- and outside urban areas CROW (2020) (§ 10.5)

This is a design for dedicated bus lanes at a traffic light regulated intersection (see Figure A.5 and Table A.5).

Table A.5: Dedicated bus lanes at a traffic light regulated intersection CROW (2020) (§ 11.2.3)

Function	Regulate the priority at an intersection
Application	Traffic light regulated intersection with dedicated bus lanes on one or more roads
Implementation	Dedicated bus lane is a integral part of the traffic light regulation Buses apply to the traffic light from a distance All conflicts are included in the traffic light regulation Bus is regulated with (controlled) priority All possible bus directions should have dedicated lights so that travel time loss for other traffic can be minimised No arrow markings on the dedicated bus lane
Considerations	Limited loss of travel time for the bus Continuous route for other traffic must be logical, markings can support this

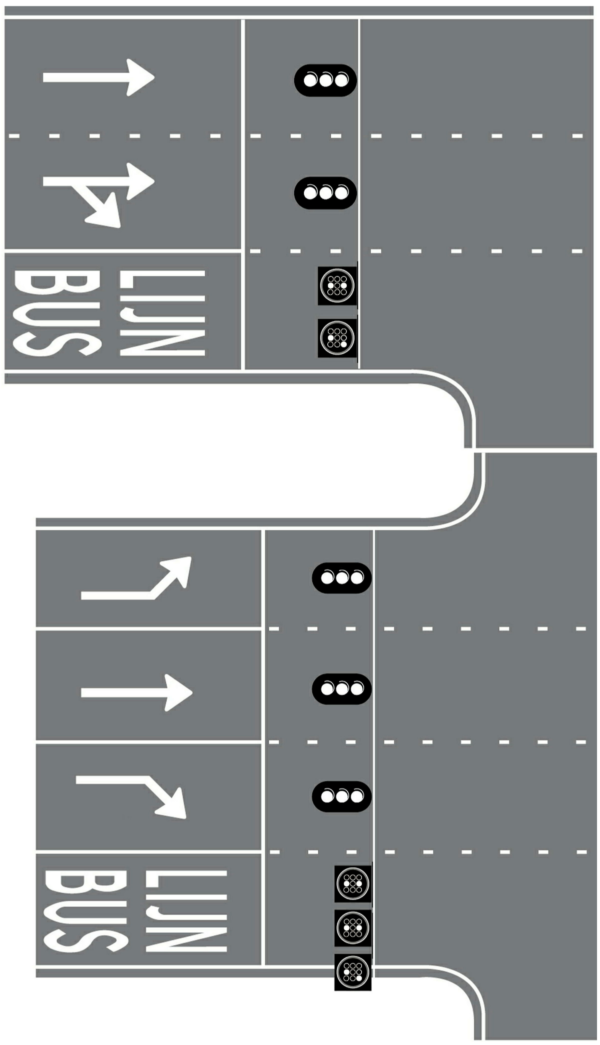


Figure A.5: Dedicated bus lanes at a traffic light regulated intersection CROW (2020) (§ 11.2.3)

This is a design for a crossing between pedestrians and bicycle traffic and a road with median bus lanes (see Figure A.6 and Table A.6).

Table A.6: Crossing between pedestrians and bicycle traffic and a road with median bus lanes CROW (2020) (§ 11.3.1)

Function	Crossing without special priority regulation
Application	Crossing between bus lanes and crossing bicycle traffic and pedestrian traffic On road sections of distributor roads in urban areas with dedicated bus lanes 50 km/h speed limit
Implementation	Traffic islands as support Priority of bicycle traffic and pedestrians is equal No zebra crossings on the bus lane Lowered kerbs for crossing traffic
Sizing	Traffic islands at least 2 m wide for pedestrians Traffic islands at least 3 m wide for bicycle traffic
Considerations	Limited loss of travel time for the bus Bus lanes cannot be a resting area for crossing traffic Bidirectional traffic can be confusing for crossing traffic Chance for accidents due to blocked sight lines
Combination possibilities	Stop should be placed a sufficient distance to allow crossing traffic to anticipate departing buses from the stop Traffic calming on the general traffic lanes
Alternatives	Pedestrian crossing with a zebra

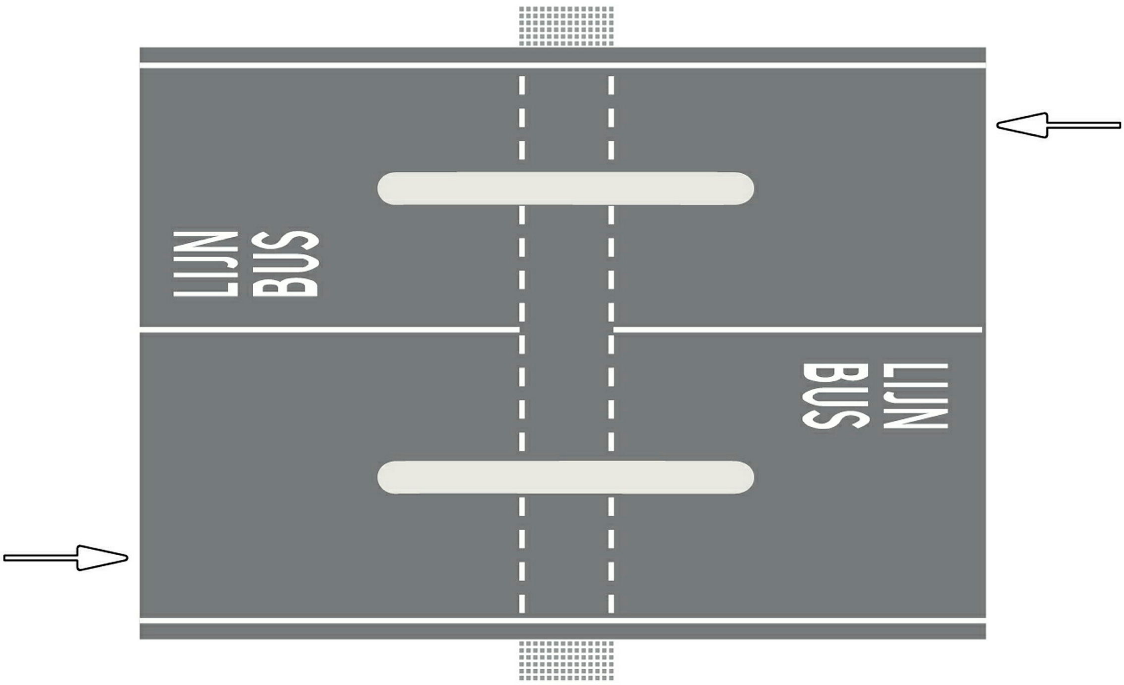


Figure A.6: Crossing between pedestrians and bicycle traffic and a road with median bus lanes CROW (2020) (§ 11.3.1)

This is a design for a zebra crossing across a road with median bus lanes (see Figure A.7 and Table A.7).

Table A.7: Zebra crossing across a road with median bus lanes CROW (2020) (§ 11.3.2)

Function	Intersection of bus and pedestrian traffic
Application	Bus lanes within urban areas Speed limit of 50 km/h
Implementation	Placement of the L2-sign Lowered curb for crossing pedestrians
Sizing	Minimum length of zebra stripes 4.00 m Width of zebra stripes 0.50 - 0.60 m Space between zebra stripes is equal to width of zebra stripes
Considerations	Zebra crossing over bus lanes not desirable due to travel time loss for the bus In case of high pedestrian volumes, bus cannot cross Do not apply mixed forms where some lanes are crossed by a zebra and some are crossed using canalisation stipes
Combination possibilities	Warning sign J22 Speed reductive precaution for general traffic lanes Bus stop
Alternatives	Crossing with canalisation stripes Crossing with traffic light regulation

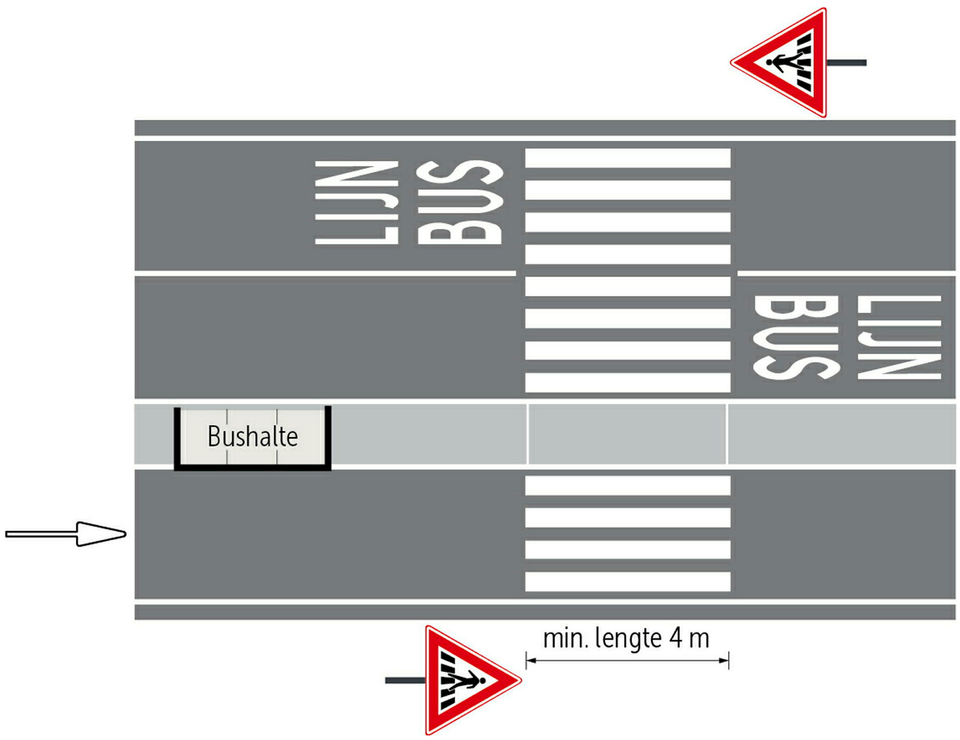


Figure A.7: Zebra crossing across a road with median bus lanes CROW (2020) (§ 11.3.2)

This is a design for a pedestrian crossing with canalisation stripes across a road with side-separated bus lanes (see Figure A.8 and Table A.8).

Table A.8: Pedestrian crossing with canalisation stripes across a road with side-separated bus lanes CROW (2020) (§ 11.3.3)

Function	Crossing of bus and pedestrian traffic
Application	Bus lanes within urban areas 50 km/h speed limit
Implementation	No priority for pedestrians Canalisation stripes across all lanes, general traffic and bus Place J23 sign
Sizing	Length of and gap between marking lines 0.50 m Width of marking lines 0.10 m
Considerations	No loss of travel time for the bus Long crossing length Do not use mixed forms where parts of the crossing are zebra crossings and other parts use canalisation stripes
Combination possibilities	Traffic calming on the general traffic lanes
Alternatives	Zebra crossing met zebra Traffic light regulated crossing

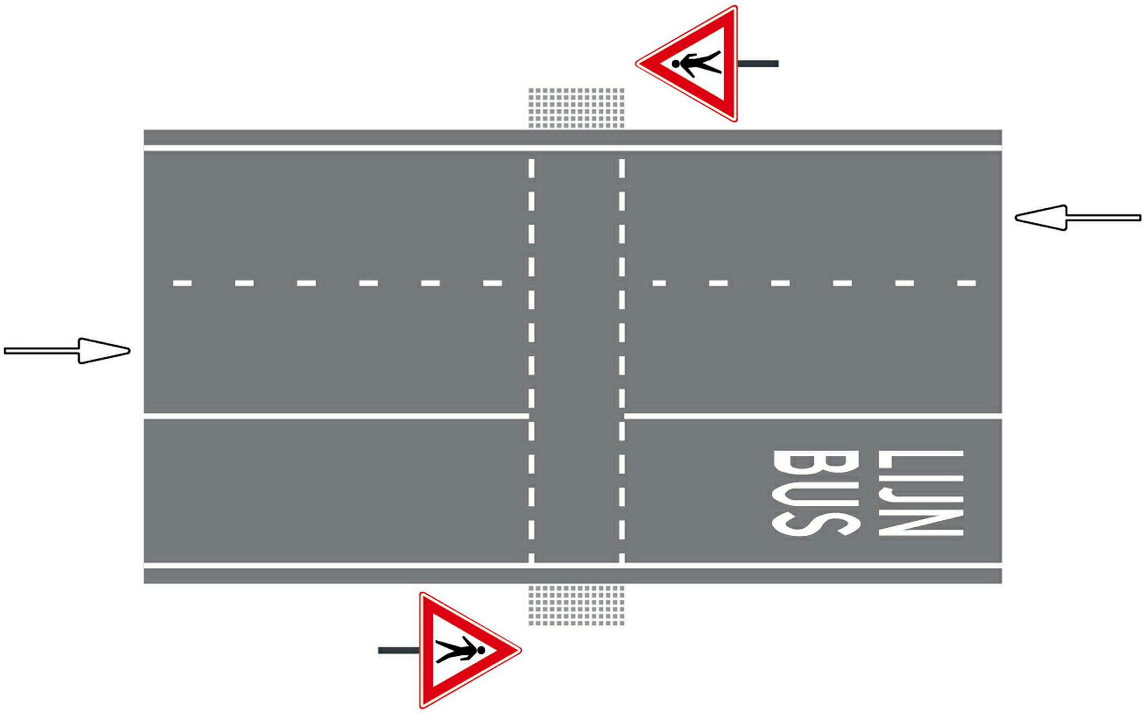


Figure A.8: Median bus lanes on distributor roads in- and outside urban areas CROW (2020) (§ 11.3.3)

This is a design for a bicycle crossing across a road with side separated bus lanes (see Figure A.9 and Table A.9).

Table A.9: Bicycle crossing across a road with side separated bus lanes CROW (2020) (§ 11.3.4)

Function	Crossing for bicycle traffic
Application	Access roads and distributor roads within urban areas
Implementation	Bicycle traffic has to give priority Mark crossing with canalisation stripes Do not apply block markings Apply shark's teeth and place sign B6 Crossing preferably perpendicular to the to-be-crossed traffic lanes
Sizing	Length of and gap between marking lines 0.50 m Width of marking lines 0.10 m
Considerations	No loss of travel time for the bus Long crossing length
Combination possibilities	Create traffic island of at least 3 m wide between travel directions
Alternatives	Bicycle crossing with warning installation Traffic light regulated bicycle crossing

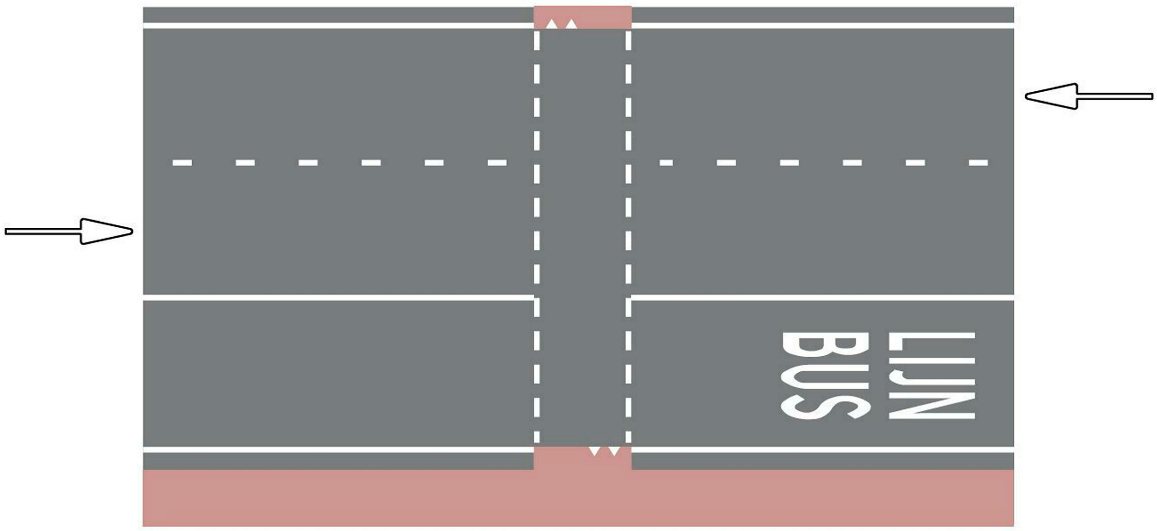


Figure A.9: Bicycle crossing across a road with side separated bus lanes CROW (2020) (§ 11.3.4)

This is a design for a bicycle crossing across dedicated bus lanes with bus warning light installation (see Figure A.10 and Table A.10).

