30 AS THE NEW 50

DEVELOPING A GEO-INFORMATION TOOL TO SUPPORT DECISION-MAKING ON SPEED LIMITS IN AN URBAN CONTEXT, CONSIDERING CYCLING INFRASTRUCTURE IN THE NETHERLANDS.

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August 2022

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Enschede, The Netherlands, August, 2022

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Spatial Engineering.

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ABSTRACT

In recent years, many cities in the Netherlands have had to deal with increasing pressure on the urban bicycle network. When adapting the bicycle network, however, other road users must also be taken into account while available space is often already scarce. This means that cities have to make choices about how the space should be allocated and whether it is necessary to make changes. From interviews in this thesis, it was found that currently, policymakers have to deal with the discussion on speed limits in urban environments. Some parties are in favour of lowering speed limits from 50 km/h to 30 km/h to accommodate cycling changes, but many considerations have to be made in this decision.

Geo-information tools are increasingly being used for understanding, discussing, and naming these kinds of spatial challenges. These are programs based on GIS (Geographical Information Systems), which allow discussing a spatial challenge from different perspectives. Stakeholders can use these tools to develop alternative planning scenarios, for brainstorming sessions, or to outline different planning alternatives.

In this thesis, a geo-information tool to support decision-making on where it is possible or necessary to change the speed limit to 30 km/h is proposed. The aim of this tool is to provide insight into the planning problem for users, as well as support creating a common understanding of other stakeholders' viewpoints. Using spatial multicriteria analysis, the tool can be used in an analytical way, or to support a participatory setting. The tool's interface and functions were tested in a participatory setting.

From the testing of the tool, it became clear that before the tool can be used in real-life settings, some alterations are necessary. Because of missing data, it is not possible to include all indicators that testing participants would expect to see in this discussion. Secondly, a clear distinction should be made between the discussion on lowering speed limits from 50 km/h to 30 km/h, and the necessity to change the road design on roads that are already 30 km/h but do not meet safety standards. Finally, it is important to consider the target group for this tool, since not all stakeholders might be familiar with the use of data-supported analysis in GIS software.

Keywords: Participatory Planning, PSS, Geo-information Tools, Cycling

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Lisa Doornbos

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1. INTRODUCTION

1.1 RESEARCH BACKGROUND

In recent years, cycling has increasingly become an attractive mode of transport. Cycling is an inexpensive way to travel around a city and is often linked to a more environmentally friendly lifestyle (Milakis & Athanasopoulos, 2014). Cycling also has a positive effect on the physical and mental health of cyclists, reduces emissions and can reduce travel times (Arellana et al., 2020; Castañon & Ribeiro, 2021). The Netherlands is well-known for its' cycling culture, which since the 1970s is being prioritised in urban planning (Pucher & Buehler, 2008). This has resulted in a vast cycling network of over 37,000 kilometres of fully segregated bike lanes, and with a fatality rate of just 0.9 per 100 million kilometres cycled, the Netherlands is often regarded as the world's most successful cycling nation (Dutch Cycling Embassy, 2021).

However, several Dutch cities are facing issues related to an excessive number of cyclists (Kruyswijk, 2017). Some consequences of the large numbers of cyclists are an increase in accidents, overcrowded bicycle parking's at train stations, and cycling congestion at traffic lights (APPM, 2021; Karman & Kruyswijk, 2013). Next to that there are still missing cycling lanes in the network, long waiting times at intersections and traffic lights, and finally, narrow cycling paths which lead to unsafe situations (TRIDÉE, 2020).

Another change in Dutch cycling is the increased use of faster modes, such as the electric bicycle. The introduction of the electric bicycle means that travelling by bicycle becomes faster and more attractive for long distances, but potentially reduces the safety of other cyclists. The increased speeds can be as much as 20% higher than the speed of a normal bicycle, which can result in conflicts and unsafe situations (Castañon & Ribeiro, 2021). This makes cycling more dangerous for vulnerable groups like children and elderly (Bakker et al., 2012).

These issues call for changes in the current cycling infrastructure. The current dimensions and layout of the cycling network are not suitable for the changing users (Tour de Force, 2020). This new division of space presents spatial challenges since priorities need to be negotiated. Next to that, both government and society's support is needed for this drastic new distribution of road users (Tour de Force, 2020). Creating support and understanding for these needed changes presents challenges, and a common vision of how to deal with changes in cycling is needed (Bakker et al., 2012; Gorris, 2019; Tour de Force, 2020).

1.2 CYCLING INFRASTRUCTURE PLANNING AS WICKED PROBLEM

Societal challenges that involve multiple or unknown causes, a certain level of disagreement among stakeholders about the nature or even the existence of a problem, and the suitability of solutions, are called wicked problems (Georgiadou & Reckien, 2018). What makes the redistribution of users of the current cycling infrastructure a wicked problem and the reason it needs attention in research, relates to several characteristics of wicked problems. First of all, there is often uncertain knowledge and missing data in wicked problems. Another component of a wicked problem is that there are no right or wrong solutions, just better or worse solutions. Finally, there is no defined end to the problem (Rittel & Webber, 1973).

These characteristics apply to cycling infrastructure planning in several ways. First of all, cycling infrastructure projects deal with interconnected, ever-changing conditions, which means that an iterative planning process is necessary. Secondly, there are different ambitions in city planning. There is an ambition to limit car use, which results in the densification of urban areas in Dutch planning strategies (Nabielek, 2012). Densification allows for easier and more attractive cycling environments (Claassens et al., 2020; Nabielek, 2012), but also presents challenges in availability of space (APPM, 2021). Consequently, other ambitions such as the need to be able to cope with climate change, and especially extreme weather events in the near future, need to be considered (Arcadis, 2020). Figure 1 illustrates the pressure on space for the city of Utrecht (Gemeente Utrecht, 2021), which is apparent in many Dutch cities.

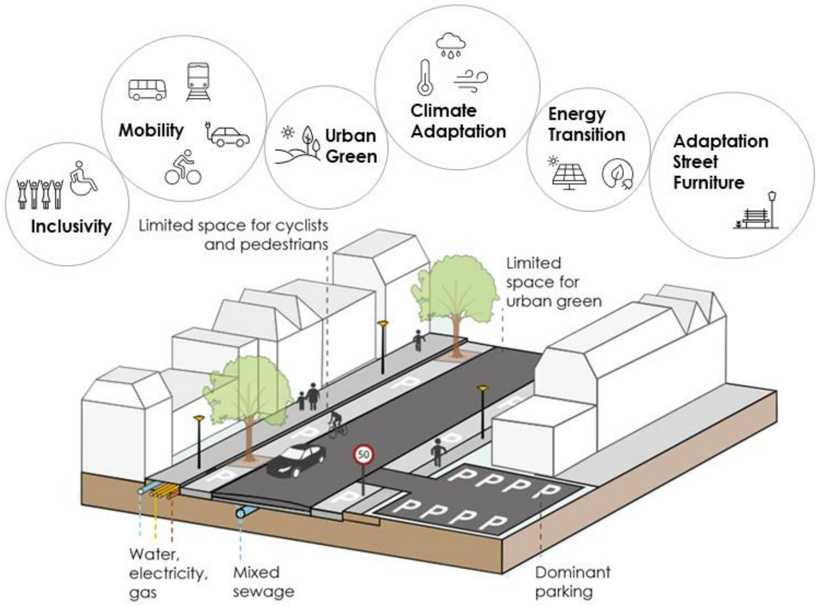


Figure 1: Original image created by the Municipality of Utrecht, displaying the wide array of spatial challenges (at the top) that the city will encounter in the near future, adapted from (Gemeente Utrecht, 2021, p. 85)**.**

As a result, compromises need to be made on the available space. There is dissensus among stakeholders in creating a common understanding of the possible cycling infrastructure alterations that might be needed for the beforementioned cycling changes (Tour de Force, 2020). Thus, this means that there is no one right solution possible, but rather a solution that is generally agreed upon. Next to that, there is a limited budget available for cycling planning (Bakker et al., 2012). Moreover, since there is not a one-solution-fits-all option, there is a high chance of stakeholder dissensus (Ghorbanzadeh et al., 2018). Finally, since the planning process is iterative, there is no set end goal. Based on the definition of a wicked problem by Rittel & Webber (1973), it is possible to conclude that planning for cycling infrastructure is a wicked problem. What will be addressed in this research, is how decision-making on one specific cycling infrastructure problem can be supported, considering the complexity of cycling infrastructure planning and the current cycling developments.

1.3 PARTICIPATORY PLANNING IN WICKED PROBLEMS

In order to tackle the wickedness of a problem, stakeholder consensus is essential (Rittel & Webber, 1973). Moreover, the inclusion of end-users in the planning process is increasingly called for (Milakis & Athanasopoulos, 2014). A way to deal with multi-stakeholder settings is facilitating participation in planning. Participatory spatial planning (PSP) can contribute to principles of openness, accountability, empowerment and commitment of implementation (McCall & Dunn, 2012). In order to achieve PSP, recently more attention is given to geo-information tools using GIS (Geographical Information Systems) to map spatial concerns. These geo-information tools can serve different purposes, depending on the spatial problem at hand (McCall & Dunn, 2012).

Georgiadou & Reckien (2018) relate the wickedness of a policy problem to the role of geo-information tools. Table 1 shows the four types of policy problems and related tools that can support them (Georgiadou & Reckien, 2018, fig. 1). In the case of wicked problems, there is an endless debate between stakeholders about what the problem is, and how it should be tackled. Ideally, the problem should become less wicked by contributing to both the uncertainty of facts, and encouraging consensus among stakeholders (Georgiadou & Reckien, 2018).

Table 1: Four types of policy problems and related tools from (Georgiadou & Reckien, 2018, fig. 1).

Spatial Knowledge	Policy Goals and Values	
	Consensus among Stakeholders	**Dissensus among Stakeholders**
Certain (facts and cause-effects)	**(1) Tame or structured problems** - Debate on technicalities - Geo-information tools as *problem solver*	**(3) Moderately structured problems** - Participation to debate goals and values - Geo-information tools as *mediator*
Uncertain (facts and cause-effects)	**(2) Moderately structured problems** - Participation to debate cause-effects and optimise the collection of facts - Geo-information tools as *analyst* and/or *advocate*	**(4) Wicked or unstructured problems** - Endless debate - Geo-information tools as *problem recogniser*

Geo-information tools have improved significantly in recent years. Calculations and software have become faster, making it possible to use geo-information tools in participatory workshop settings. Next to that, the improvement of hardware allows for use on new devices such as interactive touch screens (Pelzer et al., 2014). However, what is often missing is the evaluation of the added value of these decision support tools (Pelzer et al., 2014). Consequently, there are still several challenges in the development of geo-information tools, such as a missing link between the development, implementation and usage of the tool (te Brömmelstroet & Schrijnen, 2010).

Finally, the usability of such tools is often a limiting factor, and the diversity of evaluation criteria makes it difficult to compare the useability of different tools (Aguilar et al., 2021).

Considering potential stakeholder dissensus and the current discussions surrounding cycling infrastructure planning, the development of a geo-information tool in a multi-stakeholder context in this thesis is aimed at supporting decision-making on one specific cycling infrastructure planning problem in the Netherlands. The decision on rearrangement of cycling infrastructure involves many considerations, and not all stakeholders agree on what could be the best solution. Furthermore, this research aims to contribute to creating a better understanding of the usability of a geo-information tool in a participatory setting, and aims to support improving knowledge on the added value in the planning process and stakeholder involvement.

1.4 RESEARCH OBJECTIVES & QUESTIONS

This research aims to develop a geo-information tool to engage stakeholders, in order to support decision-making on one specific cycling infrastructure challenge in the Netherlands. Since there are many aspects that influence cycling infrastructure planning in general, a focus had to be decided on at the beginning of this research. After this, a tool was developed. Finally, the tool was tested. Hence, there are three parts to this research.

OBJECTIVE 1: ASSESS CHALLENGES IN CYCLING INFRASTRUCTURE PLANNING BY CONSULTING PRACTITIONERS ON A NATIONAL, REGIONAL, AND MUNICIPAL LEVEL, TO FIND OUT WHICH CYCLING PLANNING PROBLEM NEEDS ADDRESSING.

RQ 1.1 What are the different steps in planning for cycling infrastructure (i.e. planning cycle)?
RQ 1.2 What types of policies and interventions have been implemented so far?
RQ 1.4 What are current cycling infrastructure planning problems?
RQ 1.4 How could these problems be addressed with the use of spatial data?
RQ 1.5 Which specific cycling infrastructure problem would be most suitable for addressing in a participatory tool?
RQ 1.6 Which stakeholders could be involved in a participatory setting?

OBJECTIVE 2: DEVELOP A GEO-INFORMATION TOOL ON A LOCAL LEVEL IN A CHOSEN CASE STUDY AREA.

RQ 2.1 Which Dutch municipality deals with the selected cycling infrastructure problem?
RQ 2.2 What is the target group and setting of the geo-information tool?
RQ 2.3 What information and functions should the geo-information tool provide?
RQ 2.4 What are the expected outputs of the geo-information tool?

OBJECTIVE 3: TEST THE EFFECTIVENESS OF ADDRESSING THE CHOSEN CYCLING INFRASTRUCTURE PLANNING PROBLEM BY TESTING A PROTOTYPE OF THE GEO-INFORMATION TOOL.

RQ 3.1 What should the workshop setting look like and what should be the outputs?
RQ 3.2 Which indicators are relevant to the decision that needs to be taken?
RQ 3.3 Which functions of the tool are missing in the prototype?
RQ 3.4 How could the tool be useful for the stakeholders in a participatory setting?

2. LITERATURE REVIEW

In this chapter, previous research on the main concepts of this thesis and any current developments in cycling infrastructure planning in the Netherlands will be discussed. First, the current Dutch cycling developments in spatial planning will be explained. Secondly, a list of current policies and interventions to understand Dutch cycling planning will be included. After this, cycling infrastructure planning is divided in the different steps of the planning cycle. Finally, the importance of participatory planning in these steps and the link to geo-information tools will be made.

2.1 CYCLING DEVELOPMENTS

2.1.1 SUSTAINABLE SAFETY

Like mentioned in the introduction, the Netherlands is often regarded as the world's most successful cycling nation. To reach this status, several improvements have been made to the cycling infrastructure over the past decades. The *CROW Design Manual for Bicycle Traffic,* which has been developed over the years, is internationally used as a guideline for creating a successful cycling infrastructure network. The five design principles in this manual are cohesion, directness, (road and social) safety, attractiveness, and comfort. (CROW Fietsberaad, 2016; Dutch Cycling Embassy, 2021)

A term that reflects similar design principles, is Sustainable Safety. It is a term that has been developed in the Netherlands in the 1990s and relates to the entire infrastructure, not just cycling. Sustainable Safety was developed from the assumption that the road system was inherently unsafe, and needed to change drastically (SWOV, 2018).

Sustainable Safety relates to functionality, homogeneity, predictability, forgivingness, and state awareness (SWOV, 2018). The Institute for Scientific Research on Road Safety of the Netherlands (SWOV) describes that any measures that have been presented based on Sustainable Safety have led to a significant decrease in road deaths, especially among vulnerable road users like pedestrians and cyclists (SWOV, 2018). The measures taken between 1998 and 2007 have resulted in a 30% decrease in traffic fatalities (Dutch Cycling Embassy, 2021). However, there were also points of discussion. The Dutch Cycling Embassy (2021) states: *"One of the main barriers turned out to be discussions about conflicting interests in terms of physical space and financial means."* (Dutch Cycling Embassy, 2021, p. 56)

2.1.2 POLICIES AND INTERVENTIONS

Next to the principle of Sustainable Safety, there are several other policies and interventions that are relevant for bicycle infrastructure planning in the Netherlands. Table 2 on the next page provides an overview of the most recent developments in the field of policies, and Table 3 on the next page shows the most recent interventions.

Table 2: Overview of recent policies for cycling in the Netherlands in alphabetical order.

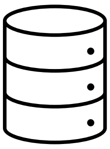
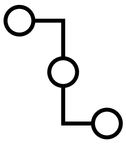
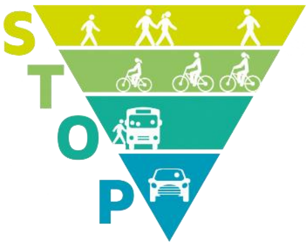
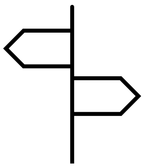
Policies	
	**Data-Driven Decision-making** This development is described as an aim to collaborate between road authorities, companies and research on future cycling demand, like utilising data on cyclist behaviour and use of the cycling path (Dutch Cycling Embassy, 2018).
	**Network Planning** Network Planning relates closely to Sustainable Safety. The main goal of network planning is offering different safe options for travelling by bike, and therefore facilitating cycling for all types of cyclists and ages. Next to that, special attention is given to providing a dedicated space for cyclists in the network. Finally, having a good network makes cycling more attractive. For this to succeed, there need to be enough parking facilities on locations of destination. and opportunities to change between different modes of transport, like the train or bus. (Dutch Cycling Embassy, 2021)
	**STOP – principle** The STOP principle stands for priority for pedestrians first, cyclists second, public transport third and finally the car (**S**tappen, **T**rappen, **O**penbaar vervoer en **P**ersonenwagens). This principle was first introduced in Belgium, and currently is receiving more attention in the Netherlands (Fietsersbond, 2019). *Image: https://www.duurzame-mobiliteit.be/tags/stop-principe*

Table 3: Overview of recent interventions for cycling in the Netherlands in alphabetical order.

