The bicycle metro

Feasibility study for continuous urban cycling infrastructure

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The bicycle metro

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by

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Preface

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Summary

Concept

The Association of Dutch Municipalities has set ambitious goals for sustainable and efficient forms of transport, one of which is to make cycling the most logical choice for trips under 15 kilometres. To achieve this, cars are banned from city centres and efforts are being made to make cycling more attractive and accessible through concepts such as bicycle highways and park+bike. However, cycling is not always attractive to everyone, though it is one of the only modes of transport effective to get people to use their cars less. Therefore to let society benefit more from the bicycle, more effort is needed to create a bicycle-friendly environment and make cycling the best option for everyone.

To better facilitate cyclists, the bicycle metro concept has been conceptualised. The bicycle metro is an urban network of high-quality bike lanes, sometimes underground, sometimes covered, and everywhere disconnected from other infrastructure without intersections to ensure a continuous cycling experience. As a result, the bicycle metro should bring an improvement in travel time, convenience and safety.

Research goal

Although the bicycle metro could have many advantages, this has never been studied. It is also plausible that the concept has drawbacks, such as potential costs and uncertainty about its effectiveness. It was therefore valuable to conduct a feasibility study. For this, the following research question was formed:

What is the feasibility of the bicycle metro in the Netherlands, and what are the potential policy implications of this feasibility analysis?

To answer the research question, it was divided into several sub-questions and an approach was devised, which is three-part. First, the effects that the introduction of the bicycle metro will bring about had to be identified. This actually applied as a knowledge base for the research. After this, a way had to be found to assess the feasibility of the bicycle metro. Finally, the knowledge from the first two sub-questions could be applied to a case study to see if the developed method was applicable in reality. For this approach, the following sub-questions were appropriate:

SQ 1 *What are the possible effects and feedback mechanisms at work in the implementation of bicycle metro in the Netherlands?*

SQ 2 *What does the feasibility model look like for the bicycle metro in the Netherlands?*

SQ 3 *How do the system and the feasibility model relate to real-life application of the bicycle metro?*

Societal relevance was tested with the sustainable development goals of the UN. The proposed topic relates to four of them, namely: 'good health and well-being', 'industry, innovation and infrastructure', 'sustainable cities and communities' and 'climate action'. As for scientific relevance, no research has ever been done on the bicycle metro which makes it an exciting research topic. Furthermore, it is valuable to have a model to assess the feasibility of these innovative infrastructure concepts.

Method

The methods, following the sub-questions, were divided into three parts. Beforehand, however, a small scientific exploration was done in the literature. As mentioned earlier, little to nothing was known about the bicycle metro and so much was investigated in the sub-questions themselves. Relevant knowledge was gained in the areas of (urban) cycling, what exactly the bicycle metro is and offers and underground construction. For this brief literature review, the search engines Scopus and Scholar were used by means of a search table. Further relevant literature was then found using the snowball technique.

To identify the effects of the introduction of the bicycle metro for the first sub-question, a system diagram was used. This was done because a system diagram handles complexity well, and also simultaneously provides a good medium for communication.

A feasibility model was developed for the second sub-question. This was done based on the political-economic model of Feitelson and Salomon (2004), which was adapted for this study. After this, the elements were assessed where possible to get an early idea of the feasibility of the bicycle metro. Experts were interviewed for additional information using a semi-structured interview technique.

For the case study, the first step was to select the case on the basis of size, location, relevance and data availability. This was followed by a brief literature review of the city and experts were sought and interviewed to gain more knowledge. Next, the feasibility model was applied and developed for the specific city. After this, a conclusion was drawn about the case-specific feasibility.

Scientific exploration

Bicycle highways already exist. These are high-quality cycle paths to facilitate longer bicycle trips and are often used as a regional connection. Due to the characteristics of the cycle highway, higher average speeds are possible for cyclists, and thus they can cover more distance. However, However, the bicycle metro differs from the bicycle motorway in a number of ways:

Purpose The primary purpose of a bicycle metro is to reduce travel resistance for cyclists, providing a transport option for short- to medium-distance trips within a city. The primary purpose of a cycle highway is to facilitate longer-distance travel, often between inside and outside the city, and for recreational purposes.

Infrastructure A bicycle metro usually has detached infrastructure, while bicycle highways may also share the road with other infrastructure, more akin to traditional roads with dedicated bike lanes or paths. A cycle highway may still be interrupted by a traffic light or something similar, a cycle metro does not cross at level with other traffic.

Service level Bicycle metros may offer a higher level of service than bicycle highways, such as better infrastructure quality (dedicated tunnels, bridges, covering), and amenities such as bike-sharing stations, bike racks, and other support infrastructure.

System diagram

The system diagram in Figure 1 is divided into three parts: supply, behaviour and effects. The introduction of the bicycle metro creates an infrastructure supply with the characteristics offered by the bicycle metro. These characteristics together with the supply then have an effect on people's travel behaviour which alters the mobility mix. This in turn has a multitude of societal effects.

The travel behaviour in the system was evaluated using a utility-based framework, assuming that individuals try to maximise their utility and minimise their disutility (caused by things like monetary cost, physical effort, and time). The bicycle metro is assumed to lower resistance for cycling which leads to a higher percentage of cyclists in the urban mobility mix. This modal shift is an effect in itself, but also has secondary effects on public health, pollution, traffic safety and public costs. Accessibility was also affected, but rather directly by changes in travel behaviour and the infrastructure supply.

The effect on the mobility mix due to the modal shift was estimated to be a minimal increase of 2.2% for cyclists, up to 3.8% if half of these cyclists have an electric bike. The impact on public health is difficult to assess in general without a case study. People who cycle are healthier and less often ill, this is amplified by the effects of pollution as the percentage of cars decreases. Moreover, public health forms a reinforcing feedback loop with travel behaviour, since more people that cycle creates more healthy people and this in turn causes more people to cycle. This same reinforcing feedback loop was seen for pollution and nuisance. Putting an exact number on this is again difficult when it is not a specific case. Traffic safety is affected both positively and negatively. On the one hand, the bicycle metro is disconnected from the rest of the infrastructure, this saves many serious accidents as the majority of bicycle fatalities are in combination with a motorised vehicle. But on the other hand, especially with the advent of electric bikes, the risk of an accident is much higher on a bicycle than in, say, a car, especially among older people. Public costs are directly affected by the introduction of the bicycle metro, as it will cost a considerable amount of money to build. Table 2 shows the estimated cost

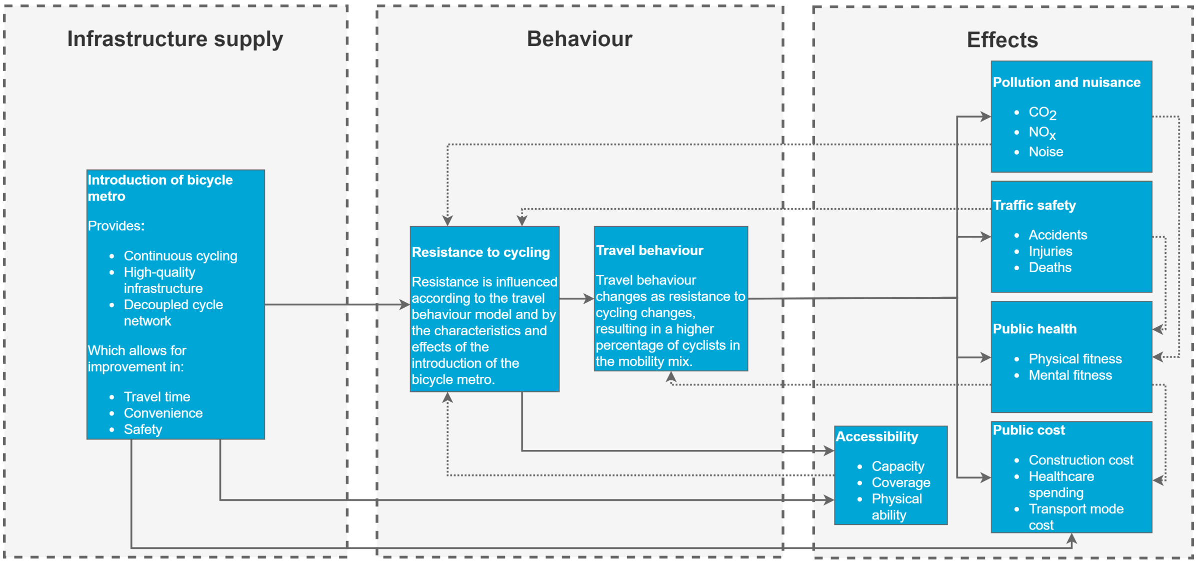

Figure 1: System diagram for the bicycle metro.

per metre. However, costs are saved for people themselves as cycling is one of the most cost-effective ways of getting around. Also, improving public health results in lower healthcare costs, as well as less pollution and nuisance leading to higher productivity and avoiding climate change.

Type	Cost per meter
Cycle path	€717
Covered cycle path	€1 592
Underground cycle path	€17 000
Urban motorway	€2 194

Figure 2: Cost per meter for different cycle paths in euros.

Accessibility is affected by the introduction of bicycle metro and travel behaviour. It is defined by people's physical ability, coverage, and capacity. Physical ability refers to the challenges that cycling may pose to some elderly or disabled individuals, but also the ways in which the bicycle metro can make cycling more accessible for them. Coverage refers to the extent to which the bicycle metro network reaches important areas such as business parks and outlying neighbourhoods. Capacity refers to the maximum number of people that the bicycle metro can handle at one time. If it becomes too crowded, travel resistance increases and accessibility decreases.

Feasibility model

As a basis for the feasibility model, the political-economic framework developed by Feitelson and Salomon (2004) is used. The final feasibility model, shown in Figure 3, was adapted for use with the bicycle metro. In the feasibility model, there are four requisites for the adoption of the bicycle metro: technical, social, political and economic feasibility. Each of the types of feasibility is determined by factors and active agents and some are dependent on other feasibilities.

Active agents consist of non-business interest groups and experts. The non-business interest groups have no decision-making power but should be heard because they represent stakeholders and are essential to securing public support. Experts can present, review and advise on the innovations. For this study, three experts were interviewed, Carlo van de Weijer, the initiator of the bicycle metro and smart mobility expert, Bas Braakman, bicycle policy advisor of Eindhoven municipality, and finally Ruud Arkesteijn, underground construction specialist. Their knowledge and views are used, among

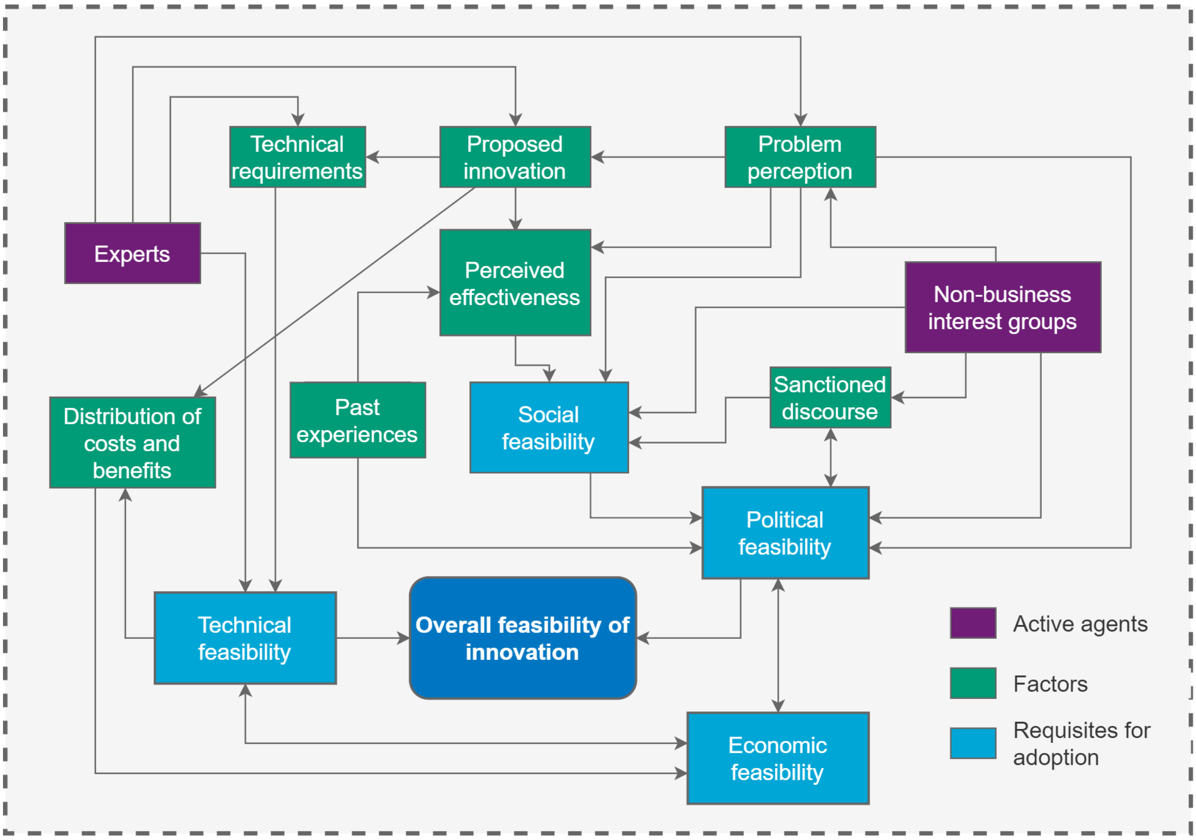

Figure 3: The feasibility model used for the bicycle metro (adapted from Feitelson and Salomon (2004))

other things, to gain knowledge about the various factors in the feasibility model.

All factors are evaluated one by one and assessed case-independently where possible. To assess perceived effectiveness, all barriers and enablers that people have for choosing the bicycle were identified. After this, the impact of the bicycle metro on this was assessed. Based on which barriers the bicycle metro (partially) removed and which enablers it provided, the effectiveness was assessed positively. The sanctioned discourse refers to the dominant perspective of society and politicians. A discrepancy was noted between the narrative and the actual resources available for cycling infrastructure. This led to negatively sanctioned discourse.

The social feasibility of the bicycle metro is complex, with several factors and actors influencing feasibility. While there are challenges in implementing the project, its perceived effectiveness and support from non-business interest groups suggest that it could be a socially viable transport option for cities. Political feasibility may be more uncertain due to a discrepancy between sanctioned discourse and the limited budget available for cycling infrastructure, which past experience has shown, among others. Technical feasibility is challenging but can be overcome with careful planning and consideration for potential construction nuisances. Economic feasibility has not yet been established as it is very much dependent on the case. In general, it is important to consider all aspects of feasibility when evaluating the possible implementation of a bicycle metro.

Case study

The case study looked at the city of Eindhoven to concretise the information and conclusions discussed in earlier chapters by focusing on the location-specific characteristics of the city and its mobility. The study examines the feasibility of implementing a bicycle metro in Eindhoven, using a cost-benefit analysis and techniques developed in earlier chapters. The city of Eindhoven was chosen for its relevance to the subject and the fact that the author is well-acquainted with the city.

The analysis looked at social, political, economic and technical feasibility. Eindhoven residents were found to consider distance and time as the main reasons for taking a cycle route and that there are areas for improvement of cycle highways in terms of safety, maintenance and quality. However, the public perception of the express cycle route is that it caused a nuisance for residents and there are concerns about the cycling speeds, these are too fast. The political will is there in Eindhoven to realise an extensive cycle network, but the initial investment of the bicycle metro is too high, the cost of the entire cycle metro network was estimated at €830 million. The social cost-benefit ratio shows a negative balance for the bicycle metro with an optimistic ratio of 0.63 and a pessimistic ratio of 0.32, and thus would take a very long period to repay itself. The benefit per kilometre for the bicycle metro was estimated at €0.172. Technically it is feasible provided there are sufficient economic resources, but there are always economic constraints. Concluding that the bicycle metro is not feasible and a middle ground has to be found using smart solutions that could save in costs.

Conclusions

In conclusion, this study successfully identified the main effects of introducing the bicycle metro by making a system diagram. A model has been created to assess the feasibility of the bicycle metro by assessing the feasibility according to four types: social, political, economic and technical feasibility. By using the city of Eindhoven as a case study it was found that the initial cost of a bicycle metro network is high at €830 million, in combination with the annual maintenance and operation costs of €8.3 million and a discount rate with a period of 100 years, it will not reach break even in that period. Therefore, the bicycle metro was deemed politically and economically unfeasible.

Hence, policymakers need to find other ways to improve cycling infrastructure. The study on the bicycle metro did show that valuable improvements are possible for cycling infrastructure and what the effects could be. Moreover, the fact that a whole bicycle metro network is not possible does not mean that it cannot be built in parts. This will spread the initial investment costs over several years. More use can also be made of technically smart solutions such as platooning combined with green waves or smart traffic lights giving cyclists an artificially continuous cycling route. Ultimately, a worthwhile ambition is to keep trying to lower the travel resistance for cycling.

Discussion

The discussion reflected on the research and the sub-questions and addressed the limitations and further possibilities for research. For the first sub-question, many choices were made regarding the demarcation of the system diagram. A system diagram can be made infinitely complex, but it is precisely the system diagram that is meant to make complex problems comprehensible. For the feasibility model developed in sub-question 2, a broad look was taken at feasibility. This has had the consequence of remaining somewhat on a superficial level for these different topics. It would also have been valuable to delve deeper into only economic feasibility, for example, this would have warranted a much more comprehensive cost-benefit analysis among other things. The cost-benefit analysis for the third sub-question was complex and many factors were left out to make it manageable. Factors such as population growth, benefits of modality shift to the bicycle and increase in safety for cyclists were not taken into account. It is important to note that not all cyclists will cycle in the bicycle metro and there will still be cyclists on normal paths who come into contact with cars and other motorised vehicles.

It should be taken into account that models have been used for this study. This creates uncertainties because they are a simplification of reality and the scope was determined by the author himself, this could have created bias. Also, the study used expert consultation and attempted to be objective, but the use of an external interviewer could have reduced bias in the interviews. All in all, this study has been sufficient in providing an initial insight into the feasibility of bicycle metro in general.

There are many opportunities for further research. But one of the most interesting might be to explore the possibilities and feasibility of different techniques that have the same benefits as the bicycle metro but in a cheaper way. Consider automatic green traffic lights for cyclists, other ways of segregating cycle lanes and green waves for groups of cyclists. This study focused on a Dutch situation, but the research can be applied to other countries where cycling is less accessible. Factors such as the mobility mix, existing infrastructure, and city size should be taken into account when applying the feasibility model to other locations.

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1 Introduction

As urbanisation continues to increase, the need for sustainable and efficient forms of transport is ever-present (van Wee et al., 2013). The Association of Dutch Municipalities (VNG) has set ambitious mobility goals for the future, including the aim for the bicycle to become the most logical choice for journeys between one and fifteen kilometres (APPM, Tour de Force, 2022). This goal reflects the recognition that bicycles can make a significant contribution to new urban mobility goals, such as reducing traffic congestion, improving air quality, and promoting physical activity (VNG, 2022).To facilitate this future vision of the bicycle, the car is increasingly banned from city centres and the bicycle is made more appealing through concepts like the bicycle highway and park+bike (CROW-KpVV, 2016; van Noort, 2022).

However, for some people, cycling may still not always be a practical or desirable option, particularly for longer trips or for those who are unable or unwilling to ride a bike. In these cases, public transportation can be a viable alternative. However, public transportation can be expensive for the government, and also for those who rely on it as their primary means of transportation. Thus, for the VNG to achieve this goal, it requires efforts to make the bike more appealing and accessible to a wider range of people. These efforts should create a more bike-friendly environment, making it easier and more enjoyable for people to incorporate cycling into their daily routines.

1.1. Problem introduction

As stated above, currently many people may be hesitant to use a bike for their daily transportation needs due to concerns about safety, convenience, and comfort (Willis et al., 2013). Not only that, more and more the phenomenon of bicycle congestion is often observed (RTV Utrecht, 2017). Because travel time is one of the most important determinants in route choice, this can discourage people from cycling to work (Ziemke et al., 2017). Moreover, cyclists are still subjected to elements like wind and rain, which can sometimes make cycling very unpleasant. There is room for improvement to make cycling a more attractive alternative, new infrastructure concepts can help make cycling a good solution in all circumstances.

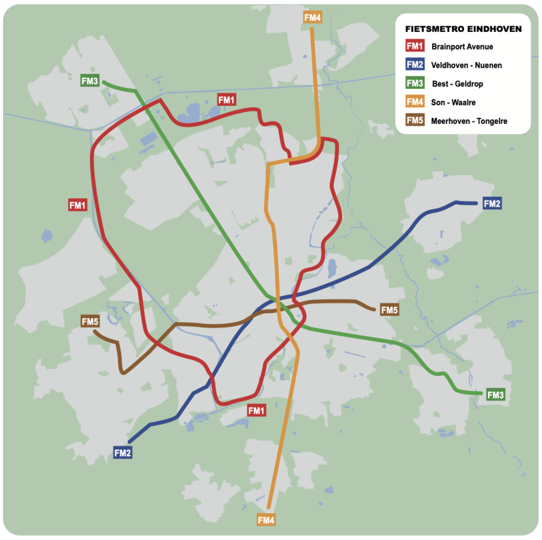

Figure 1.1: The bicycle metro, Eindhoven.

The bicycle is particularly useful as it appears very suitable for making people use the car less. It has the highest satisfaction rating, 8.3 out of 10, of all mobility options, and half of new e-bike users say they use the car less than before (Fioreze & Lenderink, 2020; Harms et al., 2017; Rayaprolu et al., 2020). In addition, the bicycle requires a lot less investment in infrastructure from the government compared to public transport (PT) (Schroten et al., 2022).