Table A.10: Bicycle crossing across dedicated bus lanes with bus warning light installationCROW (2020) (§ 11.3.5)

Function	Crossing for bicycle traffic
Application	Access roads and distributor roads in- and outside urban areas
Implementation	Bicycle traffic has to yield Crossing marked with canalisation stripes Do not apply block markings Apply shark's teeth and place sign B6 Crossing preferably perpendicular to bus lanes Use auditory signal when lights start blinking
Considerations	Take use by pedestrians into account Pedestrians determine speed of crossing traffic
Combination possibilities	Pedestrian crossing Bus stops
Alternatives	Bicycle crossing with priority regulation Bicycle crossing with traffic light regulation

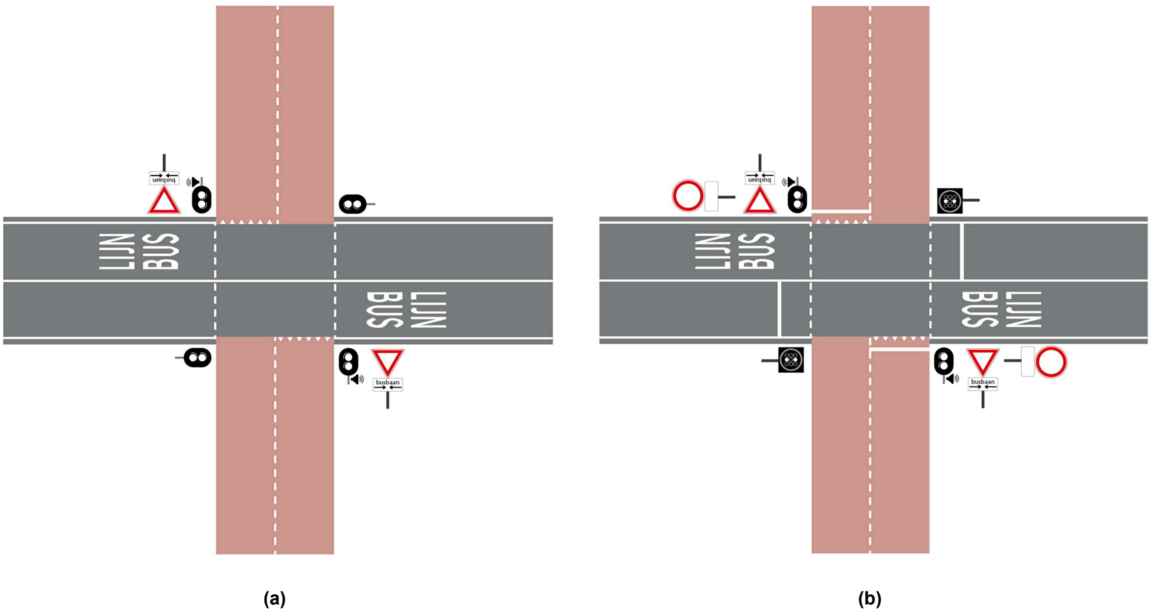


Figure A.10: Bicycle crossing across dedicated bus lanes with bus warning light installationCROW (2020) (§ 11.3.5)

This is a design for a bicycle crossing across dedicated bus lanes with bus warning light installation (see Figure A.11 and Table A.11).

Table A.11: Bicycle crossing across dedicated bus lanes with bus warning light installationCROW (2020) (§ 11.3.6)

Function	Crossing for bicycle traffic
Application	Access roads and distributor roads in- and outside urban areas
Implementation	Also apply priority regulated in case the traffic light does not work Crossing marked with canalisation stripes Do not apply block markings Apply shark's teeth and place sign B6 Crossing preferably perpendicular to bus lanes Permanently in use while buses are running
Considerations	Limited loss of travel time for the bus Green light for bicycle traffic in unless a bus is approaching
Combination possibilities	Pedestrian crossing Bus stops after the crossing
Alternatives	Bicycle crossing with priority regulation Bicycle crossing with warning lights

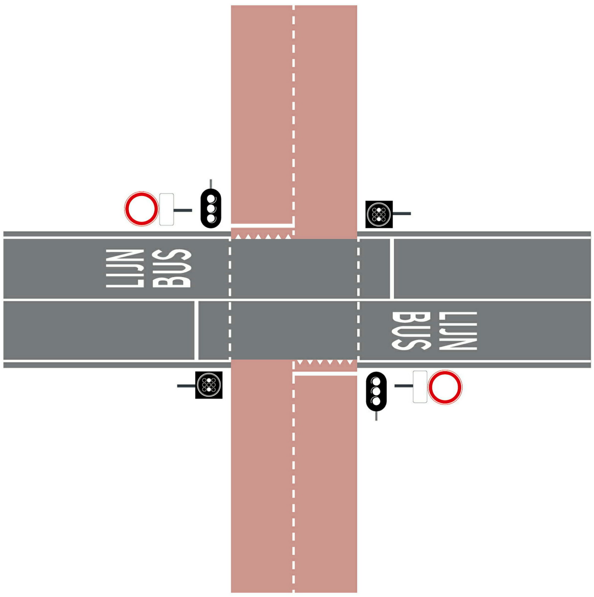


Figure A.11: Bicycle crossing across dedicated bus lanes with bus warning light installationCROW (2020) (§ 11.3.6)

In Figure A.12 a base design for a priority regulated intersection of two distributor roads with median tram lanes is shown. The design includes tram warning lights that warn other road users when a tram is passing. Turning traffic might have limited vision on the tram. If there is a turning lane for turning traffic, straight-going traffic can continue going parallel to the tram lanes when a tram is passing. When there is no tram, the intersection functions as a regular priority regulated intersection.

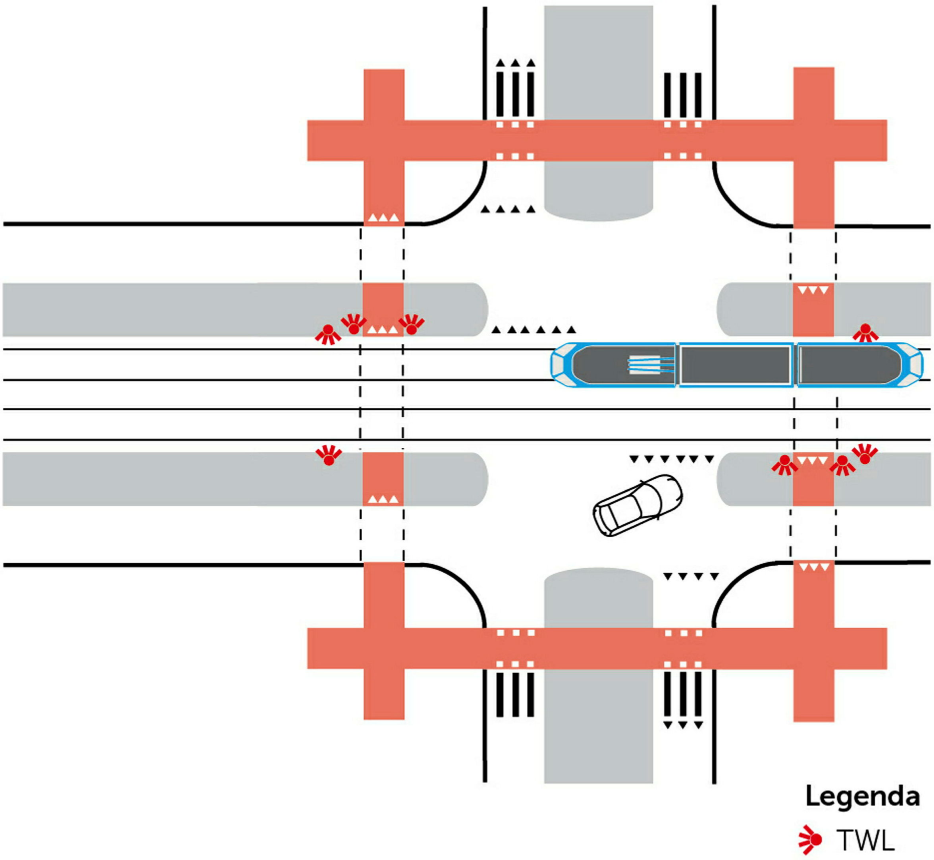


Figure A.12: Base design for priority regulated intersection of two distributor roads with median tram lanes CROW (2022b) (§ 13.2.4)

When there is limited vision, a complex traffic situation or high traffic intensity, it can be safer to apply a traffic light regulated intersection instead (see Figure A.13).

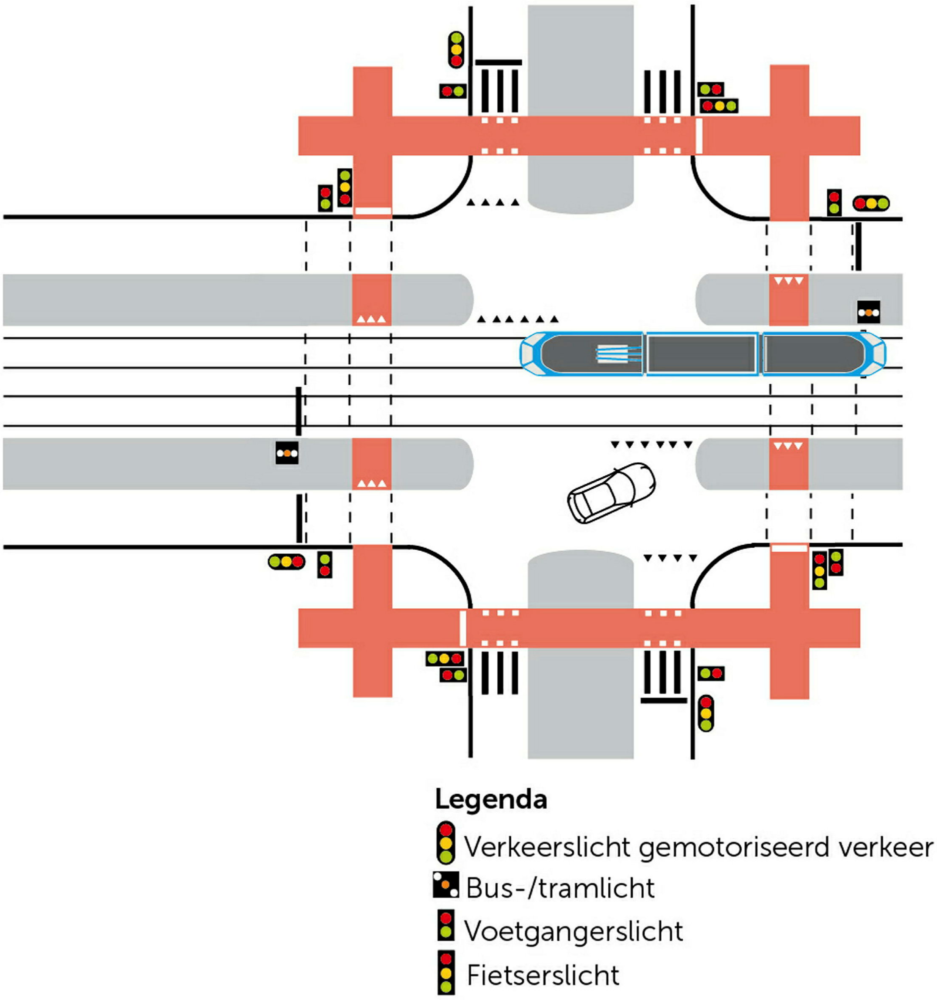


Figure A.13: Base design for traffic light regulated intersection of two distributor roads with median tram lanes CROW (2022b) (§ 13.2.4

Trams often cross access roads at points where these connect onto distributor roads. In these situation the priority is indicated using an exit configuration. In Figure A.14 the base design for such a connection onto a distributor road with median tram lanes is shown. In Figure A.15 the base design for a distributor road with side separated tram lanes is shown. In both designs there should be enough waiting space (around 5 metres) for turning traffic, so that straight-going traffic can continue parallel to the tram lanes. In the same way traffic from the access road can wait safely before and after the tram lanes when entering the distributor road. When there is too little space, traffic to and from the access road can block the passage of trams and other traffic.

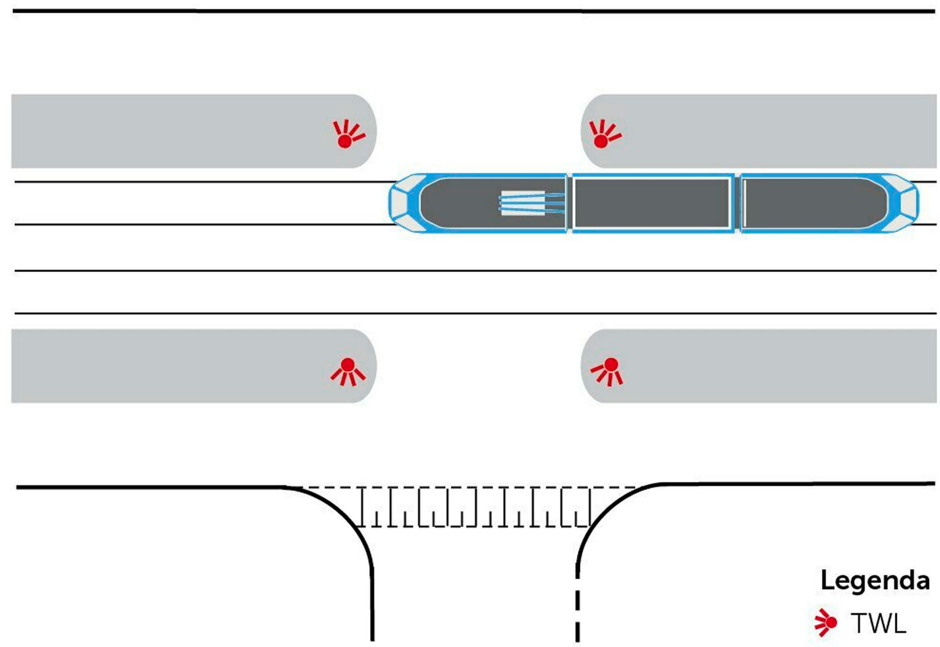


Figure A.14: Base design for a connection of an access road to a distributor road with median tram lanes CROW (2022b) (§ 13.2.5)

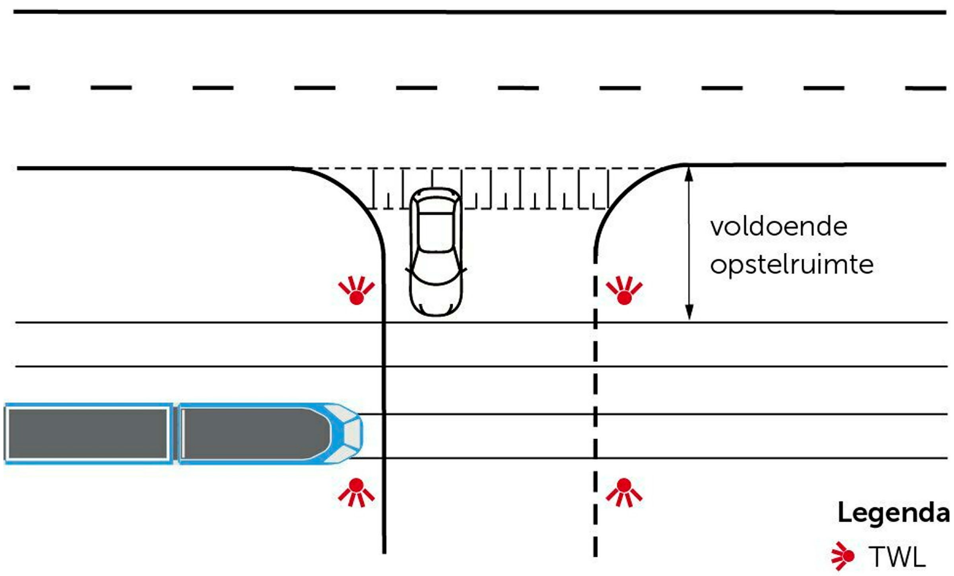


Figure A.15: Base design for a connection of an access road to a distributor road with side separated tram lanes CROW (2022b) (§ 13.2.5)

When a tramway switches from a location in the median to a location at the side of the road, the tram makes an S-turn on the intersection. A warning to other road users is necessary, because this movement is unexpected. Therefore traffic light regulation is preferred for such a situation. In Figure A.16 a base design for this situation is shown.