Interventions	
	**Adaptation of intersections** Some adaptations of intersections in favour of cyclists are advanced green lights for cyclists, advanced waiting positions, cyclist short-cuts to make right-hand turns before intersections, and consecutive green lights for cyclists at some intersections (green wave) (Pucher & Buehler, 2008, p. 512). *Image: Google Maps*
	**Bicycle Streets** The bicycle street is a recent spatial intervention where the car is not intended to be the main road user anymore. *"Instead of cyclists feeling they are a guest in the car realm, the design and rules state clearly: the car is the guest."* (Dutch Cycling Embassy, 2021, p. 21) *Image:https://www.tubantia.nl/enschede/fietsers-in-enschede-sneller-op-bestemming-door-3-nieuwe-routes~a7961ca4/?referrer=https%3A%2F%2Fwww.google.com%2F*
	**Cycle Highways** *"The bicycle is not only the most efficient way to move around cities, it can also be an attractive mode of transportation between cities. In recent years, the Netherlands has been developing a network of fast, super high-quality connections between cities, making recreational and functional cycling even more attractive."* (Dutch Cycling Embassy, 2021, p. 29) *Image: https://www.rtvoost.nl/nieuws/330763/fietssnelweg-f35-we-liepen-voorop-maar-we-zijn-links-en-rechts-ingehaald*

	**Parking** Parking is an essential spatial intervention that can be linked to network planning. In order to stimulate cycling, not only the infrastructure itself needs to be attractive. Especially locations like the city centre and train stations need large parking facilities. Another topic that receives attention when talking about bicycle parking is bicycle theft, which is still a problem that many cities would like to diminish. (Dutch Cycling Embassy, 2021) *Image: https://www.ns.nl/fietsenstallingen*
	**Wayfinding** Improving wayfinding is especially beneficial to make cycling easier and more accessible, not just in the close surroundings of home. Recreational cyclists can often benefit from improved wayfinding and can encourage cycling for longer distances. (Dutch Cycling Embassy, 2021)

The main driver for the most recent policy developments and interventions is the prioritisation of the cyclist over other transport modes. This can be seen in the development of bicycle streets, and more focus on parking and wayfinding. Consequently, cycling safety and creating better cycling connections are of high importance as well, which can be seen in the further development of a vast cycling network and the introduction of the STOP-principle.

Next to different policies, a large part of the cycling infrastructure is designed based on recommendations. These recommendations are developed and updated by CROW, like the beforementioned *CROW Design Manual for Bicycle Traffic,* and serve as guidelines for designers (CROW, n.d.). An example of updated recommendations is the recent publication on the width of bicycle paths, which describes per user intensity the desired width of the cycling path (Veroude et al., 2022). Another example is Figure 2 on the next page. This decision chart developed by CROW (2021) shows considerations that have to be made whether a speed limit of 50 km/h can be achieved in a safe manner, or if there is a necessity to change to 30 km/h. Cycling advocacy groups such as the *Fietserbond* (Dutch Cyclists' Union) support a speed limit of 30 km/h or even lower to increase safety for cyclists (Hendriksen et al., 2018).

The decision chart in Figure 2 aims to support decision makers in deciding from a road safety point of view, on which roads it might be necessary to lower the speed limit to 30 km/h. The user first needs to distinguish between the different functions of roads in the network. Roads with a residential function, according to the scheme, should remain ETW30 roads. These are roads for slow traffic, without any separation between modes. Consequently, roads with a traffic function should remain a GOW50 road if this can be safely achieved. These roads are meant for a steady flow of traffic at 50 km/h, with separation between road users. This often means that there is a separate bike lane. Sometimes, a road can be defined as a road with a double function. These are for example busy roads with many shops, or a road in a residential area on an important bus route. In case of a double function, the decision chart structures the considerations that have to be made whether a road should become an ETW30, GOW30 or GOW50. (CROW, 2021)

Road Typologies

GOW and ETW represent a type of road in the Dutch classification system, and 50 and 30 represent the associated speed limit with these road types. More about these road types and their typical designs can be read in Annex I.

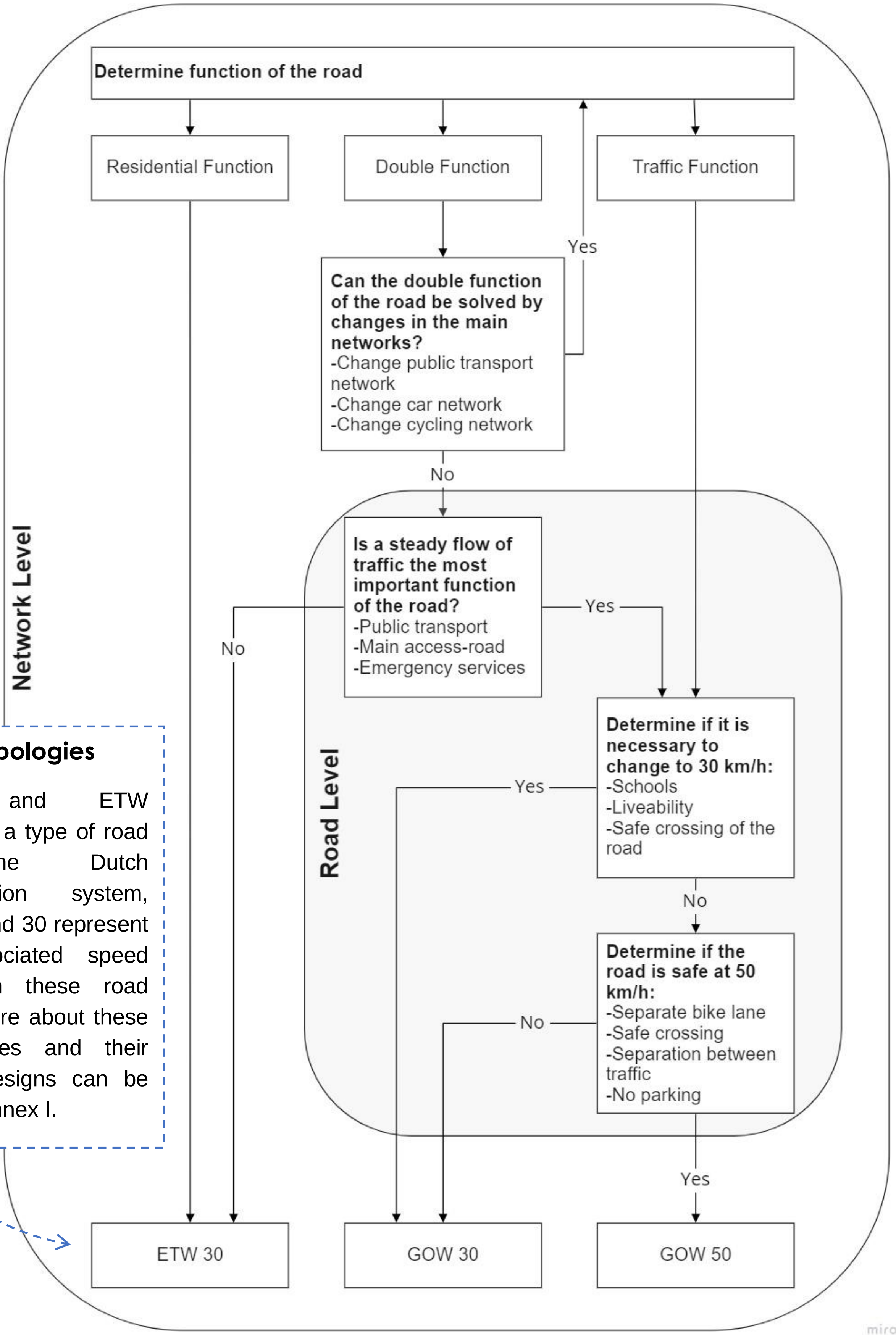


Figure 2: Decision Chart for 30 km/h or 50 km/h, translated from (CROW, 2021, p. 12).

2.2 CYCLING INFRASTRUCTURE PLANNING

2.2.1 PLANNING CYCLE

The planning cycle for cycling infrastructure planning can be divided into several steps. Greiving & Fleischauer (2006) provide a simplification of a general planning process. The first phase of a planning process is the problem analysis, leading from certain conditions that are regarded as unsatisfactory. In this phase, goals should be developed, including the desired future conditions. Also in this phase, there should be data collection to analyse the current conditions. The second phase is the assessment of alternatives. In this phase, it is important to estimate the different impacts of each alternative. Also, to what extent can the alternatives meet the desired goals. The third phase is the decision phase, in which the necessary measures for the selected alternative need to become clear. Finally, the implementation phase allows for the examination of the projected impacts (Greiving & Fleischhauer, 2006).

In practice, there can be different incentives for changes in the cycling infrastructure. On the one hand, there can be advocacy groups like the *Fietsersbond* that bring up potential bottlenecks of cyclists to the road managers. In the context of a city, this is often the municipality (Fietsersbond, 2022b). The *Fietsersbond* values to be included as early on in the planning process, which would be in the problem analysis phase. On the other hand, municipalities that have the ambition to put more emphasis on cycling, either investigate different alternatives themselves, or outsource to consultancy. Larger cities like Amsterdam, Den Haag, Groningen, Rotterdam, and Utrecht are some examples of cities with extensive policy documents on how to support bicycle use and ensure safety (Gemeente Amsterdam, 2017; Gemeente Den Haag, 2020; Gemeente Groningen, 2019; Gemeente Rotterdam, 2021; Gemeente Utrecht, 2021). An example of how a municipality can involve cyclists in the problem analysis phase, is the 'Fietstevredenheidsmonitor' (Cyclists' Satisfaction Monitor) developed by the municipality of Amsterdam. Every year, cyclists are asked to rate their cycling experience at several locations in the city. This allows the municipality to gain insight in the city's most urgent locations for development (Gemeente Amsterdam, 2021).

The role of consultants and independent research organisations is often to create a better understanding of any problems that might arise in realising these ambitions. They are therefore bringing together the problem analysis and the alternative solutions. Take for example approaches for dividing space between cyclists and other modes (Goudappel, 2022), strategies for increasing cycling quality (CROW Fietsberaad, 2019), and dealing with changes in the types of cyclists (DTV Consultants, 2022). The final steps, the decision and implementation phase, seem to often rely on the municipality.

2.2.2 PARTICIPATORY PLANNING

Participation can happen in several stages of the planning process and is a term that is increasingly used. Participation can for example assist in providing information, or contribute to monitoring implementation (Amado et al., 2010). One of the goals of participation is that preferably all conflicts are minimised and all relevant parties are involved. However, this is not always possible (Resch et al., 2020). Other goals of participation can be assessing the needs and expectations of involved stakeholders as well as providing local knowledge (Amado et al., 2010), or co-designing to meet the requirements of stakeholders and being able to evaluate to what extent these are met (Aguilar et al., 2021).

Resch et al. (2020) state that a participatory planning approach is increasingly becoming more important. This is because for example citizens are becoming more vocal about being involved in urban planning and decision-making. Next to this, making sure that many stakeholders are involved can increase acceptance through better transparency, become more accurate and comprehensive, and reduce the costs of the planning process (McCall & Dunn, 2012; Resch et al., 2020). Finally, including the end-users of spatial interventions can help improve the planning process by addressing problems and possible solutions more accurately (McCall & Dunn, 2012; Milakis & Athanasopoulos, 2014).

Stakeholder involvement can vary from informing through media or mailings, conducting surveys and interviews, to workshops and organising formal meetings (Ruiz-Villaverde & García-Rubio, 2017). Participation in cycling planning in the Netherlands, on a larger scale, is most often informing. Some examples of these are promotional campaignes, websites and cycling education programs to stimulate cycling (APPM, 2021). On a local scale, participation is often initiated by the municipality. An example of this is gathering residents in interactive sessions with professionals, to find a most suitable solution for a local cycling problem (Godefrooij, n.d.).

2.2.3 PARTICIPATION AND GEO-INFORMATION TOOLS

Since the development of a geo-information tool is the objective of this thesis, it is important to understand what has been done already in this field of research. Georgiadou and Reckien (2018) provide several examples of geo-information tools and their purpose. A tool like remote sensing allows for signalling any changes in normal conditions and present these (Georgiadou & Reckien, 2018). Tools as mediators can serve as a way to bring several stakeholders together, start a discussion to help people develop an understanding of the problems at hand, and even collaborate on any solutions (Georgiadou & Reckien, 2018).

Geo-information tools in a participatory setting that are used to support planning decisions are planning support systems (PSS). With the use of PSS, participants can map and discuss their thoughts, concerns, current situations or possible solutions for spatial problems in interactive sessions. These PSS are increasingly used and are a new method to include several groups of stakeholders in spatial problems. PSS are developing at a fast pace because of technological improvements, and there is an increasingly better understanding of what components to include in the tools (Geertman & Stillwell, 2020).

Even though PSS are receiving more attention, Geertman et al. (2013) state that at the moment of writing, there is a lack of insight into how planning support tools can generate knowledge to achieve planning goals (Geertman et al., 2013). Firstly, there is a lack of transparency regarding how data gathered from workshop settings will lead to recommendations, and secondly, there is yet a limited role for PSS in the evaluation and monitoring phase of the planning process (Geertman & Stillwell, 2020). Moreover, more research is needed on the usability and effectiveness of geo-information tools in the planning process (Kahila-Tani et al., 2015). Aguilar et al. (2021) write that assessing the useability of PSS is important to consider since users' perception of the added value to the planning process and their potential to support participation is essential (Aguilar et al., 2021). Finally, the added value of PSS is up for discussion, and something that is often not assessed (Kahila-Tani et al., 2015; Pelzer et al., 2014).

2.2.4 MAPTABLE PSS

Interactive PSS can involve the use of a large, horizontal touch-screen that stakeholders can interact with, a so-called MapTable (Flacke et al., 2020). These interactive touch screens allow stakeholders to interact with the geospatial software and discuss any changes that are visualised (Aguilar et al., 2021). An example of a tool that can be deployed on a MapTable is COLLAGE. COLLAGE is an interactive planning support tool that was developed to support decision-making on renewable energy. By involving local stakeholders early in the decision-making process, it was possible to help create a better understanding of the needed changes in order to meet the policy goals. This tool also shows the relevance of making decisions with spatial implications visual, therefore contributing to the legitimacy and consensus of local decision-making (Georgiadou & Reckien, 2018).

Open Geospatial Interactive Tool (OGITO) is another example of a tool that can be deployed on a MapTable. The goal of OGITO was established based on a participatory approach, where end-users were involved in the development of the tool. By creating user stories, the purpose of the tool and the associated tasks could be developed. The effectiveness, efficiency and satisfaction were also evaluated, to create a decision tool that was useable by its intended users (Aguilar et al., 2021).

Pelzer et al. (2014) provide an overview of the added value of using a PSS, like a MapTable. Previous research has shown that on an individual level, the extent of the problem and the viewpoints of the other stakeholders become more clear. On a group level, collaboration, communication, consensus and efficiency can be achieved. Finally, using a PSS can lead to better-informed decision-making (Pelzer et al., 2014). However, what is important to keep in mind is that measuring these kinds of experiences is very limited, and not done extensively enough to be able to conclude this for specifically MapTable users. Therefore, Pelzer et al. (2014) recommend more research on the user experience of MapTables, especially when similar software packages are used. This would make outcomes better comparable (Pelzer et al., 2014).

3. METHODOLOGY

In this research, the main steps of the Engineering Design Cycle as described by Wieringa (2014) were used. This cycle is divided in problem investigation, treatment design and treatment validation (Wieringa, 2014). In the problem investigation phase, stakeholders and their goals are assessed. Additionally, creating a better insight in the causes and effects of the problem is essential. The treatment design phase is about specifying requirements for the goals established earlier on. In this phase it is also important to consider any existing solutions to the problem, or develop new ones. The treatment validation phase is for assessing the effects and whethers these effects satisfy the requirements (Wieringa, 2014, fig. 3.1). Figure 3 below shows the methodology for this thesis, based on Figure 3.1 from (Wieringa, 2014, p. 28).

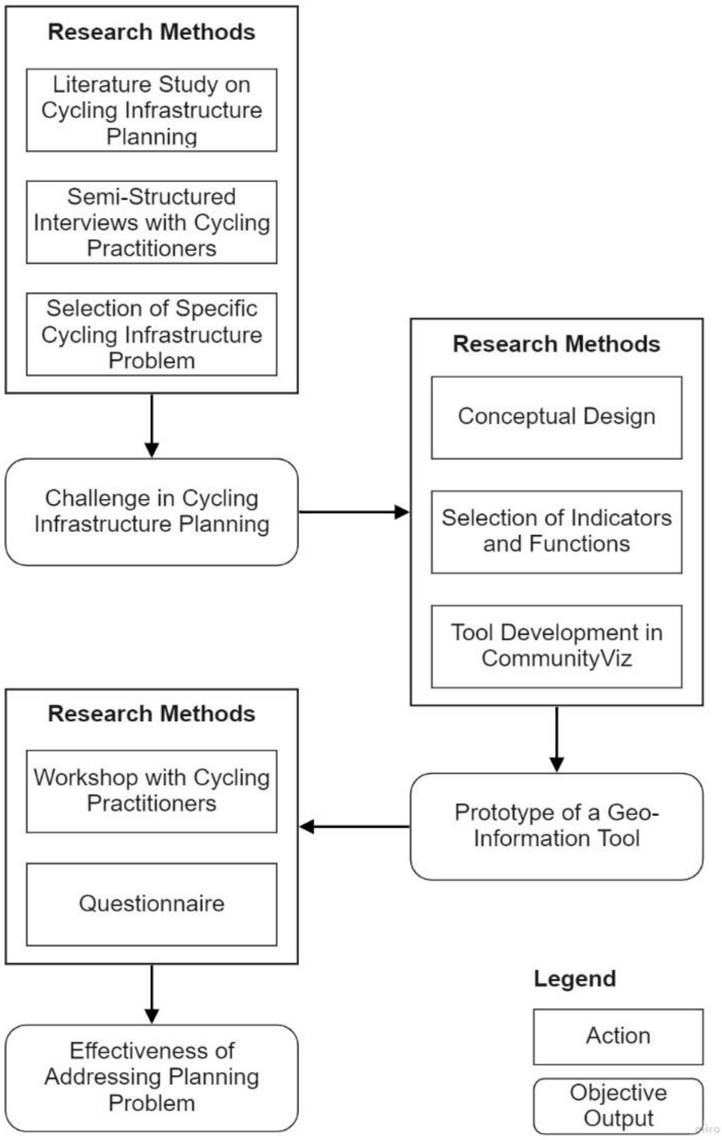


Figure 3: Research Methods and Expected Output.