1.1.1. The bicycle metro

Invariably, cycling gets less attention than PT, including in terms of budget (Rienstra, 2022; van de Weijer, 2021). While cycling is seemingly a lot better at getting people out of the car. This is why Carlo van de Weijer, director of smart mobility at the Eindhoven University of Technology, advocates for a so-called bicycle metro to be implemented in the city of Eindhoven (van de Weijer, 2021)(Appendix A). Bicycle highways already exist, they connect cities with smaller towns or business areas, for example in Groningen and Utrecht (Goudappel Coffeng, 2019). The bicycle metro differs from the bicycle highway mainly in that it is exclusively urban, at times covered or underground, and has no interaction with other traffic, just like a normal metro. However, it is the same as a bicycle highway in that it provides a high-quality infrastructure for cyclists and increases the average cycling speed. It could make a major contribution to the further development of the bicycle network as it gives cyclists a place to shelter from bad weather, improves efficiency, and can be implemented underground in for example old city hearts. An example of how the bicycle metro could be implemented in the city of Eindhoven can be seen in figure 1.1. There is one ring road, and then several lines connecting the centre with the suburbs, parking lots or business parks.

1.1.2. Problem statement and research question

The relevant literature is searched using keywords mentioned in Chapter 3. As far as the author is aware, there are no peer-reviewed scientific articles on the bicycle metro anywhere to be found. However, there are studies that focus on bicycle highways and other types of cycling infrastructure. Some things can be deduced from these studies. In the literature study in Chapter 3, it is concluded that the bicycle metro concept could be a valid option to facilitate a more efficient urban cycle infrastructure. However, the concept also has disadvantages, such as the potential cost and the uncertainty of its effectiveness.

The aim is to research the factors that lead to the determination of the feasibility of the bicycle metro concept, thereby providing insight into what conditions could make the bicycle metro a success. The framework adds to a standard cost-benefit analysis or technological superiority, as these indications cannot guarantee whether a concept will actually be adopted.

In summary, there is a knowledge gap regarding the feasibility and usefulness of the bicycle metro. This is mainly because it is a new concept and thus there is little to no literature available, it has also been established that it is worth exploring further. From these findings mentioned above, the following research question is formulated:

What is the feasibility of the bicycle metro in the Netherlands, and what are the potential policy implications of this feasibility analysis?

1.1.3. Problem approach

To properly answer the research question, the research question is approached and translated into smaller sub-questions. As mentioned in Section 5, the introduction of a transport innovation is based on four elements: social, technical, economic and political feasibility. These elements are in turn determined by a number of active agents and factors that together form the feasibility model. This model is a good addition to a conventional cost-benefit analysis to get a realistic result (van Wee et al., 2013).

The first step was, investigating the possible effects or impacts of introducing the bicycle metro. An overview of the mobility effects, e.g. traffic flow and safety, but also costs, gives a better picture of the situation and helps answer the sub-questions that follow. With this theoretical system, a system analysis could be performed to see the interactions and dependencies. A first assessment of the feasibility of the bicycle metro concept was made possible.

Secondly, a method had to be developed which enables a reliable assessment of the feasibility of the bicycle metro. Many factors are possibly already known, but a robust framework or model would be valuable for this research and others, hence the purpose of the second sub-question.

Figure 1.2: United Nations sustainable development goals.

With this theoretical system and the feasibility model, a case study can be performed to test the model in reality. A first overall assessment of the feasibility of the bicycle metro concept is made possible. This will be covered in sub-question number three. Considering these steps, the following distribution of sub-questions would be a logical approach:

SQ 1 *What are the possible effects and feedback mechanisms at work in the implementation of bicycle metro in the Netherlands?*

To understand what changes in travel behaviour the bicycle metro might cause. But also more general parameters including but not limited to cost, environment and health. This information can be used to create a system diagram and give insight into the system.

SQ 2 *What does the feasibility model look like for the bicycle metro in the Netherlands?*

Deepen the political-economic model and complete it so that it can be utilised to draw conclusions regarding the bicycle metro's technical, social and political feasibility.

SQ 3 *How do the system and the feasibility model relate to the real-life application of the bicycle metro?*

Explores the complete situation of the implementation of the bicycle metro. A brief case study can be employed in order to draw a location-specific conclusion.

1.1.4. Relevance

To underline the relevance of this research, the subject was tested against the seventeen sustainable development goals of the UN (United Nations, 2019). These goals guided this research, and the proposed bicycle metro was an attempt to get a step closer to these goals. The proposed topic relates to four of them and they are shown in Figure 1.2.

First, the goal of good health and well-being would be relevant, as increasing the use of bicycles as a mode of transportation has positive health benefits (van Wee & Nijland, 2006). Second, a bicycle metro would also contribute to the goal of industry, innovation and infrastructure, as it would involve the development of new infrastructure. Additionally, the bicycle metro would also contribute to the goal of sustainable cities and communities, as it would provide a sustainable and efficient transportation option that can help to reduce traffic congestion, air pollution, and greenhouse gas emissions in urban areas (Hendriksen & van Gijlswijk, 2010). Finally, the bicycle metro would also contribute to the goal of climate action, as it would help to reduce the carbon footprint of transportation and contribute to the overall effort to reduce greenhouse gas emissions and combat climate change. Overall, a feasibility study on the bicycle metro in the Netherlands would be highly relevant and important for advancing these sustainable development goals.

As for scientific relevance, no research has ever been done on the bicycle metro which makes it an exciting research topic. Especially at a time when sustainability is increasingly a key issue, including in mobility. Furthermore, it is valuable to have a model to assess the feasibility of these innovative infrastructure concepts.

1.2. Structure

In this document, a feasibility study was proposed by investigating the infrastructure concept of the bicycle metro. The scientific exploration in Chapter 3 shows that no research has been done on this concept yet and therefore there is a knowledge gap. The results should provide insight into which factors determine the success or failure of the concept and what the corresponding effects are. Furthermore, in Chapter 2 a research approach with methods is presented. The various expected effects and relations between them needed to be investigated in order to have a clear picture. This was done in Chapter 4 developing a system diagram. Thanks to the feasibility model discussed in Chapter 5 the factors that influence the feasibility of the adoption of transport innovations are known. Still research had to be done on what these imply specifically for the bicycle metro. Moreover, the feasibility model is put into practice using a case study in Chapter 6. Finally, the study finishes with the conclusions answering the sub-questions and research question and also a discussion is provided.

2
Approach and Methodology

This chapter discusses the methods and research approach employed to answer the research and sub-questions. Starting with the approach where research flow is presented, consisting of three steps. The research flow gives a coherent overview of how this report is conducted. Then the methodology in Section 2.2, where the methods used for each sub-question are described. This chapter is thus necessary to understand how the study is put together.

2.1. Approach

Figure 2.1 provides a graphical representation of the research flow which guided this study. As the graphic shows, the research process consisted of three steps. Beginning with answering sub-question 1, which required defining the system and developing a system diagram. Then sub-question 2, where the feasibility model was constructed. The third and last sub-question applied the knowledge and insights developed from the previous steps to a case study. By synthesising the findings from all three sub-questions, the study was able to provide conclusive answers to the research question.

2.2. Methodology

An exploratory study was designed with the primary objective of being and assessing the feasibility of the bicycle metro. Starting with a general literature search for urban cycling in order to acquire general knowledge about the subject. As the bicycle metro was a new concept, there was no literature available on it specifically. Therefore, similar projects and studies covering cycling were sought. Key concepts in the literature study are urban mobility and planning and bicycle infrastructure. A search table was used for the initial literature search, after which the snowball technique was applied to find more studies. The initial research found is shown in Appendix B. Search engines Scopus and Google Scholar were used, Google Scholar due to its ease of use and Scopus because of its up-to-date database. Continuing with a conceptual model in the form of a system diagram. The diagram is used to map and visualise the expected effects of the bicycle metro in the Netherlands. An essential part of this research was going to be the method of assessing the feasibility of the bicycle metro. With the help of the information gathered from this search and other provided literature, a framework was developed to determine the feasibility. Interviews with mobility and policy experts were done to gather more relevant information where needed. To make it all concrete, the last sub-question took a real-world example to see how the model holds up. Synthesising all the information finally led to a well-formulated answer to the research question.

2.2.1. Sub-question 1: System diagram

The first step or sub-question is to understand the effects the implementation of a bicycle metro will have and what mechanisms are at play. A good method to do this is to make a system diagram (Enserink et al., 2010). The system diagram helps understand complex environments and is constructed using a conceptual diagram mapping method. The data for the system diagram is collected and validated through different strategies. The literature review done in Chapter 3 helped with this and can also

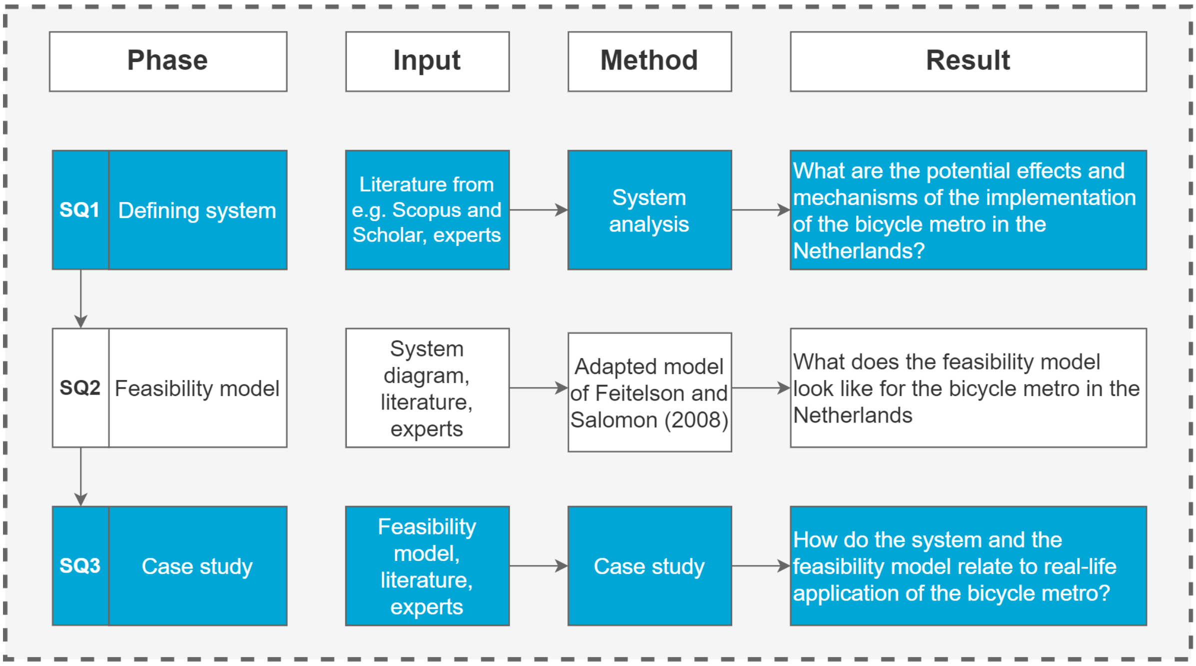

Figure 2.1: Graphical representation of the research flow.

serve as a basis for finding more information. The system diagram can already be formed with this information, after which it can be validated with the help of semi-structured interviews with experts and other literature. These methodologies are discussed in more detail below.

The system diagram was chosen because this methodology lends itself particularly well to providing insights into the complex relationships between the introduction of a bicycle metro, behavioural changes and the resulting effects. Meanwhile, the method is capable of managing uncertainty and missing information. It allows for seeing the different effects policy measures have. The system diagram thus worked as a conceptual framework or model and, in this capacity, was a tool to create an abstraction of reality in order to better comprehend the system in reality. It also facilitated a clearer communication of the system (Enserink et al., 2010).

A system diagram was developed in various steps and consists of factors in a system and the relations between these factors. In the case of this study, the factors and relationships were obtained from two strategies. Namely, literature and the author's own insights. First, the factors and relationships were compiled using the literature, all these studies were then combined in the system diagram by the author. Special attention was required in the selection of factors. As mentioned earlier, a system diagram is meant to provide an abstract reflection of reality to make the system more understandable. Obviously, the system can therefore be made infinitely complex with countless factors and relationships. To avoid this, the problem had to be demarcated, which was done according to the author's judgement in combination with the scope of this study.

2.2.2. Sub-question 2: Feasibility model

The second sub-question focused on the development of the feasibility model. Subsequently, with the help of the knowledge gained from sub-question 1 and interviews with experts, it was possible to already delve into some aspects of the feasibility model in detail.

Political-economic model

The feasibility model was based on literature, with the political-economic model (Figure 5.1) of Feitelson and Salomon (2004) serving as the fundamental framework for its development. The model was created to assess whether a transport innovation has a chance of being adopted. So this is very relevant in the case of the bicycle metro and was therefore taken as a starting point for the feasibility model. The first step involved adapting the political-economic framework to better suit the specific context of the bicycle metro and providing justification for the changes made. From this, the feasibility model resulted. Subsequently, an effort was done to fill in the unknown factors and other elements of the feasibility model as much as possible.

Perception study

The feasibility model consists of several elements, some easier to assess than others. Perceived effectiveness was a complicated factor, so a brief explanation of how this factor was assessed is given. To investigate the perceived effectiveness, another literature study was done using a search table and continuing via the snowball effect. The studies which were found relevant were put in Appendix C. Studies were reviewed that dealt with perceptions around cycling and bicycle highways. More specifically, studies were sought that examined what cyclists see as barriers or enablers in choosing the bike as a transport mode. This information was used to make a list of all the barriers and enablers perceived by cyclists, and also potential cyclists. In fact, it is important to include non-cyclists as well, as the aim is precisely to get more people to switch to cycling.

Subsequently, these enablers and barriers were compared with the effects and features offered by the bicycle metro concept, this is where the system diagram came in useful. This allowed an assessment of which barriers are theoretically removed or reduced by the bicycle metro, or which ones are actually added or increased, and the same goes for the enablers. By being able to see this, an expectation of perceived costs and benefits was made, which also gave way to a clear assessment of the perceived effectiveness.

Interviews

To validate the system, help was sought from experts in policy, infrastructure and cycling. Semi-structured interviews were used as a method for two purposes. First, to detect any factors and relationships missed in the system diagram. Second, to validate the feasibility model. As mentioned earlier in this chapter, there was no literature on the bicycle metro, so the opinion of mobility experts was extra important. Semi-structured interviews are conducted with mobility experts to test the developed feasibility model and system diagram. The study was exploratory in nature and there was limited information, interviewing experts was appropriate to get more in-depth knowledge (Gill et al., 2008). The interview has a clear purpose and a semi-structured interview ensures that this focus is maintained by the structure this method of interviewing gives (Kallio et al., 2016). These reasons justify that a semi-structured interview is an appropriate method for its purpose.

A disadvantage of using interviews in the research was that this method is very time-consuming. It is therefore desirable to find a balance between the number of interviewees and the amount of information gathered. For this sub-question, this is fine because one expert has a lot of knowledge, which allows the number of interviewees to be kept low.

The respondents are chosen with the help of the author's network and will consist of policymakers, academics and lobbyists. The aim was to interview at least three experts and they have to have experience with either transport policy, urban mobility or biking or travel behaviour and this with a societal view. At least three because in the feasibility model, experts influence three other elements, so there had to be at least one expert for each element. In Chapter 5 this is more elaborated on. This allowed qualitative information to be gathered from relevant experts and the applicability of the developed model to be examined. The entire process of the semi-structured interview is illustrated in Figure 2.2.

The interviews were analysed by recording and transcribing the conversations. After this, a compact summary or report was made with the relevant information for this study which can be found in Appendix D.

Feasibility model

With the information obtained on perceived costs, benefits and effectiveness, the feasibility model could be used to draw preliminary conclusions on the feasibility of the bicycle metro. This was done by weighing the various known elements, and also by passing judgement on the effectiveness of the bicycle metro. Though a case study was still needed to make definite conclusions.

2.2.3. Sub-question 3: Case study

This final sub-question combined all the information gathered in the first two sub-questions to apply the feasibility model in the real world. The case study investigated what the implications were in the context of a Dutch city. Experts are interviewed to provide additional information about the case. All in all, this also allows the policy implications to be examined and ensures robust conclusions.

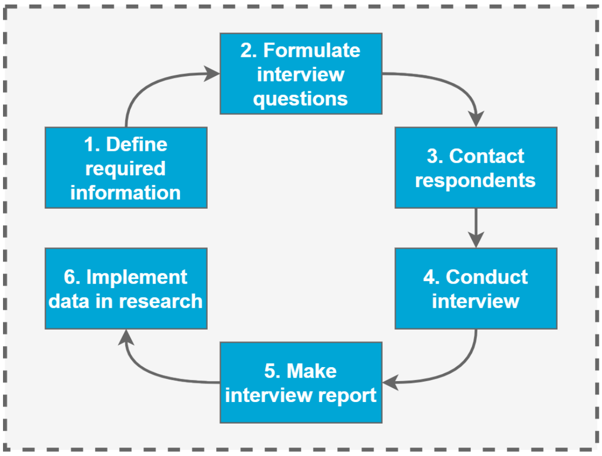

Figure 2.2: Interview methodology steps.

Case selection
First, a location was chosen for the case study. There were a few requirements for this:

Size and location It had to be a Dutch city with a population of at least 100 000, as it is likely to have a higher population density and multiple concentrated areas of development to be connected. For a smaller city, the concept would quickly become unfeasible due to costs.

Relevance It must be relevant to the city. Either sustainable mobility is already on the agenda or the city needs a solution for traffic congestion, efficient bike infrastructure, etc. But conversely, the city must also be relevant to the research. In this way, the final conclusion can also shed light on the possibilities for other cities.

Data availability The city must be able to provide data, such as transportation data, population demographics, or mobility patterns.

After case selection, case-specific research was conducted. This was to become familiar with the city and collect data. Experts were also sought to interview. For the interviews, the same method was used as for the second sub-question.

Cost-benefit analysis
One factor in the feasibility model was the distribution of costs and benefits, and to find out this distribution, a social cost-benefit analysis was done (SCBA). "MKBA informatie" (2022) was used as a guideline for the analysis. The SCBA sought to estimate the positive and negative effects of the project on society and this is where the system diagram from Chapter 4 came in useful since the various effects had already been discussed here. For the SCBA these effects were monetised, allowing them to be compared by value to society in euros. These values were estimated on an annual basis and were realistically calculated for the future using a discount rate. In the end, the SCBA showed the balance between costs and benefits. Here, a positive distribution between costs and benefits would be when the benefits were higher than the costs for the bicycle metro.

Feasibility
The feasibility of the case study was determined according to the feasibility model developed in Chapter 6. With all the information gathered on the case, each feasibility, social, political, economic and technical was addressed one by one. After this, a conclusion was formed on the case-specific situation.

After all sub-questions were evaluated, a synthesis of all these conclusions was used to form an answer to the research question.

3

Scientific exploration of urban cycling

This scientific exploration studies the relevant knowledge available on urban cycling, bicycle infrastructure and determining the feasibility of the bicycle metro. A general view is provided on the state of the art, relevant for the bicycle metro. This chapter lays the knowledge base for the research. Using a search table seen in Table 3.1 an initial search is done on Scopus and Scholar, after which more literature was gathered using the snowball effect. A list of initial papers is found in Appendix B.

3.1. Research strategy

The subject of this research is the bicycle metro as a new or improved form of mobility infrastructure to enable more efficient use of the bicycle and the feasibility of this concept. In examining the feasibility of the bicycle metro, the intended users of the system and the political, technical, economic and social factors that may influence the adoption of the bicycle metro in the Netherlands are considered. This section first describes the scope of this study, by explaining in more detail what the bicycle metro is and what is considered in the study. The problem statement is then further analysed and sub-questions are posed to provide guidance in answering the research question.

3.1.1. Scope

First, the scope of this feasibility study was described by explaining in more detail what the bicycle metro encompasses. Starting with a more in-depth description of the cycle superhighway, then where the cycle metro differs from it, and finally a concise characterisation of the intended users.

The bicycle highway

Before the bicycle metro is described in detail, a brief description of the already existing bicycle highway concept is given. The bicycle highway uses high-quality bicycle infrastructure to facilitate longer cycle trips compared to traditional bicycle paths. Though it can use cycle paths and lanes for this, also separated cycle paths from existing road infrastructure is possible. Often a bicycle highway acts as

	Concepts		
Search terms	Urban	Planning	Cycling
	City	Infrastructure	Bicycle
	Commute	Traffic	Bike
		Tunnel	Cycle
		Highway	
		Policy	

Table 3.1: Search table for urban cycling infrastructure. Search terms are formed by combining concepts. The concepts in each column are combined using OR and the columns are combined using AND.

a regional connection between a city and residential areas or business parks. Ideally, it supports an existing cycle network as a backbone and connects multiple networks. Old and unused infrastructure like railways or canals can be transformed to cut costs since it offers a flat surface and often connects important places (European Commission, n.d.). In terms of specifications, the literature review by Grigoropoulos et al. (2021) sums it up nicely. The recommended maximum speeds are 30 and 40 km/h, for inside and outside built-up areas respectively. The average speed which includes acceleration, deceleration, intersections and the like is 20 km/h. The maximum recommended average waiting time is 15 seconds. In terms of dimensions, a width of 2,5 to 3 metres is recommended for a unidirectional cycle highway and 4 metres for a bidirectional cycle highway (*Design manual for bicycle traffic*, 2007). For clarity, a list with characteristics is provided later in this Section.

The bicycle metro

Now the bicycle metro is explained in more detail to eliminate any ambiguities and clarify its difference from the bicycle highway. Like the existing bicycle expressway concept, the bicycle metro is distinguished from normal cycling infrastructure by the higher quality of the infrastructure. However, the bicycle metro goes a step further by completely decoupling the cycle path from other infrastructure and offering continuous bicycle traffic throughout the network. Together with wider tracks to allow safer overtaking, this increases the average speed of cyclists (Rayaprolu et al., 2020). A bicycle highway connects different municipalities or even cities, the bicycle metro is urban, underground or covered in some places and is located within the city to be a substitute for other mobility options; without traffic lights but with priority rules. The bicycle metro is underground in some places to save travel time or when the existing built-up area does not allow for above-ground operation, e.g. old town centres. The overhead cover gives cyclists the option of shelter or even overall protection from the weather during cycling. Unlike PT, no stations are needed, as entry and exit lanes are made to the existing urban cycle path network. It is relatively easy to plan because cycle paths do not require long straights or large radii for bends. Due to the small size and weight of bicycles, tunnels and bridges are less expensive than those for cars or PT (van de Weijer, 2021).