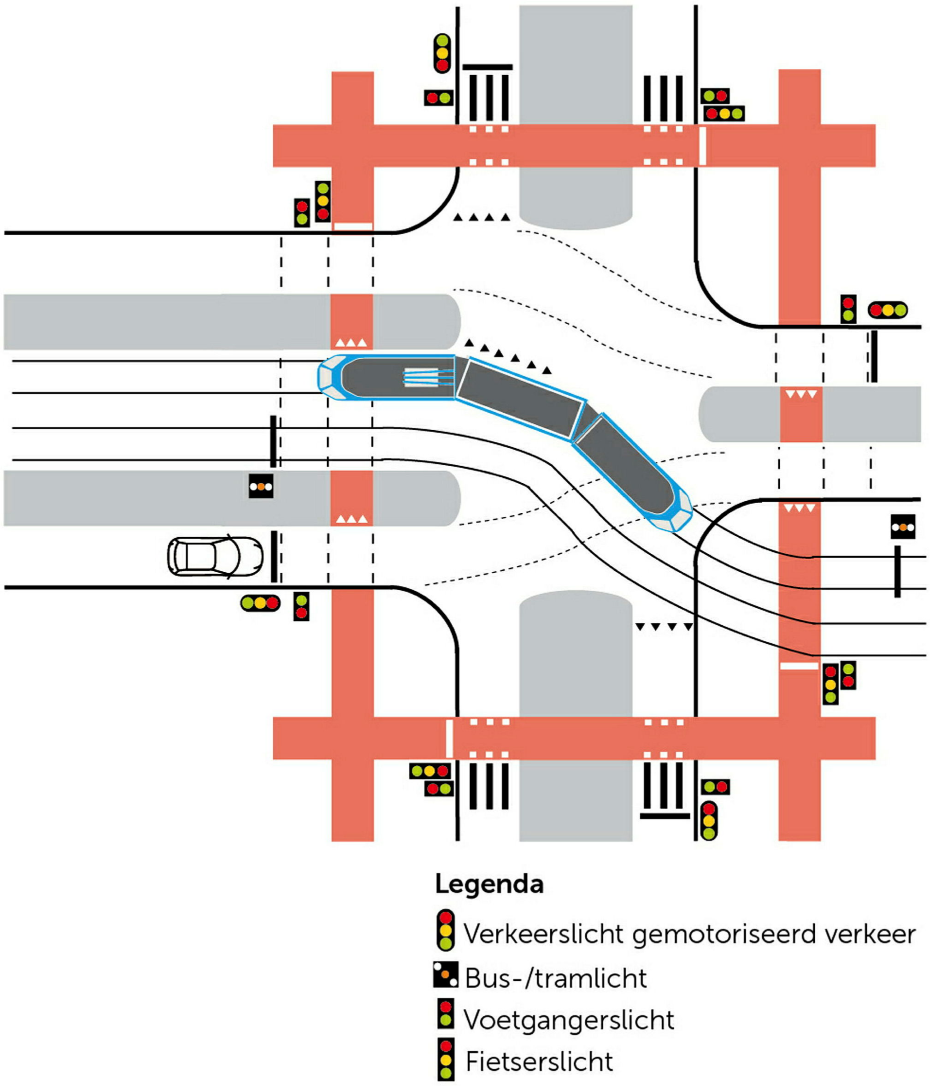


Figure A.16: Base design for a connection of an access road to a distributor road with side separated tram lanes CROW (2022b) (§ 13.2.6)

A tram can also make turns on or off the road further away from intersections. In Figure A.17 a base design is shown for when tram lanes turn off a road into a dedicated tramway. In this design the intersection is far away enough that it does not influence the design of the tram lanes. Two coloured traffic light regulate the priority for the tram.

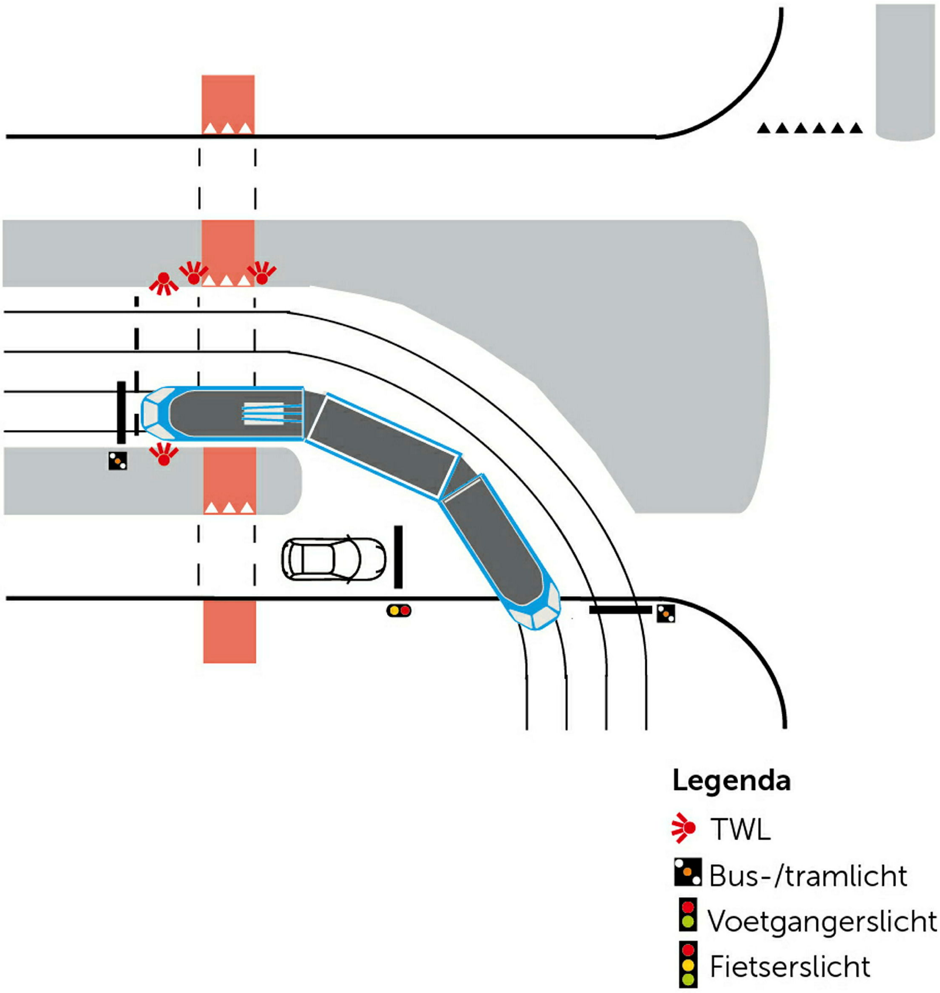


Figure A.17: Base design for a connection of an access road to a distributor road with side separated tram lanes CROW (2022b) (§ 13.2.7)

In Figure A.18 the base design for a turning tram from a distributor road with median tram lanes to another distributor road with median tram lanes is shown. In this case traffic light ensure a safe traffic handling.

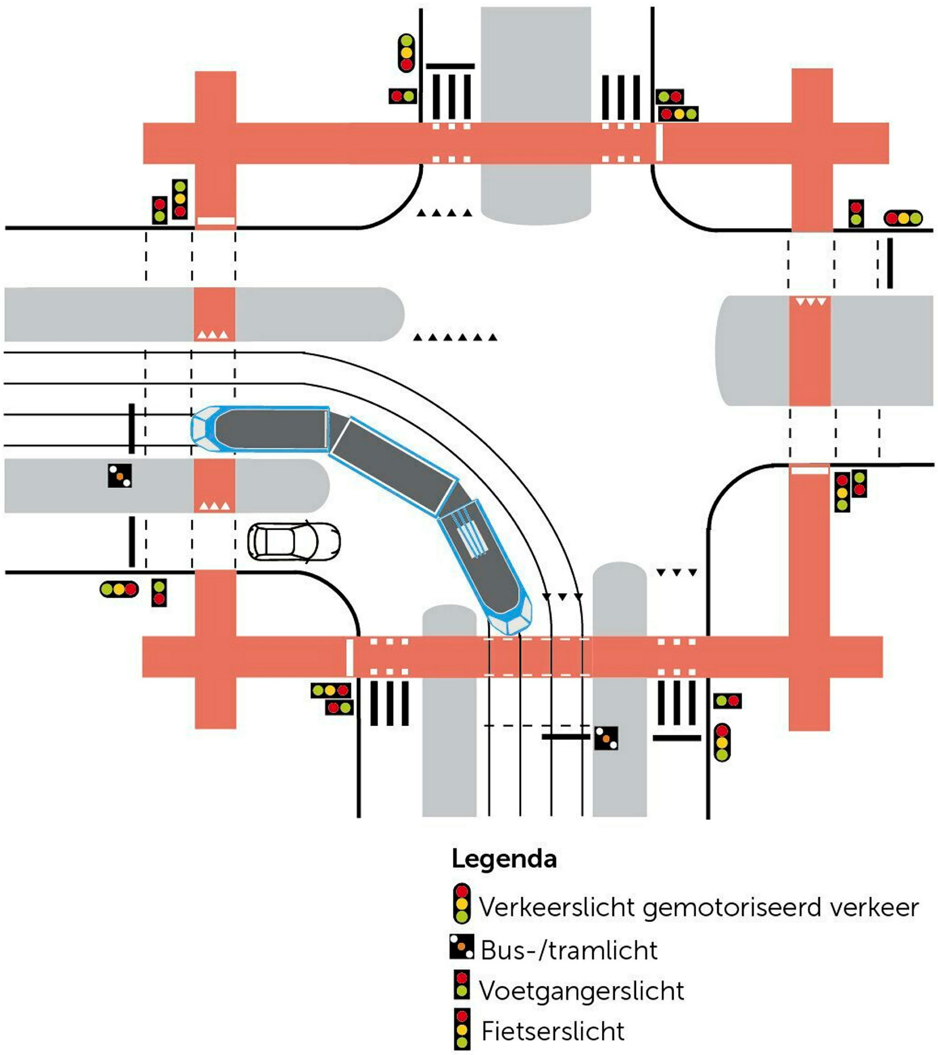


Figure A.18: Base design for turning tram lanes from median tram lanes to median tram lanes CROW (2022b) (§13.2.7)

At intersections tramways can also turn from a location in the median to a location at the side on the crossing road. In such cases traffic lights should be used to regulate the intersection safely. In Figure A.19 a base design is shown for trams turning from the median to the side before an intersection. Two coloured lights regulate the priority for the tram. The lights should be integrated with traffic lights for the intersection if the traffic volume on the intersection demands it.

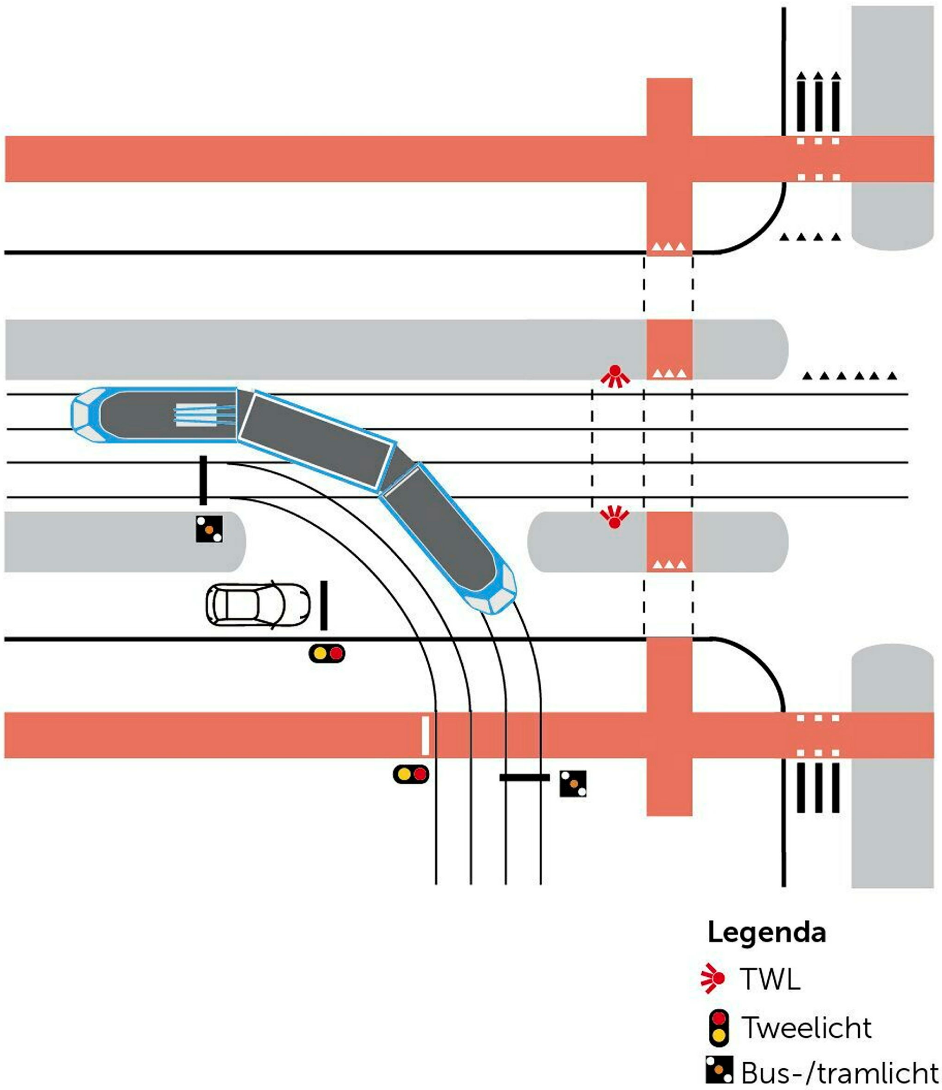


Figure A.19: Base design for turning tram lanes from median tram lanes to median tram lanes CROW (2022b) (§13.2.7)

In Figure A.20 a base design for trams turning from the median to the side after an intersection is shown. In this case traffic lights regulate the safe handling of traffic at the intersection.