Because the research was caried out in the three steps that can be seen in Figure 3, which correspond with the three objectives of this research, the following chapters also follow this sequence. In every chapter, the intermediate steps of the research will be explained, after which the results from each objective will be presented. The reason that the methods and results are presented in this manner, is because the results from each part of the research lead to the decisions in the next steps of the thesis.

The first research methods that were selected for addressing the first objective, were literature study and semi-structured interviews with cycling practitioners. These methods were chosen, because many current challenges in cycling infrastructure planning can be found recent literature. However, from this literature it was not directly possible to determine which specific challenge would be suitable for addressing in a geo-information tool. That is why interviewing cycling practitioners and comparing their viewpoints was decided as most suitable. In case of overlapping answers, it was possible to select a specific cycling infrastructure challenge to address. This first step will be addressed in Chapter 4.

In order to develop a prototype of the geo-information tool for the selected problem, the following research methods were selected: developing a conceptual design, selecting indicators and functions, and finally use an existing software to create the prototype. These actions were all supported by existing literature, and guided by the definition of the selected challenge in the previous step. The prototype development will be addressed in Chapter 5.

To be able to test the prototype of the tool, a workshop with cycling practitioners and a supporting questionnaire were chosen. To be able to assess the useability of the tool, it was decided that getting the potential users of the tool involved would be the most suitable. The use of both a workshop setting and a questionnaire allowed for comparison of input during the workshop session, as well as individual experiences. This final step of the research will be addressed in Chapter 6.

4. INTERVIEWS WITH CYCLING PRACTITIONERS

Following Figure 3, the first step in this research was creating an understanding of the problem. To understand the current cycling planning strategy, an overview was created of the types of policies and interventions that have been implemented so far. To be able to relate current cycling problems to practice, it was also important to inquire with cycling practitioners. Therefore, interviews were conducted. Policymakers from different levels of government (national, provincial, municipal) were considered, as well as cycling experts from different organisations. A list of participants can be seen in Table 4. This list is anonymous, considering privacy of the participants. All participants received and signed an informed consent document, stating the purpose of the interview and the storage and useage of data. The blank version of this document can be found in Annex II.

Table 4: Participants for semi-structured interviews.

No.	Profile	Logo	Organisation	Date
1	Advocacy	Fietsersbond	Fietsersbond	26/1/22
2	Consultancy	DTV CONSULTANTS	DTV Consultants	25/1/22
3	Consultancy	TRIDÉE	Tridée	31/1/22
4	Independent Research	kennisplatform CROW	CROW Fietsberaad	1/2/22
5	Policy Advisor	Provincie Noord-Brabant	Provincie Noord-Brabant	20/1/22

The interviews with these practitioners were semi-structured. The choice for semi-structured interviews was mainly because it allowed for a prepared set of questions, but also provided space for more specific questions if the interviewee could provide more insight. Next to that, the results of the semi-structured interviews could easily be compared but were not constrained like a structured interview (Knox & Burkard, 2009).

The sample size for these interviews was five participants. Not only was it important to consider the time limitations of this thesis, but also the principle of saturation. Saturation is reached when no new insights are acquired or no new themes can be identified (Kumar et al., 2020). It was found that with five interviewees saturation was reached since the participants were not able to provide much new information. Also, previous research has shown that with the inclusion of experts in the field, a smaller group of participants is necessary (Kumar et al., 2020).

The interview questions can be found in Annex III. The goal of the interviews was selecting one specific cycling planning problem that could be addressed in a geo-information tool. The following results section is divided in two parts. First, an overview of the results regarding the main cycling infrastructure planning problems is given. After that, all stakeholders involved in cycling infrastructure planning that were mentioned in the interviews are listed.

4.1 RESULTS OF CYCLING INFRASTRUCTURE PLANNING PROBLEMS

Limited public space. The first challenge that was addressed by most interviewees is not something that is just limited to cycling infrastructure. That is because in this challenge not only cyclists are important, but also pedestrians, other modes of transport, and other ambitions like climate goals, decreasing nitrogen emissions, and introducing design principles like STOP

(Interview 1, 2, 4). A more specific challenge that is associated with limited space for cycling, is mainly occuring in city centres. City centres often have a shared space between cyclists and pedestrians, and the main function of this space is recreational. This can lead to conflict, because for some cyclists the main goal of cycling is to get from A to B as quickly as possible (Interview 3, 4). This is also found in the second challenge that was mentioned.

Extending "Cycling Family". Many different modes use cycling infrastructure, and the challenge arises whether all these (new) modes can fit on the current cycling infrastructure. The term cycling family was mentioned as a way of grouping all the different modes that currently use the cycling path. There are many different types of cyclists, both in size and in speed. The Dutch Cycling Embassy (2021) describes the distinction between cyclists as follows: Practical cyclists want to get from A to B efficiently, need comfort and attractive routes, safe and straightforward traffic situations and sufficient parking facilities. Recreational cyclists, on the other hand, want a sense of enjoyment from the journey. The activity of cycling should bring relaxation, and ideally has minimal interaction with other modes of transport (Dutch Cycling Embassy, 2021).

Increasing variety on the cycling path is also relevant in combination with vulnerable groups that use the cycling infrastructure, like elderly and children. Next to that, it is difficult to classify attractive cycling routes, because what makes one cycling path more attractive and enjoyable than another (Interview 5)? A discussion that arises from these issues is what could be the best solution to deal with these changes (Interview 1, 3, 4). An example that was mentioned was the lack of regulations for the new modes of transport, like the cargobike (Interview 3). Is the solution to widen existing cycling paths, or should there be a different strategy (Interview 1, 2, 3, 4)? Some cities have already started with the introduction of new cycling paths or widening and alteration of existing cycling paths (Gemeente Amsterdam, 2017; Gemeente Groningen, 2019; Gemeente Utrecht, 2021), but whether this is enough remains a topic of discussion.

Establishing a cycling network on a regional level and Cycling Highways. This next challenge was mentioned as a challenge that mainly takes place on a regional level, so collaboration between different municipalities and provinces is necessary (Interview 5). It is a very current topic, as some municipalities in the Netherlands are already working on fast-cycling connections that connect the city and its surroundings (Gemeente Enschede, 2012; Gemeente Groningen, 2019). To establish these networks, there are discussions on how to implement such a network for cyclists, how to ensure cycling quality on cycling highways (in Dutch called "fietssnelweg", "snelfietsroute", "doorfietsroute" or "snelle fietsroute"), and what parts of the cycling network need priority (Interview 2, 5). For this final discussion point, data with bottlenecks in the infrastructure is available, but it was mentioned as difficult to prioritise actions based on this data (Interview 5). However, such data could assist in developing risk-based approaches (Interview 2), or in the development of spatial assessments of the current cycling infrastructure with the support of GIS (Interview 3).

Speed limits. To deal with the large differences in speed between road users, and the relocation of certain modes in the infrastructure, a national discussion has started to change the speed limit from 50 km/h to 30 km/h in locations where this is deemed necessary (Interview 1, 2, 3, 4). This discussion originated from a proposal of a few political parties in October 2020, which suggested to lower all speed limits within cities to 30 km/h, unless a higher speed could be safely achieved (VVN, 2020). This would, in some cases, mean a total rearrangement of public space (Interview 4). Next to that, the question arises where this change can be made, and where not (Interview 2, 3, 4). Certain roads have a function where 50 km/h is necessary for a steady flow of traffic, and in cases when there is enough space for a separate bicycle lane there might not be a need to change to 30 km/h. Not only is this discussion very current and keeping many cycling practitioners busy, it has not been implemented on a large scale yet. Therefore the impacts of changes in speed limit are not clear yet.

There are multiple benefits of going from 50 km/h to 30 km/h, according to the *Fietsersbond*. First of all, the difference in speed between different modes of transport decreases. Therefore cars have a shorter braking distance, as well as less emissions and noise pollution. Furthermore, the chance of a deadly accident in 50-zones is 35%, in 30-zones 10% (Hendriksen et al., 2018). Furthermore, the ANWB (Royal Dutch Tourist Association) writes in a recent publication that on roads with a speed limit of 30 km/h, three to five times less casualties occur compared to a road with a speed limit of 50 km/h (ANWB, 2022). However, in some cases a speed limit of 50 km/h is deemed necessary. Public transport and emergency services are benefitted by a steady flow of traffic, and are often hesitant towards lowering the speed limit, especially if this means that speed-limiting measures will be installed (Andriesse, 2021).

Not only was this issue raised during the interviews with practitioners, it is also a current topic in consultancy (Andriesse, 2021; Sweco Nederland, 2021), in research by CROW (2021), SWOV (Dijkstra & Petegem, 2019), and *Veilig Verkeer Nederland* (VVN) (2020). Even though the benefits of changing the speed limit to 30 km/h are acknowledged by many municipalities, there are difficulties regarding implementation. Not only can current 50 km/h roads be unsafe from a cyclists' point of view, some current 30 km/h roads are not designed as such. Sweco Nederland (2021) estimates that around 40% of current 30 km/h roads are too wide, and half of these have asphalt surfaces, which means that motorised traffic tends to drive faster (Sweco Nederland, 2021). Next to that, real speed in 30 km/h zones is often much higher than dictated, resulting in a high number of complaints among residents living in current 30 km/h zones (VVN, 2020).

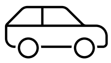
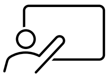
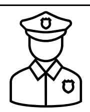
The decision to focus on this discussion for the development of the tool was taken based on a few characteristics of the problem: it is current, it is contested, and there is not one solution to solve the problem. Therefore, it fits in with the criteria of being a wicked problem, like discussed in the introduction. The discussion on speed limits also overlaps with the other cycling infrastructure problems that were mentioned in the interviews, and spatial characteristics and use of the environment shape the decision on possible interventions. It is therefore possible to address the problem with the support of spatial data, making this problem suitable for addressing in a geo-information tool.

4.2 STAKEHOLDERS FOR POTENTIAL INVOLVEMENT

Stakeholder involvement is considered important in this thesis, because of the potential users of the geo-information tool need to be established later on. From the interviews it becomes clear that there are many stakeholders involved in the development of cycling infrastructure. Which stakeholders are of importance to consider, depends on the scale of the project, the desired level of involvement and the interest of each stakeholder. In Table 5, an overview can be seen from all the stakeholders that were mentioned in the interviews, and their interest or significance for participation.

It was difficult for the interviewees to make a distinction in importance of all stakeholders. That is because stakeholder involvement also depends on the stage of the project, and the preference of a municipality. However, some stakeholders were mentioned by more than one interviewee, so it can be assumed that some of these stakeholders might be more relevant to include in participatory settings.

Table 5: Project Level Stakeholder Interest Table from interviews, in alphabetical order.

Icon	Stakeholder	Interest	Source / Interview
	Car Users	Car users like to get from point A to B as fast as possible. Parking close to home or destination is often seen as essential.	kennisplatform CROW, Fietsersbond, Provincie Noord-Brabant
	Consultancy	Consultancy organisations recommend cycling measures to governments for creating safer and better cycling networks.	DTV Consultants, TRIDÉE
fietsberaad CROW	CROW Fietsberaad	CROW Fietsberaad (part of CROW) invests in making cycling the main mode of transport and is an independent platform for sharing/generating knowledge about cycling.	kennisplatform CROW, Fietsersbond, TRIDÉE
	Different Types of Cyclists: Children	Children are part of vulnerable cyclists. Little is known about the cycling behaviour of children.	kennisplatform CROW, Provincie Noord-Brabant
	Different Types of Cyclists: Elderly	Elderly are part of the vulnerable cyclists. With more cycling elderly, cycling infrastructure needs to remain safe, clear and accessible.	kennisplatform CROW, Fietsersbond
	Different Types of Cyclists: Students	Students are frequent cyclists, but little is known about their cycling behaviour.	kennisplatform CROW, Provincie Noord-Brabant
	Different Types of Cyclists: Vehicles	The range of vehicles ('fietsfamilie') is expanding, which results in different speeds and behaviour on cycling paths. Discussion remains about the location of each vehicle in the road system.	kennisplatform CROW, TRIDÉE
	Disabled People	Disabled people are not always included in spatial design. However, their opinion can be of great value when it comes to accessibility.	Fietsersbond
	Emergency Services	Consulting emergency services is important for ensuring a safe infrastructure network.	kennisplatform CROW

Fietsersbond	Fietsersbond	The *Fietsersbond* is a strong advocate for the improvement of cycling infrastructure, policy and safety.	kennisplatform CROW Fietsersbond Provincie Noord-Brabant
Ministerie van Infrastructuur en Waterstaat	Ministry of Infrastructure and Water Management	The Ministry ensures investment in safe, sustainable infrastructure taking climate adaptation in mind.	TRIDÉE
	Municipality	Municipalities are the managers of the road network in cities. Their goal is to create a safe, accessible bicycle network within the city, with links to surrounding cities. All modes of transport and different types of roads have to be considered.	kennisplatform CROW DTV CONSULTANTS Fietsersbond Provincie Noord-Brabant TRIDÉE
	Pedestrians	Pedestrians do not have a strong advocacy group but should be considered when working on cycling measures.	Fietsersbond
	Province	Provinces aim to facilitate a provincial bicycle network for all types of cyclists. Next to that, they can act as a mediator when working with multiple stakeholders.	DTV CONSULTANTS Fietsersbond Provincie Noord-Brabant
	Research Institutes	Universities and other research institutes generate knowledge to support discussions about cycling infrastructure.	DTV CONSULTANTS Provincie Noord-Brabant TRIDÉE
	Residents	Residents are important stakeholders on a local project level. With participation early on in the planning process, there is a higher chance of support and understanding for proposed measures.	kennisplatform CROW DTV CONSULTANTS Fietsersbond TRIDÉE
	Shop Owners	Shop owners and other tradesmen have local knowledge that can be useful in decision-making.	kennisplatform CROW TRIDÉE
	Traffic Engineers	Traffic engineers aim to design infrastructure that is safe, taking into account the available guidelines. Sometimes users come across practical issues after implementation.	DTV CONSULTANTS Fietsersbond
Tour de Force	Tour de Force	Tour de Force is a collaboration between many different stakeholders on all planning levels, to ensure better communication, common goals and knowledge sharing on cycling.	DTV CONSULTANTS

Relating stakeholder involvement to the potential target audience of the tool in this thesis, it depends on the setting that the tool is used in and the scale that is discussed, which stakeholder could be useful to include. Discussions on a city level would most likely include parties that have the task to ensure the quality of the network, like the municipality. If there is a discussion about a specific project or road segment, other stakeholder such as the emergency services and residents become more relevant.

5. TOOL DEVELOPMENT

5.1 CASE STUDY AREA

The next step in the research was deciding on a case study area. First of all, the case study area needed to be representative of the main planning challenge that was identified (Mills et al., 2012). Considering that all municipalities in the Netherlands to a certain extent deal with the discussion of changing speed limits to 30 km/h, the case study area was decided to be the city of Enschede. The reason Enschede is a suitable case study area mainly relates to the ambition of the municipality to prioritise cycling and cycling safety. However, in these ambitions it is also specifically mentioned that sometimes concessions are necessary, because of limited space in the city (Smuling et al., 2019, p. 25). Next to that it was possible to include local participants in the next steps of the research.

Enschede is a city of 160.558 inhabitants, in the province of Overijssel in the Netherlands (AlleCijfers, 2022). The municipality aims for a sustainable and innovative city, with high ambitions for traffic safety, efficiency, and public support. In 2019, two-third of all traffic movements within Enschede was internal traffic, of which 50-60% was car traffic. It was also expected that car traffic on some main access roads would increase in the coming years. The municipality aims to go from 'able to cycle to invite to cycle'. (Smuling et al., 2019)

For the bicycle to become the most used mode of transport, the municipality aims to give more priority to the bicycle, so that cycling becomes more attractive for short distances (Smuling et al., 2019). Figure 4 shows the lay-out of the different neighbourhoods in the city.