In the way explained above, the bicycle metro may also be regarded as continued development of the bicycle highway, and not as an entirely new concept. It has the same functionality for cyclists, and the previously mentioned differences mainly concern the location and method of deployment. Therefore, the same design guidelines can be used for the bicycle metro as for the bicycle highway. Below a summation is given to show the differences between a bicycle highway and a bicycle metro:

Purpose The primary purpose of a bicycle metro is to reduce travel resistance for cyclists, providing a transport option for short- to medium-distance trips within a city. The primary purpose of a cycle highway is to facilitate longer-distance travel, often between inside and outside the city, and for recreational purposes.

Infrastructure A bicycle metro usually has detached infrastructure, while bicycle highways may also share the road with other infrastructure, more akin to traditional roads with dedicated bike lanes or paths. A cycle highway may still be interrupted by a traffic light or something similar, a cycle metro does not cross at level with other traffic.

Service level Bicycle metros may offer a higher level of service than bicycle highways, such as better infrastructure quality (dedicated tunnels, bridges, covering), and amenities such as bike-sharing stations, bike racks, and other support infrastructure.

In summary, the aim of the bicycle metro is to reduce the resistance to taking the bike and thereby increase the percentage of cyclists. The bicycle metro does this by providing a continuous decoupled cycle path with high quality. From this, in theory, two levels of effects flow. and First, the bicycle metro will provide faster travel time and safer cycling conditions. This results in a smaller resistance to cycling and thus more cyclists, which provides a second level of effects, namely: healthier travellers, fewer traffic accidents, affordable transportation and fewer emissions.

3.1.2. Building underground

An additional search is conducted for underground construction to identify any special features and other things to take into account. Initially, the website of the Dutch knowledge centre for underground construction and underground space use (COB) is consulted. From there, several other articles and studies were found.

Building underground can offer a great solution in densely populated areas such as the Netherlands. However, the advantage of using space underground is offset by several disadvantages, since building underground is usually more expensive and risky than building above ground (COB, n.d.). For example, underground construction requires a great deal of knowledge and expertise to prevent damage to buildings in the vicinity. In practice, this means that there must be careful consideration from case to case whether the advantages of building underground outweigh the disadvantages (van Tol, 2004). The bicycle metro concept does not always have to be underground, it can, if it is more convenient or cost-effective, be constructed above ground or even elevated, just like a normal metro line. What is important is that the bicycle metro offers a continuous cycle infrastructure, does not interact with other traffic and makes cycling more attractive.

Safety must also be carefully considered. In case of an emergency, there must be sufficient escape routes and entrances for emergency personnel, especially underground. Many cyclists and pedestrians have a fear of badly lit viaducts and (cycle) tunnels. If there is poor visibility or abstraction from sight through a tunnel, for example, people cannot see danger coming and there is less surveillance from the surrounding area. This can cause a feeling of both physical and social insecurity (CCV, 2014).

3.1.3. Traffic

One of the advantages that the bicycle metro tries to achieve is to increase the average speed of the cyclist. The proposed bicycle metro is similar in dimensions to the bicycle highway. It may therefore be deduced that the cyclist will on average have the same increase in average speed. Which is found to be an increase from 15 km/h to 18 km/h for normal bikes and from 18 km/h to 24 km/h for e-bikes (European Commission, n.d.). Interestingly, the difference in speed between regular bikes and e-bikes is not that large, but along with the fact that e-bikes require less effort, people are willing to spend more time on them, thus making the radius of action greater than proportional to the increase in speed (Harms & Kansen, 2018).

The capacity of a cycle highway with a width of 3 meters is 17 000 cyclists per hour, this contrasts with the 2 000 cars that can cross such an equally wide road per hour (Botma & Papendrecht, 1991).

The study from H. Li et al. (2018), concluded that the London Cycle Hire Service resulted in an increased travel speed of 13.3% and a decrease in travel time of 11%. This is supported by Grigoropoulos et al. (2021), which presents similar numbers. Not only travel speed and time are improved with the introduction of bicycle highway infrastructure, but also travel time reliability. Transport of London (2011) presents a reduction in the standard deviation of average travel, delay and waiting times. The performance thresholds set in the official standards for cycle highways can only be reached by introducing special traffic control measures for cycling. Even at the maximum studied volumes, the bicycle traffic operated under free flow conditions, which indicates that the intersections with traffic lights remain the bottleneck for the studied traffic performance indicators (Grigoropoulos et al., 2021).

3.1.4. Urban cycling

Current research on cycling highways mainly focuses on the expected changes in mobility behaviour and the distribution among the different transport modes as a result of the construction of cycling highways and the perception by the end user.

On the topic of route choice, travel time and length are considered the most important parameters in selecting a specific route (Ziemke et al., 2017). Differences in altitude also to a lesser extent, although this probably plays a smaller role in the Netherlands. What is especially interesting for this research is that cyclists strongly favour infrastructure for continuous cycling, because this is what a bicycle metro will provide (Krizek et al., 2009; Z. Li et al., 2012). In the planning of the proposed concept, it is also valuable to consider car parking spaces and PT stops, to provide good cooperation between different mobility options (Z. Li et al., 2012). The average distance of a bicycle trip is 3.6 km for normal cyclists and 5.5 km for e-bikes (Fietsen123, 2018).

Finally, the bicycle metro offers several features highly valued by cyclists, such as continuous cycling, wide cycle paths and shorter travel time (Hull & O’Holleran, 2014).

3.1.5. Environment

A city where a large part of the mobility mix is represented by the bicycle saves a lot of emissions. Copenhagen, for example, saves about 90,000 tonnes of CO_2 per year because of its high percentage of cyclists (Kaparias et al., 2021).

Most air pollution in cities can be attributed to road transport and domestic and commercial heating systems. In addition to the negative impacts on mobility and air quality, previous studies indicate that severe congestion has a negative impact on GDP and an efficient transport system significantly improves the city's economic competitiveness (Bhuyan et al., 2020; Jin & Rafferty, 2017; Slawson, 2017).

3.2. Conclusions

In conclusion, the research for this chapter provided an extensive scientific exploration on cycling in general, which highlighted the many benefits of cycling as a means of transport, such as its environmental and health benefits, and its potential to reduce congestion and improve mobility in urban areas. In addition, knowledge on underground construction was available, which provided valuable insights into the technical and logistical challenges of underground construction. However, information on bicycle metro is still limited. Therefore, the following chapters discuss bicycle metro in more detail. Through this study, a comprehensive understanding of the feasibility and potential of the bicycle metro concept is going to be provided.

4

Potential effects and mechanisms of the introduction of the bicycle metro: a system diagram

This chapter describes the formation of the system diagram. The diagram, shown in figure 4.1, gives insight into the complex system of the implementation of the bicycle metro. It combined the most relevant factors and relationships, and so as not to make the diagram too large or complex, the problem was demarcated and keeps the level of detail manageable. The system diagram is valuable because it is a good tool to communicate and simplify the problem. The results of this chapter were relevant to the follow-up sub-questions. The next chapter, for example, used this information in the operationalisation of the feasibility model and for the interviews with experts.

SQ 1 *What are the possible effects and feedback mechanisms at work in the implementation of bicycle metro in the Netherlands?*

4.1. The system diagram

The system diagram in Figure 4.1 was largely divided into three parts: supply, behaviour and effects. These parts are discussed in Section 4.2, 4.3 and 4.4 respectively. In short, the introduction of the bicycle metro creates an infrastructure supply with the characteristics offered by the bicycle metro. These characteristics together with the supply then have an effect on people's travel behaviour which alters the mobility mix. This in turn has a multitude of societal effects. To keep the system diagram compact, these social effects have been demarcated into the most important factors by the author.

4.1.1. Assumptions

The system diagram illustrates the effects of the bicycle metro on the most important factors, with the impact of travel behaviour on the mobility mix at its core. For this, a few assumptions were made concerning travel behaviour. The system was assessed according to a utility-based framework. For this purpose, an assumption was made for travellers and their modality choices, being that individuals seek to maximise their utility and hence try to minimise their disutility (Buehler, 2011). Disutility is caused by travel resistance which can consist of several things such as monetary cost, physical effort and time (van Acker et al., 2010; van Wee et al., 2013, Chapter 3).

Simply put, the bicycle metro is assumed to create a lower resistance to taking the bike. This should therefore lead to a higher percentage of cyclists in the urban mobility mix. This effect in the mobility mix in turn affects a number of factors. The main factors are public health, pollution and nuisance, traffic safety and public cost. Accessibility is also influenced although not by the change in mobility mix, but rather by changes in travel behaviour and directly by infrastructure supply. Section 4.3 takes a much deeper look at travel behaviour.

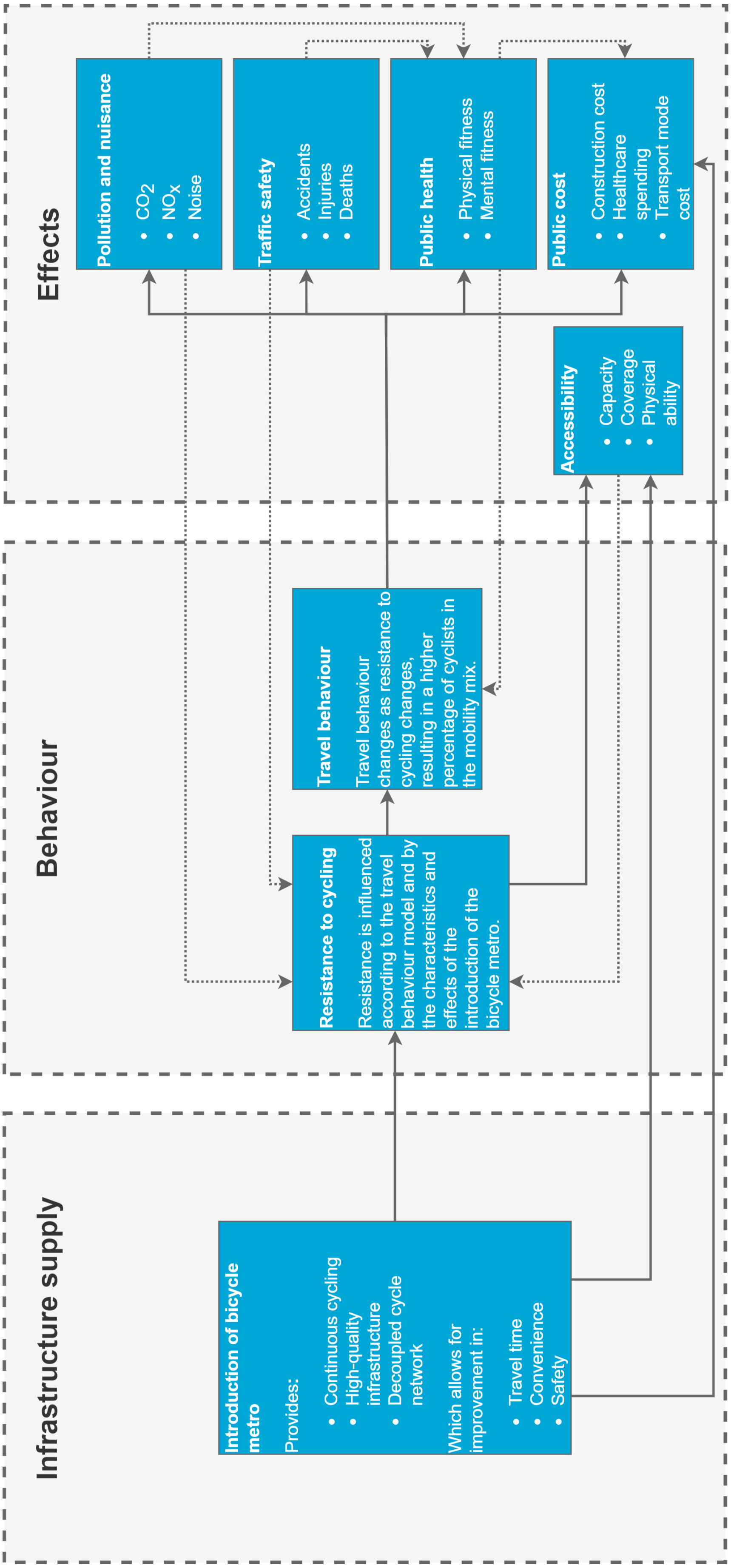

Figure 4.1: The system diagram for the bicycle metro.

4.1.2. Demarcation

The system diagram is made to represent a real-world system, however, that means that there could be an endless number of factors affecting the system, making the system far too complex. Therefore, it is defined as what is within scope and what is delimited, in other words, the system is demarcated (Enserink et al., 2010). The bicycle metro is intended for urban transport only. Only urban effects are therefore included. Also, the concept focuses on all cyclists though recreational cyclists are of less importance as these are not the cyclists that will benefit most during rush hours and such. The implementation of the bicycle metro is a public issue, therefore societal impacts are included in this diagram. To keep it compact, only the larger societal issues are included, i.e. those mentioned in the assumptions.

4.2. Infrastructure supply

Infrastructure supply is about what infrastructure is available to travellers. Introducing the bicycle metro changes this supply, adding a whole new infrastructure concept throughout the city. Naturally, this changes the available infrastructure supply. The change that takes place is determined by the characteristics of the bicycle metro. As described in the introduction, the bicycle metro offers three features: continuous cycling, high-quality infrastructure and a decoupled cycling network. These features ensure that cyclists save travel time, experience higher convenience and safety is improved. These are the direct effects of the bicycle metro, however, this is only part of the final effects.

The introduction of the bicycle metro also affects a number of other factors. For a start, the bicycle metro and what it has to offer has an effect on the resistance to cycling, however, more on this in the next section. Furthermore, the bicycle metro also affects public costs, as building such a bicycle network costs money. Also, a change in infrastructure supply means a change in accessibility. This is because the capacity is increased, but also because there is more coverage in different places, and higher quality infrastructure and greater safety can cause people who previously did not feel confident or were not able to cycle to do so in the bicycle metro (Engbers et al., 2018).

4.3. Behaviour

This Section explains the theory of how transport volumes are formed as an effect of travel behaviour. A transport system is a multidisciplinary system and is best understood considering a combination of social, civil engineering, psychological, economical and more aspects (van Acker et al., 2010). In this section, multiple theories are combined in order to develop one model of travel behaviour which can be used in the system diagram.

4.3.1. Needs, locations and resistances

The book from van Wee et al. (2013, Chapter 3) provides a conceptual framework that will act as the starting point for this chapter. A myriad of different factors influences the transport system. The framework states that the transport volumes in this system are the result of three assumptions on which this paragraph elaborates:

1. individuals have choices to make according to their needs and desires;
2. these desires and needs are to be fulfilled in other locations;
3. there are certain resistances to transport which require effort in different forms (risk, comfort, time, money etc.).

Desires and needs

People make choices based on their desires and needs, and some of those desires and needs can only be satisfied in locations other than where they currently are. Although everyone has different needs, dividing people into groups based on their shared needs is possible. Socio-economic distinctions can be made to categorise them. Locations of needs, wants, and preferences all affect one another; a person’s desires might alter depending on adjacent activity. Locations of activities may open or close depending on the requirements and preferences of a group of people.

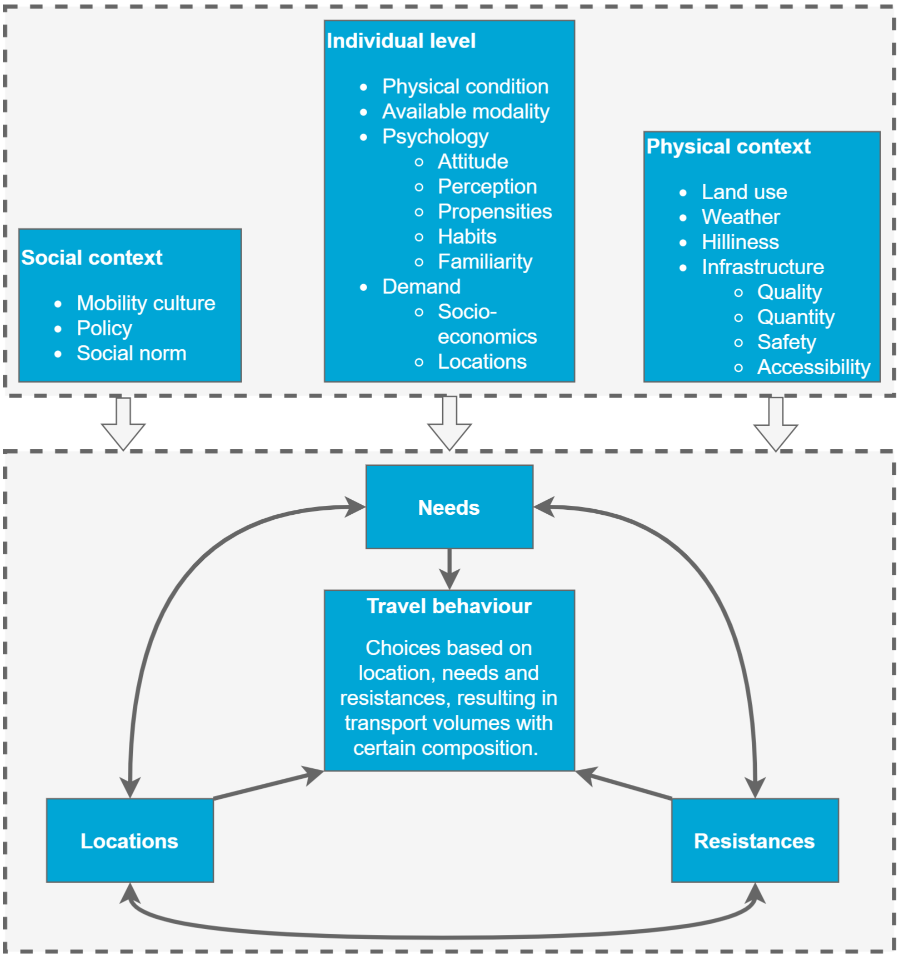

Figure 4.2: Travel behaviour, amalgamation of van Wee et al. (2013, Chapter 3) and Götschi et al. (2017).

Location
Location is an important type of factor as well. An individual that works in another city will travel more than someone that works close to or at home. This is valuable information when, for example, planning the bicycle metro layout.

Resistances
Trip resistance refers to the effort a person has to put in to make the trip. Or in other words, at what cost the trip comes. This can be expressed in time and money but also in other things like risk. A way to quantify this resistance is using the term generalised transport costs (GTC) (van Wee et al., 2013, Chapter 3). The higher the GTC, the fewer trips are made. The main factors that play a role are time and monetary costs. Other factors are known as effort and consist of things like comfort, reliability and safety. For safety, a distinction can be made between objective and subjective safety (Sørensen & Mosslemi, 2009). Subjective safety refers not only to the perception of safety of a particular road but also, for example, to a social situation. Thus, a poorly lit cycle tunnel feels riskier than an adequately lit tunnel (CCV, 2014). These factors are relevant in different ways, depending on the perspective from which they are viewed. The aim of the bicycle metro is to remove as many barriers as possible and add enablers to make the resistance to taking the bike as low as possible.

4.3.2. Active travel behaviour
A comprehensive study by Götschi et al. (2017) has synthesised 65 studies in order to make a conceptual framework for active travel behaviour. The framework is also relevant to this study and this paragraph will present a study-specific version for the bicycle metro. The framework identifies three different domains of factors: social context, physical context and individual level. It can be combined

with the conceptual framework of van Wee et al. (2013, Chapter 3) to provide a holistic approach, the framework is illustrated in figure 4.2.

Social context
The social context is the context in which an individual's choices are made, which are not tangible. It consists of several factors: mobility culture, policy and social norms. They are discussed further below.

Mobility culture
Mobility choice and usage may depend on location or socio-cultural background. These differences can be grouped into different mobility styles or cultures (Haustein & Nielsen, 2016). The concept of mobility cultures can be used to understand the variations in mobility behaviour between different locations. A good example is the Dutch cycling culture. On average, the Dutch are cycling more, not only because of policies and good infrastructure but also because of mobility culture (Pucher & Buehler, 2008). On the other hand, a higher proportion of the population may be non-native, for instance in big cities, and if the country of origin does not have a cycling culture, this may affect travel behaviour (Rietveld & Daniel, 2004).

Policy
Policy is a formal tool that can influence mobility behaviour in various ways, in the short and long term. For example, it can be used to promote the use of public transport or discourage car ownership and in this way influence mobility decisions (Müggenburg et al., 2015). But also the built environment is subjected to policy which also plays a role in travel behaviour.

Social norms
Contrary to policy, social norms are informal factors that influence mobility behaviour. Social norms for mobility behaviour are closely related to mobility culture, yet the two concepts are not the same. The primary distinction between the two is that social norms affect people's lives and also cause structural changes in society. Meanwhile, mobility culture is often not something that is forced onto a person but rather something that they have internalised over time.

Physical context
Physical context is the context in which individual choices are influenced which are tangible. These can be in the form of natural environments like geography, climate, weather and hilliness and human-made built environments and conditions. A distinction between climate and weather is made, defining weather as the day-to-day weather conditions and climate as the weather over a thirty-year period (Heinen et al., 2010).

Infrastructure
Infrastructure plays an important role in travel behaviour, its quality, quantity, safety and accessibility influence trip resistance (van Wee et al., 2013). Quality, quantity, safety and accessibility.

Case studies of Rayaprolu et al. (2020) and Skov-Petersen et al. (2017) considering bicycle highways suggest that the construction of a bicycle highway by itself is not enough to bring about a major switch to bicycle use in Copenhagen and Munich. Hull and O'Holleran (2014) proposed a list of design recommendations for the improvement of the existing bicycle infrastructure and attractiveness. A few points on this list are particularly interesting, like 'wide cycle lanes', 'routes connecting all land uses' and 'segregation where possible'. These are interesting because they are features of the proposed bicycle metro concept. This claim is supported by a literature study of Heinen et al. (2010), which states that cyclist value dedicated and continuous bicycle infrastructure. And in terms of safety, subjective safety is most important. All infrastructure elements that require a cyclist to stop, such as a traffic light or stop sign, are perceived as inconvenient. Nevertheless, the study cannot give a definite answer on the effects this has on the share in the mobility mix.

Land use
Land use refers to the type of built environment in a given area. It is anything that alters the natural environment. According to Ewing and Cervero (2010) there are five major factors in land use that influence travel behaviour. These factors are density, diversity, design, destination accessibility and distance to transit. The study also finds that one factor alone has a minimal effect on travel behaviour, however, a combination of the factors can have a large impact.