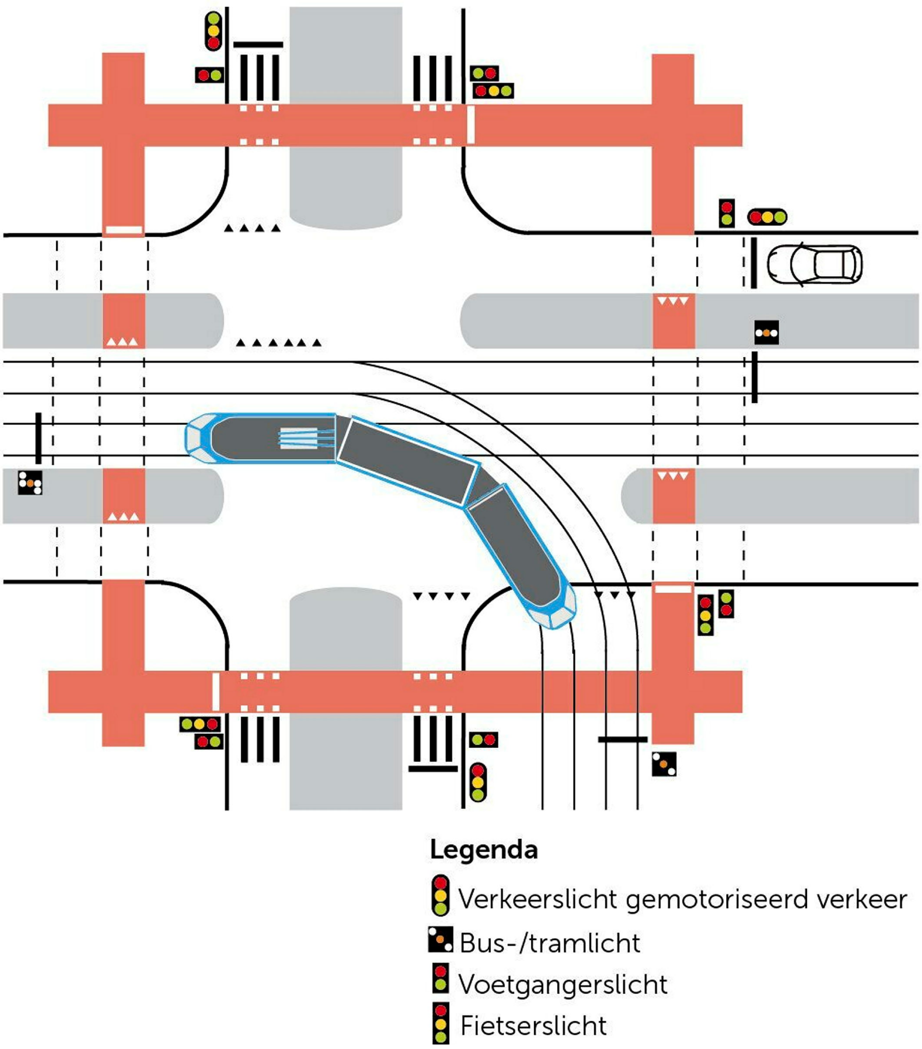


Figure A.20: Base design for turning tram lanes from median tram lanes to median tram lanes CROW (2022b) (§13.2.7)

At crossings for slow traffic over a combination of general traffic lanes and tram lanes, it is preferred to have a waiting area at a median. This makes for a safer crossing for pedestrians and bicycle traffic. In Figure A.21 and Figure A.22 a base design for a slow traffic crossing with median tram lanes and side separated tram lanes respectively is shown.

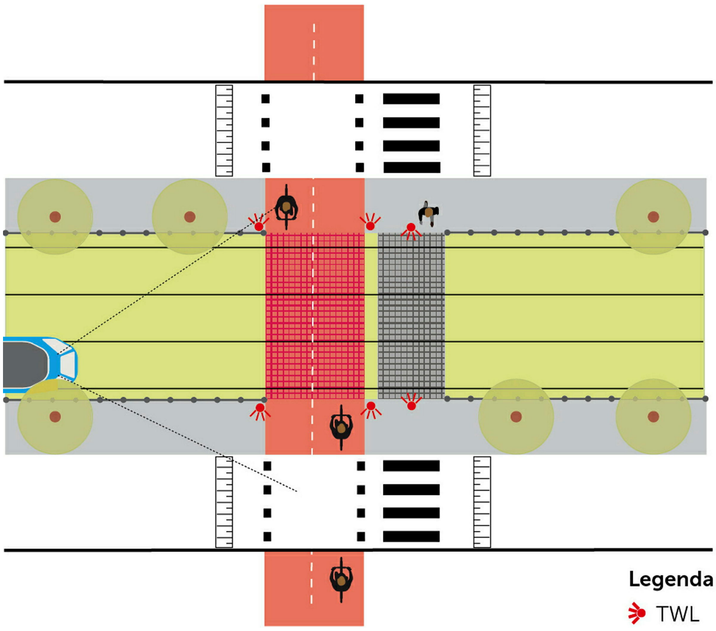


Figure A.21: Base design for slow traffic crossing a distributor road with median tram lanes CROW (2022b) (§13.2.9)

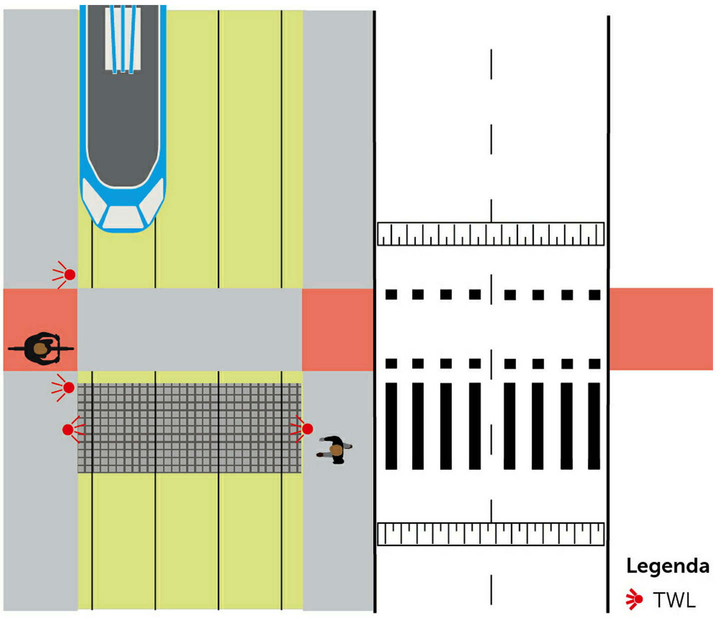


Figure A.22: Base design for slow traffic crossing a distributor road with side separated tram lanes CROW (2022b) (§13.2.9)

B

Appendix B

In this appendix all the street cross-section profile alternatives from the development of concepts (see chapter 7 are shown for each design section. The variants labelled as 0 are the current situation.