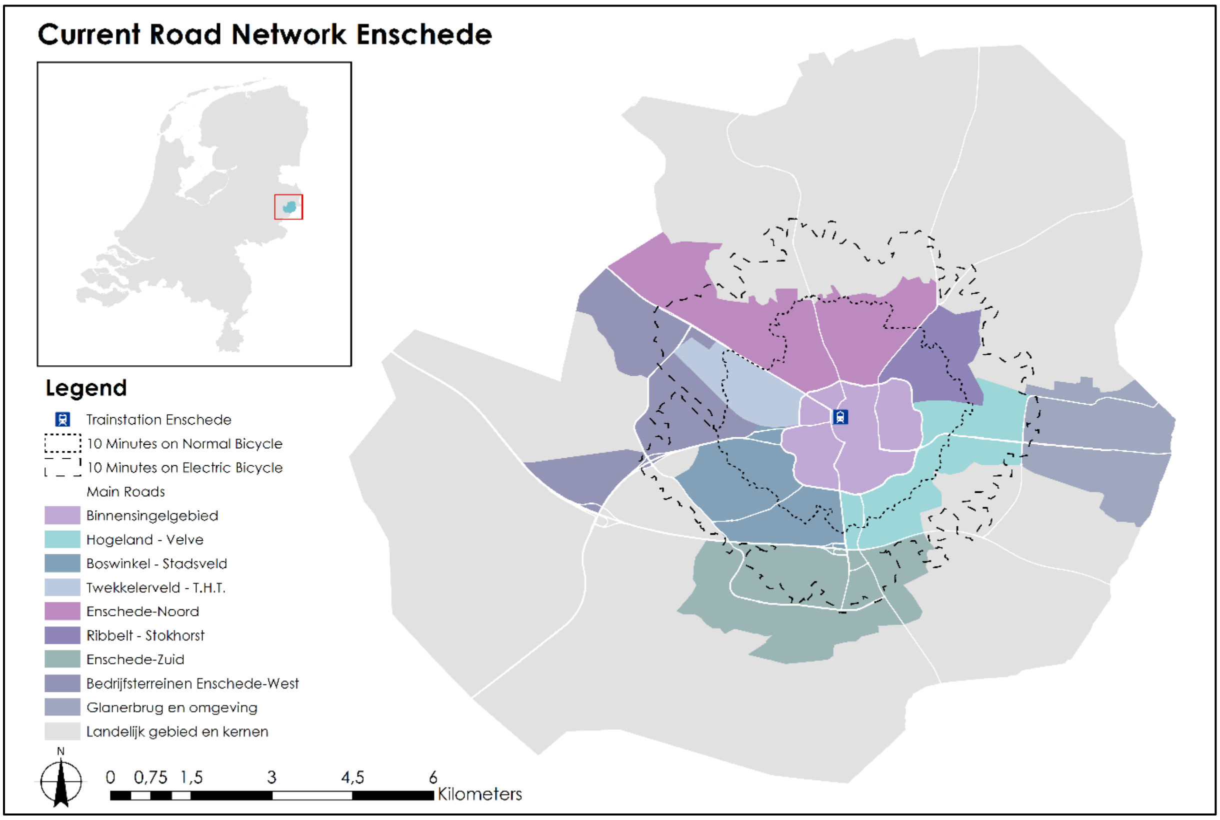


Figure 4: The municipality of Enschede in the Netherlands.

Figure 4 was inspired by the figure on page 41 in Smuling et al. (2019), and calculated using the Service Area Calculator in the Network Analyst Tool in ArcGIS, using an average cycling speed of 15 km/h for a normal cyclist (Fietsersbond, 2022a), and 24 km/h for an electric bicycle user (Rijksoverheid, n.d.). The estimation of cycling time for a regular bicycle and an electric bicyle is measured from the train station in the city centre, and shows that in optimal conditions a large part of the city can be reached within 10 minutes of cycling.

5.2 TOOL PURPOSE

After establishing the case study area a prototype of the tool could be developed. In this phase the purpose of the tool, the environment where the application will be used, and the tasks that intended users are expected to complete during use needed to become clear (Aguilar et al., 2021). These characteristics can be addressed first in a conceptual design (Draghici & Banciu, 2004), which can be seen in Figure 5.

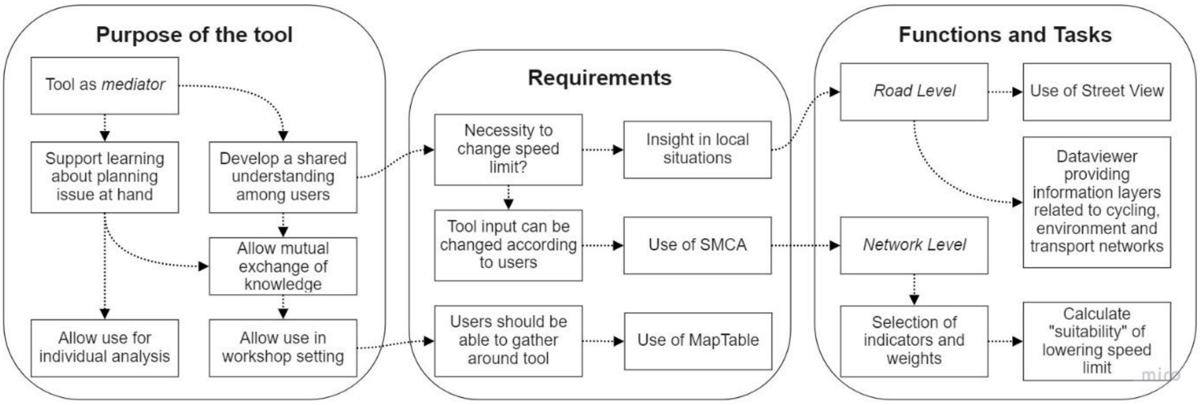


Figure 5: The purpose of the tool, leading to the requirements, functions and tasks of the tool.

The purpose of the tool was decided based on the specific cycling infrastructure problem that was chosen in the first part of this thesis. Considering that there is knowledge and data available about road safety with 50 km/h, but there is disagreement on which roads could become 30 km/h and what these roads should be designed as, a tool as mediator (Table 1) would be most suitable for the type of problem (Georgiadou & Reckien, 2018). PSS as mediators aim to structure the mutual exchange of knowledge among many actors, and are typically organized in a setting of one or more workshops. In these workshops, the purpose is often to learn about the planning issue at hand and to develop a shared understanding of possible solutions (te Brömmelstroet, 2017). Figure 5 illustrates how this purpose leads to the requirements of the tool. The environment where the application will be used is, for this thesis, a controlled participatory setting, where multiple stakeholders can gather around the tool. It was decided that a MapTable would be most suitable for such an environment, considering that users can gather around the tool. Because there are different considerations that can be made, the use of the tool is divided in two levels: the network level and the road level. These are in line with the decision chart developed by CROW (2021), which was introduced in Figure 2.

On a network level, spatial multicriteria analysis (SMCA) was chosen to map the necessity to change the speed limit. The associated task with this level is mapping the current roads that do not meet the requirements of a safe 50 km/h road. SMCA involves a set of geographicallydefined alternatives, that are based on a set of evaluation criteria. These criteria can be weighted differently, depending on the decision makers' preferences. SMCA does therefore not only consider the geographical input data, but also the different interpretations and importance given to the indicators by decision makers (Ascough II et al., 2002).

There are three relevant components for the use of SMCA in the context of a MapTable (Ascough II et al., 2002). There should be a data viewer, and the tool should allow for easy changes in distribution of weight among the different criteria. Finally, the results need to be displayed for the different input weights, from which results can be compared and discussed (Ascough II et al., 2002). Based on these components, a prototype was created with existing software. For this the extension of CommunityViz was installed in ArcGIS 10.8.2. In this extension, it is possible to select indicators and attribute different weights to each indicator using the Suitability Wizard. This extension was chosen because of time constraints of this thesis, limiting the options of developing a new open-source tool.

On a road level, it was decided that the tool should serve a different purpose. On this level, the decision of how 30 km/h can be achieved is more important. The current function and use of the road are more relevant in this discussion, and to be able to support the discussion, several information layers were added to the tool's interface. Finally, the function to open Google Street View from the tool was added. This was done by using the add-in of Street View in Arcmap. This last function was added, because before decisions can be made on potential solutions, an insight in the current traffic situation is important.

5.3 SELECTION OF INDICATORS

To be able to set up the SMCA indicators, some criteria had to be selected in an intermediate step. These criteria were selected based on the different steps in the decision chart in Figure 2, and supported by additional literature. The following criteria (in alphabetical order) were identified for determining: what is the necessity of change to a speed limit of 30 km/h?

Built Environment. The presence of buildings and shops on both sides of a road are more suitable for the realisation of a credible 30 km/h zone (CROW, 2021). In this case, with buildings closer to the road, road users tend to drive slower (Andriesse, 2021). Therefore, the presence of buildings and shops close to the road results in a more favourable environment for 30 km/h.

Emergency Services. Both the main routes and locations of emergency services are of importance for the decision of a 30 km/h zone. On these routes a steady flow of traffic is very important, so a speed limit of 30 km/h and the associated speed limiting measures might not be desirable (CROW, 2021). Table 6 shows an overview of the aspired or regulated arrival times that can be taken into account. Emergency services' arrival times are the needs of users of the road network, and not environmental characteristics. That is why this information layer can potentially be used to test the effects of changes in the speed limit, not necessarily guide the discussion on suitability.

Table 6: Brief overview of considerations for emergency services.

Fire Department	Arrival time should not increase beyond aspiration of 5-10 minutes (Brandweer Nederland, n.d.).

Ambulance	Arrival time should not increase beyond national norms, which is 97% of population within 12 minutes (Minister voor Medische Zorg, 2021).
Police	Arrival time should not increase beyond aspiration of 90% of population within 15 minutes (Tweede Kamer der Staten-Generaal, 2019).

Proximity to schools. In close proximity of schools, a speed limit of 30 km/h or lower is advised (CROW, 2021). Currently, most primary schools have measures in place signifying school zones: in these zones a low speed is obligatory, and speed limiting measures combined with safe crossings are installed. However, where the border of a school zone should ideally be, is not clear. Depending on the situation, a fitting solution and extent of a school zone is chosen (CROW & SWOV, 2020a).

Public Transport Routes. Like emergency services, public transport benefits from a steady flow of traffic, so a speed limit of 30 km/h and the associated speed limiting measures might not be desirable (CROW, 2021). This can result in longer travel times which might negatively influence the use of public transport, but this is still a point of discussion (Jacobs, 2021). Like arrival times of emergency services, travel times of public transport can be calculated before and after a speed limit change. This way, impacts can be assessed.

Road Profile. There are a few characteristics of the road profile that are of importance. The following characteristics contribute to a safe higher speed limit: separate bikelanes (preferably one-way for cycling safety (Wijlhuizen et al., 2014)), no parking alongside the road, safe crossing facilities (CROW, 2021), no buildings close to road, and no vegetation alongside the road (Andriesse, 2021). Higher speeds are also often associated with an even road surface, a higher number of lanes, and a wider road (Andriesse, 2021). This would mean that a narrow road without separate bikelanes, with parking alongside the road, no crossing facilities, and buildings and vegetation close to the road are less suitable for 50 km/h, from a road safety point of view.

Traffic Flows. Whether a road meant for low volumes of traffic actually functions as such, traffic flows are important. The number of cyclists, number of cars, and number of lorries are important to establish a connection between the road typology, and the actual use of the road (CROW, 2021; Hendriksen et al., 2018). Next to that, the number of cyclists in relation to other modes of transport are important for cycling safety (Wijlhuizen et al., 2014).

Zoning. Zoning is about the use of public space. There are three different types: *Verblijfsfunctie, Dubbele functie,* and *Verkeersfunctie.* This is to determine whether a location mainly has a residential function, a traffic function, or a combined/double function. These functions are closely related to the decision on road typology, and the speed limit (CROW, 2021).

Based on the criteria that were selected, the availability of data was checked, and the criteria were translated to indicators. These indicators will be presented in the results section of this chapter, and were determined based on data availability and whether a criterium could be displayed as a spatial characteristic in ArcGIS. Table 11 in Annex IV shows an overview of the selected indicators and the operationalisation in CommunityViz. Every indicator that is included in the tool, was assigned an operationalisation to calculate the necessity for change of the speed limit (in CommunityViz called suitability), on a scale of 0 to 100. A score of 0 indicates a low suitability, and a score of 100 a high suitability based on environmental characteristics. CommunityViz offers a few options for calculation of suitability: Proximity to other features, Amount of overlap with another layer, Average value of underlying grid, and From an existing numeric attribute. This last calculation option was based on predetermined suitability scores for different characteristics of a road segment, such as the existence of a bike lane on the main road. These scores were added manually in the attribute table of the road segment layer used for the calculations, and ranged between a score of 0 and 1, based on either a positive or a negative effect on the suitability score.

This effect relates to the indicators being assigned either as factors or constraints, where factors can be further split into benefits and costs (Keshkamat et al., 2009). A spatial benefit is a criterion that contributes positively to the output, and a spatial cost is a criterion that contributes negatively to the output. This means that with a spatial benefit a higher value means a higher suitability, and a spatial cost implies the opposite. Low scores of a factor can be compensated by higher scores of another factor, but constraints can never be compensated. This means that road segments with constraints are directly not suitable for the proposed development (Keshkamat et al., 2009).

For the calculations of suitability in the Suitability Wizard, the layer with road segments from the *Fietsersbond* was used as a dynamic layer. This layer was needed to display any changes made in the indicators and weights. The colourscheme and display of this layer was changed multiple times based on feedback from peers and teachers. Before the suitability layer could be made dynamic, all numeric attributes that are needed for the analysis needed to be added in the attribute table. After the layer of road segments was added as a dynamic layer, all changes to the layers in the suitability wizard affected the outcome of the calculations.

5.4 DATA PREPARATION

While determining the indicators, data availability was important. Table 7 shows a list of data sources that were used as input for the tool, with in Annex V a more detailed version. This data was selected based on the following requirements: the data needs to be recent, complete, and open-source. These requirements were chosen, because basing decisions on outdated or incomplete data could lead to false recommendations. The reason that data needs to be open-source, is because this allows for easy transition of the tool from one municipality to another municipality, without facing issues of unavailable data sources. This makes the tool applicable to multiple environments. The only data source that does not fully comply with these requirements, is the dataset provided by the *Fietsersbond* through the Department of Civil Engineering of the University of Twente. It was included in this thesis because there was no other recent, complete dataset including characteristics of the current cycling infrastructure.

Table 7: List of data sources used as input in the tool.

Data Source	Date	Information Layers	Type
PDOK Top10NL	02/2022	Buildings, landuse and water	Polygons
		Train tracks	Lines
PDOK Luchtfoto	2022	Luchtfoto Landelijke Voorziening	Raster

		Beeldmateriaal, Quick Ortho HR, WMTS	
Open Street Map (OSM) Points of Interest	02/2022	Emergency services, schools and universities	Points
Fietsersbond	03/2022	Road and cycling network	Lines
		Cycling hubs and potentially unsafe locations	Points
ArcGIS Hub	04/2022	Traffic accidents, road signs, shops	Points
ArcGIS Hub	04/2022	Public transport the Netherlands	Points and Lines

5.5 RESULTS OF TOOL DEVELOPMENT

Now that the different criteria in accordance with the specific cycling infrastructure problem have been decided on, this problem determined the functions and desired outputs of the tool. Like established before, the purpose of the tool is to help create a better understanding of the problem, and structure the discussion to support reaching a common understanding from the different opinions of stakeholders on this matter. First, the tool indicators will be presented. After that, the functions and the expected outputs of the tool will be presented.

5.5.1 TOOL INDICATORS

Table 8 provides the indicators that were determined as relevant for the suitability analysis in ArcMap, or as supporting information layers. Even though these indicators were established based on the criteria known from literature, not all are included in the tool. Because not all data was available for all indicators, there is some missing information in the prototype of the tool. The layers including numbers of cars, cyclists and lorries are not available, as well as the layers with the number of lanes, the width of the road, parking alongside the road and vegetation alongside the road. Hence, these are not yet included in the suitability calculation.

Table 8: Criteria for determining the suitability, with associated indicators and rationale. This symbol ▼ stands for a factor with costs, ▲ means a factor with benefits. This means that with a higher value, a lower (▼) suitability score is given, or with a higher value, a higher (▲) suitability score is given (Keshkamat et al., 2009)**.**

	Criterion	Indicator	Rationale
▲	Built Environment	Buildings on both sides of road	If there are buildings on either side of the road, this encourages driving at a lower speed (Andriesse, 2021; CROW, 2021). If these buildings have a residential function, 30 km/h is advised (CROW, 2021).
▲	Built Environment	Presence of shops	With more shops present, a lower speed is desirable (CROW, 2021).

▲	Road Profile	Bike lane on road	If there is a bike lane (or suggestion lane) on the road, a decision must be made for cyling safety. If a roads' speed limit is 50 km/h, a physical separation of a bike lane is advised (Hendriksen et al., 2018).
▲	Road Profile	Road surface	When a road has an even surface, road users tend to drive faster (Andriesse, 2021; Sweco Nederland, 2021). If a current 30 km/h road has an asphalt surface, adaptations to the design might be necessary.
▼	Road Profile	Number of lanes	Higher number of lanes makes a speed limit of 30 km/h less attainable (Andriesse, 2021).
▲	Road Profile	Parking alongside road	If yes, encourages driving at lower speed (Andriesse, 2021; CROW, 2021).
▲	Road Profile	Vegetation alongside road	If yes, encourages driving at lower speed (Andriesse, 2021; CROW, 2021).
▼	Road Profile	Width of the road	Wider road makes a speed limit of 30 km/h less attainable (Andriesse, 2021).
▲	Road Typologies	Main Cycling Network	If a road is part of main cycling network, limiting speed to 30 km/h can increase safety (VVN, 2020). On some roads a speed limit of 20 km/h or even 15 km/h might be needed (Hendriksen et al., 2018).
▼	Road Typologies	Main Road	If a road is part of the main connections in the city, fast connection by car might be a priority (CROW, 2021).
▲	Schools	School Zones	Streets around primary schools become safer with lower speed limits (CROW & SWOV, 2020a).
▼	Traffic Flows	Number of cars	If speed limits are lowered, a high number of cars can result in unwanted congestion. Therefore, a steady flow of traffic might be desired in these locations (CROW, 2021).
▲	Traffic Flows	Number of cyclists	If there is a high number of cyclists, a lower speed limit for all traffic can result in safer cycling conditions (ANWB, 2022; Hendriksen et al., 2018).
▲	Traffic Flows	Number of lorries	If there is a high number of lorries, and these lorries use the same road segment as cyclists, this can lead to unsafe situations (CROW, 2021).
▲	Traffic Flows	Traffic Accidents	'Black spots', locations with a high number of accidents, can lead to risk-based approaches (CROW & SWOV, 2020b).

Figure 6 provides an overview of all the layers that were included in the tool, and their visualisation in the tool. The suitability layer (*Geschiktheid voor 30 km/h*) is a dynamic layer, which means that this layer shows the output of the SMCA. The other layers are information layers, of which some are included in the suitability calculation.