Climate and weather conditions
Some areas are more suitable for cycling weather-wise than others. This can be permanent, or only during specific parts of the year. Cyclists are more prone to weather conditions and climate than other types of transport. For example, when it is raining PT and most motorized traffic keep travellers dry and even while walking one can carry an umbrella. Precipitation, snowfall and wind speeds play a role in travel behaviour, mostly through trip resistance, where precipitation is the most significant one (Heinen et al., 2010; Martinez, 2017). Also, temperature influences the modal choice of travellers, a higher temperature causes higher cycling percentages (Parkin et al., 2008). What is interesting here is that commuters are influenced less by temperature than other types of cyclists (Bergström & Magnusson, 2003).

Geography and hilliness
This factor is naturally more relevant for active modes of transport, as it takes more effort and thus causes more travel resistance if one has to actively climb a hill, for example walking or cycling (Parkin et al., 2008). Multiple studies have shown that a hilly landscape, that is, a cycle path with slopes, has a negative effect on the modal share of cycling. (Heinen et al., 2010; Parkin et al., 2008; Rietveld & Daniel, 2004). As this study focuses on the Netherlands, this will be less relevant as most cities, if not all, are located in very flat landscapes.

Individual level
Individual factors, in addition to a person's social and physical context, are important in shaping travel behaviour. The individual level is split up into psychology, physical condition and demand.

Available modality
The available modality is simply the available modes of transport at one's disposal. So in the case of using the bicycle metro, one must have a bicycle of one's own or shared and obviously be able to cycle physically.

Psychology
So far, this study has mainly looked at external factors that influence an individual's travel behaviour, or, in other words, the context where travel behaviour is done. So far, this study has mainly looked at external factors that influence an individual's travel behaviour, or, in other words, the context where travel behaviour is done. For internal factors influencing the individual, it is necessary to look at theory within social psychology and lifestyle (van Acker et al., 2010).

According to van Acker et al. (2010) psychology describes the influence of various internal processes like attitude, perception and propensities, which are considered reasoned influences. Since perception says a lot about social feasibility and thus plays a big role in the second sub-question, there is extra interest in this. Attitude is the way an individual feels about something, like a specific mode of transport. Attitudes can change, by a positive or bad experience for example (van Wee et al., 2013, Chapter 3).

Contrarily, habits are considered unreasoned influences, which comprise a large part of individual travel behaviour (Bamberg et al., 2003; Müggenburg et al., 2015; van Wee et al., 2013). Habits are especially important when the context of an individual is constant, if the situation changes and thus the context, habits cannot be used anymore to predict travel behaviour (Heinen et al., 2010).

Physical condition
Depending on someone's physical condition their needs and resistances will differ (Heinen et al., 2010). For example, an elderly with limited physical mobility could not be able to cycle anymore and will be more dependent on public transport. A reduced physical condition is expected to cause or lead to a person choosing less active modes of travel.

Demand
Socio-economic factors like sex, age and income have a significant influence on modal choice, but also on average kilometres per person per day and the number of trips. It is common to use socio-economic data to make certain groups with similar travel behaviour (van Wee et al., 2013, Chapter 3).

Transport mode preference and demand are also correlated with people's residential location. An individual living close to a railway station is also more likely to prefer the train as a mode of transport on average. This phenomenon is called self-selection (van Wee, 2009).

Modality	With bicycle highways	With bicycle highways and 50% electric bikes
Car	-1.4%	-2.3%
PT	-2.3%	-3.9%
Bicycle	2.2%	3.8%

Table 4.1: Change in number of trips due to bicycle highways in The Hague/Rotterdam (ter Avest et al., 2011).

4.4. Effects and mechanisms

This section discusses the right-hand part of the system diagram: the effects. The change in travel behaviour has the effect of changing the mobility mix, from which other social effects flow. Apart from accessibility, because this effect is separate from the rest. Each effect will have a subsection below, where they are explained in more detail.

4.4.1. Mobility mix

A main objective of the bicycle metro is to lower the resistance to taking the bike. This will cause a modality shift to the bicycle meaning a greater share of cycling in the mobility mix. Multiple studies support this, saying that the introduction of the cycle highway will ensure a greater share of cycling and willingness to cycle (Grigoropoulos et al., 2021; H. Li et al., 2017; Liu et al., 2019; Rayaprolu et al., 2020; Skov-Petersen et al., 2017). A parallel with the bicycle metro can be drawn here.

One of the most important effects the bicycle metro tries to achieve is this modality shift, or in other words, getting people to take the bike instead of the car. Because if only people that already cycle will make use of the bicycle metro, there would be no effect on the number of cars in the city. Therefore, in a cost-benefit analysis of the bicycle metro, the modality shift is where a lot of benefits can be achieved (van Ommeren et al., 2012). From this so-called modality shift, a new equilibrium forms in the mobility mix, this is an important factor in the system.

Improvement of the bicycle infrastructure does have a positive effect on the attractiveness of cycling and may lead to a reduction in car use. An improved cycling infrastructure could lead to a growth in cycling between 1.3% and an enormous 209% (Spapé et al., 2015; ter Avest et al., 2011; Transport of London, 2011). Although, the effect is expected to be smaller in countries with good cycling infrastructure, like the Netherlands (Transport of London, 2011). The study ter Avest et al. (2011) estimated the change in modality due to urban cycle highways in the region of The Hague/Rotterdam. This situation of this estimate is the closest to the bike metro as could be found, as it is urban, with the same bike lane dimensions and located in the Netherlands. The estimates can be observed in Table 4.1.

However, the above-mentioned studies examined the growth in the number of cyclists resulting from the construction of a bicycle highway, whereas the bicycle metro has some additional benefits. The most obvious one being that the cyclist is protected from bad weather, where rain has the biggest influence. A study in New York shows that for every inch (24.5mm) of rainfall approximately 31% fewer trips are made (Martinez, 2017). This study is comparable in the sense that it is an urban environment, for which the bicycle metro is conceived. However, New York has a completely different biking culture compared to the Netherlands. More comparable is the study of Brandenburg et al. (2004), done in Vienna. This study states that on a rainy day, defined as a day with at least 1mm of rainfall 22% fewer trips are made. The number of rainy days (≥1mm) in De Bilt, Netherlands was between 2019 and 2021 on average 138 days (CLO, 2022). This indicates that a covered bicycle track could increase cycle trips. However, it is not studied what percentage of these trips will be done later by bike or are replaced with trips using other transport modes.

4.4.2. Public health

As the proportion of cyclists increases, the positive and negative public health effects of cycling will become relatively more prevalent. Some positive physical effects are an increase of 13% in fitness when regularly biking to work and cycling is a good way of staying on the right weight and if overweight a great way of losing weight (Hendriksen & van Gijlswijk, 2010). This is very good at preventing cardiovascular disease, among the most common causes of death in the Netherlands (Hilderink & Verschuuren, 2018).

So good, in fact, that the study Andersen et al. (2000) in Denmark showed that people who regularly cycle to work have a 39% lower chance of dying prematurely. And because most people can already cycle, there is infrastructure and the risk of injury is very low, the barrier to entry for people is also lower than some other sports (Hendriksen & van Gijlswijk, 2010).

Cycling is not only good for physical fitness, but also for mental health, a growing issue for the younger part of the population. Mental disorders are already one of the biggest contributors to the loss of healthy years (Hilderink & Verschuuren, 2018). Exercising benefits mental health and cycling also does in this capacity. A few examples are: cycling can reduce effects of stress (Froböse, 2004), it enhances the plasticity of the brain which reduces brain decay (Hilderink & Verschuuren, 2018), Cavill and Davis (2007) mentions multiple benefits such as fewer sleep problems, decrease in fatigue, better stress tolerance and increased self-confidence. Not to forget that more than 60% of the Dutch associate cycling with feelings of happiness, compared to a little more than 10% for PT. When all these public health benefits are monetised, it means, as an example, that a 1% increase in regular commuting cyclists saves 27 million euros in absenteeism costs (Hendriksen, 2009).

A drawback is that people who cycle inhale pollutants because they are in traffic, especially during rush hours. This air pollution is even worse for motorists themselves, however, due to lower physical effort, they inhale less deeply than cyclists do (Kingham et al., 1998; van Wijnen et al., 1995). As a result, the pollution gets deeper into the lungs of cyclists (van Wee & Nijland, 2006). For Dutch levels of air pollution, however, it can be said that the health benefits outweigh the costs (Boogaard et al., 2009; Hoek, 2008). Cycling actually has even more public health benefits, in the form of reduced pollutant emissions due to fewer cars, for example. However, this will be discussed in the subsection on the effect of 'pollution and nuisance'. The feedback of better public health could work reinforcing since more healthy people enable more people on an individual level to choose the bike.

4.4.3. Pollution and nuisance

Evidently, the bicycle has zero emissions during its use. Thus, a higher percentage of cyclists in the mobility mix will ensure an immediate decrease in emissions. The same can be said about nuisance since the bike causes less vibration and noise than most alternatives. To support this claim, some effects with sources are listed below.

Less greenhouse gasses:

- Yearly cars are used for 3.6 billion trips shorter than 7.5 kilometres. Replacing these trips with bicycles would save 2 megatons of CO_2 a year (CBS, 2016; Harms & Kansen, 2018; Hendriksen & van Gijlswijk, 2010; Otten et al., 2015).
- If the bicycle is chosen instead of the car, this saves 1 kilo of CO_2 for every 4 kilometres, for the bus it is 8 kilometres and for the moped 16 kilometres (Hendriksen & van Gijlswijk, 2010; Otten et al., 2015).

Less pollution:

- Switching from the car to the bicycle saves 0.2 grams of NO_x and 0.01 grams of particulates each kilometre (Otten et al., 2015).
- Replacing the 3.6 billion trips shorter than 7.5 kilometres would save approximately 2.6 kiloton NO_x and 0.13 kiloton particulates each year (CBS, 2016; Harms & Kansen, 2018; Otten et al., 2015).

Less nuisance:

- The bicycle is a quiet mode of transport and 30% of the population experiences severe noise nuisance from traffic (Franssen et al., 2004; Harms & Kansen, 2018; Hendriksen & van Gijlswijk, 2010).
- A halving in motorised traffic reduces noise by 3 dB, which is observable by humans, but not a big difference. Other factors such as road and type of motorised vehicles also have a major influence here (Harms & Kansen, 2018; Hendriksen & van Gijlswijk, 2010; World Health Organization, 1995).

- An increase in the use of bicycles also leads to an increase in the nuisance of parked bicycles if not managed properly.

4.4.4. Traffic safety

There are several ways to express traffic safety and it is important to choose the right one. Comparing road fatalities on a one-to-one basis gives the wrong picture. For example, the car would then be attributed to many more deaths than the motorbike, while the motorbike is many times more dangerous. Bicycles lead the list of modes of transport with the most road deaths at 33.6% (SWOV, 2017). If one then looks at risk, expressed as deaths per billion passenger kilometres, a completely different picture is painted. Looking at risk, cycling comes in at number three with 14.25 deaths per billion passenger kilometres (SWOV, 2017). As the risk of cycling is relatively high, especially when compared to the car (1.5 deaths per billion passengers), it is reasonable to assume that an increase in cycling in the mobility mix will reduce traffic safety.

Multiple studies show that a separated cycle path reduces the number of collisions and injuries (H. Li et al., 2017; Lusk et al., 2011; Reynolds et al., 2009; Teschke et al., 2012). And the bicycle metro has more features that could improve safety, for example, segregation from other traffic, no intersections with other traffic and wider cycle lanes. It is difficult to determine what the effects on traffic safety will be for the cycling metro as there is no data available. To get a better idea, the effects of bicycle highways may be considered. Because in terms of use and dimensions, these are very similar to the bicycle metro. The study Skov-Petersen et al. (2017) found that there was a significant increase in the perceived safety of cyclists after upgrading to a cycle highway infrastructure. H. Li et al. (2017) concludes that despite a nearly 20% increase in cyclists, there is no significant increase in accidents. All in all, it is difficult to put a number on it, but it is reasonable that implementing the bicycle metro will reduce accident risk and make cycling itself safer.

Bicycle tunnels can be unsafe because people are less visible, making it an attractive place for people with bad intentions (Thornton, 2014). Decreasing the number of cars will positively affect urban road safety. The bicycle metro could amplify this effect as it can not only decrease the number of cars on the road but also decrease the number of cyclists on shared roads. In terms of safety, a study concerning the London Cycleway Network shows that in spite of a significant increase in bicycle usage, there was no significant divergence in the rate of collisions with cyclists (H. Li et al., 2017). This may indicate a good and safe infrastructure design. This is supported by Pucher and Buehler (2012) and Schepers, Twisk, et al. (2017), which say that a proper infrastructure design has a much greater effect on cycling fatalities than safety gear such as helmets and lights. Special attention must be paid to the safety of bicycle-motorised vehicle collisions, since these account for the largest part of cyclist fatalities (Prati et al., 2018). The majority of studies have identified factors related to road users' behaviour (59.3%) and infrastructure characteristics (57.6%). A minority of studies identified variables related to exposure (40.7%) and vehicles (15.3%) as contributor factors to BMV collisions. A small but significant proportion of studies (20.3%) provided evidence that environmental factors may also play a role, although to a lesser extent, in determining BMV collisions. An increase in bicycle use need not lead to more accidents, as long as infrastructure safety and traffic flow are carefully considered (H. Li et al., 2017).

4.4.5. Accessibility

Accessibility is unique in the sense that it is directly influenced by the introduction of bicycle metro and travel behaviour. Accessibility is defined as people's physical ability, coverage and capacity.

Cycling is and will always be a physical activity, so it is important that cycle paths are usable. A simple example is that a slope that is too steep can cause some people to be unable to cycle uphill (van Boggelen et al., 2009). But cycling itself can also be an extra challenge for some elderly or disabled people. However, many can still cycle, the elderly benefit greatly from e-bikes and people with disabilities sometimes use a slightly adapted bike or sometimes heavily adapted. In 2016, the Netherlands signed the UN Convention on Disability, which states that the Netherlands is required to implement effective measures to help people with disabilities have the highest level of independence possible in their personal mobility (UN, 2006). Thus, careful attention must be paid to accessibility for the disabled (van der Have & Bot, 2021). The bicycle metro provides higher quality infrastructure and more spacious cycle paths compared to normal cycle paths. This should mean that the bicycle metro will be more accessible for disabled people. Moreover, its especially suited for e-bikes, which

Type	Cost per meter
Cycle path	€717
Covered cycle path	€1 592
Underground cycle path	€17 000
Urban motorway	€2 194

Table 4.2: Cost per meter for different cycle paths in euros.

increases the ability of the elderly to continue using the bike as they get older (C. van de Weijer, personal communication, December 12th 2022).

It is good to think about the coverage of the bicycle metro network. This will of course be different for each city but important areas to consider are business parks and outlying neighbourhoods. Especially the places far from the centre you want to make easily accessible by bike, and each neighbourhood should have the same facilities so as not to put people behind.

Like any infrastructure, the bicycle metro will have a certain capacity, measured for instance in passengers per minute. If the bicycle metro were to attract more cyclists, accessibility will decrease. This is because travel resistance increases if it becomes too crowded.

4.4.6. Public cost

Every type of mobility solution comes with costs and benefits. These costs are often paid by the users themselves, for example: petrol, train tickets or buying a bicycle. However, a lot more can be included in the calculations of these costs and benefits. Think of air pollution, health, safety, subsidies and infrastructure costs.

A new bicycle lane with a width of 3,5 meters and thus suitable for the bicycle metro costs an average €717 per meter length, this is including construction, property and process costs (Rijkswaterstaat, 2020). However, the bicycle metro will have a higher price tag as it is either underground or covered.

The building cost database, IGG bouweconomie (2019), helps with the calculation of these costs in combination with real-life examples. For an underground cycling tunnel, costs are found between €14 000 and €20 000, so an average cost of €17 000 per meter length is taken (Edelenbosch, 2019; IGG bouweconomie, 2019; Landsat/Copernicus, 2019). However, because the bicycle tunnel will be a longer tunnel than most bicycle tunnels currently, the cost may be lower. Long tunnels are cheaper per metre than the often short-cycle tunnel. This is due to the fixed costs that are already there for any tunnel length.

Furthermore, when the cycle path is not underground, it will be covered to protect the cyclist from bad weather. These costs are roughly estimated by looking up product cost and combining it, again with help of the building cost database, with average additional costs for civil projects. The additional costs are averaged at 30.3% and these include but are not limited to legal, procedural, preparation and authorisation costs (IGG bouweconomie, 2019; Larbaletier, 2022). With a material cost of €671 (rounded to the nearest integer), the cost of the cover for a cycle path with additional costs is estimated at €874 per meter length (again rounded to the nearest integer). The earlier-mentioned cost of a cycle path still has to be added to this sum, arriving at €1 591 per meter. The results can be seen in table 4.2, which shows directly how much more expensive underground building is. These estimations have been verified by a construction expert (R. Arkesteijn, personal communication, December 7th 2022).

A modality shift from car to bicycle can also have a negative impact on costs. This is because the government makes a profit from the excise duty on fuel (Schroten et al., 2022).

4.5. Conclusion

In the end, a clear conceptual system diagram was developed. The system diagram consists of three parts: infrastructure supply, behaviour and effects. Each of these parts are explained. The introduction of the bicycle metro creates an infrastructure supply with the characteristics offered by the bicycle metro. These characteristics allow for improvement in travel time, convenience and safety. These characteristics together with the supply then have an effect on people’s travel behaviour which alters the mobility mix. Travel behaviour in the system was evaluated using a utility-based framework, assuming that individuals try to maximise their utility and minimise their disutility. The changing mobility mix in turn has a multitude of societal effects. Accessibility was also affected, but rather directly by changes in travel behaviour and the infrastructure supply. Overall, the system diagram proved to be a useful starting point for the feasibility study, by providing a clear understanding of the scope and potential challenges, as well as opportunities for innovation or optimisation.

5

Assessing feasibility: a framework

The effects and internal mechanisms of introducing the bicycle metro are known thanks to the system diagram in the previous chapter. This was useful for the upcoming chapter in which a method was developed to assess the feasibility of the bicycle metro. More specifically, a framework meant to determine the adoption of transport innovations, developed by Feitelson and Salomon (2004), was addressed. This so-called political-economic framework is discussed in this first section, Section 5.1. The political-economic framework was then adapted for application to bicycle metro; the changes made are accounted for in Section 5.2. As a result, the feasibility model was presented, consisting of active agents, factors and specific feasibilities. All these elements together were needed to establish the feasibility of the bicycle metro. Some elements could already be evaluated and that was done, other elements were case-specific and thus could not be determined in a general sense. Finally, this chapter has answered the second sub-question by having developed and presented the feasibility model.

SQ 2 *What does the feasibility model look like for the bicycle metro in the Netherlands?*

5.1. Adoption of transport innovations

So far, the bicycle metro seems to be a concept that can contribute to a more sustainable city and is in line with the goals of the VNG. For an innovation to be successful, however, more factors play a role. Therefore, these factors were investigated further to obtain a complete understanding. A search is done aiming for mobility innovation, the search table is seen in Table 5.1. Not all articles were retrieved online, van Wee et al. (2022, Chapter 6) was brought to attention by researcher Dr. J.A. Annema, whose expertise lies in this area. The chapter presents a political-economic framework of Feitelson and Salomon (2004), that assesses the feasibility of the adoption of transport innovations. The model is shown in Figure 5.1. This model has been used as a starting point for this chapter because it was developed for determining the feasibility of transport innovation. This is what the bicycle metro is essentially and therefore it seems a suitable basis.

Bıyık et al. (2021) explains the dimensions of smart mobility concepts and divides them into innovation, social and organisational characteristics. The political-economic framework of Feitelson and Salomon (2004) operationalises the three dimensions and divides them into technical, social and political feasibility. It, therefore, provided a good starting point for assessing the feasibility of the bicycle

	Concepts	
Search terms	Feasibility	Transport
	Innovation	Planning
	Adoption	Mobility

Table 5.1: Search table, for mobility innovation adoption. Functioning in the same manner as 3.1.

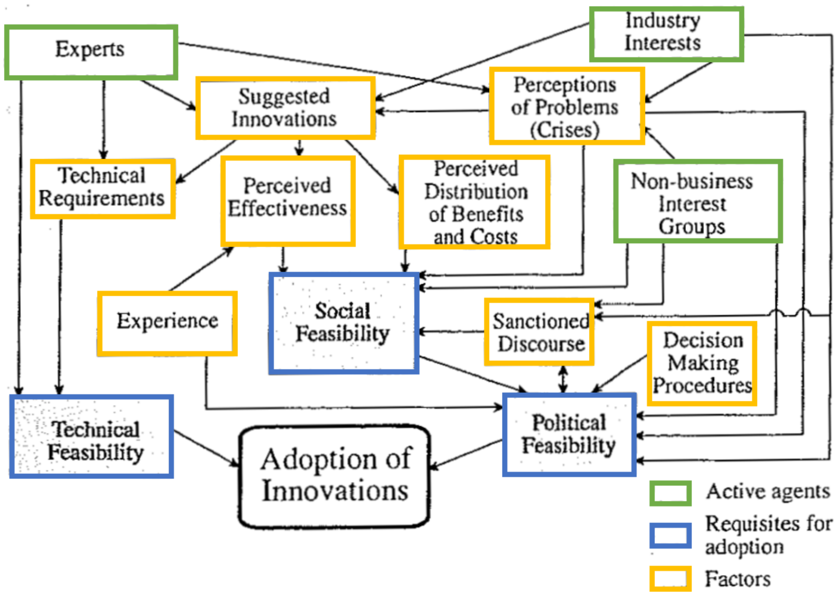

Figure 5.1: Political-economic framework: a framework for analyzing transport innovation adoption.

metro as a transport innovation. However, the economic facet was missing here and some other factors and agents were irrelevant to the bicycle metro's situation. Therefore, the framework was modified to represent economic feasibility and some other elements were removed, more on this later in this Section. The new feasibility model that was then obtained is shown in Figure 5.2.