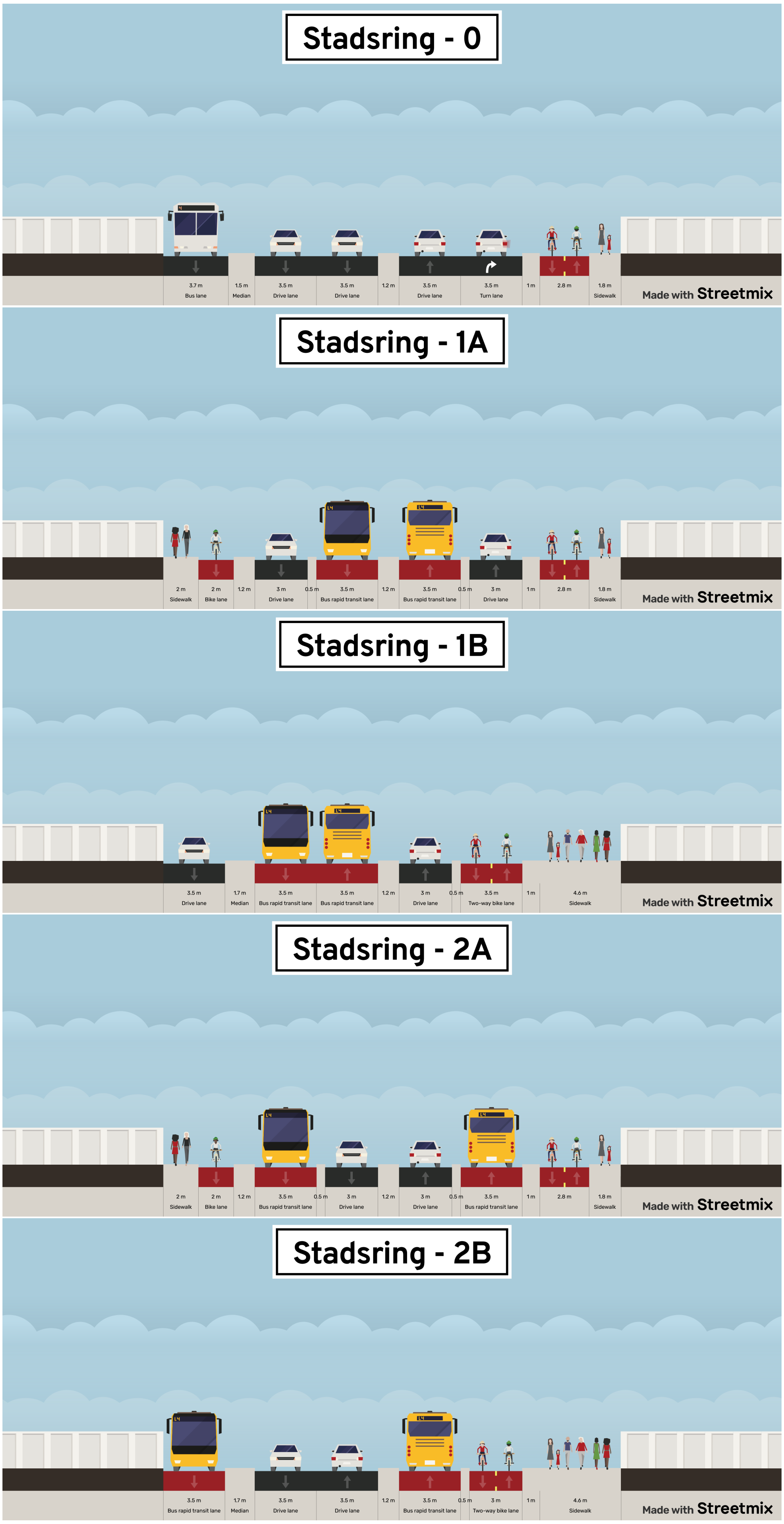


Figure B.1: The design alternatives 0-2B for the Stadsring

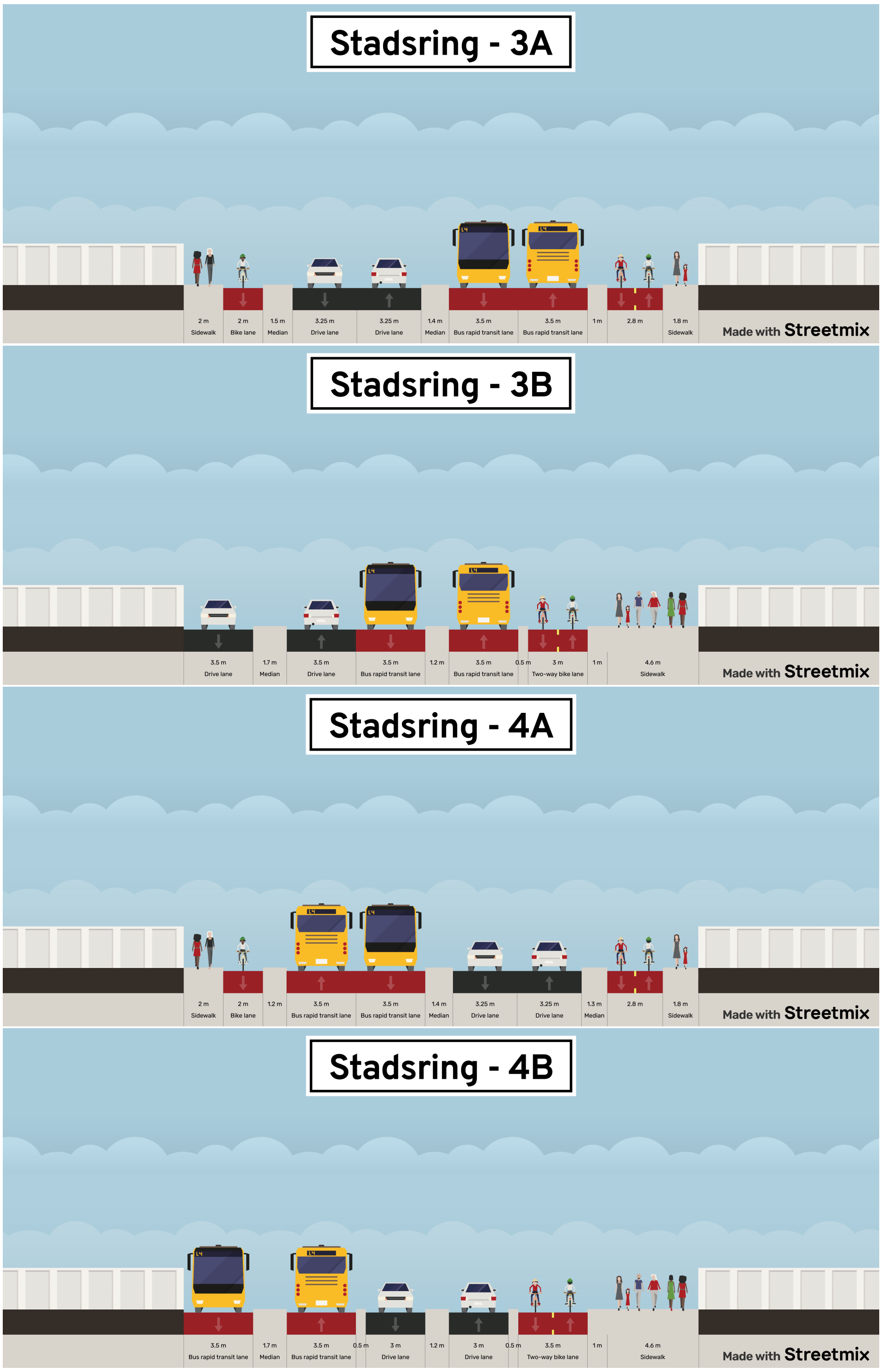


Figure B.2: The design alternatives 3A-4B for the Stadsring

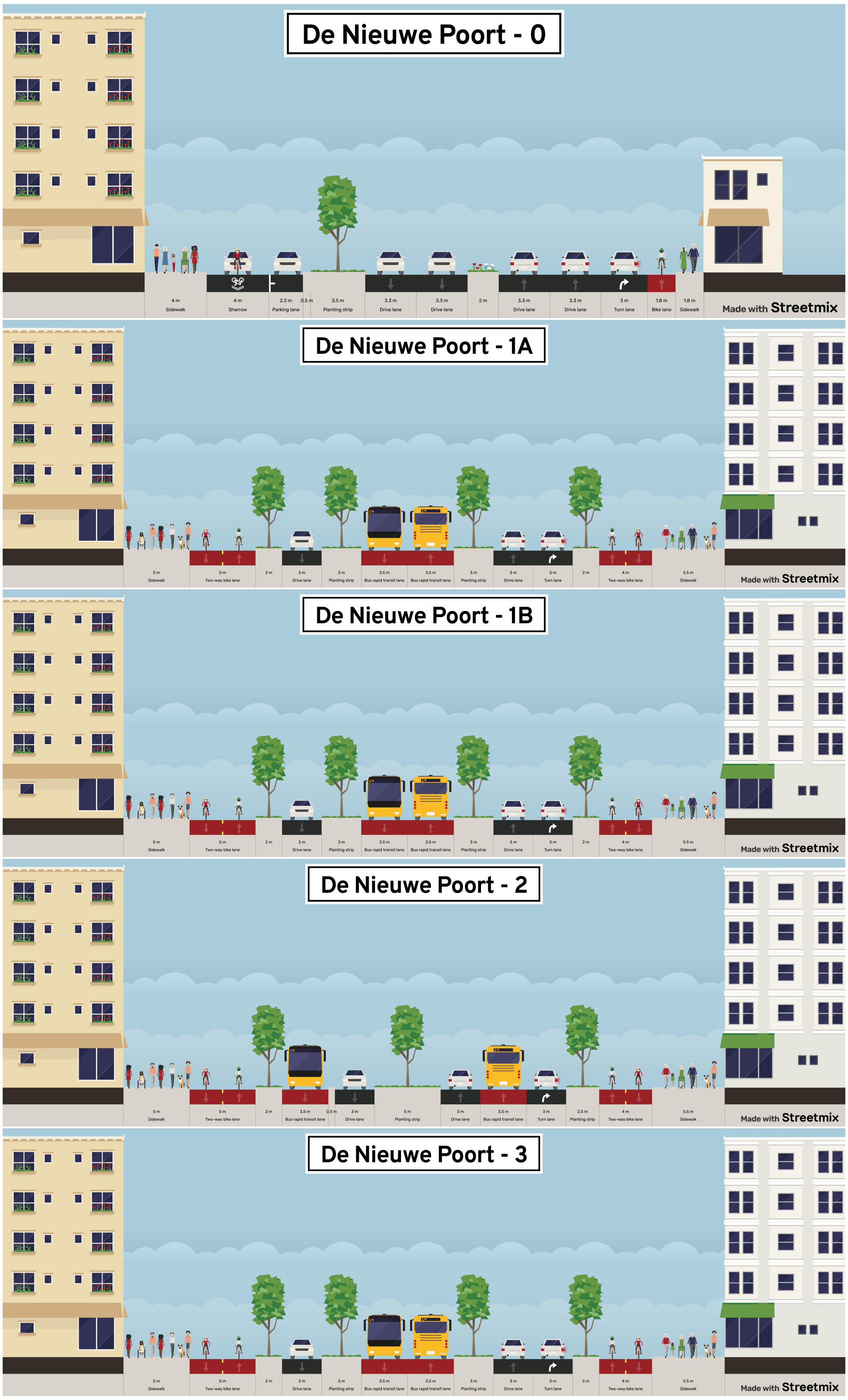


Figure B.3: The design alternatives for De Nieuwe Poort

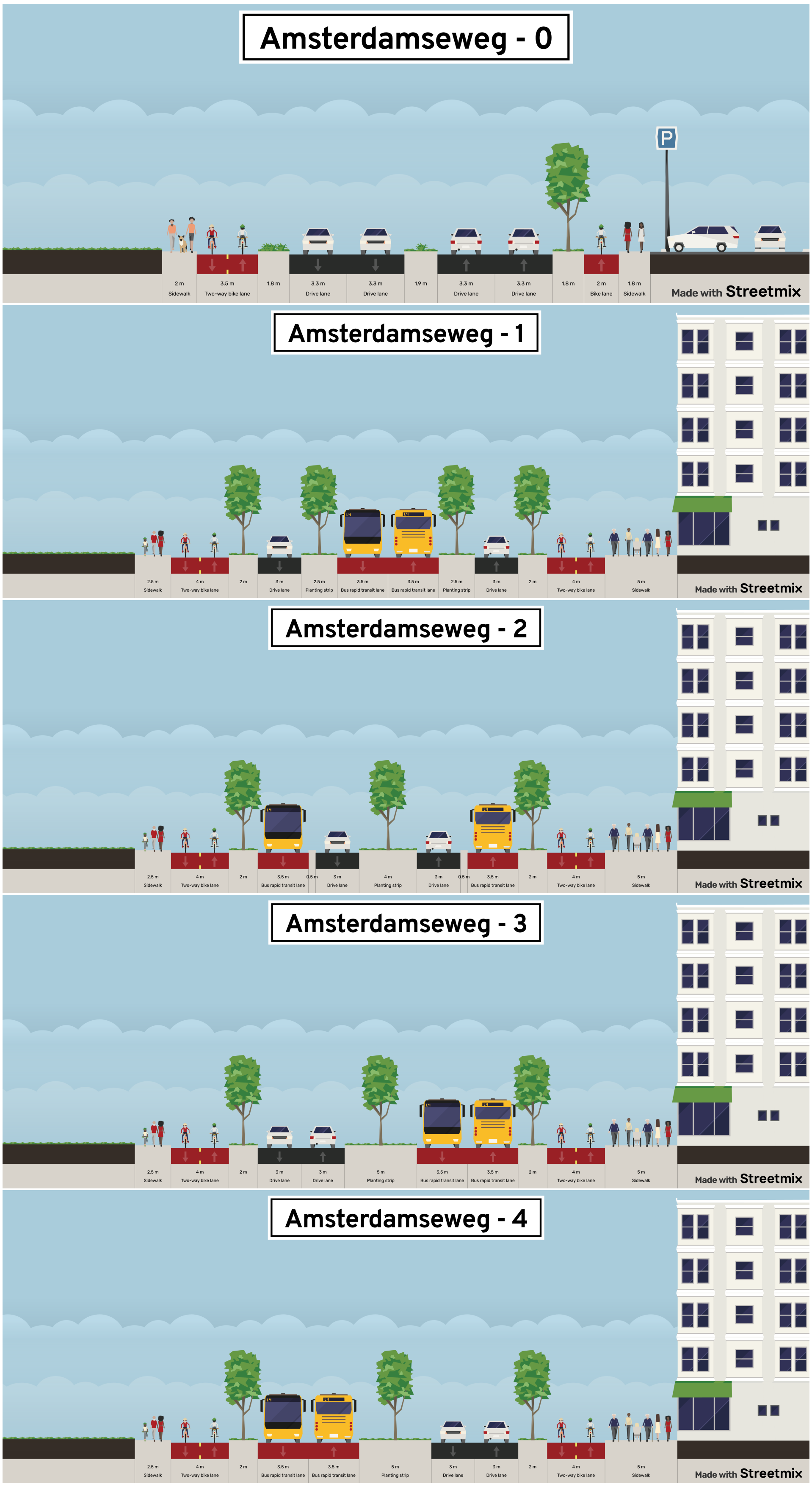


Figure B.4: The design alternatives for the Amsterdamseweg

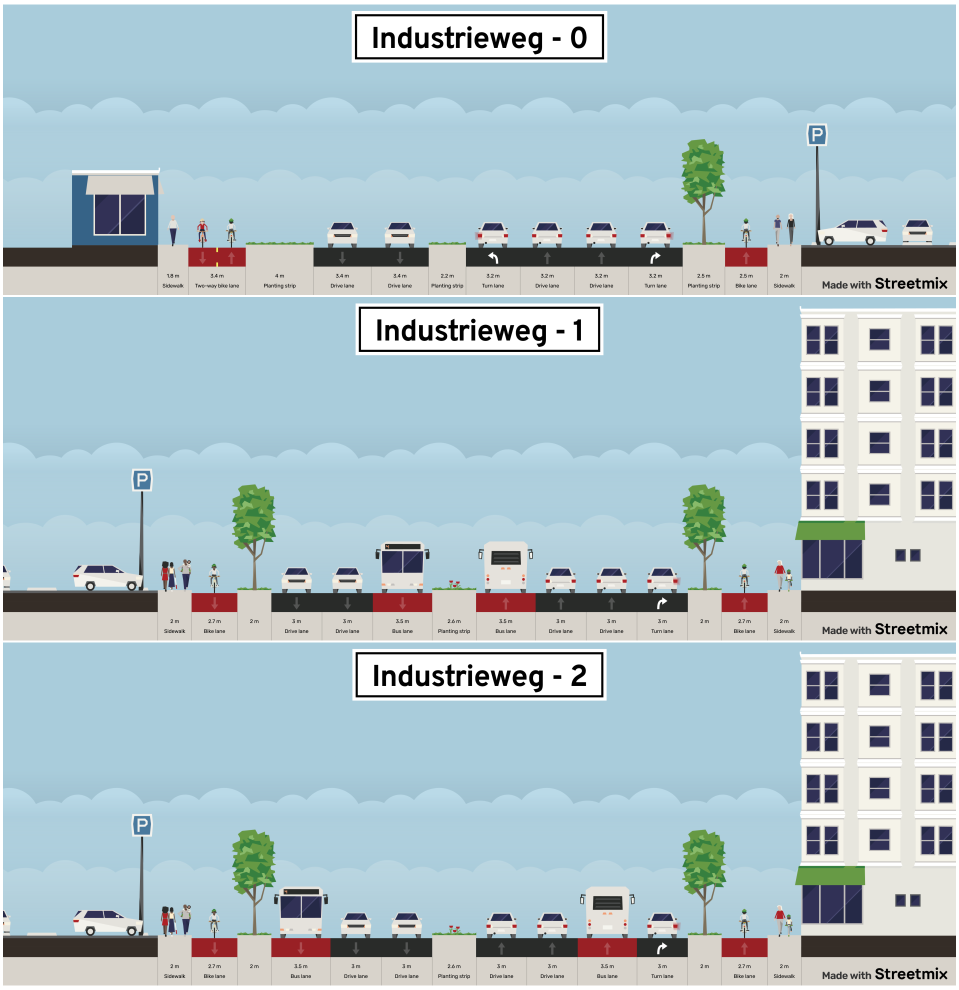


Figure B.5: The design alternatives for the Industrieweg

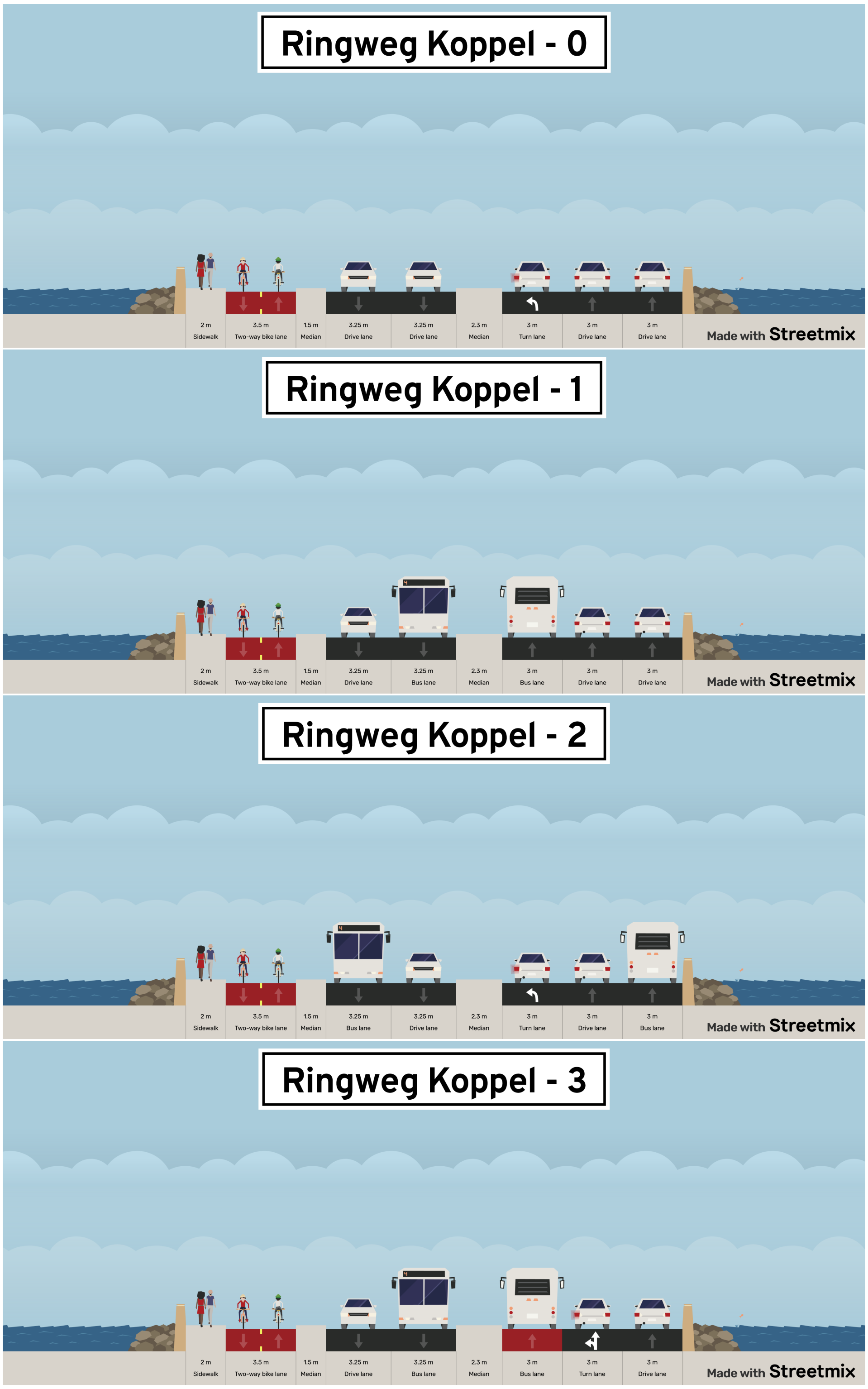


Figure B.6: The design alternatives 0-3 for the Ringweg Koppel

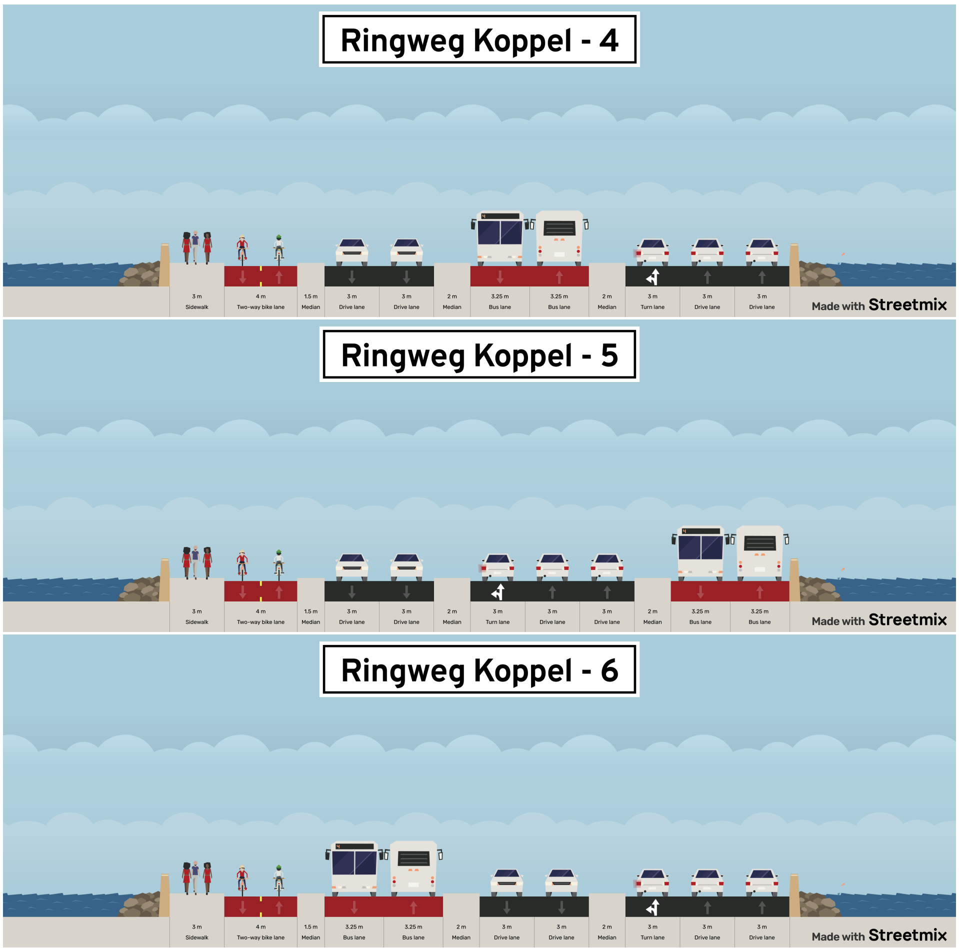


Figure B.7: The design alternatives 4-6 for the Ringweg Koppel

C

Appendix C

In this appendix all the boundary condition street cross-section profiles (see section 5.4) are shown.