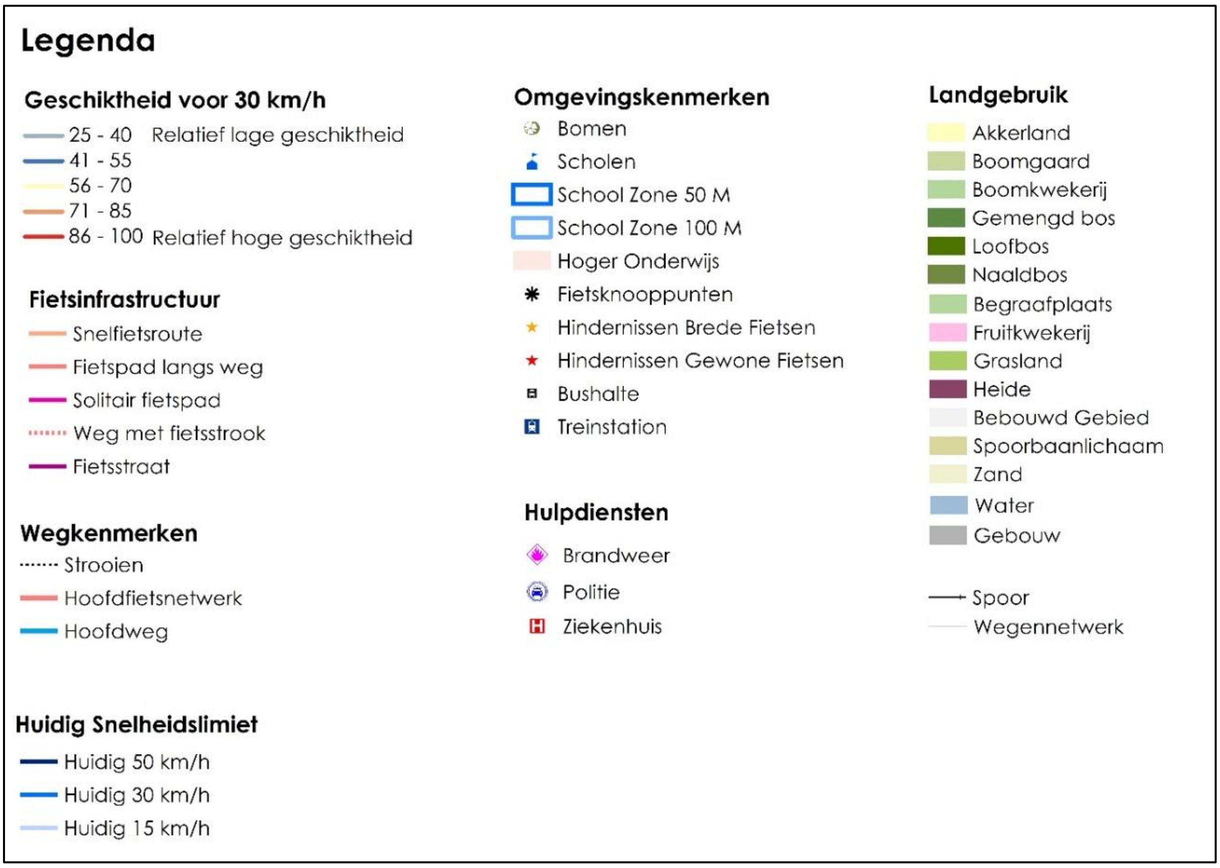


Figure 6: Legend of the layers available in the tool.

The seven main categories in the legend are as follows, starting from the top left corner. **Suitability for 30 km/h**, ranging from a relatively low suitability (25-40) to a relatively high suitability (86 – 100). The suitability is displayed using a threshold of 25 to exclude all unsuitable roads, and using equal intervals. **Cycling infrastructure**, including cycling highways, separate bicycle lanes, solitairy cycling paths, roads with bicycle lanes without separation, and bicycle streets. **Road characteristics**, separated into roads that are included in de-icing routes, the main cycling network and the main car network. **Current speedlimits**, divided into 50 km/h, 30 km/h and 15 km/h. **Environmental characteristics**. These include the location of solitary trees, schools, school zones, higher education, cycling hubs in the regional recreational network, potentially dangerous locations for wide bikes and potentially dangerous locations for normal bikes, bus stops and train stations. **Locations of emergency services**, including the fire department, police, and the hospital. **Landuse**, including agricultural land, orchards, tree nurseries, mixed forest, deciduous forest, coniferous forest, cemeteries, fruit farms, grassland, heather, built-up area, railroad, sand, water, and buildings. Finally, the train tracks and the entire road network are included.

5.5.2 TOOL TASKS

The intended tasks that users are expected to complete during the use of the tool depend on the type of use of the tool. On one hand, the tool can serve an analytical purpose, which means that the tool could be used by an individual. The analytical purpose allows the user to gain insight in the planning problem at hand. On the other hand, including several stakeholders in a discussion, the tool can help create a better shared understanding of the extend of the planning issue, as well as support the development of different solutions and common goals (te Brömmelstroet, 2017).

If the goal of the use of the tool would be to create a better insight in the potentially dangerous locations in the network from a cyclists' perspective, the selection of indicators and attributed weights would happen from this perspective. The interface in ArcGIS is as follows.

- In the Table of Contents different layers can be turned on and off.
- Some layers are only visible when zoomed in or zoomed out, creating a difference between network level (1:80.000) and road level (1:2000).
- The viewer shows the selected layers and the calculated suitability .
- The Scenario 360 toolbar allows for changes in the included indicators (yes/no), and the attributed weight (1-10). These can be changed by the users of the tool.
- The workshop toolbar includes options to zoom in and out, pan, open the assumptions window, save the session, and open the Street View window.
- Finally, the Scenario 360 Content window shows the input data, assumptions, different scenarios, dynamic attributes with associated calculations, indicators, and results.

The output of the tool is a map that shows the suitability for changing the road to 30 km/h. This 'suitability' is a result of whether a road is safe to remain 50 km/h (making it 'unsuitable' for 30 km/h), or if there are certain environmental/road characteristics that determine that a current 30 km/h road does not meet the safety requirements (resulting in a high suitability, all according to the users of the tool). Figure 7, 8 and 9 on the following pages show examples of the output of the tool, and include all roads within the city boundaries in the calculation. Displayed are the current 50 km/h roads that do not meet the safety standards, but also the current 30 km/h roads that do not meet safety standards for a 30 km/h road. The actions that can be taken based on these output maps can be lowering the speed limit to 30 km/h, or make alterations to the current street design. In Chapter 6 the implications of including both discussions in one suitability calculation will be discussed.

Figure 7 on the next page shows a low to moderate suitability for the majority of the city. However, there are a few locations in the city that show a high suitability, which could potentially be input for a discussion whether changes are necessary. All indicators were included in this output, and they were all given equal weights. Changing the weights of the indicators can still be done after this output, resulting in different scores and different potential locations for discussion. Figure 8, also on the next page, illustrates what happens when only environmental characteristics are considered for the suitability calculation. In this example Buildings on both sides of road, Presence of shops, and School zones were selected. The result of only selecting these indicators is clearly visible, resulting in locations with relatively more shops, schools and residential buildings as more suitable.

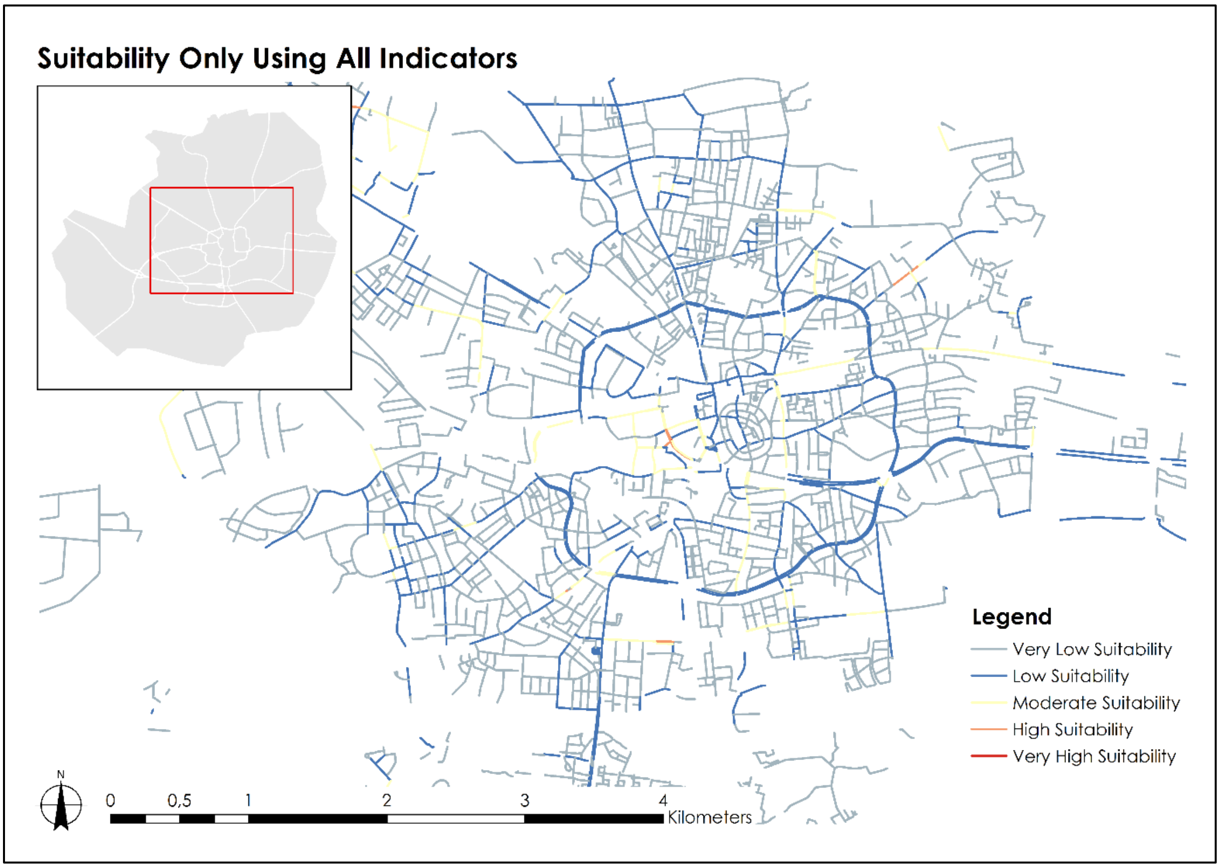


Figure 7: Example of suitability scores after using equal weights for all indicators.

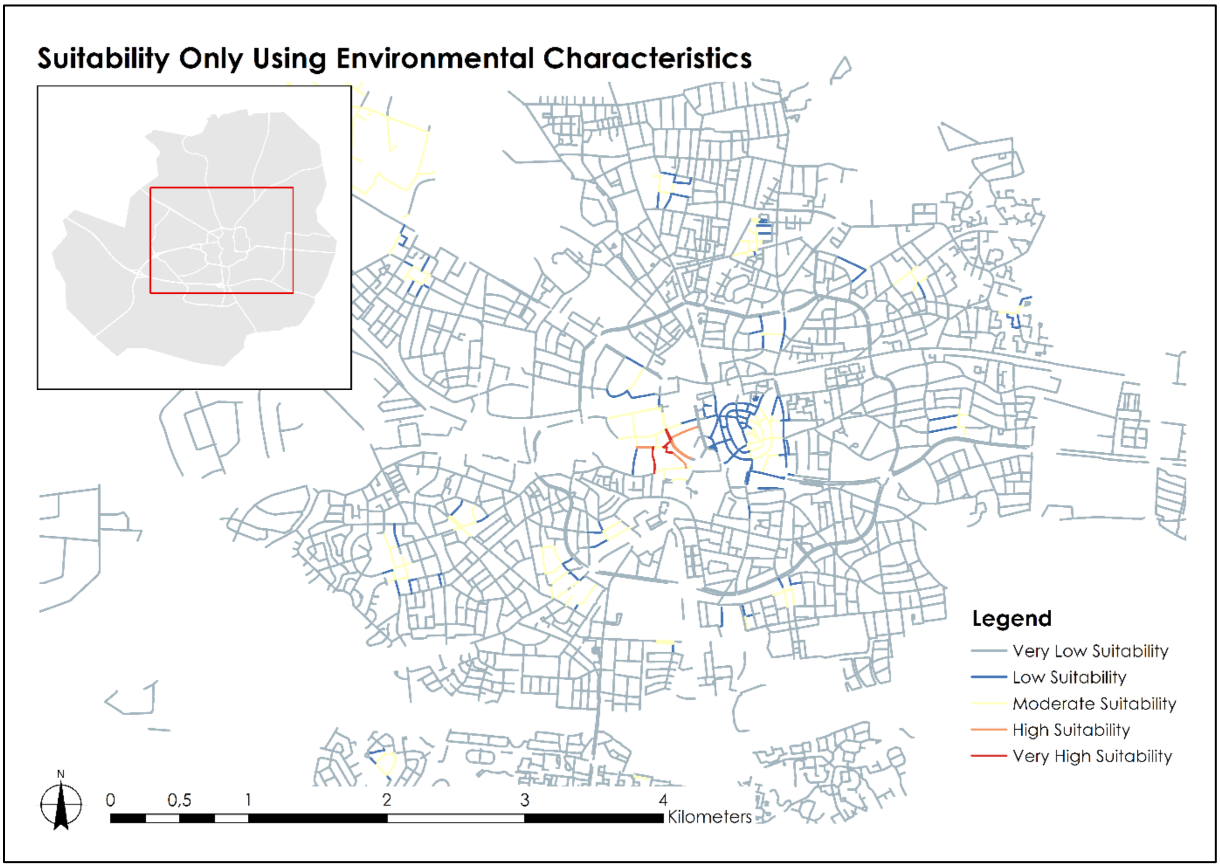


Figure 8: Example of suitability scores after using indicators for environmental characteristics.

Finally, Figure 9 illustrates the use of only road characteristics, which are Traffic Accidents, Main Road Network, Main Cycling Network, Road Surface, and Bike Lane on the Road. The result of using only these indicators is very diverse, showing large differences between road segments. All outputs that were generated provide an overview of the city, and are incentives for a further discussion on road level. Questions that can be asked are: what is the current speed limit? Is this road part of one of the larger networks in the city? What does this road segment look like? Why could there be a higher suitability score on this segment? What kind of change would be necessary from a cycling safety point of view?

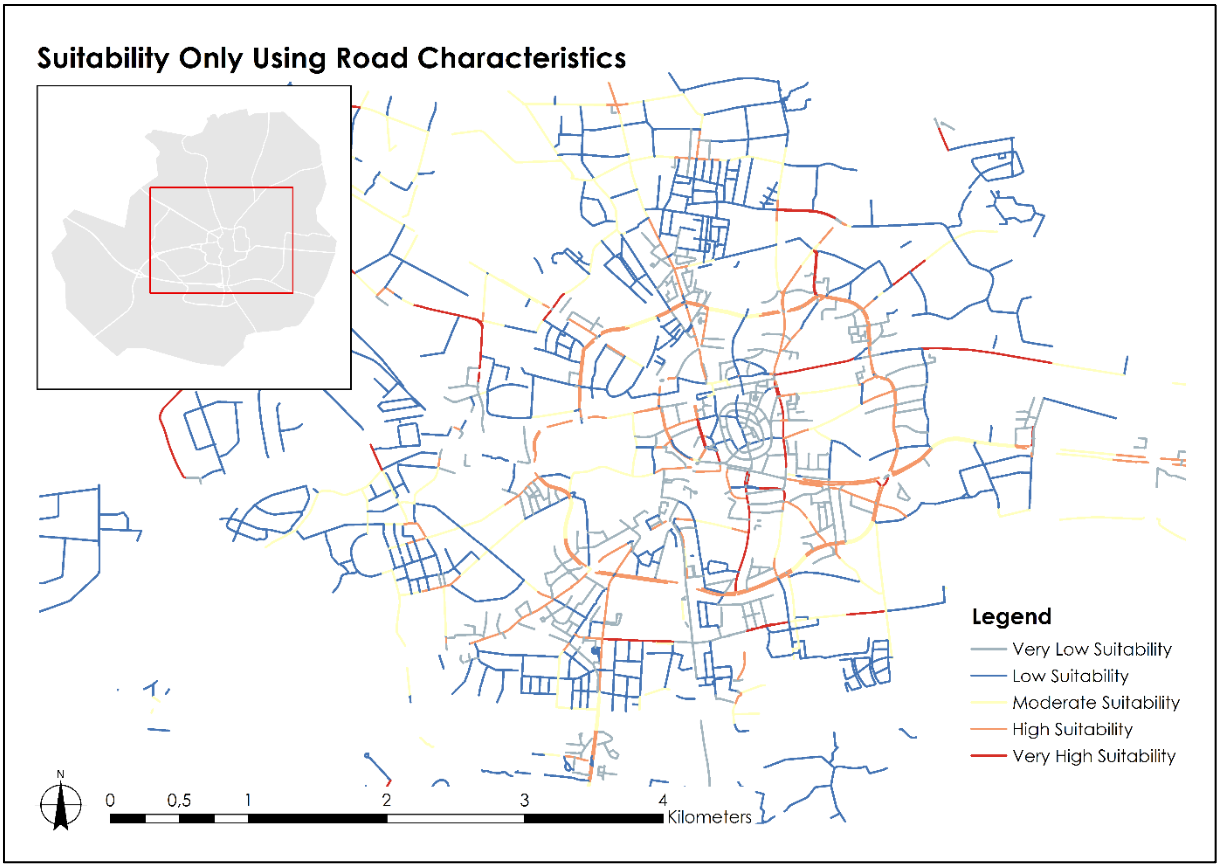


Figure 9: Example of suitability scores after using indicators for road characteristics.

The three figures together illustrate a large difference in suitability calculations. Hence, different priorities of users can result in very different calculated suitabilities. What this means for credibility of the tool and user satisfaction will be discussed in the next chapter.