The four requisites for adoption suggest that innovations will only be successful and thus adopted if the innovation is feasible in these four aspects. Here political feasibility is depending in part on social and economic feasibility. Social and economic feasibility are requisites for adoption that are not directly connected to the overall feasibility. This is because politics makes the policy and decisions, but it is under much influence of public opinion not least because politicians are elected. The same holds for economic feasibility, it will politically be very hard to push something if it is not economically feasible. These four requisites for adoption, technical, economic, social and political feasibility, in turn, depend on a number of factors and active agents that are also indicated in Figure 5.2. Technical feasibility is largely determined by experts, e.g. academics, policymakers or engineers. They can assess if a concept has the right technical requirements. Experts can also directly assess technical feasibility and even suggest innovations.

Social feasibility, which means that a majority of the population is in favour of the concept, depends partly on the perceived effectiveness of the suggested innovation, the perception of problems and the sanctioned discourse, meaning the established course of actions and dominant thinking which is followed by the media, citizens and politicians (Feitelson & Salomon, 2004). The suggested innovation is, of course, the bicycle metro and the perception of problems is what the concept wants to contribute to a solution. Industry interests are removed in the feasibility model because the development of cycling infrastructure is not a commercial issue. Non-business groups are relevant though because they can try to alter the social feasibility by influencing popular opinion. For example, stakeholder groups or lobbyists can support or oppose certain innovations through media or publications, and in doing so, challenge the sanctioned discourse of decision-makers and the public. As no bicycle metro exists yet, there are no past experiences but regular cycling and cycle highways to influence the perceived effectiveness or political feasibility. Perceived effectiveness refers to how effective people think the concept is. Perceived effectiveness also includes a balance of costs and benefits. If the perceived costs and benefits have a negative outcome in the end, there is a small perceived effectiveness. That is why the feasibility model only shows the perceived effectiveness and not the perceived distribution of costs and benefits. However, costs and benefits do show up, but in determining economic feasibility. Consequently, it can be said that political feasibility depends on social feasibility - after all, it is a politician's job to serve the people - and the existing sanctioned discourse. According to which procedures political choices are then made is not relevant to the bicycle metro and this study at the moment, since

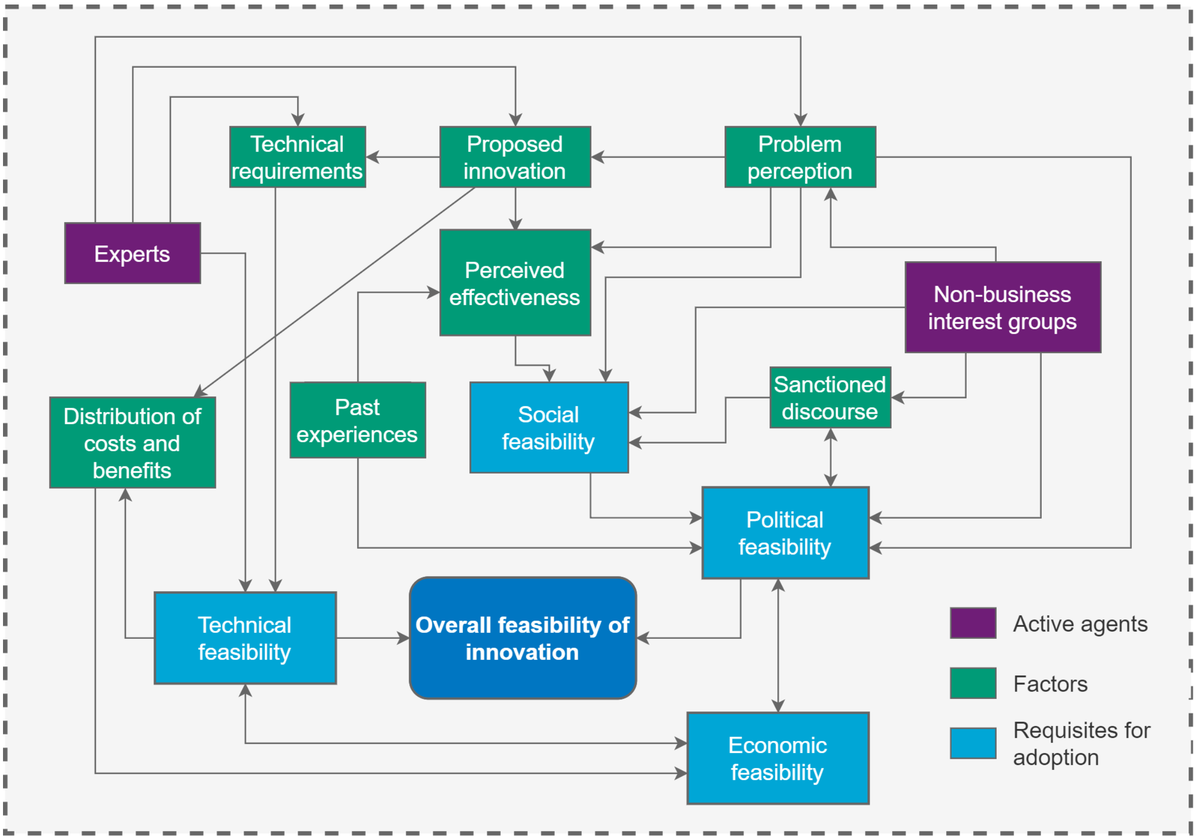

Figure 5.2: Feasibility model: a framework for analysing the feasibility of the bicycle metro (adapted from Feitelson and Salomon (2004)).

it is an exploratory study. Later this may become relevant, but for now, decision-making procedures have been removed from the feasibility model.

Perceived effectiveness is largely based on how effective people think the bicycle metro is. This perception is formed by past experiences and the characteristics of the proposed innovation. Although there are no experiences with the bicycle metro in particular, people can form a perception through their experience with normal cycling and infrastructure. So to put it in other words, the perceived effectiveness of the bicycle metro is the extent to which people perceive the proposed innovation to solve the perceived problems. This can include factors such as the level of usage by cyclists and the safety and convenience of the route.

The perceived effectiveness of a bicycle metro may vary depending on the perspective of the person evaluating it and may be influenced by factors such as the individual's personal experience with the route and their overall attitude towards biking as a means of transportation. As the study Harms et al. (2017) shows Dutch people give cycling a very positive rating, which can indicate that they are satisfied with its effectiveness. To assess the perceived effectiveness for this study, literature is reviewed about the enablers and barriers people perceive in choosing to cycle. Then, with the help of the system diagram of Chapter 4, an evaluation is made on which of these enablers the bicycle metro has a positive effect and which barriers it reduces.

5.2. Feasibility model

After the development of a feasibility model in Section 5.1, it is known that four requisites are needed for the adoption of the bicycle metro: technical, social, political and economic feasibility. Each of the types of feasibility is determined by factors and active agents and some are dependent on other feasibilities. In the following section, these factors and active agents are addressed one by one along with the feasibility types to establish conceptual and thus non-site-specific feasibility.

5.2.1. Active agents

Covering the feasibility model begins with the active agents as they are autonomous entities in the model and therefore not dependent on other factors. This is also reflected in the fact that no arrows go into the active agents' boxes. The active agents that influence the model are experts and non-business interest groups.

Non-business interest groups

Non-business interest groups are influential stakeholders in the social feasibility of the bicycle metro. These groups, representing a variety of interests beyond mobility, strive to shape public opinion, policy and sanctioned discourse through their advocacy. It can be challenging to measure the exact impact of these groups, but although they are not part of the decision-making process, it is important to consider their perspectives, knowledge and expertise during the decision-making process. By taking into account the views of non-business interest groups, it is possible to build support for the bicycle metro and align it with the needs of the community, making it more valuable to a diverse range of stakeholders.

Experts

Experts have an important role to play in the feasibility model. Besides assessing the proposed innovation, often on a technical level, they can also suggest innovations. For this study, three experts were interviewed, Carlo van de Weijer, the initiator of the bicycle metro and smart mobility expert, Bas Braakman, bicycle policy advisor of Eindhoven municipality, and finally Ruud Arkesteijn, underground construction specialist. Their knowledge and views are used, among other things, to gain knowledge about the various factors in the feasibility model.

Van de Weijer initiated the idea of the bicycle metro as a reaction to an ongoing discussion about infrastructure supply. In Van de Weijer's view, the bicycle as a means of transport does not get the amount of attention or budget that it deserves or needs. Whereas it is capable of solving a lot of urban transportation issues. With regard to the feasibility model, Van de Weijer's main influencing factor is the proposed innovation (C. van de Weijer, personal communication, December 12th 2022).

Braakman indicates that Eindhoven municipality is actively looking at solutions to encourage bicycle use. Nevertheless, he agrees with van de Weijer in that cycling is allocated relatively few resources. In the past, there have been projects for advanced suburban cycling highways. However, these have been realised with less extensive functionalities than originally intended, this was mainly due to costs. Especially in the 1970s and 1980s, attempts were made to decouple bicycle traffic from car traffic, and this is now being pursued again. However, a completely decoupled network does not seem possible in terms of urban planning and costs, i.e. economically and politically. Braakman can be seen as an expert who has a lot to do with the problem perception factor, being partly responsible for policies to solve mobility problems (B. Braakman, personal communication, December 23rd 2022).

Arkesteijn sees no problem with urban underground construction, especially as long as it is done under canals or existing roads. However, it does get complicated at intersections; these have to be broken up, which can cause a lot of traffic disruption, especially in old city centres. Also, of course, each city is located in different soil and thus different conditions have to be taken into account in the construction. Nevertheless, the bicycle metro seems technically feasible and overall the cost estimates for underground construction made in Chapter 5 seem credible (R. Arkesteijn, personal communication, December 7th 2022).

5.2.2. Factors

Having described the active agents, the next step is to describe the factors. These, unlike the active actors, are interconnected. That is, one or more factors and/or active agents impact their state. Once all factors, active agents and their impact are known, the feasibility can be assessed.

Sanctioned discourse

Concerning the sanctioned discourse, it refers to the official narrative or dominant perspective on the bicycle metro or cycling for that matter. Sanctioned discourse is a product of the communication from actors and according to the feasibility model, is affected by non-business interest groups and political feasibility. The political feasibility affects the sanctioned discourse by their policy and how they articulate it, which is in turn very dependant on the social feasibility (Krabbenborg et al., 2021).

It is clear that cycling takes an important role in the mobility mix, especially in the Netherlands. Yet the bicycle often loses out to the car and PT when it comes to attention or budget. So it seems that the sanctioned discourse is positive in that the importance of cycling as a transportation mode is acknowledged with all the benefits it can bring. However, the sentiment and the actual resources available do not match, leading to a sanctioned discourse which seems negative for bicycle metro, as it requires a far greater investment compared to a regular cycle track (B. Braakman, personal communication, December 23rd 2022; C. van de Weijer, personal communication, December 12th 2022).

This discrepancy in sanctioned discourse between the narrative and reality for cycling infrastructure is caused by the factors and actors influencing sanctioned discourse according to the feasibility model, but it is unclear what specifically causes it. One cause could be that the influence of other interest groups like the automobile lobby is greater than that of cycling interest groups. Another cause can be that while cycling has a positive sanctioned discourse, still other initiatives that are competing for budget, simply have a higher priority. Note that these are hypotheses and no supporting data have been found.

Perception of problems
While most problems are already discussed in the introduction (Chapter 1), some explanation needs to be added on how they are addressed in the feasibility model. The problem perception affects social feasibility directly since the greater the perceived problem the more people will desire a solution or innovation. This is also the reason why the perception of the problems directly affects proposed innovation.

Perceived effectiveness
The perceived effectiveness of the bicycle metro is the extent to which people perceive the proposed innovation to solve the perceived problems. To assess this, the first step is to look at what people perceive as barriers or enablers to cycling. Then, using literature and the system diagram from Chapter 4, the impact of cycling metro on those perceived barriers and enablers is reviewed. Ultimately, it can then be examined whether the metro is effective in removing the barriers and enhancing the enablers, which then gives a picture of its effectiveness.

Perceived barriers and enablers
Appendix C includes a table of 18 studies on perceived barriers and enablers to cycling; the table lists the specific perceived barriers and enablers to cycling, in which country the study was done and the population size. Only those perceptions that may also relate to bicycle metro are considered. For example, Bopp et al. (2012) finds that people have a sense of traffic safety while cycling on campus, hence this is not relevant to the bicycle metro concept. Moreover, a number of studies used are from the United States or other countries outside Europe. However, it is important to keep in mind that there is a significant difference between the mobility culture in the United States and the Netherlands. Therefore, the perceptions of Americans and the Dutch can also be very different. Again according to Bopp et al. (2012), for example, there is a perception in the United States that a person is less flexible before and after work when travelling by bike, this is probably due to the greater distances and the fact that the United States infrastructure is often car-oriented. In the European study Mertens et al. (2016) on the contrary, it says that cycling offers more flexibility. It was therefore decided not to include studies from the United States altogether in the rest of this chapter.

Another issue is to which extent the barriers and enablers are aggregated. For example, studies show that lack of greenery, cycling in tunnels and not being able to see landmarks are barriers. This can all be aggregated to underground cycling as a barrier, which is then quite generic. These are not aggregated because they are not all equally as important and solutions can be found for some of these perceived barriers. Vice versa, some studies refer to bad weather influencing trip perception while others denote it more specifically like rain, wind or snow. In this chapter these cases have been aggregated, because if a bicycle path is covered or underground it does not make a difference if it rains or snows, in both cases the cyclist is protected. Thus, it is important to keep in mind the distinctions made.

Several perceived barriers were identified during the literature review. Traffic safety is a barrier seen many times, although this is more the case outside of the Netherlands. Fitness, skill and discomfort are barriers that are often experienced by people who do not cycle regularly or are not bike commuters. Regular cyclists have more facilitative and instrumental barriers such as parking availability and road and infrastructure quality (Gatersleben & Appleton, 2007; Titze et al., 2008; Willis et al., 2013). A collection of all perceived barriers is shown in Table 5.3.

Traffic safety	Uneven road	Bad weather
Fitness	Skill	Uncomfortable
Delay	Tunnels	Noise
Air pollution	Social safety	Hilliness

Figure 5.3: Perceived barriers to cycling.

Well-lit infrastructure	Dedicated bike lanes	Bike parking
Economic	Physical health benefits	Avoiding traffic congestion
Environment	Convenience	Distance and travel time
Continuous bike paths	Mental health benefits	Multiple route options
Scenery	Good infrastructure	Low level of crime
	Low traffic speed	Freedom

Figure 5.4: Perceived enablers to cycling.

There are various perceived enablers to biking, clear themes are convenience, monetary cost and health. Many enablers do not experience as much stimulation from the bicycle metro because they are inherent to cycling, such as: improving physical and mental well-being or the convenience of being able to take the bike anytime (Gatersleben & Appleton, 2007; Willis et al., 2013). Others, on the other hand, may very well be provided for by features of the bicycle metro, e.g. adequate lighting and decoupled cycle lanes, or may be provided for in the design of new infrastructure, such as sufficient parking spaces (Kalter & Groenendijk, 2018; Rondinella et al., 2012; van Boggelen, 2010). A complete list of the enablers is shown in Table 5.4.

Remarks
There are other factors that influence the assessment of barriers and enablers. Namely, there are differences in how people perceive or weigh barriers and enablers. There are also other factors that have an influence. Some of these factors are discussed in more detail below.

Instrumental and affective Anable and Gatersleben (2005) listed the most important attributes people value in their leisure and work trips. It is found that people attach more importance to instrumental factors (especially convenience) when considering work trips instead of leisure. Instrumental barriers and enablers are thus particularly relevant. Important instrumental and affective factors are shown in Table 5.2.

User experience There are significant differences in perception between people who already use a bicycle and people who do not. All positive perceptions increase with somebody who is a frequent cyclist (Rondinella et al., 2012). Therefore, it can be valuable to promote cycling through, for example, a campaign to entice more people to take the bike.

Time perception When perceived trip time is a motivator for a certain travel choice. It is important to question whether this choice considers objective time or subjective time. Often subjective time, or perceived time, is not the same as objective time (Kalter & Groenendijk, 2018; Tenenboim & Shiftan, 2018). People tend to have a longer perceived travel time than the actual travel time (Rietveld et al., 1999).

Weather apps It is possible that with the emergence of weather applications for smartphones (e.g. Buienradar, Buienalarm), the role of precipitation as a barrier has decreased (C. van de Weijer, personal communication, December 12th 2022). This is because people can now more easily plan their trips around bad weather. However, no research has been found on this.

Instrumental	Affective
Health	Excitement
Environment	Relaxation
Predictability	Freedom
Cost	Control
Convenience	No stress
Flexibility	

Table 5.2: Instrumental and affective attributes (Anable & Gatersleben, 2005).

Synthesis

Now that a lot more is clear about the enablers and barriers of cycling, it is now possible to assess what impact the bicycle metro can have on these. This is the final step before determining perceived effectiveness. In Tables 5.3 and 5.4, colour is given to the various barriers and enablers. In Table 5.3, the barriers that are (partly) removed by the bicycle metro are coloured green, and those that the bicycle metro actually reinforces are coloured red. The same is done in Table 5.4, where the enablers are reinforced by the bicycle metro colour green and enablers taken away by the bicycle metro colour red. For attributes where it cannot be determined with certainty whether and what impact the bicycle metro will have, the colour orange applies. The attributes that the bicycle metro is unlikely to affect are not given a colour.

Figure 5.3 shows various perceived barriers. The bicycle metro positively influences the barrier of bad weather because it shelters the user from the weather. It improves traffic safety and decreases delays due to the increased quality of infrastructure, continuous cycling and wider lanes (H. Li et al., 2017; Transport of London, 2011). Noise and air pollution are also less of a barrier because the bicycle metro is decoupled from existing road infrastructure, meaning there are no cars. It is complicated to comment on social safety, in general, bicycle tunnels provide low feelings of social safety (CCV, 2014). This happens because there is less social control and less visibility, therefore tunnels are coloured red. But because the bicycle metro does differ from a standard bicycle tunnel and countermeasures can be taken. In any case, there is a good chance that the feeling of safety will be negatively affected by the bicycle metro, however, this cannot be said with certainty and is therefore coloured orange. Thus, almost half of the barriers are reduced or eliminated should the bicycle metro be implemented, and one barrier would be increased.

Many perceived enablers are inherent to cycling and therefore not influenced as much by the bicycle metro. Well-lit infrastructure, dedicated bike lanes, continuous bike paths and good infrastructure quality are characteristics the bicycle metro provides. Furthermore, it is not sure if distance is reduced by the bicycle metro, but travel time will be due to the increased average speed. The separated bicycle path of the bicycle metro lets the cyclists avoid traffic congestion above ground. Moreover, because the bicycle metro is partly underground, enablers such as scenery and multiple route options are offered to a lesser extent. Cyclists are still free to choose their route, however, there will be fewer options than in a normal cycle network since one can only leave the route at specific points. Altogether the bicycle metro provides cyclists with six out of eighteen enablers, whereas it takes away three.

Now that the perceived barriers and enablers have been compared with the characteristics of the bicycle metro, something can be said about its perceived effectiveness. As shown in Tables 5.3 and 5.4, the bicycle metro has more positive influences than negative on the perceived barriers and enablers. However, this is not quantified, thus it is hard to say if it also outweighs the negative influences. The distinction between instrumental and affective attributes in Table 5.2 helps to determine which attributes weigh more in commuter travel. Scenery, multiple route options and tunnels are all affective attributes, while safety, environment, delay and cost are all instrumental. Thus, it can be observed that the bicycle metro has a predominantly positive effect on instrumental attributes. These outweigh the affective attributes on which the bicycle metro shows a mostly negative impact. It can thus be said that the bicycle metro has a predominantly high perceived effectiveness.

Past experiences

The municipalities of Eindhoven and Helmond were already working on a similar concept to the bicycle metro twenty years ago. There was a plan to create a covered cycle path including solar panels and even fans to assist cyclists through tailwind. In the end, this did not seem economically and therefore politically feasible (B. Braakman, personal communication, December 23rd 2022). Yet bicycles have also been shown to be the best way to get people out of cars (van de Weijer, 2021). So from past experiences, it can be learned that as infrastructure costs increase, especially when it comes to cycling, the political will to incur these additional costs decreases sharply. This is in line with the earlier discussed sanctioned discourse. Moreover, when a plan has failed in the past, it will be extra difficult to try it a second time. Especially in politics, because a politician may not think it is worth trying a second time or may not want to take the risk of failure and the possible associated loss of reputation.

Technical requirements

The technical requirements can largely be taken from the introduction (Chapter 1). For this feasibility study, however, it is not important that everything is specified technically. After all, it is the conceptual feasibility that is being studied in this chapter. Setting up the technical requirements can come at a later stage of concept research.

Distribution of costs and benefits

An important part of economic feasibility is the distribution of costs and benefits. After all, if costs exceed benefits, the economic feasibility quickly becomes a difficult story. Though the costs and benefits need not always be of monetary nature, they will be expressed in euros to enable comparison. The costs and benefits are case-specific, so stating about it in general comes with large uncertainties. Construction costs depend very much on the built environment or soil and benefits in turn depend very much on the demographics and characteristics of the city. In general, therefore, nothing meaningful can be said about the cost-benefit distribution. Though, the case study in the next chapter will allow a more in-depth analysis. Part of the costs are known thanks to the cost estimate per metre from Chapter 4, Figure 4.2. It can already be deduced from this that the percentage of bicycle metro that is underground will strongly influence the costs. It looks like the initial investment costs will be quite high.

5.2.3. Feasibility

Now that all factors and active actors have been covered, the data can be synthesised via the four distinguished feasibilities, namely: social, political, technical and economic. Below, they are discussed one by one, starting with social feasibility.

Social feasibility

Social feasibility is assessed using the factors: perceived effectiveness, perceived problems and sanctioned discourse. On top of these, non-business interest groups also have influence. The analysis showed that there is a discrepancy in the sanctioned discourse around the bicycle metro, but also cycling in general. It results in a positive sentiment towards cycling yet limited resources and support. The study into perceived effectiveness resulted in the bicycle metro being perceived as an effective transportation infrastructure.

In conclusion, the social feasibility of the bicycle metro is a complex question, with different factors and actors influencing feasibility. Although there are big challenges in implementing a bicycle metro, its potential effectiveness, the support of some non-business interest groups and the positive image towards cycling suggest that it could be a socially feasible transport option for cities.