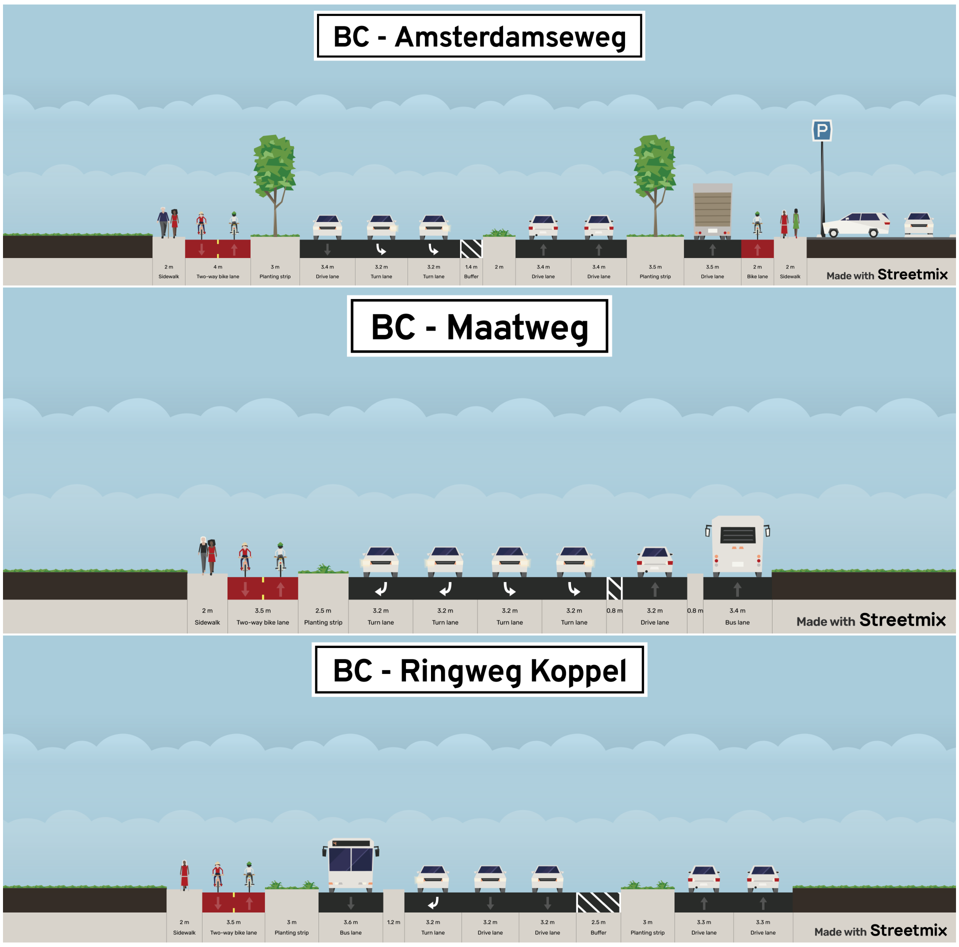


Figure C.1: The boundary conditions on a similar level in the road structure

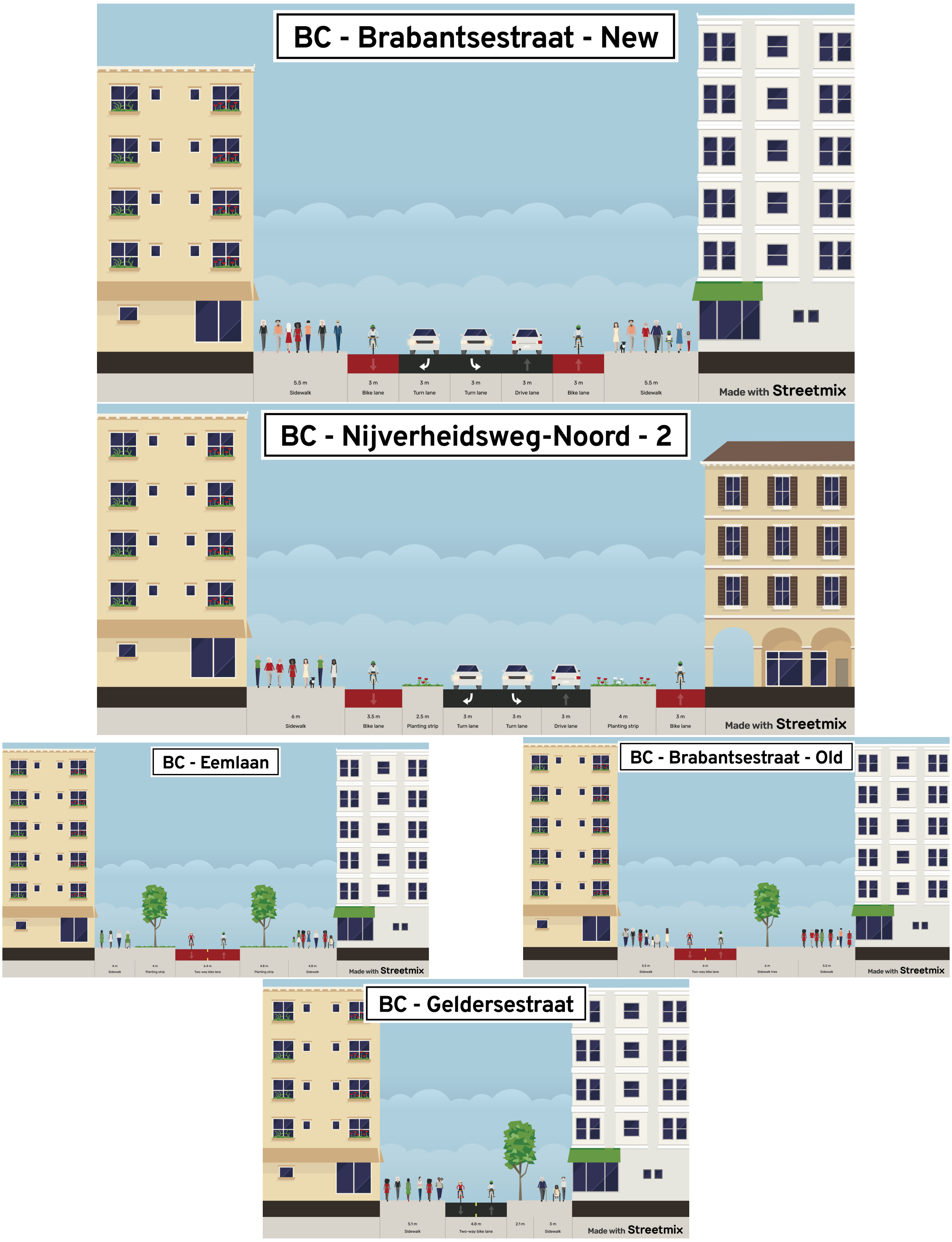


Figure C.2: The boundary conditions connecting into the LES-area

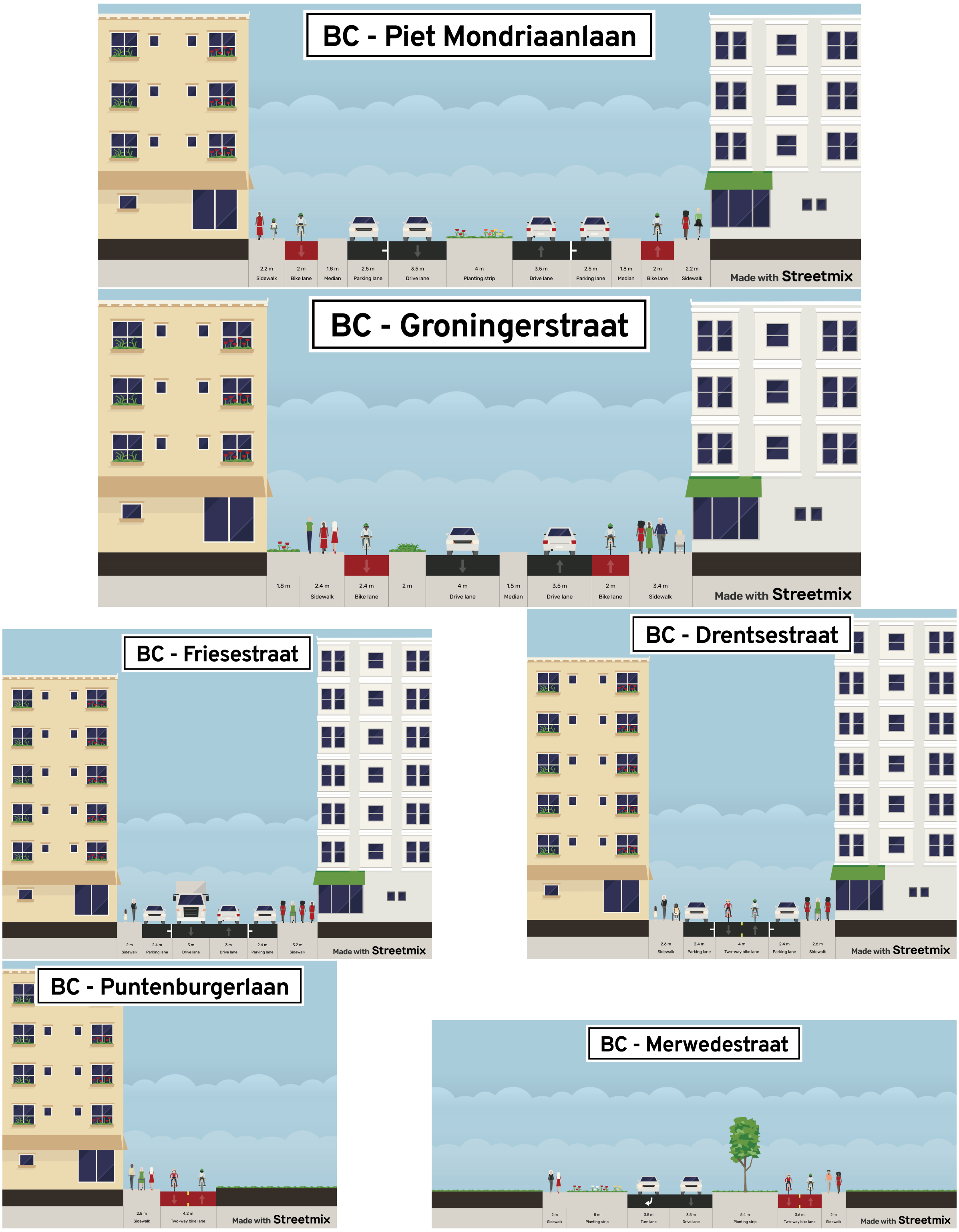


Figure C.3: The boundary conditions connecting into the Soesterkwartier

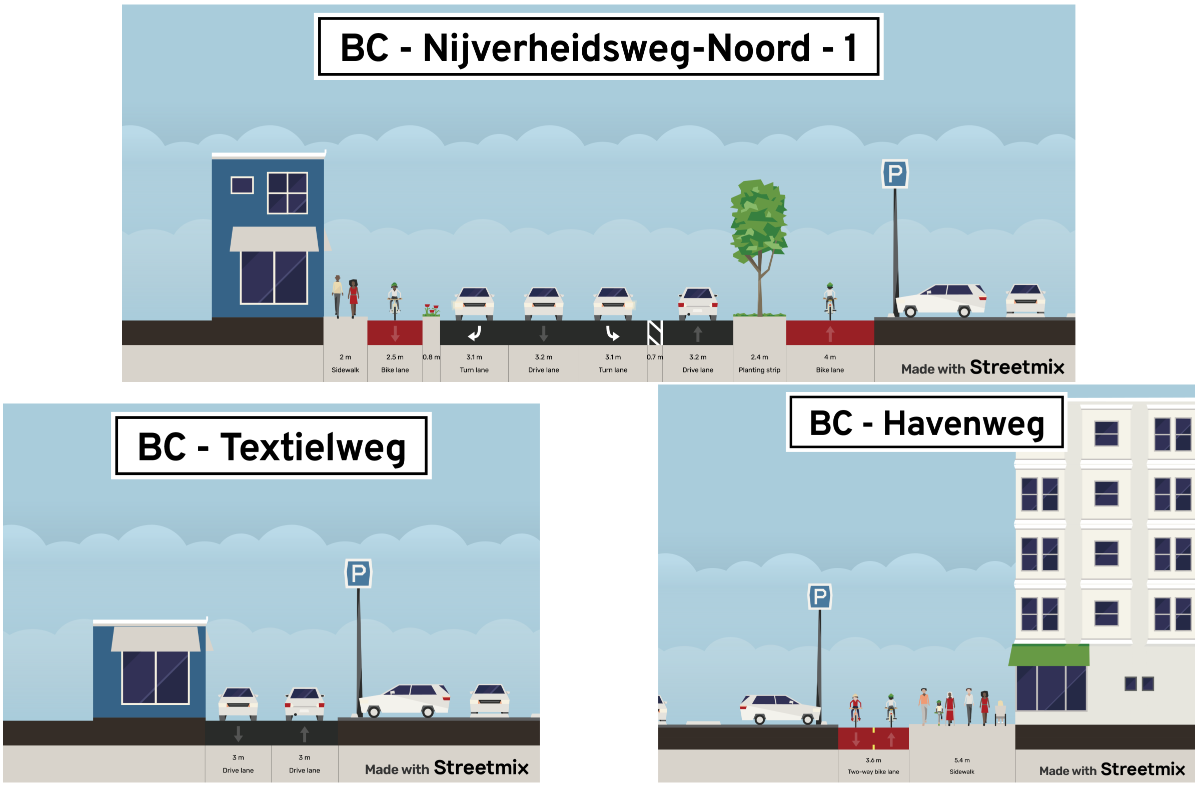


Figure C.4: The boundary conditions connecting into the Isselt

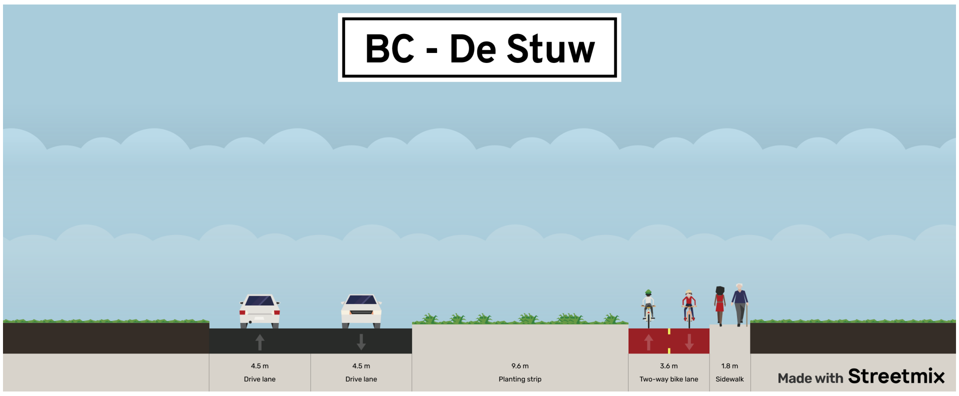


Figure C.5: The boundary condition north of the river Eem

D

Appendix D

This appendix describes in more detail how certain elements of the traffic model in Paramics Discovery 28 were built and used. The elements are the traffic light modelling and the modelled traffic demand.

D.1. Traffic light modelling

When an intersection is designed with traffic light regulation, the phases of the traffic light must also be assigned and modelled. The number of traffic light phases that are required depends on the number and type of connections that the intersection allows for. The number of phases will be kept as low as possible to reduce the complexity of the traffic lights. To determine the required number of phases a schematic drawing of an intersection is made in which all directions that the traffic light facilitates are shown. Using such a drawing the conflicts between different directions can be determined.

In one phase multiple non-conflicting directions at the traffic light are given green at the same time. For example, at a simple three-way junction, where a road from the east connects to a north south road, one phase could have, straight traffic north-south, straight traffic south-north and turning traffic south-east. A second phase could then have turning east-north and turning east-south traffic. In this way phases are added and combined until all directions are facilitated in a phase without conflict. The phases follow a standardised order in which they are continuously cycled through.

Each phase consists of three steps; the green-light step, the yellow-light step and the red-light step. All directions that are not included in a phase are shown red during the entire length of the phase.