6. TOOL TESTING

To test the tool, a distinction was made between useability and usefulness. Useability is the ease of use for planning practitioners and end users, and usefulness is the added value on the quality of the planning tasks (te Brömmelstroet, 2017). Aguilar et al. (2021) distinguishes a similar way of evaluation, divided between effectiveness and efficiency. Effectiveness is defined as the perceived completeness, which means that all stakeholders should be able to easily contribute to the discussion, based on a complete input map. Efficiency is defined as the perceived ease of use, and satisfaction as whether the user is satisfied with the use and output of the tool (Aguilar et al., 2021). All of these evaluation considerations were included in the testing of the tool, while also referring back to the intended purpose of the tool.

The testing of the prototype tool took place in a participatory setting. For this, a focus group was necessary. The size of a group of four participants was the initial aim. This way it was possible to include stakeholders with different backgrounds. The workshop session allowed participants to discuss the functionality of the tool. In Table 9 a list of the workshop participants can be seen, as well as some participants that were asked, but unfortunately not able to attend. Like the interviews, the participants are listed anonymously.

Table 9: Participants of the workshop.

Profile	Logo	Organisation	Date
Advocacy	Fietsersbond	Fietsersbond	21/6/22
Consultancy	KEYPOINT	Keypoint	21/6/22
Research	UNIVERSITY OF TWENTE.	University of Twente	-
Policy Advisor	Gemeente Enschede	Municipality of Enschede	-

At the start of the workshop, an introduction to the planning problem and the scope of the thesis was given. Participants were informed of the purpose of the workshop and the use and storage of the gathered data through oral informed consent. After that, the goal of the workshop and the tool were explained. In a first short exercise the participants were made familiar with the functions of the tool. After this exercise, it was time for testing the tool. In two exercises different tasks were given to the participants. After this, a questionnaire was given to the participants, and final experiences were discussed. A structured way of asking questions allowed for the comparison of different points of view (Knox & Burkard, 2009). The questionnaire can be seen in the Annex VI, together with a more detailed planning of the workshop session (Annex VII). The questionnaire had a few yes/no questions, two open questions, and disagree/agree questions. These last questions were scaled from one to five, with one representing 'strongly disagree', and five representing 'strongly agree'. At the end, there was the option to add some additional comments that were not said yet during the workshop. Finally, it was possible to conclude on the usability of the developed geo-information tool.

6.1 RECOMMENDATIONS FROM THE WORKSHOP

Depending on the user, the experiences of testing the tool were different. On the one hand, the tool was said to be interesting based on the new insights the tool might provide, and the discussion this might result in. However, there were also doubts about the useability of using a tool based on ArcGIS and spatial data, in a setting where participants might not be familiar with calculations such as SMCA. Figure 10 shows the set up that the participants of the workshop used. An enlargement can be found in Figure 16 in Annex VII.

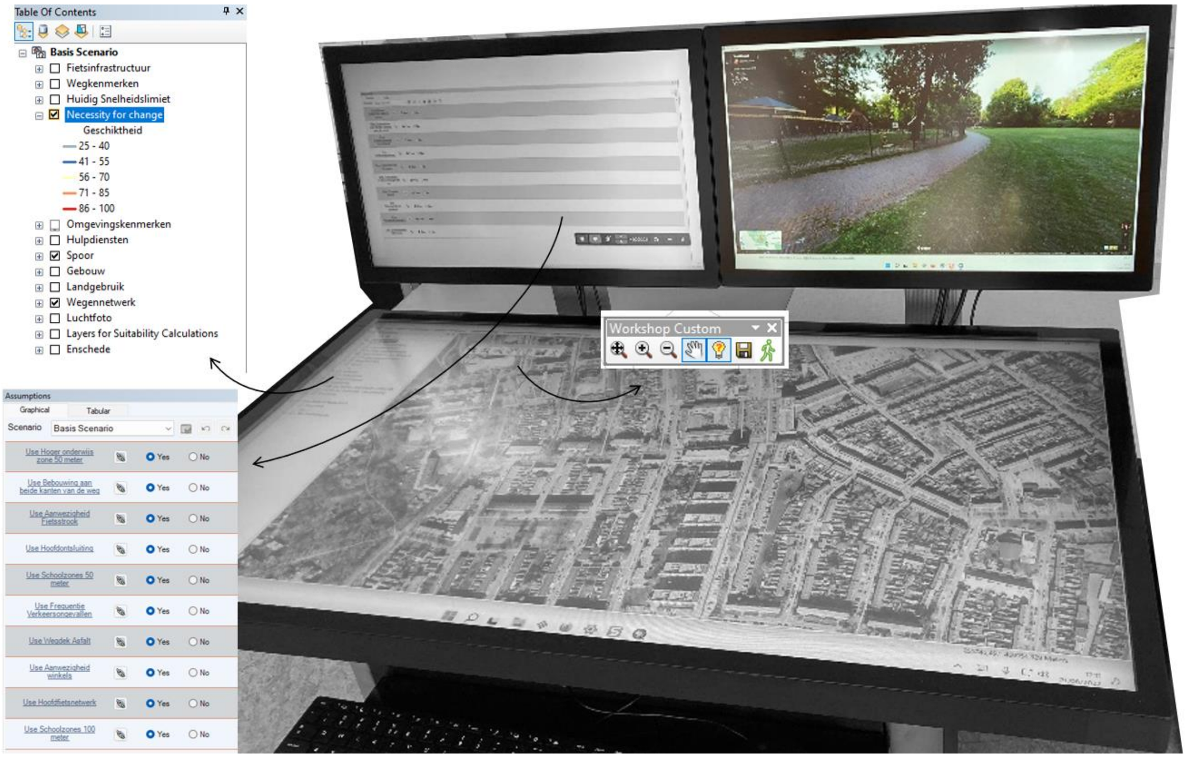


Figure 10: The interface of the tool in ArcMap, with the table of contents and the assumptions window on the left, the toolbar in the middle, and at the right the Google Street View window.

The first recommendation from the workshop is that framing of the tool is very important. Calling it 'suitability for 30 km/h' might already steer the participants in a certain direction, while you would want to provide an objective base for discussion. That is why it was seen as more useful to frame the tool as a way to test a set of requirements (such as cycling safety in a 50 km/h zone), and show all roads that do not meet the set requirements. A scaling of the indicators would not be necessary in such a setting. The roads in the output map would then be input for a discussion on what needs to change to make the roads safe from a cyclists' point of view, and one of the options could be lowering the speed limit to 30 km/h.

A point that was raised by both participants, is that it is not clear why the suitability calculations include all roads, so also the roads that are currently 30 km/h. For current 50 km/h roads there are other arguments and input relevant compared to roads that are already 30 km/h. This is confusing and makes the tool more difficult to understand for participants.

Finally, it was seen as important to include more indicators. Including more indicators would make the tool more credible, because there are many considerations that need to be made. Even though not all data is complete or available, this is essential for supporting the discussion. Including more indicators would mean that the model becomes more complex, but to be able to make an informed decision some are necessary. Some missing data that was mentioned: traffic flows, the width of the road, the width of the cycling infrastructure in place, the 'real' speed compared to the speed limit, traffic accidents specifically involving cyclists, and the use (function) of the road.

6.2 QUESTIONNAIRE RESULTS

At the end of the workshop, a questionnaire was given to the two participants. Answering the first question (see Annex VI), one workshop participant had used a similar tool before (yes), and one workshop participant had not (no). Some doubts were raised about the willingness of stakeholders involved in cycling planning to use such a tool in a participatory setting because they are often not familiar with these tools and how they operate. One participant had been involved in a participatory setting previously (yes), and one participant had no experience in a participatory setting (no). The participant that had no experience being in a participatory setting found it enjoyable to try out a geo-information tool in the workshop setting (score 4). The participant that has been involved in participatory settings before, did not enjoy the use of the geo-information tool in this setting (score 2).

6.2.1 EFFECTIVENESS OF TOOL

Perceived completeness

The perceived completeness of the tool was experienced very differently by both participants. One participant agreed that the tool indicators were complete, but more indicators can be added (score 4). However, it was mentioned that this will increase the complexity of the model, which might be unwanted. The other participant did not agree (score 1) and argued that the issue represented in the tool is very complex and many important indicators such as traffic flows were not included. The approach to the indicators was, according to this participant, also opposite of what they would find useful: instead of showing which road could potentially become 30 km/h, all roads that can remain 50 km/h in a safe manner would provide better input for discussion.

About the functions, the two participants were also divided. One participant agreed with the completeness (score 4), and the other participant did not agree (score 1). An added function of being able to zoom on the MapTable as one would do on a smartphone was mentioned. Unfortunately, the ArcGIS software does not enable this yet, but it was observed that participants instinctively tried to use the zoom function in this way. A function that would show why a certain road is or is not suitable for 30 km/h was also recommended, otherwise, the tool remains a black box for participants.

For the clarity of underlying calculations, both participants agreed to a certain extent on this question (score 3 and 4). Still, there is more to gain here, since participants asked multiple times for an explanation of the different indicators, and how they were included in the calculations.

Easy contribution to the discussion

Both participants agreed that it was easy to contribute to the discussion (score 4 and 5), although it was mentioned that if participants are less open to discussion and have already taken a strong standpoint, it is more difficult to keep a discussion going. It was also observed that with a small group of participants, it is more difficult for the moderator to not be included in the discussion.

Both participants agreed that the goal of the exercise was clear (score 4 and 5). One participant agreed that the tool helped structure the discussion about the problem (score 4) and one participant disagreed (score 2). Both participants disagreed that the tool helped structure the discussion about possible solutions (both score 2). It was mentioned that the tool does not really provide options to be able to discuss future solutions easily. It was mentioned to not be useful for getting to a final design decision.

6.2.2 EFFICIENCY OF TOOL

Perceived ease of use

One participant agreed (score 5) and one participant disagreed (2) that they understood the functions of the tool quickly. Initially, it was observed that there was confusion about the actual process of the suitability calculation; the output was not always as expected. This was specifically the case for data of indicators that was not complete according to the participants, or did not match their expectations. Furthermore, both participants agreed that the software did <u>not</u> have a very clear interface (score 3 and 5), mainly because the tool can only be used in ArcGIS. The interface is not created in a way that all indicators, weights, and buttons are clearly visible, readable, or easy to locate.

The weights of the indicators were changed by the moderator, because the touchscreen on the MapTable did not support the interface provided by CommunityViz satisfyingly. This process of weighing and selection of indicators was steered by the participants, and all indicators were discussed one by one. The issues with the touch screen probably resulted in a score of 2 and 3 for easy changes to the weight of the indicators. Both participants agreed that the indicators were easier to select or deselect, resulting in a score of 4 and 5.

Satisfaction of use

The satisfaction of the tool was scored differently by both participants. One participant was enthusiastic about the opportunities that the tool gives, but was not entirely convinced that the tool could be used in its current form (score 4). The other participant was not satisfied (score 2). They commented that they do not see such a tool being used in a participatory setting with residents or other stakeholders that are not familiar with the software. Additionally, one participant agreed that the focus of the tool was sufficient (score 4), and one participant disagreed (score 2). The level of detail was enough for both participants (score 4 and 5).

Satisfaction of output

The output map did not meet the expectations of the participants, resulting in scores of 1 and 3. This score relates to the incompleteness of indicators. For clarity, a legend of all layers was displayed above the MapTable. In case the visualisation was not clear, the moderator would point to this sheet (Figure 17 in Annex VII). One participant scored the clarity of the tool with a 3, and the other participant scored a 5. It was observed that there was limited confusion about what could be seen on the map, but the suitability legend proved to be a challenge. This was also related to the confusion between current 30 km/h roads, and current 50 km/h roads. Finally, the credibility of the output map was scored highly (score 4 and 5). In the end, both participants saw opportunities for further development of the tool, but some changes are recommended before it is useable in the 'real world'.

DISCUSSION

There are several points that could be improved or could have been done differently in this research, as well as some points that went well. The following research questions were addressed in the literature review: RQ 1.1 What are the different steps in planning for cycling infrastructure (i.e. planning cycle), and RQ 1.2 What types of policies and interventions have been implemented so far? The answers to these questions were aimed at creating a structured overview of Dutch cycling infrastructure planning that is useful for the reader to understand the context of the research problem. This overview is not very extensive, but because the cycling infrastructure problems as seen from the interviewees' perspective are introduced later, this was seen as sufficient background.

The following research questions were addressed in the round of interviews with cycling practitioners: RQ 1.4 What are current cycling infrastructure planning problems, RQ 1.4 How could these problems be addressed with the use of spatial data, RQ 1.5 Which specific cycling infrastructure problem would be most suitable for addressing in a participatory tool, and RQ 1.6 Which stakeholders could be involved in a participatory setting?

The interviewees were able to provide a comprehensive insight in the current cycling infrastructure problems, and mentioned several problems that overlapped with the other interviewees. Not all interviewees were able to address the use of spatial data, but some interviews that were more familiar with this provided interesting ideas for the development of a tool, such as risk-based decision-making or using SMCA to assess the current state of cycling infrastructure. However, before going into the round of interviews, the specific cycling infrastructure problem had not been selected yet. Therefore, RQ 1.6 about stakeholders did not result in a satisfactory answer related to a potential tool. As a result, it was not possible to conclude on this round of interviews which relevant stakeholders should be included in a participatory setting for testing the tool, but it did result in a comprehensive overview of all the different roles of stakeholders in discussions on cycling infrastructure.

The next research questions were answered based on literature review and certain considerations made by the author: RQ 2.1 Which Dutch municipality deals with the selected cycling infrastructure problem, RQ 2.2 What is the target group and setting of the geo-information tool, RQ 2.3 What information and functions should the geo-information tool provide, and RQ 2.4 What are the expected outputs of the geo-information tool?

The selection of Enschede as the case study area was found most suitable for this thesis, but might have not been most representative of the planning problem. In theory, every municipality in the Netherlands has to provide a plan of how they will deal with the transition to 30 km/h in their municipality. However, in practice the problem is not as relevant in every municipality. Figure 14 in Annex I illustrates that not many roads are 50 km/h in the city of Enschede, so in hindsight deciding on a different case-study area might have been useful. Nonetheless, it was a challenge to find participants for the workshop setting in Enschede.

The target group, setting, data and functions, and expected output of the tool were all selected by the author based on previous research and criteria supported in literature. From a research perspective, these decisions could have been supported in a much better way by including cycling pracititioners early on in the development of the tool by letting them write user stories, and use these to come up with tool requirements. This could have resulted in a co-designing process. Because of time constraints it was also not possible to do multiple iterations of the tool testing with cycling practitioners. Hence a few unofficial testing moments were planned, but it was not possible to include these results in the thesis because the test groups included fellow students and staff from ITC.

Most of the data that was included in the tool is recent and open source, which means that updating this input data or selecting different study areas is relatively easy. A disadvantage of the data that was used in the tool, is that the data provided by the *Fietsersbond* to the university was not openly available. Even though most municipalities probably have similar datasets, this can be a disadvantage.

The following research question was addressed based on requirements established by the author in the previous step: RQ 3.1 What should the workshop setting look like and what should be the outputs? The final questions were addressed in the workshop setting: RQ 3.2 Which indicators are relevant to the decision that needs to be taken, RQ 3.3 Which functions of the tool are missing in the prototype, and RQ 3.4 How could the tool be useful for the stakeholders in a participatory setting?

The workshop setting was decided based on the purpose of the tool, and a workshop planning was made accordingly. What could be improved is the inclusion of a more diverse group of stakeholders, because availability of participants was limited in this thesis. Next to that, it is recommended from a useability point of view to develop a tool on an open-source platform, to allow a clearer user interface. Much of the feedback on the current tool was that the ArcGIS software is difficult to use on the MapTable. Some simple tasks such as zooming in and out were difficult because ArcGIS does not support this.

Table 10 shows a SWOT analysis for the development of the tool. This analysis was created by the author, based on feedback during the workshop session (1), input from the first round of interviews (2), literature on participatory decision tools, and practical issues during the development of the tool (3). The strengths closely relate to the expectations and the purpose of the tool, and the weaknesses, opportunities and threats relate to the experience of developing and using the tool.

Table 10: SWOT analysis of the tool development in this thesis, based on feedback during the workshop session.

Strengths	**Weaknesses**
• Inclusion of different stakeholders can lead to better supported decisions (McCall & Dunn, 2012; Resch et al., 2020) • Stakeholders gain insight in other opinions and might reach a common understanding (Georgiadou & Reckien,	• Biases in inclusion of indicators (1) • Tool does not run on open-source platform; license is needed (3) • Inclusion of many stakeholders might increase difficulty of decision-making (1) • Data is often not complete or up-to-date (3)

2018) • Tool can assist in providing new insights in hard to solve situations (2) • Ability to locate spatial challenges and test interventions (2)	
Opportunities	**Threaths**
• Further development of tool in open-source platform (1) • Inclusion of more detailed data in the future might lead to better supported decisions (1) • Data-driven decision-making and risk-based decision-making is a new development that can increasingly be used (2) • Co-designing of the tool (3) • Inclusion of 'what-if' scenarios (2)	• Decisions could be made based on incorrect or incomplete data (1) • Analysis of tool does not structure debate but only further polarises (1) • Users see analysis as 'the truth' and do not consider the tool only as a support for decision-making (3)

RECOMMENDATIONS

To conclude, there are some opportunities for future research. Useability and added value of decision tools is difficult to determine, and this thesis has shown that experience between users can differ significantly. It is therefore recommended to use multiple test rounds for further or future development of participatory decision tools. More research is also needed in the development of software with an interface specifically aimed at use on a MapTable. This could further increase useability of similar tools.

Furthermore, the tool developed in this thesis could serve as a basis for further research, looking more closely at functions and indicators, as well as the framing of the tool to the potential users. The development of the tool in an open-source platform is one of the important improvements that should be considered. However, there are also some issues that are not as easy to solve. Some participants might not see the opportunities that a geo-information tool can offer. A threat of using such tools is further polarisation of a discussion when incorrect or incomplete data is included, and changing the attitude of users towards the use of geo-information tools is a difficult task. What is therefore recommended, is investing in tools that provide an objective basis to a planning problem. Next to that, it is important to inform participants and manage expectations before the use of the tool, and finally provide a clear insight in how certain calculations are made, where data is from, and what the output of the tool shows.