Political feasibility

In summary, the bicycle metro may not be politically feasible due to a discrepancy between the sanctioned discourse and the limited budget available for such a project. Past experiences with similar, albeit less extensive, plans have also shown that they are not always or partially realised, adding to the uncertainty about the political feasibility of the bicycle metro. However, it is important to note that the social feasibility of the bicycle metro may be more positive, with potential benefits for the community and non-business interest groups supporting the project.

Technical feasibility

The ground is full of all kinds of essential infrastructures, such as sewerage, electricity, water and so on. In some cities, this is better organised than in others, but the reality is that underground construction is getting increasingly complex (Expertisenetwerk Bodem en Ondergrond, 2019). A bicycle metro will contribute to this, and should therefore be carefully planned with a view to the future.

The construction of a bicycle metro, especially underground and in the city centre, will cause serious inconvenience during the construction period (R. Arkesteijn, personal communication, December 7th 2022). Especially in old city centres, the closure of major passageways can have disastrous consequences for accessibility. Building, and especially underground building, also affects the quality and quantity of groundwater (Barshini, 2022). Therefore, it is important to think about this in advance and plan various scenarios. So although there are a lot of factors to be taken into account, technically the bicycle metro seems feasible.

Economic feasibility

Economic feasibility is very important in determining overall feasibility. However, nothing can be said about this yet because it depends too much on the location where the bicycle metro will be implemented. The next chapter will shed more light on this.

5.3. Conclusions

In this chapter, a framework has been developed to assess the feasibility of the bicycle metro. The framework, or feasibility model, has three types of elements, active agents, factors and requisites for adoption. The requisites for adoption must each give the green light, as it were, before the bicycle metro is considered feasible in its entirety. The requisites for adoption consist of, social, political, economic and technical feasibility and these are determined by various active agents and interconnected factors. Many of these are known or explored in this chapter; others, such as the distribution of costs and benefits, are too case-specific to make a general statement about. In the next chapter, the feasibility model will be applied to a case in order to see if the bicycle metro is feasible for the municipality of Eindhoven.

6 The bicycle metro in Eindhoven: a case study

This chapter uses a case study of Eindhoven to apply the theoretical insights gained so far and evaluate whether this application leads to useful policy insights. The study focused on the city's characteristics, the implementation of the bicycle metro, and the use of the feasibility model. Many factors have already been covered in Chapter 5 and can be carried over to the Eindhoven case. But as mentioned, some factors are really location-dependent. Therefore, this chapter paid extra attention to the characteristics of Eindhoven and a cost-benefit analysis for the evaluation of the economic feasibility of the bicycle metro.

Eindhoven was selected for several reasons, including the author's familiarity with this city, it being the birthplace of the bicycle metro idea, and the city of Eindhoven is already looking at various innovative solutions in its cycling policy. Hence the subject is also relevant to Eindhoven. Firstly, a short description of the city of Eindhoven is given, including its characteristics and mobility. After that the bicycle metro is discussed and how it would fit in the city of Eindhoven. With this information, it was possible to do a feasibility analysis using the techniques developed in earlier chapters of this report, more specifically using the feasibility model. Since most of the model has already been elaborated in the previous chapter, the focus was on the SCBA specific to Eindhoven. In the end, a conclusion was given about the feasibility of the bicycle metro in Eindhoven and the usability of the feasibility model in real-life, which answered the last sub-question.

SQ 3 *How do the system and the feasibility model relate to the real-life application of the bicycle metro?*

6.1. Eindhoven

With a population of almost 240 000, the city of Eindhoven is the fifth largest municipality in the Netherlands and is located in the province of Noord-Brabant (Gemeente Eindhoven, 2023). The municipality has a total land area of 88.84 km^2 and is an industrial city with many businesses, several railway stations, a university and an airport. Due to the high level of business activity, the population is growing rapidly; in the past five years, the population has grown by 5.1% (Gemeente Eindhoven, 2023). Eindhoven is part of the technological Brainport region, and there is considerable investment in mobility to facilitate its growth (Rijksoverheid, 2023).

6.1.1. Characteristics

Gemeente Eindhoven (2014) gives a nice overview of how the infrastructure of Eindhoven came to be. Eindhoven has changed shape many times and has gone through several major transformations. These always took place in times of economic development. The current city life is the sum of several major transformations. Each large-scale development that the city has gone through is still recognisable today by specific urban planning characteristics from the relevant time period. Eindhoven has four types of infrastructure networks, city centre and inner ring road, city districts and radial roads, city districts and ring road and regional/train connection, a representation of these can be seen in Figure 6.1.

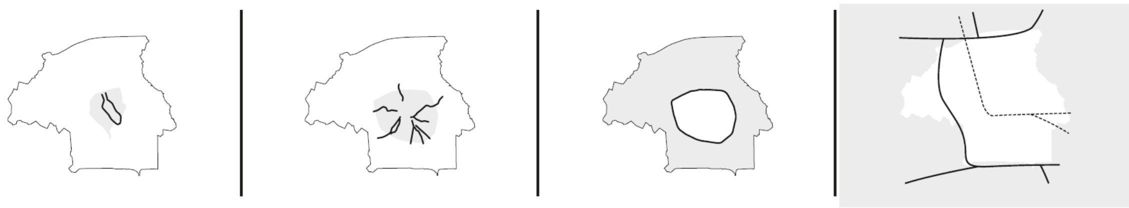

Figure 6.1: Eindhoven infrastructure networks from left to right: inner ring, radial roads, ring road and regional road/train (Gemeente Eindhoven, 2014).

The inner ring in the city centre is one of the main structures still seen today, showing Eindhoven as an original medieval market town. In the Middle Ages, the market was the economic force behind the emergence of Eindhoven as a regional centre of trade and industry, accessible to the surrounding countryside via the radial roads. Eindhoven as an industrial city only started to really flourish with the construction of new roads in the 19th century. Railway connections also appear from 1866 onward. With the arrival of Philips, Eindhoven increasingly develops into a true industrial city. New factories are built. City and villages become increasingly intertwined, but cannot cope with the growth. The annexation of the adjacent municipalities in 1920 enables planned urban expansion. New, green urban thoroughfares often connect residential areas, parks and community buildings. After the second world war, the modern radials and ring road were built; the newly constructed heightened railway was also part of the post-war reconstruction. The traffic structure in particular was developed with the aim of coping with industry and economic growth. It is this sum, the layering of the fortified city, industrial city and modern city that gives Eindhoven a shape unique to the Netherlands. What these time periods have in common, is that in all these periods the infrastructure always served the industry and directly connected all the important economic locations. This historical information from Gemeente Eindhoven (2014) helps to understand the city and its infrastructure better.

Continuing, Gemeente Eindhoven (2014) also provides information on where the municipality intends to move towards. Eindhoven's city centre must be easily accessible and attractive to stay in. This should be achieved, among other things, by keeping cars out, greenery and paying special attention to both cyclists and pedestrians. A very important road in Eindhoven is the ring road. This provides an efficient connection to get around the whole of Eindhoven. The ring road is connected to the outer city districts and to the centre thanks to the radial roads, these also connect Eindhoven to the regional and peripheral roads. Whereas the historic radial roads in the city centre are instead only used for pedestrians and cyclists. The ring road and the radial roads outside the ring road will be equipped with intelligent systems to provide cyclists with an undisturbed journey and improve transit (B. Braakman, personal communication, December 23rd 2022). Furthermore, Gemeente Eindhoven (2014) states a few ambitions on spatial and mobility dimensions for the city in 2040:

Testing ground Eindhoven is a city where technology, design and creativity are visibly part of everyday life.

Open Eindhoven is an open, social city where everyone is welcome, with lots of diversity and mixed residential cultures and each district has its own identity.

Faster and better Eindhoven is a city in which the historical radials are the identity carrier of a city district and the ring road including parallel roads and the modern radials form the ideal traffic structure with its own spatial recognition.

Worldly Eindhoven is a city with a centre that is lively, modern and historical, in which a sustainable network of streets, pavements and squares connects the various city quarters and the inner ring functions as a pleasant city boulevard, with the pedestrian and cyclist central, good public transport and optimal accessibility to the car parks.

Boldness and leadership Eindhoven is a city in which room is made for change in logical places.

6.1.2. Mobility

So as indicated above, Eindhoven is open to new ideas in infrastructure and has innovative plans of its own like its 'doorfietsroutes' (B. Braakman, personal communication, December 23rd 2022). In the

(a) Cycle path below ground level (Google Streetview, 2018)

(b) Cycle path above ground level (Sjees, 2018)

Figure 6.2: Decoupled cycle paths in Eindhoven.

current situation, there are already some 'doorfietsroutes' decoupled from other infrastructure, below ground level and above. Examples can be seen in Figure 6.2.

To get a better picture of the mobility culture, we look at Eindhoven's mobility data, this is provided by Gemeente Eindhoven (2023). Figure 6.3 shows what the most frequently chosen mobility modes are and thus gives a picture of the mobility mix. As can be seen, cycling is very popular alongside the car, but PT is the most chosen mobility mode for only 5% of the population. For commuters, the bike is even more popular, being the most chosen mode of transport for 42%. In total, about a quarter of all movements are done by bike (Gemeente Eindhoven, 2014). The bicycle-friendliness of Eindhoven is assessed by its residents with an 8, as is the accessibility of the city centre. This is far worse for the car whereas it gets a 6.1 for accessibility to the city centre. 32% sometimes experience traffic nuisance in the city and 34% sometimes feel unsafe in traffic, with the biggest cause being speeding.

Gemeente Eindhoven (2014) was reviewed for some additional information. The area within Eindhoven's ring road is completely cyclable, with everything in reach within 12 minutes or 3 km. From the city centre to the east and south of the city can be cycled in comparable time. Double the time, so 24 minutes is required for the north and west, again starting from the city centre. Thus, all city destinations can be reached within roughly half an hour of cycling. Moreover, almost half of the commuting involves short distances of up to 7.5 km. This will continue to be the case in the future. However, half of the trips shorter than 7.5 km are made by car, so there is still plenty of potential for cycling. Especially if the effect of e-bikes is included. This leads to increasing the range to 10-15 km and may lead to 20% more bicycle use (CROW-KpVV, 2013).

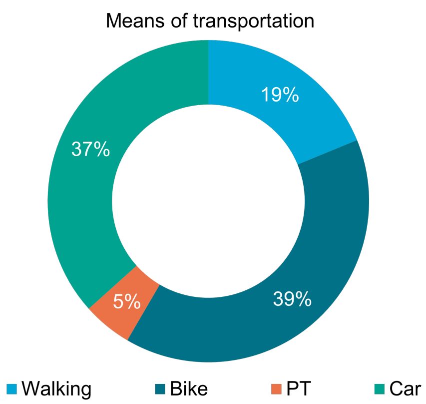

Figure 6.3: Amount of trips for the population of Eindhoven. (Gemeente Eindhoven, 2023).

Only good and fast cycling infrastructure is not enough to facilitate more use of the bicycle. The main focus is on developing a system of regional and local 'doorfietsroutes'. These connect places of interest in the city. The cycle routes are decoupled from other traffic. The cycling routes are not always the

Figure 6.4: Eindhoven's interpretation of the 'doorfiets' network (Gemeente Eindhoven, 2019).

fastest, but they are the most attractive, both for the user and the environment. The routes mainly run along the historical radials and converge on the inner ring. Outside the inner ring, they connect to routes to the surrounding districts. There is as little delay as possible on the routes and the infrastructure is of high quality, recognisable, continuous where possible, safe and there is a varied and lively environment (B. Braakman, personal communication, December 23rd 2022). All major destinations are provided with sufficient, attractive and well-designed bicycle parking facilities that are well-connected to the cycle route and to the walking route. The design of facilities is considered at the start of the (re)design of a site. Important capacity issues, such as around the station and the city centre, are solved in this way. Expansion of parking facilities, especially in the city centre, is accompanied by strict enforcement in public spaces. This is currently the bike policy of Eindhoven municipality and will also shape decisions in the near future (Gemeente Eindhoven, 2014).

6.1.3. The bicycle metro in Eindhoven

Unknown at the start of this study but coincidentally, Eindhoven has been working on a concept similar to the bicycle metro. The municipality of Eindhoven has initiated the plan to optimise the city cycling network with the help of express cycle routes. The so-called F-routes should ensure that existing cyclists and new ones, thanks in part to the e-bike, can move efficiently and easily through the city (B. Braakman, personal communication, December 23rd 2022). Whereas the cycle routes were first called express cycle routes or 'snelfietsroutes', they are now renamed to 'doorfietsroutes', because there was a negative public perception of the 'snelfietsroutes' (B. Braakman, personal communication, December 23rd 2022). A big part of the project is not only the physical routes but especially increasing the infrastructure quality in terms of recognisability and making destinations findable while cycling. Like the bicycle metro, the target group consists mainly of commuters. Figure 6.4 shows the map envisioned by the municipality of Eindhoven.

However, Eindhoven's plan was less extensive and radical than the bicycle metro. Cyclists still intersect with other traffic in a few places and there was no covering. Instead, Braakman explained, they work with smart systems where, for example, the cyclist will have a little box on the bike that prevents them from having to wait for a red light, rather the traffic lights will jump to green. Eindhoven municipality is also researching platooning or 'pelotonvorming', which will allow them to give groups of cyclists a green wave. In cases where it is impossible to provide cyclists with a continuous route, efforts are being made to compensate cyclists in other ways (B. Braakman, personal communication, December 23rd 2022). Furthermore, Braakman told that the biggest reason for not being able to complete continuous cycling is lack of space. This could also be an indication of budget constraints because there is thus not enough money and/or political budget to build tunnels or bridges in those places.

Sjees (2018) conducted a survey on the opinion of the Helmond-Eindhoven express cycle route, indicated in Figure 6.4 as route F270. From this, information can be extracted that may be relevant to the feasibility of the bicycle metro in Eindhoven. The 524 respondents indicated that with 62%, time and distance of the route was the biggest reason for choosing it. Furthermore, the top three areas for improvement were safety, maintenance and quality. A factsheet of this study can be seen in Appendix E.

6.2. Distribution of costs and benefits

Most of the factors in the feasibility model are known from Chapter 5 and also apply to Eindhoven. However, the distribution of costs and benefits is very case-specific, which is why a social cost-benefit analysis is done. To make a concise cost-benefit distribution, information from the website "MKBA informatie" (2022) was used as a guide. Also, data from the study on the societal costs and benefits of cycling by van Ommeren et al. (2012) was consulted. This study uses public health, public costs, pollution and nuisance, and traffic safety as cost and benefit items. These items were also covered in the system diagram of Chapter 4, therefore those data can also be considered relevant for this study. Two calculations were included, namely the cost-benefit per passenger kilometre and the cost-benefit when switching from bus or car to bicycle. The cost-benefit analysis is based on some general assumptions which, in consultation with the first supervisor Mr Annema, are as follows:

- The cost-benefit analysis uses a discount rate of 5.5% and the sum of all costs and benefits is expressed as net constant value (NPV).
- The time horizon is 100 years.
- Travel time valuation is estimated at 10 euros per hour.

The following discusses first the costs and then the benefits, followed by an overview of the cost-benefit distribution.

To provide a cost estimate, the lengths of the cycling routes proposed by Eindhoven were estimated with help of Google Maps. As the bicycle metro is only urban, the distances to other cities such as Tilburg and 's-Hertogenbosch were not included. Table 6.1 shows the estimated distances, they are rounded to whole kilometres. To make an estimate for the cost, the calculated costs per meter from Chapter 4, Table 4.2 were used. To determine what the distribution between underground, covered and normal cycle path is, a parallel was drawn with the normal metro. This was done because the conventional metro line is underground for the same reasons as the bicycle metro is and is therefore considered a reliable example. About a quarter of the Amsterdam metro is underground, in addition, it is assumed that the rest of the length of the bicycle metro is half covered and the other half, not (GVB, 2023). Other costs are operation and maintenance costs which are calculated per year, for this study 1% of the investment cost per year is used (van Ommeren et al., 2012). With these data, a total investment cost of €830 million is calculated, and thus an annual operating and maintenance cost of €8.3 million. For this annual cost, the net present value (NPV) has to be calculated with

$$\sum_{t=0}^{100} \frac{C}{(1+i)^t}, \tag{6.1}$$

where C is the net cash flow during a single year, t the number of years and i the discount rate (Fernando, 2022). Resulting in operating and maintenance costs of €158 million NPV. Thus the total costs for a bicycle metro network in Eindhoven are €988 million.

F-route	Kilometres	Cost
F2	18	€92 mln
F40	36	€184 mln
F50	14	€72 mln
F58	9	€46 mln
F60	15	€77 mln
F67	15	€77 mln
F69	15	€77 mln
F80	9	€46 mln
F90	17	€87 mln
F270	14	€72 mln
Total	**162**	**€830 mln**

Table 6.1: Estimation of distance (rounded to whole kilometres) and cost of a bicycle metro in Eindhoven. 25% underground, 37.5% covered and 37.5% uncovered.

6.2.1. Bicycle kilometre

van Ommeren et al. (2012) did a cost-benefit analysis for a bicycle kilometre, some data from this analysis is used for this research and the results are shown in Table 6.2. The various costs and benefits are briefly discussed below, as they have already been discussed in Chapter 4 as well.

Accessibility affects the delay or travel time savings for road users, this is related to the speed of travelling. For cars, for example, traffic jams can cause delays, while bicycle metro can provide faster travel time for cyclists. van Ommeren et al. (2012) estimated this for the car at a cost of €0.33 per kilometre, mostly due to urban traffic. The bicycle metro actually provides travel time savings due to the increased average speed as indicated in Chapter 3. For the normal bicycle, the increase in average speed is 3 km/h; for the electric bicycle, it is 6 km/h. For this analysis, it is assumed that 25% of cyclists do so with an electric bike (RIVM, 2022). To calculate the expected benefit of travel time savings per kilometre, for both the normal bicycle and e-bike, it is calculated how much faster a km is travelled thanks to the higher average speed. After this, these are proportionally multiplied by the travel time valuation of 10 euro. This shows that the average benefit for travel time savings for the bicycle metro is €0.12 per km.

Public health relates to life expectancy and productivity; since people who cycle are less likely to be sick, this increases productivity. The same effect applies to the life expectancy of cyclists. These benefits are estimated by van Ommeren et al. (2012) at €0.067. However, bus and car emissions affect the health of others too, therefore this is added to emissions later on.

Public cost is affected through subsidies and duties, the government actually earns money on duties for car users, but loses some by offering parking facilities. For PT, the government needs to pay subsidies. For cycling, there are virtually no costs.

For the external effects, there are costs due to pollution and nuisance, these are zero for riding a bike. However, for cars and buses, the costs consist of noise nuisance and emissions.

Traffic safety costs a little more for cars than for cyclists, this is because cars and cyclists do not travel the same distances and because there are on average more people in a car than on a bike. However, because the bicycle metro offers a decoupled bicycle network, accidents between cyclists and cars will drop. 75.9 % of deaths while cycling is related to motorised vehicles including PT (Schepers, Stipdonk, et al., 2017). As van Ommeren et al. (2012) calculates -€0.06 for traffic safety, this was changed to -€0.015 to adjust for the increased safety. All in all, this eventually translates to a positive societal balance of €0.172 per kilometre for the bicycle.

	Bicycle kilometre	Car kilometre <7.5km	Bus kilometre
Accessibility	€0.12	-€0.33	PM
Indirect effects			
Public health	€0.067	In emissions	In emissions
Public cost	€0.00	€0.03	-€0.29
Total indirect effects	**€0.067**	**€0.03**	**-€0.29**
External effects			
Pollution and nuisance	€0.00	-€0.042	-€0.033
Traffic safety	-€0.015	-€0.063	-€0.054
Total external effects	**-€0.015**	**-€0.105**	**-€0.087**
Benefits per kilometre	**€0.172**	**-€0.0405**	**-€0.377**

Table 6.2: Bicycle kilometre with bicycle metro in urban environment outside the Randstad (adapted from van Ommeren et al. (2012)).

	Optimistic	Pessimistic
Cost		
Investment	€830 mln	€830 mln
Maintenance	€158 mln	€158 mln
Total cost	**€988 mln**	**€988 mln**
Total benefits	**€624 mln**	**€312 mln**
Total balance	**-€364 mln**	**-€676 mln**
Benefit/cost	**0.63**	**0.32**

Table 6.3: Cost-benefit analysis for the bicycle metro, NPV with 100 years and 5.5% discount rate. The benefit is the product of the total number of kilometres and the benefit per kilometre from Table 6.2.

6.2.2. Social cost-benefit analysis

To answer the question of whether the bicycle metro is worth it economically, a social cost-benefit analysis was done, determining the ’distribution of costs and benefits’ factor in the feasibility model. An optimistic and a pessimistic estimate are made. For the positive one, all bicycle kilometres are done over the bicycle metro network and for the negative one, only half. Both costs and benefits are calculated with a discount rate of 5.5% over a period of 100 years.

To calculate the total benefit, €0.172 was multiplied by the number of cycle kilometres in Eindhoven. The average kilometres cycled per person per year in a very urbanised city (>2500 zip codes per km^2) in Noord-Brabant is 954 km (CBS Statline, 2021). From this number 184 km was subtracted to account for recreational cycling, furthermore, the modality shift caused by the bicycle metro was estimated to be between 2.2% and 3.8% (Chapter 4, Table 4.1) and the exact population size of Eindhoven was 238 326. Taking this all into account gives a total number of cycle kilometres per year of almost 190 million for the optimistic case and a pessimistic case is added because it is not likely that every cycle kilometre will be done on the new bicycle metro network. Therefore, for the pessimistic case, it is assumed that half of the trips will be done using the bicycle metro network so 95 million kilometres. This leads to a benefit for the optimistic and pessimistic cases of €33 million and €16 million per year respectively, which corresponds with €624 million NPV and €312 million NPV respectively. An overview of the cost-benefit analysis can be seen in Table 6.3. As became clear, the cost-benefit analysis is not positive and also seems to ensure negative economic feasibility.

6.3. Feasibility analysis

Having established a clear understanding of the city of Eindhoven, its ambitions and what a bicycle metro will look like for it, it is now necessary to look at feasibility. The same method as in Chapter 5 is used and each type of feasibility will thus be treated one by one, social, political, economic and technical feasibility respectively.