The green-light step is the most important step of the phase. During this step the traffic can drive freely. The length of this step can be determined dynamically based on the demand. This is done using detection loops, which can also be modelled in Paramics. In principle, the step in lengthened as long as traffic is detected to be using the directions of the phase. A maximum length of this step is given, because otherwise this step could go on indefinitely when demand is very high. The maximum duration will be chosen between 20 and 60 seconds depending on the demand. This range is commonly in use within the municipality of Amersfoort. A minimum length of this step is also given at 6 seconds (CROW, 2022a). This is used so that the traffic light remains predictable and does not change colour too frequently in case of minimal traffic.

The yellow-light step comes after the green light step. This step is included to ensure a safe transition from green to red light. The step is taken to last 5 seconds, which is given by CROW (2022a) for the worst case scenario.

Finally there is the red-light step. During this step all traffic at the intersection is shown a red light. This step gives buffer time between two phases to ensure that traffic from the previous phase has completely cleared the intersection before the next phase starts with the green-light step. Depending on the length of the paths over the intersection that were used in the previous phase, this step lasts between 1 and 6 seconds (CROW, 2022a). If the paths were short then traffic will clear the intersection faster than if the paths were long. This determines what duration the red-light step needs to be.

Because the design will introduce dedicated bus infrastructure to ensure a high quality bus service, bus priority at intersections is also vital. Therefore an extra dedicated bus priority phase is added to the traffic lights. This phase does not occur in the regular cycle of phases and is only activated when a bus is detected. The presence of the bus is determined using a detector loop over the bus lane. This detector loop is located around 200 metres before the traffic light to ensure that there is enough time to end the current phase and clear the intersection before the bus arrives there. It takes the a bus travelling at 50 km/h around 15 seconds to travel 200 metres. The bus will thus get an immediate green phase upon its arrival at the traffic light. After the bus has passed the traffic light can then continue with its regular phases. Next to the direction that the bus takes over the intersection, several other directions that do no conflict with the bus may also be green-lit during the phase priority phase.

D.1.1. Traffic lights in the model

Within the design area there are four intersections that are regulated with traffic lights. They are:

- Amsterdamseweg - Brabantsestraat
- Amsterdamseweg - Industrieweg
- Industrieweg - Nijverheidsweg-Noord
- Ringweg Koppel - Maatweg

These intersections are all also present in the redesign because the streets that intersect with the design area are considered boundary conditions. The first intersection between the Amsterdamseweg and the Brabantsestraat is moved slightly westward and the relocated Brabantsestraat is called Nieuwe Brabantsestraat. Below the design of each of the traffic lights is given. All phases are shown with the directions that are facilitated during each phase. For all intersections both design variants for the intersection are given. Because both design variants allow for the same directions, the phases are the same for both design variants. The traffic lights at each intersection thus behave identical to the traffic lights at the same intersection in the other design variant.

Amsterdamseweg - Nieuwe Brabantsestraat

The first intersection is between the Amsterdamseweg and the Nieuwe Brabantsestraat. This intersection is the simplest intersection, because it is a three-way intersection, where all the others are four way intersections. It only needs three phases to facilitate all its directions (see Figure D.1. The first phase has the green light for bus traffic. This phase is thus also used as the bus priority phase. The other two phases allow traffic from the Nieuwe Brabantsestraat access to the Amsterdamseweg.

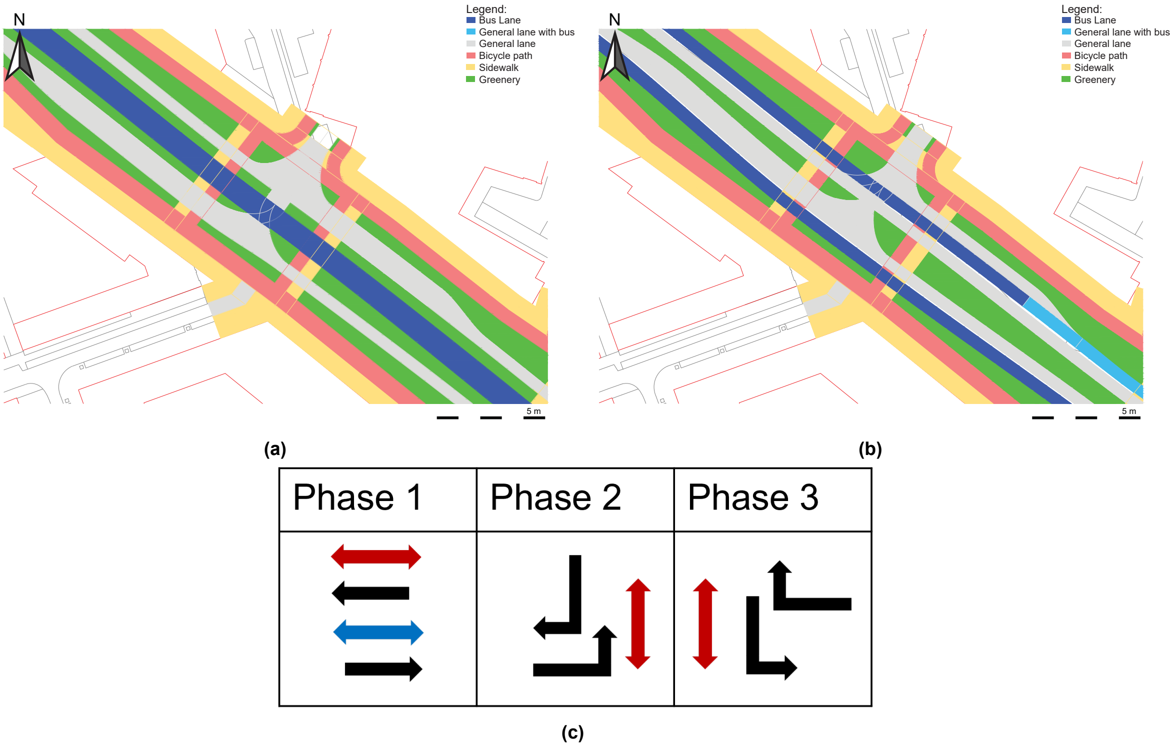


Figure D.1: A schematic indication of the traffic light phases at the intersection Amsterdamseweg - Nieuwe Brabantsestraat

Amsterdamseweg - Industrieweg

The second intersection is between the Amsterdamseweg and the Industrieweg. This intersection lies right in between the two design areas and connects them. The two designs that are included in the traffic model connect design variant 1 for design area 1 with design variant 1 for design are 2 and connect design variant 2 for design area 1 with design variant 2 for design area 2. The other two possibilities were not included in the traffic model due to time constraints. The intersection needs four phases to facilitate all directions (see Figure D.2). The first phase has the green light for bus traffic. This phase is thus also used as the bus priority phase. The second and third phases facilitate the other important directions for general traffic. The fourth phase allows traffic from the neighbourhood south of the intersection access to the Amsterdamseweg and the Industrieweg.

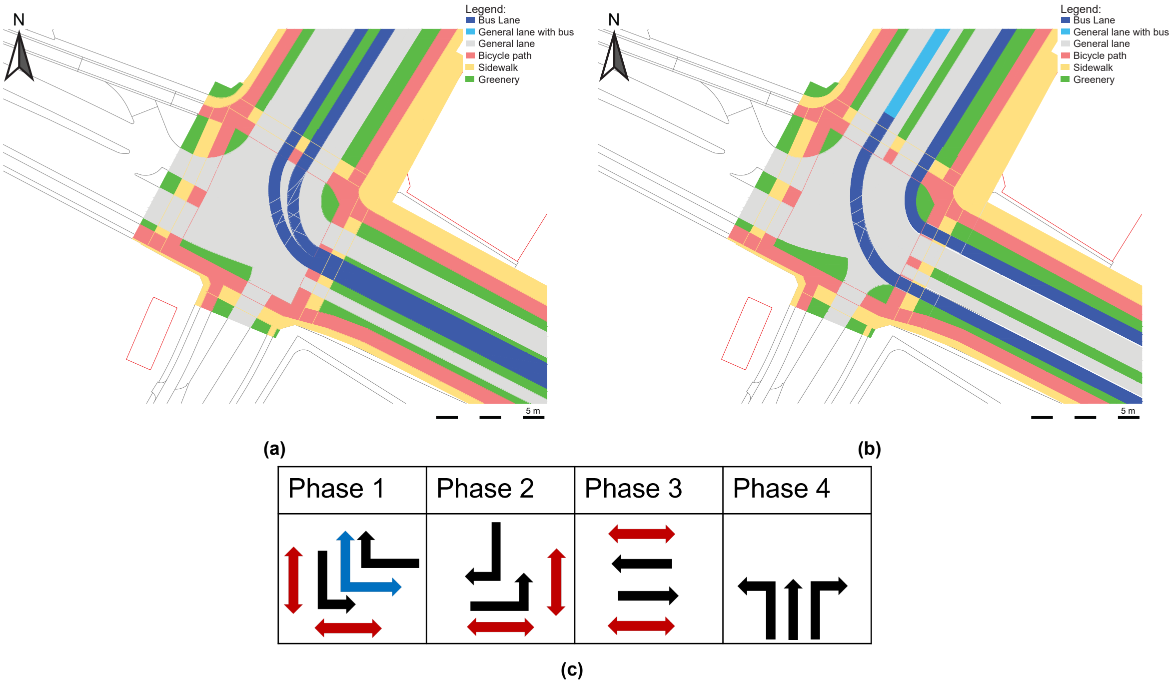


Figure D.2: A schematic indication of the traffic light phases at the intersection Amsterdamseweg - Industrieweg

Industrieweg - Nijverheidsweg-Noord

The third intersection is between the Industrieweg and the Nijverheidsweg-Noord. This intersection requires four phases to facilitate all directions (see Figure D.3). The first phase has the green light for bus traffic. This phase is thus also used as the bus priority phase. The second and third phases facilitate the connection with the new development in the LES-area, east of the intersection. The fourth phase allows traffic from the Isselt neighbourhood west of the intersection access to the Industrieweg.

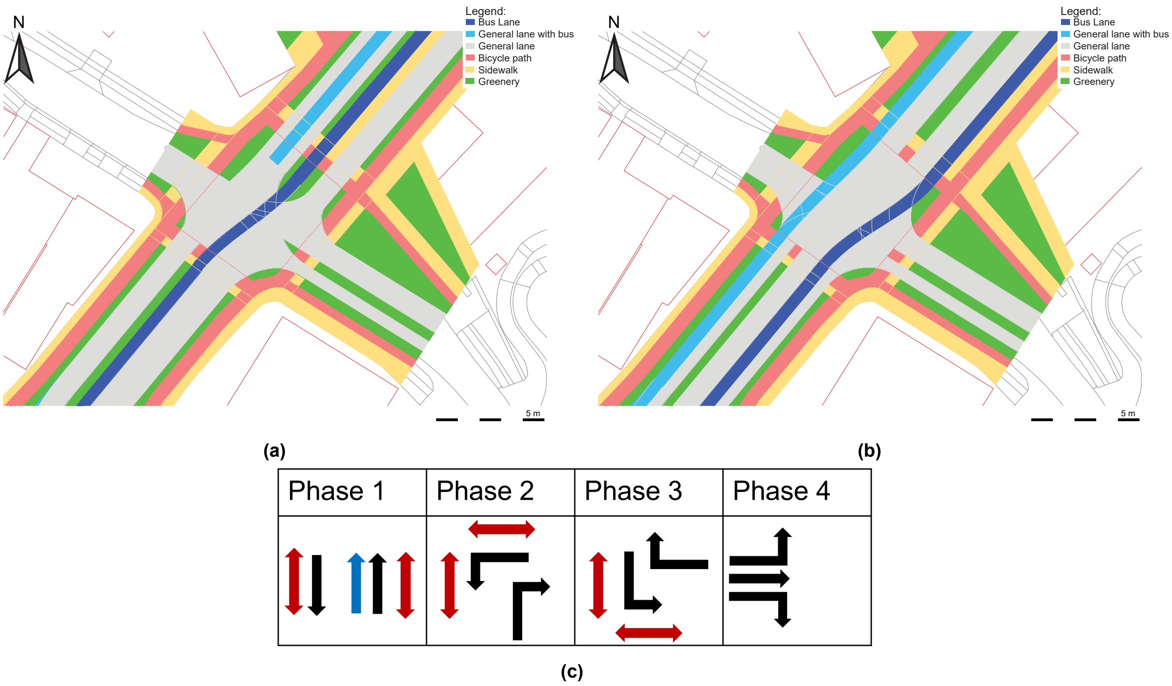


Figure D.3: A schematic indication of the traffic light phases at the intersection Industrieweg - Nijverheidsweg-Noord

Ringweg Koppel - Maatweg

The final intersection is between the Ringweg Koppel and the Maatweg. This intersection lies at the end of the design area. This intersection requires four phases for all directions to be facilitated (see Figure D.4). The first phase has the green light for bus traffic. This phase is thus also used as the bus priority phase. The second and third phases facilitate the other important directions for general traffic. The fourth phase allows traffic from the street south of the intersection access to the Ringweg Koppel and the Maatweg.

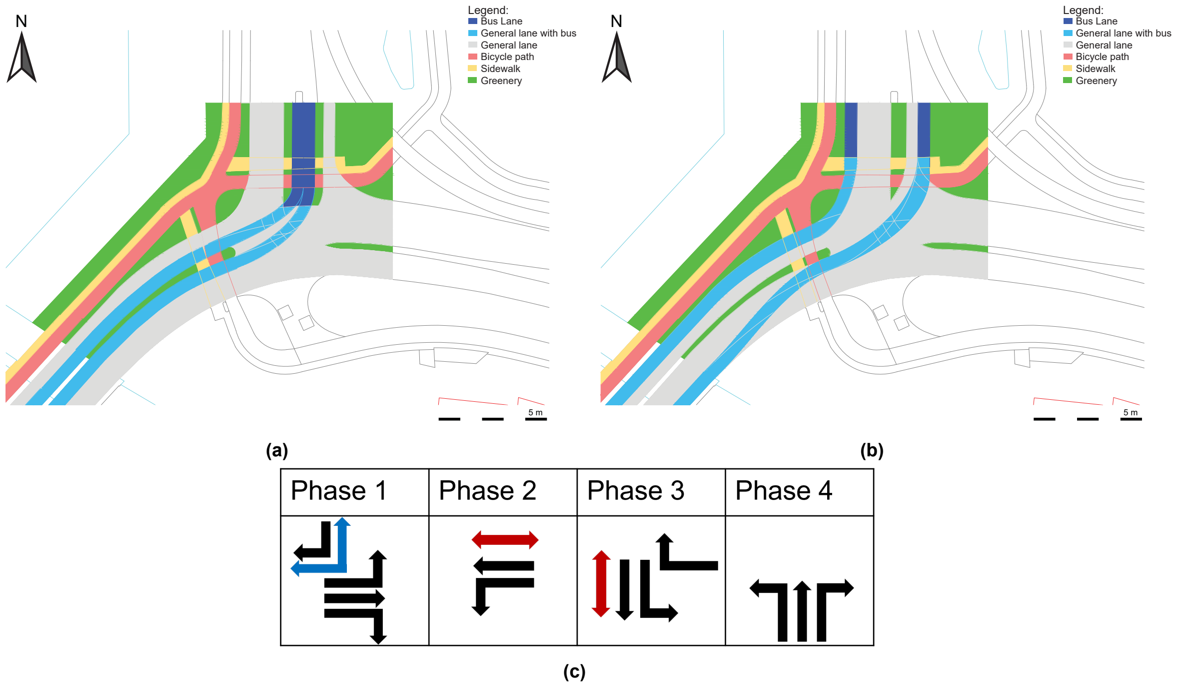


Figure D.4: A schematic indication of the traffic light phases at the intersection Ringweg Koppel - Maatweg

D.2. Modelled traffic demands

To model the traffic volumes in 2035, the demand in 2035 must be predicted for all modes of travel that are included in the model. For each of these a different data source within the municipality was used. The data from an average weekday peak hour was used (or the data was converted to peak-hour data), to create a peak-hour model. This was done because of time constraints and because the educational license of the software does not allow for day-round models. The data then had to be converted into a format that the Paramics software can use to load traffic into the model.