CONCLUSION

In this thesis, the added value and useability of a planning support tool for one specific cycling infrastructure problem in the Netherlands was addressed. Participation in planning is valued highly, and geo-information tools aimed at participation have improved significantly in recent years. However, the added value and useability of such tools is not well known. The main objective for this thesis was developing a geo-information tool in a multi-stakeholder context, for creating a better understanding of the added value of such a tool in cycling infrastructure planning in the Netherlands, while providing a tool to support decision-making.

The literature study showed that in recent years more prioritisation is given to cyclists over other road users to stimulate cycling, and to improve cycling safety. The current cycling infrastructure problems that practitioners mentioned in the interviews are: limited space for all planning goals in a city, the increase of different modes on the cycling path, realising inter-city connections for cyclists on cycling highways, and the discussion whether the speed limit should be 30 km/h on all roads in cities. In the case of lowering the speed limit from 50 km/h to 30 km/h there are many spatial considerations to make. It was found that the stakeholders that can be involved in addressing these cycling problems, vary depending on the scale and the stage of the development. For local developments, more stakeholders can be involved compared to developments on a city level.

For the development of the geo-information tool, the city of Enschede was chosen as case-study area. The tool's functions are based on a suitability analysis using spatial multicriteria analysis (SMCA), which shows the necessity for change to a 30 km/h speed limit. The purpose of the tool was decided to be a mediator, with the goal of providing insight in the planning problem, as well as contribute to creating a common understanding for stakeholders of each others opinions on the matter. The associated tasks for users are selecting the different indicators and attributing weights to determine necessity for change. If from the analysis 50 km/h cannot be achieved in a safe manner, a discussion on road level might lead to recommendations for changes. One of the solutions can be lowering the speed limit, but for current 30 km/h roads changes in the design might be necessary.

To test the tool, a workshop setting was aimed at addressing the added value of the decision tool for cycling practitioners. Because the response in the workshop from both participants varied, it was not possible to conclude that the tool in its' current form is usable for practitioners. However, many recommendations were provided of how this could be possible, making this thesis a small contribution to developing participatory tools for addressing cycling infrastructure problems in the Netherlands.

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ANNEX

ANNEX I - ROAD TYPOLOGIES

An explanation of the Dutch road typologies is included because not everyone might be familiar with the terminology. The definitions of the road typologies are leading in determining the road design and the associated speed limit, but are not always carried out as the guidelines dictate. The road typologies consist of the function of the road in the network. In the Netherlands, there are three types of roads: *Erftoegangswegen (ETW), Gebiedsontsluitingswegen (GOW), and Stroomwegen* (CROW, 2021; SWOV, 2017). *ETW* are typically 30 km/h in design, and GOW are typically 50 km/h, but not always in design. These are the so-called "grey roads", that often lack space for all modes and therefore negatively influence traffic safety (Andriesse, 2021). For the bicycle, there are also three different typologies: *Basisstructuur Fiets, Hoofdfietsnetwerk, and Snelle Fietsroute* (Hendriksen et al., 2018).

Figure 11 shows a road profile that is often seen in a *Gebiedsontsluitingweg* (GOW). This roughly translates to "access road", meaning this is one of the main roads of a city. In an ideal situation, there is space for two lanes with separation in the middle of the road, allowing for safe crossing at a few designated spots. Next to that there is often a separate cycling path on both sides of the road, and depending on the location there is often a separate lane for pedestrians, or public green space. The speedlimit in this case is often 50 km/h, because this can be achieved in a safe manner (CROW, 2021). The main challenge in this type of road profile is often the limited cycling path width for all the different modes, causing congestion or unsafe situations for vulnerable cyclists (ANWB, 2020).

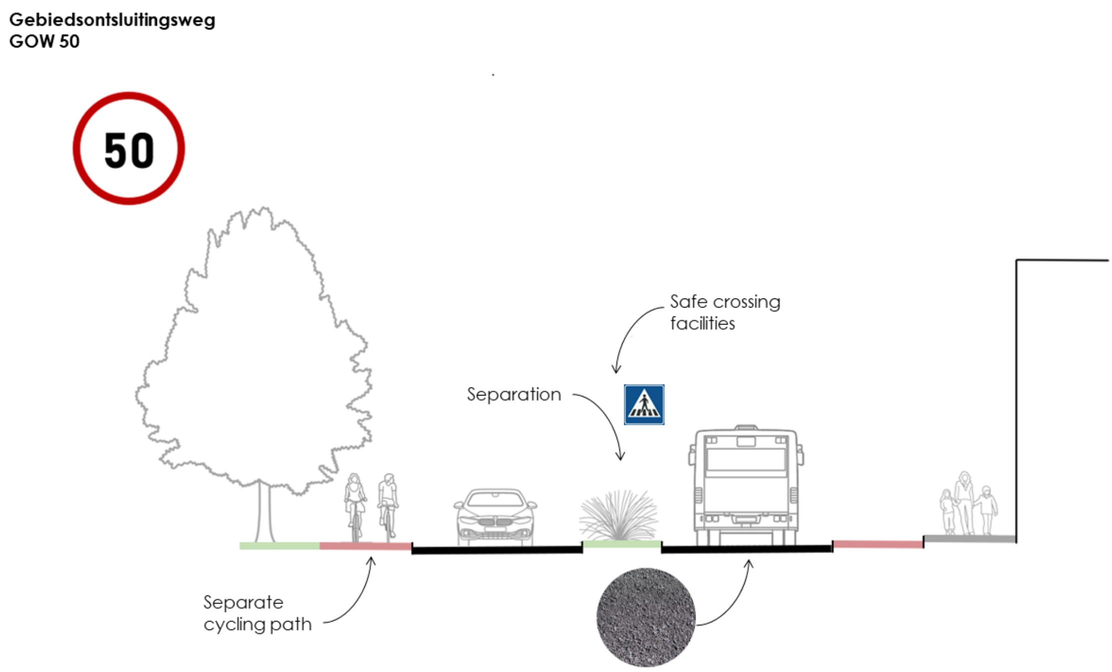

Figure 11: Profile of a GOW, with a speed limit of 50 km/h. Cyclists are separated from the main road and there is often a dividing area between the two-ways. Source: Author, with use of graphics from (Dimensions.com, 2022).

Figure 12 shows a road with a speedlimit of 50 km/h as well, but in this case there is limited space available. On both sides of the road there is built up area, which means that there is often no space for separation between the two lanes, or space for a separate bike lane. Even though this is just an example, about 40% of the current GOW50 roads have no separate cycling path (Sweco Nederland, 2021). The main challenge in this type of road profile is limited space for all main network routes, especially if the road has a double function (both traffic and residential function). This is an example of a situation where a decision needs to be made, especially if this is a road that functions as the main cycling route through a city, but is also heavily used by cars, public transport and emergency services.

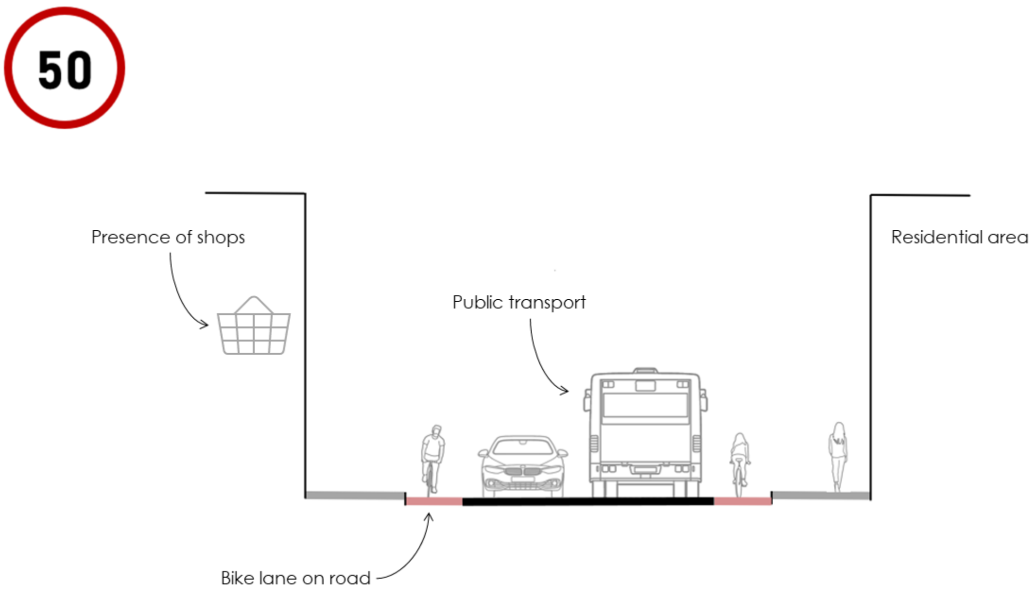

Figure 12: Profile of a gebiedsontsluitingseg (GOW) with limited space. In these cases the cyclists often are not separated from motorised vehicles. Source: Author, with use of graphics from (Dimensions.com, 2022).

It needs to be decided whether changes can be made to the main networks (emergency services and public transport), and whether a speed of 50 km/h can be achieved in a safe manner (CROW, 2021). If this is not the case, GOW30 can be considered. This is a new type of road that currently does not exist, and aims to combine the traffic function of a road with a speed limit of 30 km/h. What the design of such a road should look like, needs to be decided still (CROW, 2021).

Finally, Figure 13 shows a typical road profile of an *Erftoegangsweg* (ETW), with a speedlimit of 30 km/h. This name roughly translates to "property access road". In this case there is often parking on either side of the road, one shared space for all vehicles, and sometimes space for a public green area. Next to that there are often speed limiting measures like speed bumps and pavers (instead of asphalt) in place (Andriesse, 2021). Even though Figure 13 shows a typical 30 km/h road, the road design is not always like this. 40% of all current 30 km/h roads are too wide (Sweco Nederland, 2021), and especially if there are no speed limiting measures in place or there is a lack of trees and buildings alongside the road, road users tend to drive faster than 30 km/h (Andriesse, 2021).

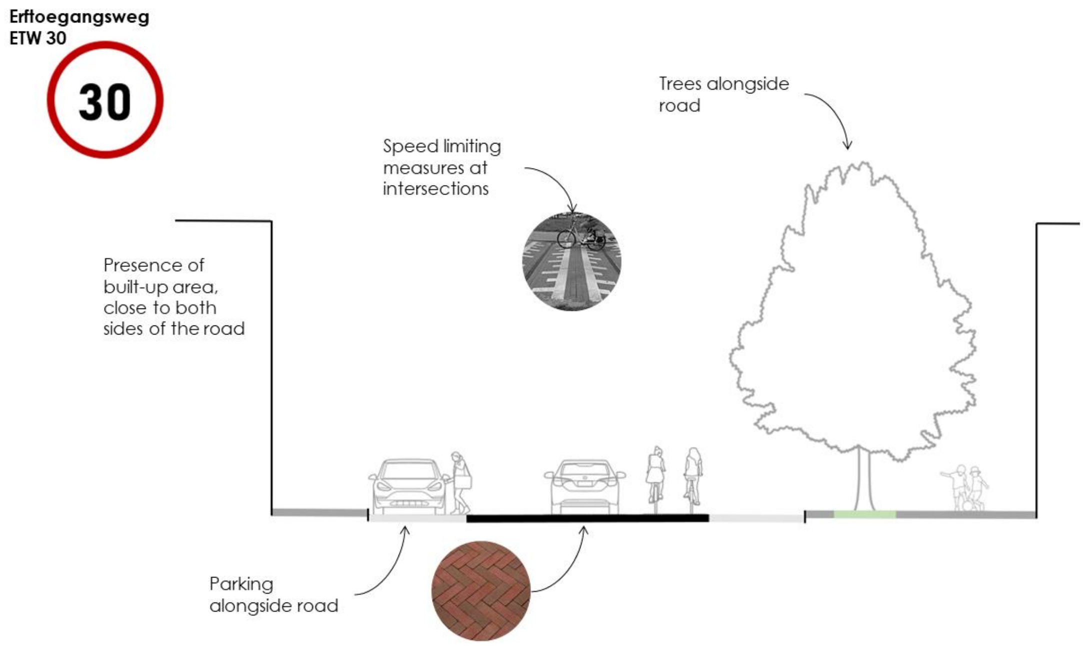

Figure 13: Profile of a Erftoegangsweg with a 30 km/h speed limit. In this profile there is often parking on the side of the road, there are speed limiting measures, and no separation between the different modes of transport. Main challenge is when these roads have to deal with a high traffic flow. Source: Author, with use of graphics from (Dimensions.com, 2022).

Figure 14 shows that currently, many roads in the city of Enschede have a speed limit of 30 km/h. Nationwide, about 70% off all roads in urban areas are 30 km/h (CROW, 2021; Sweco Nederland, 2021). These roads are classified as ETW30 roads, and the current 50 roads are GOW50. The CROW decision chart (Figure 2) proposes a new type of road; the GOW30. This road would have a combined function of traffic and recreation, or a traffic function with a lower speed limit (of 30 km/h). Whether some roads in Enschede could potentially become GOW30 roads, needs to be decided. Consequently, the design on a GOW30 road is not known at the moment of writing (CROW, 2021). Therefore, there are several design options.

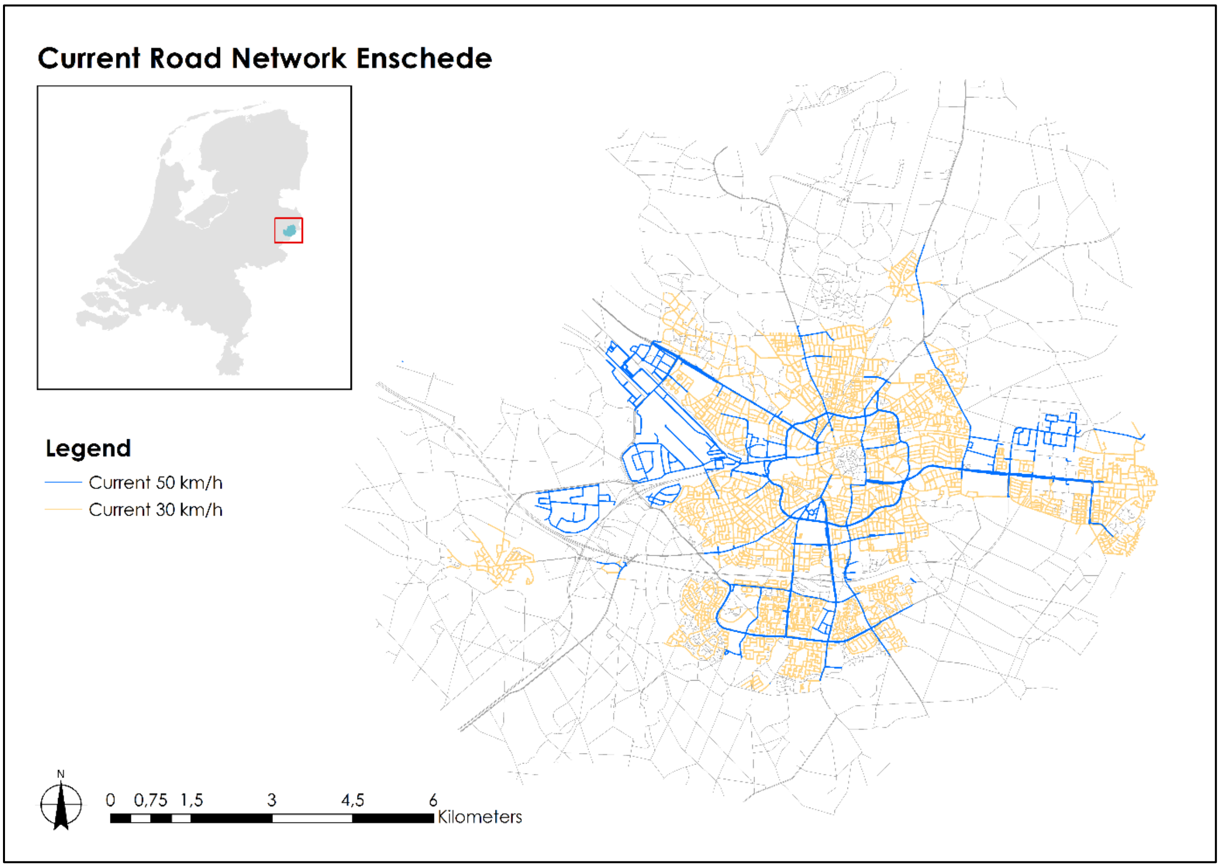

Figure 14: The current road network in Enschede, showing that many roads currently have a speed limit of 30 km/h.

ANNEX II – INFORMED CONSENT INTERVIEW MASTER SCRIPTIE LISA DOORNBOS

Dutch/Nederlands

Versie: 22/8/2022

Het interview

Vanuit de universiteit is het een vereiste on dit document met u te delen. Mocht u zich voor of na het interview toch terug willen trekken van deelname, dan kunt u dit doen door contact met de student verantwoordelijk voor dit interview op te nemen (Lisa Doornbos).

Doel van het onderzoek

De vraag die centraal staat in deze thesis, is of in het geval van de (her)inrichting van het stedelijk fietsnetwerk in Nederland, *geo-information tools* het planning proces zouden kunnen ondersteunen. Op wat voor manier en welke stakeholders hier behoefte aan zouden kunnen hebben, is echter niet eerder onderzocht. Een belangrijke stap voordat er een tool ontwikkeld kan worden, is het inventariseren in welk deel van het planning proces een *geo-information tool* eventueel het planning proces kan ondersteunen. Om deze reden is het belangrijk om te spreken met beleidsmakers en experts op het gebied van fietsen en mobiliteit. Het doel van deze thesis is om uiteindelijk een tool te ontwikkelen die het participatieproces met verschillende stakeholders kan versterken, en deze te testen op gebruiksvriendelijkheid en relevantie.