6.3.1. Social

As the survey of Sjees (2018) indicates, the main reasons for Eindhoven residents to take a cycle route are distance and time. They also see areas for improvement regarding safety, maintenance and quality. A public perception revealed by the interview with Braakman was that people thought the express cycle route was dangerous. Especially nearby residents feel that people and in particular on e-bikes cycle far too fast. By placing the cycle routes less through residential areas and more segregated, this can be solved. Eindhoven municipality is already aware of this, which is why they have changed the naming. Furthermore, Gemeente Eindhoven (2023) shows a few notable facts. Firstly, that a high percentage of the population already cycles, secondly, that accessibility to the city centre for motorists gets a rating of only 6 where cyclists give it an 8 and lastly, autos are a major cause of feelings of traffic unsafety. Bearing in mind the features offered by the bicycle metro, all this suggests that a bicycle metro could be socially feasible. However, care must be taken with placement in relation to nuisance to local residents.

6.3.2. Political

While the sanctioned discourse is certainly positive towards cycling and sustainable mobility in general, and the bicycle metro also looks socially feasible, the bicycle metro does not seem feasible politically. This is very closely related to economic feasibility. Eindhoven's political will is present to realise an extensive bicycle network, but the initial investment in the bicycle metro is simply too high. The cost of a complete bicycle metro network is estimated at €830 million, compared to Eindhoven's total traffic, transport and water costs of just under €47 million in 2021 (Gemeente Eindhoven, 2021). Of course, one could look at whether a single route at a time could be built over several years, but this study was about the entire bicycle metro network. As the interview with Braakman showed, Eindhoven does work on smart and innovative solutions to still offer cyclists a continuous bike ride, and maybe that is a viable solution.

6.3.3. Economic

As mentioned above, the initial investment sum for the bicycle metro is too large. Eindhoven's burden for traffic, transport and water management were just under €47 million in 2021, and the cost of a full bicycle metro is many times higher (Gemeente Eindhoven, 2021). Although the societal cost-benefit shows a positive societal balance for the bicycle metro, the annual and initial costs cause it to take a very long time before the network has paid for itself. In the most optimistic case, the total balance is still €364 million euro short. By applying smarter systems, it may be possible to approach the desired effects of the bicycle metro for less money. Technological advances could reduce costs, as indicated by the arrow between economic and technical feasibility in the feasibility model, but this is not currently included.

6.3.4. Technical

In practice, technical feasibility and economic feasibility are relatively closely related. This is because technically it is feasible provided there are sufficient economic resources. However, there are always economic constraints. So for technical feasibility, yes it is technically feasible, but not within the economically set limits.

6.4. Conclusions

So in conclusion, the construction of an entire bicycle metro network for Eindhoven is not feasible. The biggest reason for this is economic unfeasibility and, partly as a result, political unfeasibility. The initial investment costs and therefore maintenance costs are simply very high and a middle ground has to be found. As revealed in interviews the municipality has a lot of ideas to promote bike path continuity and it might be more economically intelligent to take these kinds of smart solutions based on technology versus the bike metro. It may be a slightly less elegant solution but it saves a lot of money. Also, because as a city it is always necessary to keep offering PT, it is not possible to make the bicycle metro a complete replacement for it.

Besides concluding on the feasibility of Eindhoven specifically, this chapter also shows that the feasibility model can be applied to a real case study. Some factors could only be investigated using a case study and were therefore not yet known in Chapter 4. It has now been shown that these can be determined and have a significant impact.

7 Conclusions

This chapter answers the research question through a case study applied to a specific situation. What will be given is a better understanding of the bicycle metro for policymakers and mobility experts. To answer the research question, three sub-questions were formulated. First, a system diagram was made to map the effects and mechanisms involved in the introduction of the bicycle metro. After this, a feasibility model was developed to assess the feasibility of the bicycle metro. Finally, the research is concretised by applying the feasibility model to a case study. The answer to the research question is a synergy of the conclusions of the sub-questions. These sub-questions are first briefly discussed again - how they were approached and what the outcome was - after which the research question is answered. Below, both the research question and the sub-questions are provided again for convenience.

RQ *What is the feasibility of the bicycle metro in the Netherlands, and what are the potential policy implications of this feasibility analysis?*

SQ 1 *What are the possible effects and feedback mechanisms at work in the implementation of bicycle metro in the Netherlands?*

SQ 2 *What does the feasibility model look like for the bicycle metro in the Netherlands?*

SQ 3 *How do the system and the feasibility model relate to real-life application of the bicycle metro?*

7.1. Sub-question 1, exploring the system

To answer sub-question 1, a system diagram was chosen as the method. The system diagram (Figure 4.1) was divided into three parts: supply, behaviour and effects. Hereby aiming to provide a clear overview of the various factors involved.

The first part of the system diagram, i.e. the infrastructure supply, specifies what the bicycle metro offers and thus adds to the infrastructure supply. In summary, the bicycle metro will provide an uninterrupted cycle path, high-quality infrastructure and a network decoupled from other infrastructure. This will improve safety, convenience and travel time.

The second part concerns traveller behaviour and thus how transport volumes and mobility mix are established. A framework was compiled from several works of literature to better understand active travel behaviour (Figure 4.2). Within the framework, travellers make their choices based on their needs, locations and resistances, which are personal and different for each traveller. Their needs, locations and resistances are determined by factors that can be divided into three domains, the social context, individual level and physical context. As mentioned in the infrastructure supply part above, the bicycle metro provides an improvement in safety, convenience and travel time. Therefore, the needs and locations of travellers are not so much affected, but the bicycle metro has an effect on travel resistance and tries to reduce it so that more people will choose to cycle and those already cycling will do so more efficiently.

The effects brought about by the introduction of the bicycle metro can first be identified as a change in the mobility mix and a change in infrastructure accessibility. Firstly, lowering resistance has an effect on the accessibility of cycling. If barriers to cycling are removed, more people will be able to cycle. This may be because capacity is increased so it is not too busy on cycle paths during rush hour, it may be because of coverage because people now have a high-quality cycle path nearby which makes it easier for them to get to their destination by bike, or it may be because increased safety and convenience allows people who would otherwise not cycle, such as the elderly or less mobile people, to use the bicycle metro. Secondly, the mobility mix changes because the resistance to cycling is lowered by the bicycle metro. Lower resistance to cycling means that more people will choose to cycle and this means that the percentage of cyclists in the mobility mix becomes higher, estimated at around a 2.2% to 3.8% increase. This comes at the expense of other modality options. A change in the mobility mix in turn creates a number of other effects. Namely, a higher share of cyclists in the mobility mix affects public health, pollution and nuisance, traffic safety and public costs. These effects affect each other and some form a feedback with travel behaviour. For instance, a higher percentage of people cycling improves public health, and healthier people lower resistance to cycling, which is a reinforcing feedback loop. Furthermore, healthier people also provide public cost savings in the form of healthcare costs. More cyclists also mean less of other polluting transport types such as cars. This, in turn, improves public health through cleaner air and reduces costs through reduced emissions. Pollution and nuisance also form a reinforcing feedback loop through a reduced resistance to cycling. Polluted air and noise nuisance make people less keen to cycle. Road safety will also improve as more people use a safer cycle path. And finally, public costs are affected, first of all, because building such a bicycle metro network costs a lot of money, but conversely, cycling is also a relatively cheap way to travel, so people will save money in terms of mobility costs.

7.2. Sub-question 2, the feasibility model

Sub-question two seeks to assess the feasibility of a bicycle metro in the Netherlands. The study by Feitelson and Salomon (2004) provides the basis for this, after which a feasibility model is developed to assess the feasibility. The resulting feasibility model that can be viewed in Figure 5.1 has three types of elements: active agents, factors and requisites for adoption.

Starting with the active agents, these are autonomous and influence the factors and requisites for adoption. The active agents consist of experts and non-business interest groups. The experts could be policymakers, or perhaps mobility and construction experts. These agents are important because they are knowledgeable, so their opinion is highly valued. The non-business interest groups consist of groups representing the interests of different stakeholders. They do not have as much of a place in the decision-making process but should be heard to ensure public support and to know what is desired from the community.

The factors within the feasibility model can be many different things and are mostly interconnected. For these factors, it has been analysed what they imply for the bicycle metro. The proposed innovation is the bicycle metro, which tries to solve the problem perception, making mobility more sustainable. The perceived effectiveness shows to what extent people find the proposed innovation effective. The technical requirements describe the proposed innovation in a technical manner. The distribution of costs and benefits sums up what these are for the bicycle metro and whether this distribution has a positive or negative outcome. Past experiences help assess the effectiveness and how people view the proposed innovation. However, there are not many past experiences with the bicycle metro as it has never been implemented before, though Eindhoven once had a fairly similar idea that failed in implementation due to high costs. Finally, sanctioned discourse is the dominant perspective and has a lot of influence on how the problem is addressed and how people view it.

Ultimately, following the feasibility model, the requisites for adoption directly and indirectly determine the overall feasibility of innovation. Should any of these requisites not be feasible, the chances of success for the innovation also decrease rapidly. The requisites consist of four different feasibilities of which two directly influence the overall feasibility, namely political and technical feasibility. If something is not technically feasible, this directly affects the overall feasibility and politics ultimately decides to implement a plan or not. Then there is social and economic feasibility. Social feasibility implies that the majority of the population supports the innovation, this obviously has a big impact on political feasibility because politicians are elected and strongly influenced by public opinion. There is also economic feasibility. This is linked to political and technical feasibility. Technical and economic feasibility are linked because technical possibilities and advancements can bring economic feasibility closer. Conversely, if something is technically challenging like a complex tunnel, for example, it is more expensive and comes at the cost of economic feasibility. Furthermore, politicians determine how much budget there is available and thus to what extent something is economically feasible, but likewise, if something is economically very attractive, this will also influence the political feasibility. Ultimately as mentioned, if these four feasibilities have a positive outcome, according to the feasibility model, the bicycle metro is considered theoretically feasible.

Socially, the bicycle metro seems feasible as the concept is perceived to be effective, also the experience of cycling is generally positive in the Netherlands. Technically, the bicycle metro also appears to be feasible, bicycle tunnels in themselves are not a new invention and have already been built. Economic feasibility is a difficult matter because the bicycle metro requires an extremely high initial investment amount. The cost of an underground cycle path has been estimated at €17 000 per metre, which ensures that the bicycle metro will be a difficult proposition economically. However, this depends on the specific situation where a cost-benefit analysis should be done to give exclusion on economic feasibility. As for political feasibility, as mentioned earlier, it is influenced by economic feasibility, this ensures that politically there has to be a lot of will to still make it politically feasible. As for sanctioned discourse, it has been discovered that there is a discrepancy between the narrative and reality. Cycling is seen as a very important part of a city's mobility mix, but when looking at how much is actually invested in it, it does not match. This, along with the uncertainty for economic feasibility and past experiences, causes the bicycle metro to be labelled politically unfeasible. It must therefore be concluded that overall, the bicycle metro does not seem feasible. However, this may vary per individual case, which is why a case-specific study should always be performed to provide a definitive answer for that specific case.

7.3. Sub-question 3, Eindhoven case study

The last sub-question used a case study in which the feasibility model is applied to the city of Eindhoven. This allows the theory to be used to see if the developed model can be applied in the real world. The city of Eindhoven was chosen as a case study because the original idea came from this city, the author is familiar with this area and the city of Eindhoven is already discussing their cycling policy. Many of the elements already covered in the previous sub-question also apply to Eindhoven. Some case-specific issues have been studied specifically for Eindhoven though, such as a concise cost-benefit analysis. Although the bicycle metro has a positive societal balance the time it would take for the bicycle metro to earn itself back is around 100 years. Moreover, the initial investment cost for Eindhoven municipality has been estimated at €830 million. For a city with a total traffic, transport and water management budget of €47 million, this is not feasible. Especially as the cost-benefit balance is also negative, the bicycle metro for Eindhoven seems politically and economically unfeasible. Socially and technically, it seems feasible, but those two alone cannot ensure overall feasibility.

7.4. Research question, feasibility of the bicycle metro

In conclusion, this study successfully identified the main effects of introducing the bicycle metro by making a system diagram. A model has been created to assess the feasibility of the bicycle metro by assessing the feasibility according to four types: social, political, economic and technical feasibility. Here, each feasibility has a veto, so to speak; if one aspect is not feasible, the whole concept is not feasible. By using the city of Eindhoven as a case study it was found that the initial cost of a bicycle metro network is high at €830 million, and in combination with the annual maintenance and operation costs of €8.3 million, the bicycle metro not going to repay itself. Therefore, the bicycle metro was deemed politically and economically unfeasible. Though, it is confirmed that the effects the bicycle metro offers on pollution and nuisance, traffic safety, public health, public cost and accessibility are in line with the UN sustainable development goals of good health and well-being, industry, innovation and infrastructure, sustainable cities and communities and climate action.

Hence, policymakers need to find other ways to improve cycling infrastructure. The study on the bicycle metro did show that valuable improvements are possible for cycling infrastructure and what the effects could be. Moreover, the fact that a whole bicycle metro network is not possible does not mean that it cannot be built in parts. This will spread the initial investment costs over several years. More use can also be made of technically smart solutions such as platooning combined with green waves or smart traffic lights giving cyclists an artificially continuous cycling route. More on these kinds of alternatives can be read in the discussion. Ultimately, a worthwhile ambition is to keep trying to lower the travel resistance for cycling.

8

Discussion

The main objective of this thesis was to investigate the feasibility of the bicycle metro in the Netherlands. This was done using three sub-questions. The development of a feasibility model enabled the assessment of the feasibility of the bicycle metro. This chapter, concerning the reflection and recommendations of this thesis, aims to analyse these findings, highlighting their significance and implications for both theoretical and practical applications. Moreover, this chapter addresses possible limitations of the study and suggests possible recommendations for future research.

8.1. Reflection on results

To begin with, the sub-questions are addressed individually. First, the main potential effects and underlying mechanisms for the bicycle metro were explored and elaborated in a system diagram. Then, the feasibility model based on the literature was developed and used to comment on the feasibility of the bicycle metro in the Netherlands. Finally, a case study was conducted for Eindhoven to use all the knowledge developed in practice. The conclusions of the sub-questions are discussed, as well as points of interest in answering these sub-questions. For convenience, they are listed again below.

SQ 1 *What are the possible effects and feedback mechanisms at work in the implementation of bicycle metro in the Netherlands?*

SQ 2 *What does the feasibility model look like for the bicycle metro in the Netherlands?*

SQ 3 *How do the system and the feasibility model relate to the real-life application of the bicycle metro?*

8.1.1. Sub-question 1

The first sub-question aimed to identify the potential effects and mechanisms that the introduction of the bicycle metro would bring about. The method chosen here was the creation of a system diagram, as this was not only a suitable way to map the effects and their relationship but could also simultaneously be used as a communication tool. A system diagram can be made infinitely complex, but it is precisely the system diagram that is meant to make complex problems clear. For this study, the system diagram was kept fairly simple and only the most prominent effects were included. But even these effects themselves are delimited. They are discussed below.

For emissions, for example, no emissions for the construction of the bicycle metro were included. Furthermore, van de Weijer revealed during the interview that people who have the opportunity to do most of their mobility needs by bike, for example, because they live in the city, save a lot of money on mobility. He also considers evidence that people with more money to spend each month are more likely to take the plane, so it could be that people who cycle more compensate for their lower emissions by taking the plane more often. Public health was kept very simple by distinguishing only between mental and physical fitness. For road safety, only statistical data was included in terms of accidents, injuries and deaths, but public perception of road safety, for example, could also be included here. For accessibility, only capacity, physical ability and coverage have been considered. While socio-economic factors may also play a role in whether people cycle. Such as their own mobility culture or the facilities available to them. Public cost is also strongly delineated, for example, a death results not only in an economic loss for the deceased but also for the bereaved.

What could possibly have been interesting is making a more comprehensive system diagram with more specific data. Making it easier to turn the knobs, as it were, and thus making it easy to test different types of policies. That being said, in the end it turned out to be a good and, above all, clear system diagram that reflects well what is happening. As mentioned, the diagram could have been much more comprehensive and specific, but for the current purpose it is in-depth enough.

8.1.2. Sub-question 2

The study is about a mobility concept that has never been implemented, therefore there was obviously a shortage of literature. Not only was there a shortage of literature on the bicycle metro, but also on a way to assess its feasibility. This shortage was addressed in this first sub-question by developing a new system for assessing feasibility. This was done through the synthesis of different studies, the author's own insights, and experts and using Feitelson and Salomon (2004)'s political-economic framework as a starting point. This framework can be used not only for bicycle metro but also in the future for other types of mobility innovations. As the study showed, the feasibility model has four key points: social, political, economic and technical feasibility. These never stand isolated, as they are interrelated. For other topics for which literature was already available, such as underground construction and travel behaviour, research was done.

During the literature search, careful attention had to be paid to the country of origin of the studies. This is because mobility culture has a great influence on cycling behaviour, and the Netherlands has a fairly unique cycling culture. Therefore, it was also chosen not to include non-European studies in much of the study. Nevertheless, there are also wide variations within Europe itself, so some data on effects or behaviour may be different in real life than assumed for this study.

The feasibility model developed could also be used for other infrastructure concepts. For example, the hyperloop or other innovations could benefit from it. This indicates that it was a relevant study with value for future studies. Wherein the rest of the sub-questions relate quite specifically to the bicycle metro itself. The feasibility model could also be valuable in terms of generalisability to other locations. However, only the framework would then have to be taken and completely reassessed. With experts familiar with the country or city in question and factors specific to that location.

Other methods could also have been used. For instance, using only a cost-benefit analysis, but much more detailed, or basing the research much more on expert opinions and interviewing more experts in that capacity, or more focus on consulting public opinion through questionnaires and a larger research population. Changing the method could indeed affect the final conclusion. Ultimately, the feasibility model was chosen to get as broad a picture as possible.

In using the feasibility model, the whole of the Netherlands was taken as an implementation area. However, the effects of an urban area were used. This may have caused ambiguity and made it difficult to draw good conclusions.

As mentioned in the discussion of the first sub-question, there were other methods that could have been used to assess the feasibility of the bicycle metro. This is discussed in a bit more detail for the discussion of this sub-question since the method developed for the first sub-question is applied here.

One alternative method would be to use a more detailed cost-benefit analysis. This could have much more accurately determined the economic feasibility of the bicycle metro. This would also make the political feasibility clear and articulate, by allowing a much better and more certain assessment of whether it will be a worthwhile concept. However, high investment costs would still be a major problem here.

What is also an interesting method is one more focused on expert knowledge. This method would have required many more interviews, which would have been very time-consuming. However, a much more complete picture could be drawn. With the current method, at least one expert was interviewed for each of the factors that were influenced by experts according to the feasibility model. Increasing the number of experts would have allowed the study to highlight these factors from even more angles. This would then ensure a more reliable and complete picture. Certainly, the level of detail in research would benefit from this as experts often know a lot about a smaller part.

Instead of experts, a method that focuses more on social feasibility could also be used. This could be done by gathering more information through the user via questionnaires, for example. This would be less intensive per interviewee than it would be with experts and a much larger research population could therefore be involved. The level of detail would perhaps not benefit much from this, but it would create a much clearer picture of public opinion and thus social feasibility and, in that capacity, political feasibility. As an intermediary between experts and questionnaires, one could, for instance, use focus groups or use questionnaires in combination with experts.

8.1.3. Sub-question 3

For the third sub-question, the cost-benefit analysis was a very complex calculation. To keep it manageable a lot of factors are left out since just like the system diagram an almost endless amount of factors could have been included. First and foremost, population growth was not taken into account in the analysis. This would probably have had a positive effect on the case of the bicycle metro. Furthermore, the benefits of the modality shift to the bicycle could have been added to the analysis. This would have given an extra perspective on how effective the bicycle metro could be. A final point of discussion is the increase in safety for cyclists in the analysis. This one is not quite correct, as it now assumes that all cyclists cycle in the bicycle metro. However, this is not true, as there will still be people cycling on normal cycle paths where they do come into contact with cars and other motorised vehicles.

8.2. Limitations

First and foremost, the writer himself was a limiting factor. This is because the writer himself interprets information in his own way and his knowledge also has limits. Another author having another perspective might have valued the same information differently.

Another limiting factor is the use of diagrams such as the system diagram or feasibility model. Although these are used to facilitate communication and make complex situations manageable, they are an abstraction of reality and therefore details are lost. As mentioned in the study, a system diagram can become infinitely complex when approaching reality. It is therefore necessary to simplify and aggregate. However, the choices made in this process affect the outcome of the study. An example is that what people think of underground cycling was not included, this could possibly have reduced social feasibility

This study was of exploratory nature towards a complete infrastructure concept which has never been realised anywhere. As a result, there is a lack of experience and this creates major uncertainties in the study and no indisputable truths in the conclusion. An attempt was made to counter this by consulting experts.

The interviews are a qualitative research method and this may cause bias (Pannucci & Wilkins, 2010). The author conducted these interviews and tried to be as objective as possible, but there is still a chance his actions may have influenced the outcome. For example, when estimating the cost of building the bicycle metro, the method of calculation was explained to the interviewee, but this may have influenced the outcome with the interviewee's own estimate. One way to avoid this could have been to use an external interviewer, which might have reduced interview bias. However, because this is not an implemented concept, it remains difficult for experts to make good estimates.

8.3. Future research

This last section discusses potential interesting topics for further research affiliated with the bicycle metro.

First, further research can be done on the system diagram. Extending the system diagram can give more insight into exactly how the effects and mechanisms of introducing the bicycle metro work. Also, the diagram can be made more reliable by adding new components or quantifying the system diagram. This will also make it easier to test differences in policies.

Furthermore, it is important to conduct research on public opinion on the bicycle metro. Through surveys or focus groups, more reliable insights can be obtained into what people perceive about the bicycle metro and where any areas for improvement lie. As a result, a more reliable assessment of social feasibility can be made.

Another important study is into the functionality of the bicycle metro itself. Much remains to be worked out about what such a bicycle metro will really look like in reality. A specification study or design study could therefore be very valuable. An addition to this could be to further investigate how the bicycle metro could be improved. For instance, solar panels on the coverings or by looking at the airflow in the cycle lanes. This could include looking at how the airflow can be made so that cyclists experience as little headwind as possible. This could be done with fans that should be hanging in tunnels anyway for air circulation or suspended from the canopy (B. Braakman, personal communication, December 23rd 2022).