For general traffic and bicycle traffic this is done using origin-destination-matrices. The origin-destination-matrices show the number of vehicles that are predicted to travel from one traffic loading zone to another. The software then knows how many vehicles it has to model to travel from one traffic loading zone to another traffic loading zone. The traffic loading zones are at the edges of the design area and correspond to the boundary conditions as defined in section 5.4. The traffic loading zones differ per traffic mode. They are shown in Figure D.5. The names of the traffic loading zones are given in Dutch as 'Auto' 1-15 and 'Fiets' 1-18. The 'Auto' traffic loading zones are for general traffic and the 'Fiets' traffic loading zones are for bicycles. In most cases a general traffic loading zone and a bicycle traffic loading zone correspond to one boundary condition.

For bus traffic the data must be formatted as a public transport schedule. The public transport schedule shows at what time a bus should enter the model. The schedule also includes bus lines and travel directions, which indicate where the bus has to be loaded into the model and what route it has to take through the network, including where it should stop.

Figure D.5: Modelled origins and destinations in the traffic model

General traffic

The municipality has recently conducted a city-wide general traffic model for a predication for 2035. This model was conducted for day round traffic volumes, the morning peak and the evening peak. The evening peak showed the highest hourly traffic volumes. The hourly evening peak traffic intensities from this city-wide model were thus used as the input for the models of the redesigned design area. At each boundary condition the calculated traffic intensity in the city-wide model is taken. This traffic intensity value can then be used as the input for the design area models.

For example, if 2000 road vehicles are predicted to travel over the Stadsring towards the design area in 2035 in the evening peak hour in the city-wide model, then in the design area model 2000 road vehicles are loaded in at the Stadsring boundary condition. Similarly if the city-wide model predicts 1500 road vehicles to travel over the Stadsring away from the design area in the evening peak hour in 2035, then in the design area model 1500 road vehicles exit the network at the Stadsring boundary condition.

Using this method each boundary condition has a value for the number of road vehicles that must enter and exit the model at that boundary condition. When each boundary condition is seen as an origin and destination the demand from each boundary condition to all other boundary conditions can be determined using a gravity model. These values form the origin-destination-matrix of the model. The resulting origin-destination-matrix for general traffic is shown in Table D.1. Within the design area the traffic distribution over the roads is determined by the Paramics microsimulation software.

Table D.1: Modelled general traffic origin-destination-matrix

	Auto 1	Auto 2	Auto 3	Auto 4	Auto 5	Auto 6	Auto 7	Auto 8	Auto 9	Auto 10	Auto 11	Auto 12	Auto 13	Auto 14	Auto 15
Auto 1	0	87	110	61	0	176	0	0	341	9	77	0	0	574	303
Auto 2	111	0	23	13	0	37	0	0	72	2	16	0	0	121	64
Auto 3	48	8	0	6	0	16	0	0	31	1	7	0	0	52	28
Auto 4	36	6	7	0	0	12	0	0	23	1	5	0	0	39	21
Auto 5	55	9	11	6	0	18	0	0	35	1	8	0	0	60	31
Auto 6	94	16	20	11	0	0	0	0	61	2	14	0	0	103	54
Auto 7	47	8	10	5	0	16	0	0	30	1	7	0	0	51	27
Auto 8	58	10	12	7	0	19	0	0	37	1	8	0	0	63	33
Auto 9	260	43	54	30	0	87	0	0	0	5	38	0	0	283	150
Auto 10	3	1	1	0	0	1	0	0	2	0	0	0	0	4	2
Auto 11	51	8	11	6	0	17	0	0	33	1	0	0	0	55	29
Auto 12	66	11	14	8	0	22	0	0	43	1	10	0	0	72	38
Auto 13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Auto 14	380	63	80	44	0	127	0	0	246	7	55	0	0	0	219
Auto 15	236	39	49	27	0	79	0	0	153	4	34	0	0	257	0

Bicycle traffic

Since the city-wide traffic model for 2035 only has data for general traffic, a different data source has to be found for bicycle traffic. For bicycle traffic measured data from the period 2022 to 2024 will be used. This data has been collected by the municipality. This data will not be adjusted to reflect the future situation of 2035, because no reliable estimation can be made for the future demand in bicycle traffic. This is a limiting factor of the data as it is unlikely that the demand in bicycle traffic is the same in 2022 as in 2035. The measured data from the municipality is for a full day and thus needs to be converted to representative peak-hour data for the peak-hour model. This was done by taking 10% of the daily total traffic volume as representative for the peak-hour.

The measured bicycle data can be converted into a origin-destination-matrix for the boundary conditions using the same method as was used for the general traffic. The origin-destination-matrix for bicycle traffic is included in Table D.2. The routing of the bicycles through the network is done by the Paramics microsimulation software.

Table D.2: Modelled bicycle origin-destination-matrix

	Fiets 1	Fiets 2	Fiets 3	Fiets 4	Fiets 5	Fiets 6	Fiets 7	Fiets 8	Fiets 9	Fiets 10	Fiets 11	Fiets 12	Fiets 13	Fiets 14	Fiets 15	Fiets 16	Fiets 17	Fiets 18
Fiets 1	0	5	7	3	6	2	1	4	2	11	0	5	2	1	10	2	6	14
Fiets 2	5	0	5	2	4	1	1	3	2	7	0	3	1	1	6	1	4	9
Fiets 3	7	5	0	3	6	2	1	4	2	11	0	5	2	1	10	2	6	14
Fiets 4	3	2	3	0	3	1	0	2	1	5	0	3	1	1	5	1	3	7
Fiets 5	6	4	6	3	0	1	1	3	2	9	0	4	1	1	8	2	5	12
Fiets 6	2	1	2	1	1	0	0	1	1	3	0	1	0	0	3	1	2	4
Fiets 7	1	1	1	0	1	0	0	1	0	2	0	1	0	0	1	0	1	2
Fiets 8	4	3	4	2	3	1	1	0	1	6	0	3	1	1	6	1	4	8
Fiets 9	2	2	2	1	2	1	0	1	0	4	0	2	1	0	3	1	2	5
Fiets 10	11	7	11	5	9	3	2	6	4	0	1	8	3	2	15	3	9	22
Fiets 11	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
Fiets 12	5	3	5	3	4	1	1	3	2	8	0	0	1	1	7	2	5	11
Fiets 13	2	1	2	1	1	0	0	1	1	3	0	1	0	0	2	1	2	3
Fiets 14	1	1	1	1	1	0	0	1	0	2	0	1	0	0	2	0	1	3
Fiets 15	10	6	10	5	8	3	1	6	3	15	1	7	2	2	0	3	9	20
Fiets 16	2	1	2	1	2	1	0	1	1	3	0	2	1	0	3	0	2	4
Fiets 17	6	4	6	3	5	2	1	4	2	9	0	5	2	1	9	2	0	13
Fiets 18	14	9	14	7	12	4	2	8	5	22	1	11	3	3	20	4	13	0

Bus traffic

Whereas general and bicycle traffic is loaded randomly onto the network based on predicted demand, bus traffic is loaded onto the network using public transport schedules. The municipality does not have public transport schedules available for 2035, because these are not made that far in advance. They do however have an aim for the number of bus lines, their routes and frequency that they want to operate within the city in 2035. From this data the hour with the highest frequency is taken to create the peak-hour model. With this information it can be determined how many buses will travel through the design area in 2035.

To mimic a realistic public transport schedule as much as possible, all bus lines will be considered separately. For each bus line the targeted frequency will be adapted to an equal interval between services. This means that a frequency of for example 4 buses per hour is modelled to mean a bus exactly every 15 minutes. Furthermore bus lines with significant portions of the same route are modelled so that they support each other. This means that two bus lines with a frequency of 6 buses per hour are scheduled in a way that they operate as one bus line with a frequency of 12 buses per hour on their shared section. This is common practise already within the municipality of Amersfoort and also prevents unrealistic scenarios in the model where all bus lines have their first bus of the hour departing exactly at the start of the new hour.

The predicted hourly timetable for an general peak-hour is included in Table D.3. Lines 2, 3, 4, 302 and 376 are bus lines that are currently in operation through the design area, although some at lower frequencies than are predicted for 2035. These five lines follow the entire designed bus corridor from south to north. Line 11 is a working name for a bus line that currently does not exist, but is predicted to be created in 2035 to provide service to the new greenfield housing development Bovenduist. It also follows the entire designed bus corridor from south to north. Line 1 and 7 are bus lines that are currently in operation through part of the design area. These buses are not considered part of the BRT corridor and are thus modelled to travel with the general traffic and not over the bus corridor. They also leave the design area halfway-through and thus do no travel along the entire designed bus corridor. The buses follow their predetermined routes through the network exactly.

Table D.3: Modelled bus schedule

	Frequency	Modelled time 1	Modelled time 2	Modelled time 3	Modelled time 4	Modelled time 5	Modelled time 6
Line 2	6	xx:00:00	xx:10:00	xx:20:00	xx:30:00	xx:40:00	xx:50:00
Line 3	6	xx:05:00	xx:15:00	xx:25:00	xx:35:00	xx:45:00	xx:55:00
Line 4	6	xx:00:00	xx:10:00	xx:20:00	xx:30:00	xx:40:00	xx:50:00
Line 11	6	xx:05:00	xx:15:00	xx:25:00	xx:35:00	xx:45:00	xx:55:00
Line 302	6	xx:02:30	xx:12:30	xx:22:30	xx:32:30	xx:42:30	xx:52:30
Line 376	6	xx:07:30	xx:17:30	xx:27:30	xx:37:30	xx:47:30	xx:57:30
Line 1	2	xx:00:00	xx:30:00				
Line 7	4	xx:07:30	xx:22:30	xx:37:30	xx:52:30		

E

Appendix E

In this appendix the evaluation frameworks for street crossings (see subsection 6.2.4) as provided by the CROW (2019) are given.

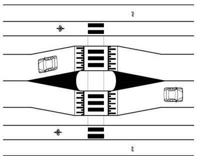
Table E.1: Evaluation of the road cross-ability for a traffic light regulated street crossing (CROW, 2019) (§ 3)

	A+	A	B	C	D
	The crossing can be completed at a casual pace and the height differences can be overcome easily. There is some extra aid like count-down lights or something similar.	The crossing can be completed at a casual pace and the height differences can be overcome easily.	The crossing can be completed, but the user has to be aware of their own safety. The crossing must also be completed at an adequate pace. The height differences are slightly difficult to overcome.	The crossing must be completed at a quick pace. The user has to pay attention to their own safety. This can be the case because the green-time is too short. The height differences are hard to overcome.	The crossing is unclear, unsafe or cannot be completed at a realistic pace. This can be the case because the traffic lights are defective. Height differences are (near) impossible to overcome.
					
Does the design of the crossing fit the local traffic situation (traffic volumes, design of public space)	Yes	Yes	Yes	No	No
Presence of dashed lines	Yes	Yes	Yes	No	No
Length of the crossing	< 5.00 m	< 7.00 m	> 7.00 m but with a median	> 7.00 m without a median	> 7.00 m without a median
Length of the median (if present)	> 1.20 m	> 1.20 m	> 1.20 m	< 1.20 m	< 1.20 m
Width of the median (if present)	> 1.80 m	> 1.80 m	> 1.20 m	< 1.20 m	< 1.20 m
Can the height differences between the sidewalk and the street be easily overcome?	There are high quality ramps	There are high quality ramps	There are mediocre ramps. They may be too narrow, too steep and/or not located opposite each other.	There are mediocre ramps. They may be too narrow, too steep and/or not located opposite each other.	There are no ramps
Height difference between the street and the gutter	0.00 m	< 0.02 m	< 0.02 m	> 0.02 m	> 0.02 m
Presence of a call button	Yes	Yes	Yes	No	No
Presence of an audible signal	Yes	Yes	Yes	No	No
Green time	More than sufficient time to cross at a casual pace	Sufficient time to cross at a casual pace	Sufficient time to cross at an adequate pace	Insufficient time to cross at an adequate pace	Insufficient time to cross
Is there visual feedback	Yes	Yes	Yes	No	No
Does the traffic light function	Yes	Yes	Yes	No	No

Table E.2: Evaluation of the road cross-ability for an unregulated street crossing (CROW, 2019) (§ 3)

	A+	A	B	C	D
	The crossing can easily be completed at casual pace and there are no height differences.	The crossing can be completed at casual pace and the height differences can easily be overcome.	The crossing can be completed, but the user has to be aware of their surroundings and cross at an adequate pace. The height differences are slightly difficult to overcome.	The crossing has to be completed at a quick pace and the user has to be aware of their own safety. The height differences are hard to overcome.	The crossing is unclear, unsafe or cannot be completed at a realistic pace. Height differences are (near) impossible to overcome.
					
Does the design of the crossing fit the local traffic situation (traffic volumes, design of public space)	Yes	Yes	Yes	No	No
Length of the crossing	< 5.00 m	< 7.00 m	> 7.00 m but with a median	> 7.00 m without a median	> 7.00 m without a median
Length of the median (if present)	> 2.50 m	> 1.20 m	> 1.20 m	< 1.20 m	< 1.20 m
Width of the median (if present)	> 1.80 m	> 1.80 m	> 1.20 m	< 1.20 m	< 1.20 m
Is the visibility of the crossing street limited by any obstacles?	No	No	Limitedly	Yes	Yes
Can the height differences between the sidewalk and the street be easily overcome?	The crossing is level	There are high quality ramps	There are mediocre ramps. They may be too narrow, too steep and/or not located opposite each other.	There are mediocre ramps. They may be too narrow, too steep and/or not located opposite each other.	There are no ramps
Height difference between the street and the gutter	0.00 m	< 0.02 m	< 0.02 m	> 0.02 m	> 0.02 m

Table E.3: Evaluation of the road cross-ability for a zebra street crossing (CROW, 2019) (§ 3)

	A+	A	B	C	D
	The crossing can easily be completed at casual pace and there are no height differences.	The crossing can be completed at casual pace and the height differences can easily be overcome.	The crossing can be completed, but the user has to be aware of their surroundings and cross at an adequate pace. The height differences are slightly difficult to overcome.	The crossing has to be completed at a quick pace and the user has to be aware of their own safety. The height differences are hard to overcome.	The crossing is unclear, unsafe or cannot be completed at a realistic pace. Height differences are (near) impossible to overcome.
					
Does the design of the crossing fit the local traffic situation (traffic volumes, design of public space)	Yes	Yes	Yes	No	No
Presence of the L2 road sign	Yes	Yes	Yes	No	No
Width of the zebra crossing	≥ 4,00 m	≥ 4,00 m	≥ 4,00 m	< 4,00 m	< 4,00 m
Distance between individual zebra markings	0,40 m	0,40 m	<> 0,40 m	<> 0,40 m	<> 0,40 m
Length of the crossing	< 5.00 m	< 7.00 m	> 7.00 m but with a median	> 7.00 m without a median	> 7.00 m without a median
Length of the median (if present)	> 2.50 m	> 1.20 m	> 1.20 m	< 1.20 m	< 1.20 m
Width of the median (if present)	> 1.80 m	> 1.80 m	> 1.20 m	< 1.20 m	< 1.20 m
Is the visibility of the crossing street limited by any obstacles?	No	No	Limitedly	Yes	Yes
Can the height differences between the sidewalk and the street be easily overcome?	The crossing is level	There are high quality ramps	There are mediocre ramps. They may be too narrow, too steep and/or not located opposite each other.	There are mediocre ramps. They may be too narrow, too steep and/or not located opposite each other.	There are no ramps
Height difference between the street and the gutter	0.00 m	< 0.02 m	< 0.02 m	> 0.02 m	> 0.02 m