Another possible study is to look at routes most suitable for the bicycle metro. A route selection study using routing algorithms would then be done to see how to best and most efficiently run routes for a specific city. If done properly, this could ensure that less distance needs to be built and thus save in costs. This is valuable because, firstly, travel distance is a major resistor for cycling and, secondly, the cost was a major reason why the bicycle metro did not appear feasible.

An interesting study topic is how valuable the bicycle metro covering is, especially with the weather apps currently available (C. van de Weijer, personal communication, December 12th 2022). This will allow us to see whether the enclosure is really necessary and whether there might be other ways to provide shelter. During the interview with Braakman, he mentioned that the sun is also beginning to prevent people from cycling. There is a decline in cyclists when the sun is very warm. That is why Eindhoven municipality is now planting trees next to some bike paths to provide shade. Trees also help somewhat to protect cyclists from strong winds.

There could also be further research into innovative ways to minimise the need for cyclists to stop. This involves looking at solutions that do not require tunnels or bridges. A few options Eindhoven is working on have already been mentioned in this study. Their effectiveness can also be examined.

The discrepancy in sanctioned discourse mentioned in Chapter 5 would also be an interesting research topic. The study will be a combination of qualitative and quantitative research. On the one hand, looking at the data about resources going to cycling infrastructure and, on the other hand, interviewing responsible politicians and policymakers about the sanctioned discourse and trying to find out how it came about. This will make it possible to see how the government and other relevant parties have developed their views on cycling infrastructure and whether there are opportunities to adjust these views. It is important that a discount rate is included, it could also be adjusted as it was relatively high for this study. Finally, economic feasibility can be looked at much more thoroughly. The cost-benefit analysis from this study was quite simple, it can be much more comprehensive with the information available.

8.4. Applicability to other locations

This study focused on a Dutch situation, while this research can also be applied to other countries where cycling may be a less accessible mode of transport. Suppose the methods used in this study are used for the same kind of research but at a different location, there are a number of factors that should be taken into account. First, the difference in the mobility mix. A lot of people already cycle in the Netherlands, so relatively fewer new cyclists will be added if the cycling infrastructure is improved. On the contrary, in countries where few people cycle, this effect will be greater. However, more effort will have to go into promoting cycling, as many people are unlikely to just take up cycling if better infrastructure is provided (Hull & O'Holleran, 2014). The already existing infrastructure is also important. This is somewhat related to the mobility mix since a country with a high percentage of cyclists will also have a relatively higher quality cycling infrastructure. The size of the city will also have an impact. The distances that can be reached by bicycle are admittedly increased with the introduction of the bicycle metro. Still, some cities are so big that cycling is not always a suitable option. All in all, this study has been adequate overall for getting an initial insight into the feasibility of bicycle metro in general.

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A

Het Financieele Dagblad

Not public transport, but the bicycle is the future

Decades of wishful thinking about the declining popularity of the car have achieved little. Car ownership is hardly decreasing, not even among young people as has often been predicted. Meanwhile, the car is becoming better, safer, more comfortable and cheaper, which will only exacerbate the space problem that those cars cause. Stationary cars need to be better hidden to keep residential areas and centres liveable. But the moving car uses a lot more space, which is especially lacking in urban areas. That is why municipalities encourage the use of space-efficient alternatives such as cycling and public transport (OV) as much as possible.

Yet in mobility plans, cycling invariably seems to lose out to public transport, not only in terms of attention but also of budget. One plan is even more pompous than the other. But it is not a sensible choice of priority, certainly not if the aim is to prevent car use.

Time and again, the bicycle proves far more capable than public transport of enticing people out of their cars. And at a much lower price, because a bicycle infrastructure is much cheaper to build and maintain, and cyclists themselves pay, maintain and operate their means of transport. The bicycle is much more sustainable than a bus, tram or metro, which are also less clean and economical per passenger kilometre than a modern electric car. We should therefore be much more consistent in using the bicycle as the backbone of the mobility transition, especially now that the bicycle, thanks to its electric drive, has an even greater range and wider audience. Public transport as the basis for urban area development should make way for bicycle-oriented development.

I advocate a 'bicycle metro', a consistently implemented system of wide, separate and conflict-free cycle paths, in some cases underground or covered. They should be wide enough to accommodate not only bicycles, but also mobility scooters, delivery bikes, electric wheelchairs or whatever else efficient smaller rolling stock may be invented in the future.

Time and again, the bicycle proves to be much better than public transport at enticing people out of their cars

You don't need any stations, because you can join and leave the existing cycle path network anywhere. It is easy to fit in because, unlike public transport, cycle paths do not require large radii of curvature or long straight stretches; indeed, cyclists prefer to meander. It is safer for both users and pedestrians. Without traffic lights, but with priority at crossings and bicycle tunnels or bridges where necessary. Due to the low height and weight of the bicycle, tunnels and bridges are much cheaper than those for cars or public transport.

For less money than the North-South line, Amsterdam could have constructed such a bicycle metro network for the entire city, including a bicycle tunnel to Amsterdam-Noord. For a medium-sized town, it is cheaper and much quicker to construct than a heavy public transport system, especially if rails are involved.

Moreover, it is safer, more inclusive, more space-efficient, cleaner, quieter, more flexible, trouble-free, friendlier, more beautiful and future-proof. And most importantly: much more successful in reducing car traffic.

Read the original article: https://fd.nl/tech-en-innovatie/1423218/niet-het-openbaar-vervoer-maar-de-fiets-heeft-de-toekomst

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B

Initial literature search

Table B.1: Overview of the initial literature found.

Source	Title	Keywords
Rayaprolu et al. (2020)	Impact of bicycle highways on commuter mode choice: A scenario analysis	Bicycle highways; Commuter mode choice; Discrete choice analysis; Multinomial logit
van Goeverden and Godefrooij (2011)	Cases of interventions in bicycle infrastructure reviewed in the framework of bikeability	Bicycle infrastructure; Case study review
Skov-Petersen et al. (2017)	Effects of upgrading to cycle highways	Cycling; Cycle highways; Infrastructure upgrade; Induced cycling; Weather; Temporal profile
H. Li et al. (2017)	Safety effects of the London cycle superhighways on cycle collisions	London cycle superhighways; Cycle collisions; Causal effects
Pucher and Buehler (2012)	City Cycling	n/a
Schepers, Twisk, et al. (2017)	The Dutch road to a high level of cycling safety	Bicycle; Road safety; Infrastructure; Safety in numbers; Conceptual model; Road hierarchy
Grigoropoulos et al. (2021)	Traffic simulation analysis of bicycle highways in urban areas	Bicycle highways; Bicycle traffic; Traffic control; Traffic efficiency
Hudde (2023)	It's the mobility culture, stupid! Winter conditions strongly reduce bicycle usage in German cities, but not in Dutch ones	Cycling; Mobility behaviour; Mobility culture; Survey data; Sustainability behaviour
Ziemke et al. (2017)	Modeling bicycle traffic in an agent-based transport simulation	Traffic Management; Cyclists; Planning and Forecasting
Krizek et al. (2009)	Analyzing the Effect of Bicycle Facilities on Commute Mode Share over Time	Data analysis; Investments; Uncertainty principles; Infrastructure; Commute; Bicycles
Bıyık et al. (2021)	Smart Mobility Adoption: A Review of the Literature	Smart mobility; Cities; trends; Opportunities

C

Perceived barriers and enablers

Table C.1: Overview of findings concerning perceived costs and benefits of the bicycle metro, part 1/3.

Source	Perceptions	Location	N
Akar and Clifton, 2009	*Enablers*: better lighting, dedicated bike lanes, dedicated trails and pathways, secured or covered bike parking, convenient bike parking. *Barriers*: Unsafe around vehicular traffic, do not own a bicycle, have to change clothes or carry things, lack of bike lanes or paths or trails.	United States	1 500
Bopp et al., 2012	*Enablers*: economic, health benefits, traffic congestion, parking difficulties. *Barriers*: travelling to other places before/after work, prefer to travel with others, concerns about appearance, concerns about safety from traffic, lack of sidewalks, poor weather, difficult terrain.	United States	375
Brandenburg et al., 2004	*Barriers*: precipitation, cold weather.	Austria	n.d.
de Geus et al., 2007	*Enablers*: economic, environment. *Barriers*: lack of skills and health, lack of time, lack of interest	Belgium	343
Dill and Voros, 2007	*Enablers*: see other people bike, work site location nearby, facilities at work, type of employer. *Barriers*: too much traffic, no bike lanes or trails, no safe places to bike nearby, too many hills, travel distance too great, poorly maintained streets or rough surfaces.	United States	566
van Boggelen, 2010	*Enablers*: adequate infrastructure lighting, smooth and level surface, short distances, separated cycle paths, continuous cycling, exercise, traffic, economic, short travel time.	The Netherlands	n.d.

Table C.2: Overview of findings concerning perceived costs and benefits of the bicycle metro, part 2/3.

Source	Perceptions	Location	N
Gatersleben and Appleton, 2007	*Enablers*: environment, health. *Barriers*: not fit, uncomfortable, uncharacteristic (pre-contemplation phase), unsafe, no cycle lanes, parking, no showers at destination.	United Kingdom	389
Gatersleben and Uzzell, 2007	*Barriers*: Unsafe, delays, inconvenience.	United Kingdom	389
Heesch et al., 2012	*Enablers*: Improving/maintaining fitness, fun, relaxing, physical activity, get outside in the fresh air, challenging, low activity impact, health, biking with friends/colleagues, convenient, environment, economic. *Barriers*: safety, biking costs more time, interaction with motorists, lack of safe places to park, inhaling fumes, no place to change clothes, decrease in daylight hours during winter months, windy weather, too far to cycle, cold weather, required to be physically capable.	United States	1 862
Kalter and Groenendijk, 2018	*Enablers*: fast routes, dedicated bicycle lane, no parked vehicles, no interaction with other traffic, greenery. *Barriers*: tunnels.	The Netherlands	1 500
Liu et al., 2019	*Enablers*: rapidity. *Barriers*: social safety.	United Kingdom, Belgium, Germany, The Netherlands, Denmark	11 (interviews)
Martinez, 2017	*Barriers*: bad weather.	United States	888
Mertens et al. (2016)	*Enablers*: cycle paths, good maintained cycle paths, pleasant environment, low traffic speed, choice between multiple routes, low level of crime. *Barriers*: litter and graffiti and trash, busy traffic, air pollution.	The Netherlands, Belgium, Hungary, France, United Kingdom	4 579
Harms et al., 2017	*Enablers*: fast in urban situations, easier to find parking spot in comparison to car, urban traffic safety, less air pollution, less noise nuisance, economic compared to PT and car, shielded from weather conditions (20%). *Barriers*: availability of cycle paths (5%), delay (10%), parking options (11%), safe traffic conditions (12%), behaviour of other road users (including cyclists) (22%)	The Netherlands	2 955
Rondinella et al., 2012	*Enablers*: short trip distance, parking options. *Barriers*: bad weather, accident risk.	Spain	3 048
Titze et al., 2008	*Enablers*: convenience and rapidity, save from bicycle theft, emotional satisfaction, low effort, high mobility (regular cyclists). *Barriers*: being in shape, traffic safety, uncomfortable.	Austria	634

Table C.3: Overview of findings concerning perceived costs and benefits of the bicycle metro, part 3/3.

Source	Perceptions	Location	N
Willis et al., 2013	*Enablers*: departure flexibility, avoiding traffic congestion, convenience and rapidity, healthy, economic, environment. *Barriers*: social safety, safety of traffic situations, uncomfortable, one has to be in shape.	n/a	Literature study, 24 studies
Winters et al., 2011	*Enablers*: away from traffic noise, travel time, away from air pollution, separated bike paths, clear infrastructure signage, shielded from weather, nice scenery. *Barriers*: risk of bike theft, no large storage capacity, safety, slippery roads.	Canada	1402

D

Interview reports

This Appendix provides a report for each interview used in the research. Interviews were conducted with several experts on the topics relevant to cycling metro. For the interview report, the interview is summarized and translated into English. The full transcripts are available on request.

D.1. Ruud Arkesteijn, underground construction specialist at Mobilis

Arkesteijn, R. (2022, December 7th). Personal communication [Personal interview].

Biggest pitfalls of urban traffic tunnels

The biggest problem will be in the construction phase. Tunnels can be built under canals or roads just fine, but problems come at intersections. The disruption this will cause with cables, pipes and existing infrastructure will be a challenge. It also depends on which technique is used. But in this case, an open construction pit method or wall and roof seems most appropriate.

Cost difference between bicycle tunnels and car tunnels

A car tunnel is more expensive, this is due to its greater width, but also because the car can handle less steep gradients and needs wider curve radii. But in terms of construction cost, the difference is not so significant. At such a difficult intersection, the costs are not very different either. It also very much depends on the kind of land being built in. It will not be more expensive on a linear basis, but per square metre, I estimate that a bicycle tunnel is 20 per cent cheaper than, say, a car tunnel.

Cost estimate for running meter

The projects you used are also at grade, so I do have a good reference there. Costs are likely to be higher at those complex intersections. But at parts where it doesn't intersect and where you can build parallel infrastructure, say under a road or canal, it will be cheaper. But I think it's a fair estimate. I think the combination of such a linear metre price and reference projects is a good approach.

D.2. Carlo van de Weijer, director smart mobility at Eindhoven University of Technology

van de Weijer, C. (2022, December 12th). Personal communication [Personal interview].

Idea formation

The idea started because of the enduring inequality that existed between bicycles and other modes of transport, both in terms of attention and spending. There was also a debate on the expansion of PT, therefore there was a need to raise awareness for cycling. Carlo then commissioned a conceptual map to make the idea more tangible. After publishing the column, it became clear that the municipality of Eindhoven has also been working on the issue since 2013 and has also developed a conceptual map.

The bicycle metro need not be covered everywhere, and only underground if it is functional. With the advent of weather apps, cyclists can see much more accurately when it is raining, this may have had a very big impact. People used to see on the news that it was going to rain and then grab the car, now they can see when it is raining and can then decide to leave a little earlier or later by bike, for example. Or take shelter under a canopy.

D.2.1. Cost

A lot of things are not factored into mobility costs. For example, people living in the city centre can save a lot of money on mobility. This is because these people can cycle almost anywhere, while people outside the city cannot. Research shows that people with more money fly more, so this can negate the savings in emissions. Also when looking at deaths in traffic accidents. The costs incurred due to the loss in economic productivity of bereaved families is also a factor that is often not taken into account.

With e-bikes gaining popularity, a significantly larger proportion of the elderly population can continue to use bicycles. The bicycle metro will only further encourage this, as it is ideally suited to the e-bike.

D.3. Bas Braakman, bicycle policy advisor for the city of Eindhoven

Braakman, B. (2022, December 23rd). Personal communication [Personal interview].

D.3.1. Social feasibility

The social feasibility or the social perception is not as self-evident as it seems. Yes, people want to be able to cycle faster and travel shorter. But as we call it ”snelfietsroutes” have an increasingly bad connotation. Because people experience them as unsafe due to the fast e-bikes and such. But what is more important than speed is continuity. People appreciate it way more if they do not have to wait over being able to bike faster. It’s important that people can cycle at their desired speed. That is why we started calling them ”doorfietsroutes”. Through new tools, we can see at what speed people are cycling. Outside the city, people are able to maintain their desired speed, but you can see that when they enter the city, this speed is reduced. The goal is to allow them to maintain this speed in the city as well. It’s a measure of the quality of your network. We can see where people are waiting more with heatmaps, but it’s still a new method. But in general, it is more important for us to have continuous cycling but not necessarily fast cycling. With a current project between the High Tech Campus and De Run we actually see a lot of social resistance against the cycle highway. This is mainly because it is increasingly seen as a throughway. In that sense, cycling is becoming sort of the new car there. People most dislike too many and too fast cyclists. People find it hard to leave or enter the cycle lane. So you see that our policy works in the sense that the amount of cyclists is increasing, however, you also run into these kinds of things.

D.3.2. High quality infrastructure

A lot of these problems are solved with a completely detached cycle network and higher-quality infrastructure which provides good and spacious entry and exit lanes. We’ve made a metro map to clarify our ambitions. This map also adds to the high quality of the cycle infrastructure. Policy is that ”doorfietsroutes” should be as conflict-free as possible. However, in the current political climate and spatial limitations it is not possible to achieve a completely untangled network. In the 70s and 80s, the first steps were made for this by moving the bicycle infrastructure to another level, minus or plus one. Well the bike also benefits quite a bit in the end. Who can cycle through without stopping. And yes, those tunnels are of course not always social, safe or comfortable, so in the latest designs of decoupled variants we try to put those bikes literally above the car. This then also has symbolic and psychological value. But at the end of the day, the goal is to get the biggest, the most important cycling routes, where the real conflicts are, where cycling suffers a lot of waiting times. And those are mainly the intersections with the ring road and the ring road. Because there, the car has absolute dominance. So there we accept that sometimes bikes have to wait for traffic lights and those are long waits. As long as those bikes are then compensated, upstream or downstream, for the waiting time loss.

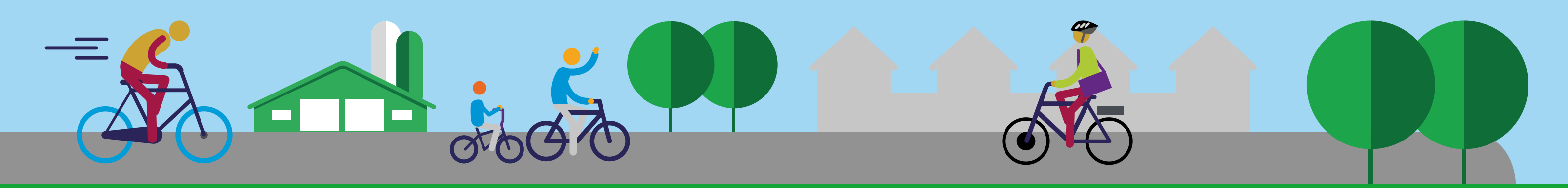
You can also put that money you invest in PT into cycling. For example, it is easy to change the bus lane to the bicycle lane. Well, then you have a nice separate cycle lane and well then you also give a bicycle one of those devices on its bike like the bus has now that communicates with traffic lights everywhere turning green. Well, I do think that's a very interesting thought, it's not policy now. What is remarkable, and I have to agree with Carlo on this, is that the bicycle offers relatively very cheap solutions. Yet, the bicycle invariably loses out to the car or PT when it comes to budget.

D.3.3. Bicycle highway concept Eindhoven/Helmond

The municipalities of Eindhoven and Helmond were already working on a similar concept to the bicycle metro 20 years ago. There was a plan to create a covered cycle path including solar panels and even fans to assist cyclists. In the end, this did not seem economically and therefore politically feasible. That's why they ended up building only the cycle track, then the rest could always be done later.

E

Factsheet Eindhoven - Helmond



Nulmeting Snelfietsroutes Noord-Brabant

Helmond – Eindhoven, meting december 2018

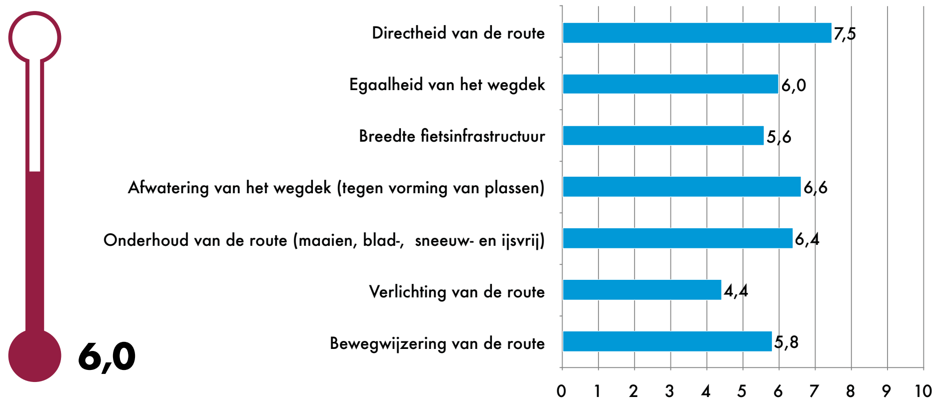
Provincie Noord-Brabant

Respons

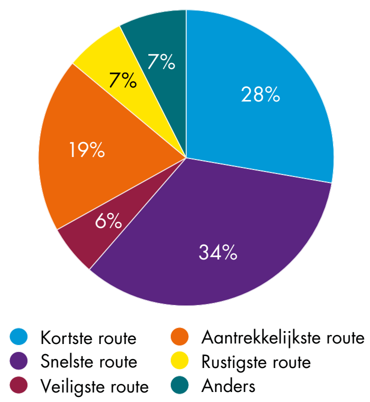
Via social media	130
Via flyer	394
Totaal	524

Totaal

Per onderdeel



Reden gebruik route



Top 3 verbeterpunten

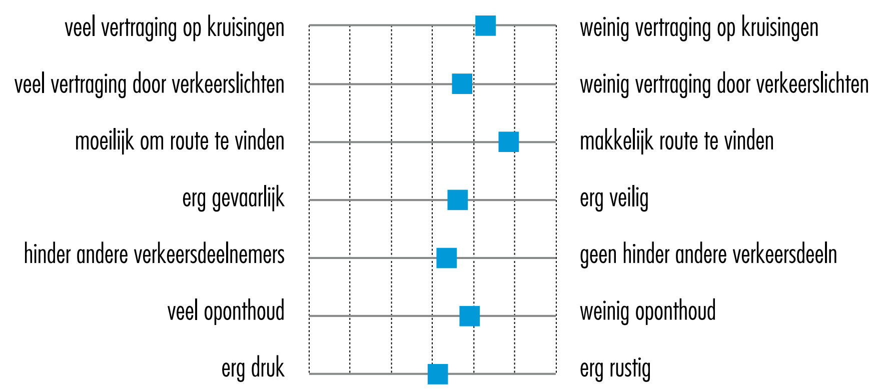
Ik ga vaker fietsen:

Als de veiligheid van de route verbeterd wordt **44%**

Als de route beter wordt onderhouden **42%**

Als de kwaliteit van de route verbeterd wordt **42%**

Ervaring fietsroute



Geldrop-Mierlo Gemeente Nuenen EINDHOVEN Gemeente Helmond