Verzamelde data

- In dit interview wordt niet gevraagd naar persoonlijke informatie die terug kan leiden naar de deelnemer.
- De audio van het interview wordt opgenomen met toestemming van de deelnemer.
- De deelnemer heeft altijd recht om verzamelde informatie in te zien, en eventuele verwijdering aan te vragen.
- Alle verzamelde informatie wordt opgeslagen in een beveiligde omgeving van de universiteit, en hiertoe hebben geen andere personen toegang behalve de onderzoeker.
- Na het interview wordt een geschreven geanonimiseerde samenvatting van het interview voor goedkeuring met de deelnemer gedeeld. Deze samenvatting bevat geen persoonlijke gegevens die het mogelijk maken om de informatie terug te leiden naar de deelnemer.
- Zodra het onderzoek is afgesloten, worden alle opnames van het interview verwijderd.
- De deelnemer ontvangt, zodra het onderzoek is afgesloten, een digitale kopie van het eindresultaat.

Toestemmingsformulier Master Scriptie Lisa Doornbos

U ONTVANGT EEN KOPIE VAN DIT TOESTEMMINGSFORMULIER

Vink de rondjes aan die op u van toepassing zijn	Ja	Nee
Deelnemen aan het onderzoek		
Ik heb de onderzoeks-informatie van 22/08/2022 gelezen of het is aan mij voorgelezen, en ik heb deze begrepen. Ik heb vragen kunnen stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	○	○
Ik stem vrijwillig in om deel te nemen aan dit onderzoek, en begrijp dat ik kan weigeren om vragen te beantwoorden en dat ik me op elk moment kan terugtrekken uit het onderzoek, zonder dat ik daarvoor een reden hoef op te geven.	○	○
Ik begrijp dat deelname aan dit onderzoek gepaard gaat met een opgenomen interview. Deze opname wordt na afronding van het onderzoek verwijderd. Een schriftelijke samenvatting wordt ter goedkeuring met de deelnemer gedeeld.	○	○
Gebruik van de informatie in het onderzoek		
Ik begrijp dat de informatie die ik verstrek anoniem zal worden gebruikt voor een schriftelijk rapport dat zal worden gepubliceerd.	○	○
Ik begrijp dat persoonlijke informatie die over mij is verzameld en die mij kan identificeren, zoals mijn naam, niet buiten het onderzoeksteam zal worden gedeeld.	○	○

Ondertekening

Naam deelnemer	Handtekening	Datum

Ik heb het informatieblad voorgelegd aan de potentiële deelnemer en heb er naar mijn beste vermogen voor gezorgd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

Lisa Doornbos	Lisa	22/08/2022
Naam onderzoeker	Handtekening	Datum

Contactgegevens voor meer informatie:

L.c.doornbos@student.utwente.nl

Contactgegevens voor vragen over uw rechten als onderzoek deelnemer

Als u vragen heeft over uw rechten als onderzoek deelnemer, informatie wilt inwinnen, vragen wilt stellen of bezorgdheden over dit onderzoek wilt bespreken met iemand anders dan de onderzoeker, neem dan contact op met de secretaris van het Ethics Committee van de Faculty of Geo-Information Science and Earth Observation: ethicscommittee-GEO@utwente.nl

ANNEX III - INTERVIEW QUESTIONS

Datum | *Date*
Tijd | *Time*
Locatie | *Location*
Aanwezigen | *Attendees*

Bedankt dat u vandaag tijd heeft vrijgemaakt voor dit interview. Mijn naam is Lisa Doornbos, ik studeer op dit moment Spatial Engineering aan de Universiteit Twente. Hiervoor heb ik Landschapsarchitectuur en Ruimtelijke Planning gestudeerd in Wageningen. Voor mijn master scriptie ben ik aan het onderzoeken op wat voor manier zogenoemde *geo-information tools* het planningsproces van fietsinfrastructuur in stedelijke gebieden in Nederland kan ondersteunen, en wie daar behoefte aan zou hebben. Stakeholders kunnen deze *tools* gebruiken voor het ontwikkelen van alternatieve planningsscenario's, voor brainstorm sessies, of voor het schetsen van verschillende planalternatieven. Verder heb ik nu eerst 2 korte vragen aan u, om een beeld te krijgen van waar u in uw dagelijks leven op het gebied van fietsen aan werkt.

a. Wat is uw professionele achtergrond op het gebied van fietsen? | *What is your professional background in the field of cycling?*

b. Wat zijn uw voornaamste werkzaamheden op het gebied van fietsen in uw dagelijks werk? | *What are your main activities in the field of cycling in your daily work?*

Dit interview zal maximaal een half uur duren, en er zijn 6 vragen. Het interview zal anoniem worden gebruikt in de scriptie, en u ontvang uiteraard de uitkomst van de scriptie als deze af is. Verder zou ik graag de audio opnemen, zoals u heeft kunnen lezen in het toestemmingsformulier. Heeft u nog vragen vooraf aan dit interview?

1. Welke ontwikkelingen zijn momenteel gaande op het gebied van planning van fietsinfrastructuur in stedelijke gebieden, en wat verwacht u van deze ontwikkelingen? | *What developments are currently taking place in the field planning of cycling infrastructure in city environments, and what do you expect from these developments?*

2. Wat zijn volgens u de <u>belangrijkste</u> ruimtelijke vraagstukken die betrekking hebben op fietsinfrastructuur? | *What do you think are the most <u>important</u> spatial issues related to cycling infrastructure?*

3. Zijn er op dit moment stakeholders die naar uw gevoel te weinig betrokken worden, waar u graag meer van zou willen horen in deze vraagstukken? | *Are there currently stakeholders who, in your opinion, are not involved enough, that you would like to hear more from in these issues?*

3a. Zo ja, op wat voor manier zou hun input waardevol kunnen zijn? | *If so, in what way could their input be valuable?*

3b: Welke informatie is hierbij cruciaal als het gaat om besluitvorming? | *What information is most important for taking decisions in this case?*

4. Op welk moment in het plannen van fietsinfrastructuur zou meer participatie/samenwerking nuttig zijn? [Participatie: het hebben van gelijke inspraak in besluitvorming] | *At what point in*

cycling infrastructure planning would more participation/cooperation be useful? [Participation: having an equal say in decision-making]

5. Hoe zou deze samenwerking georganiseerd kunnen worden? Heeft u daar ervaring mee/voorbeelden van/ideeën over? | *How could this collaboration be organised? Do you have any experience with this/examples of this/ideas about how this can be organised?*

6. Voor het ontwikkelen van een nuttige tool, is het belangrijk om inzicht te krijgen in de schaal (of schalen) waarop ondersteuning relevant is. Denk hierbij aan het spreken over het niveau van een stad, per wijk, of zelfs per type infrastructuur. Op welke schaal zijn volgens u de eerder genoemde belangrijkste uitdagingen op het gebied van fietsinfrastructuur vooral te vinden? | *To develop a useful tool, it is important to understand the scale (or scales) at which support is relevant. Think of talking about the level of a city, per district, or even per type of infrastructure. On what scale do you think the previously mentioned challenges in the field of cycling can mainly be found?*

Dank u wel voor uw tijd. Heeft u nog vragen of wilt u nog wat toevoegen? De volgende stappen in het onderzoek zijn het verzamelen van alle inzichten, en het ontwikkelen van aanbevelingen voor hoe een *tool* zou kunnen werken. Als laatste stap is het de bedoeling om een prototype te maken, en deze te testen met verschillende stakeholders. | *Thank you for your time. Do you have any questions or would you like to add something? The next steps in the research are to collect all the insights, and develop recommendations for how a tool might work. The final step is to make a prototype and test it with various stakeholders.*

ANNEX IV - OPERATIONALISATION OF INDICATORS

Table 11: List of indicators and associated operationalisation in the tool.

<table>
<tr><th>Indicator</th><th>Operationalisation</th><th>Calculation</th></tr>
<tr><td rowspan="2">Buildings on both sides of road</td><td>A higher GSI of residential buildings (number between 0-1), results in a higher suitability score.</td><td>Average value of underlying grid.</td></tr>
<tr><td colspan="2">This calculation was not operationalized because of errors in the calculation. Even though this was not solved within the time frame of this thesis, this indicator is still mentioned as an important consideration.</td></tr>
<tr><td rowspan="2">Buildings on both sides of road</td><td>Roads with buildings on both sides of the road, lead to a higher suitability score. Segments with buildings on both sides and limited green area score 1, segments with buildings on both sides but plenty of green surroundings score 0,8, otherwise score is 0.</td><td>From an existing numeric attribute (in suitability layer).</td></tr>
<tr><td colspan="2">Score bebouwing aan beide kanten van de weg
= [Assumption: Use Bebouwing aan beide kanten van de weg]
* (IfError (Norm ([Attribute: Geschiktheid voor 30 km/h: ([Attribute: Bebouwing])], 0, 100), 100))</td></tr>
<tr><td rowspan="2">Presence of shops</td><td>A higher density of shops, results in a higher suitability score.</td><td>Average value of underlying grid.</td></tr>
<tr><td colspan="2">Score aanwezigheid winkels
= [Assumption: Use Aanwezigheid winkels]
* (IfError (Norm ([Attribute: Geschiktheid voor 30 km/h: (GridMean ([Layer: Dichtheid Winkels]))], 0, 100), 100))</td></tr>
<tr><td rowspan="2">Bike lane on road</td><td>If a road has a bike lane or suggestion lane on the road, that road is suitable for 30 km/h (1), otherwise score is 0.</td><td>From an existing numeric attribute (in suitability layer).</td></tr>
<tr><td colspan="2">Score aanwezigheid fietsstrook
= [Assumption: Gebruik Aanwezigheid Fietsstrook]
* (IfError (Norm ([Attribute: Geschiktheid voor 30 km/h: ([Attribute: Fietsstrook])], 0, 100), 100))</td></tr>
<tr><td rowspan="2">Road surface</td><td>Asphalt/concrete surface has a high suitability for adaptation (1), all other surface score 0.</td><td>From an existing numeric attribute (in suitability layer).</td></tr>
<tr><td colspan="2">Score wegdek asfalt
= [Assumption: Gebruik Wegdek Asfalt]
* (IfError (Norm ([Attribute: Geschiktheid voor 30 km/h: ([Attribute: Wegdek])], 0, 100), 100))</td></tr>
<tr><td>Main Cycling Network</td><td>If a road is part of the main cycling network, that road is suitable for 30 km/h (1), otherwise score is 0.</td><td>From an existing numeric attribute (in suitability layer).</td></tr>
</table>

	Score hoofdfietsnetwerk = [Assumption: Gebruik Hoofdfietsnetwerk] * (**IfError** (**Norm** ([Attribute: Geschiktheid voor 30 km /h: ([Attribute: Fietsnetwerk])], 0, 100), 100))	
Main Road	If a road is part of the main road network, that road is not suitable for 30 km/h (0), otherwise score is 1.	From an existing numeric attribute (in suitability layer).
	Score hoofdontsluiting = [Assumption: Gebruik Hoofdontsluiting] * (**IfError** (**Norm** ([Attribute: Geschiktheid voor 30 km /h: ([Attribute: Hoofdweg])], 0, 100), 100))	
School Zones	If a road is overlapping with a school zone of either 50 or 100 meters around a school, that road is suitable for 30 km/h (1), otherwise score is 0.	Amount of overlap with another layer.
	Score schoolzone 50 meter = [Assumption: Gebruik Schoolzones 50 meter] * (**IfError** (**Norm** ([Attribute: Geschiktheid voor 30 km /h: ((**OverlapArea** ([Layer: School Zone 50 M]) / **Area** ([Attribute: Shape])) * 100)], 0, 100), 100))	
Traffic Accidents	A high density of traffic accidents (number between 0-1) leads to a higher suitability for 30 km/h, assuming that this would make the location safer.	Average value of underlying grid.
	Score frequentie verkeersongevallen = [Assumption: Gebruik Frequentie Verkeersongevallen] * (**IfError** (**Norm** ([Attribute: Geschiktheid voor 30 km /h: **GridMean** ([Layer: Dichtheid Verkeersongevallen])], 0, 100), 100))	

Buildings on both sides of the road: Ground Space Index (GSI). To calculate the building density the GSI was used. The GSI represents the built area compared to the total area, resulting in a ratio. This is calculated by dividing the built area by the total area (Harbers et al., 2019). For this calculation, only buildings with a function other than industrial or commercial were considered. First, all buildings (TOP10NL) that were not within Functional Areas (TOP10NL) were selected. After that, a grid of 100*100 meters only covering the municipality of Enschede was created with the Grid Index Features tool. Intersecting this layer with the layer of buildings resulted in a layer of buildings divided into a grid of 100*100 meters. When joining this table to the original grid layer, it was possible to calculate the GSI. The built area per 100*100 meters was divided by the total area and displayed. This layer had to be displayed as a raster layer, but this final step lead to some errors. Like mentioned in Table 11, this error was unfortunately not solved within the time frame of this thesis.

Buildings on both sides of the road: Type. The dataset provided by the Fietsersbond included some road characteristics, like the presence of buildings alongside the road. All road segments were already divided into the following categories: built (plenty of green area) and built (little to no green area). The following suitability values were given to these categories: built (little to no green area) 1, built (plenty of green area) 0,8, and all other road segments 0.

Shop Density. The density of shops was calculated using the Kernel Density tool. The Kernel Density tool calculates the density of features in a neighbourhood around those features. The points from layer shops (ArcGIShub) were used as input. A cell size of 20 was used to calculate the density of shops per square meter, resulting in a raster layer. The values of the density varied between 0 and 0,0016 shops/m².

Bike lane on road. In case a road segment in the dataset from Fietsersbond includes a bike lane on the road, a suitability of 1 is assigned. This information can be found in the row 'omgeving'. For all other roads, a suitability of 0 is assigned.

Road Surface. For an asphalt or concrete road surface, a suitability value of 1 is assigned. This data is also found in the dataset provided by Fietsersbond, in the row 'wegdeksrt'. For all other road surfaces a suitability value of 0 is assigned.

Main Cycling Network. If a road in the dataset from Fietsersbond is assigned the attribute of the main cycling network, a suitability of 1 is assigned. For all other roads, a suitability of 0 is assigned.

Main Road Network. If a road in the dataset from Fietsersbond is assigned the attritube of main road network, a suitability of 0 is assigned. For all other roads, a suitability of 1 is assigned.

School Zones. There is no one definition for where a school zone starts or ends, because this depends on local conditions. For this thesis, a buffer of 50 and 100 meters around schools (OSM) was created to simulate a school zone, based on estimations of a few current school zones in the city of Enschede. During the use of the tool can be decided which buffer will be used. For higher education, a buffer of 50 meters around locations of higher education (OSM) was created.

Traffic Accidents.. Using the Kernel Density tool, cel size 20 was used to calculate the density of traffic accidents. The points that were used as input are the number of all traffic accidents recorded (ArcGIShub). Ideally, there would be a use of barriers in this calculation, to be able to see density per road segment. Figure 15 illustrates the difference between the two calculations. However, this option was not available in the used software (ArcGIS version 10.8.2). To make the calculated grid more reliable per road segment, this option could be used.

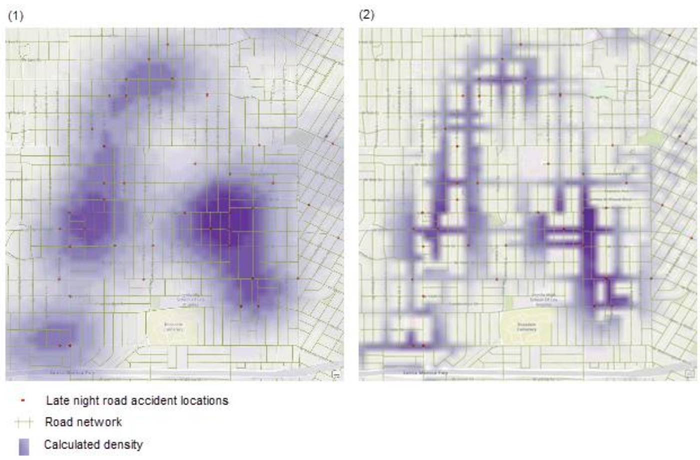

Figure 15: Difference between Kernel Density without (1) and with barriers on both sides of the road (2), from ArcGIS Pro 2.8 (ESRI, n.d.).

ANNEX V - DATA OVERVIEW

Table 12: Links to all the data used in this thesis.

Data Source	Date	Information Layers	Type	Link
PDOK Top10NL	02/2022	Buildings, land use and water	Polygons	https://www.pdok.nl/downloads/-/article/basisregistratie-topografie-brt-topnl#51677caf1a5da3c6d3d14ce520d6dc06
		Train tracks	Lines	
PDOK Luchtfoto	2022	Luchtfoto Landelijke Voorziening Beeldmateriaal, Quick Ortho HR, WMTS	Raster	https://service.pdok.nl/hwh/luchtfotorgb/wmts/v1_0?request=GetCapabilities&service=wmts
Open Street Map (OSM) Points of Interest	02/2022	Emergency services, schools and universities	Points	http://download.geofabrik.de/europe/netherlands/overijssel.html
Fietsersbond	03/2022	Road and cycling network	Lines	Provided through the department of Civil Engineering at the University of Twente
		Cycling hubs and potentially unsafe locations	Points	
ArcGIS Hub	04/2022	Traffic accidents, road signs, shops	Points	https://services.arcgis.com/nSZVuSZjHpEZZbRo/arcgis/rest/services
OpenTransportMap	10/2015	Road network	Lines	https://opentransportmap.info/download/ The Netherlands, Oost-Nederland, Overijssel, Twente
ArcGIS Hub	04/2022	Bus lines, bus stops, train stations	Points and Lines	https://hub.arcgis.com/maps/RUG::openbaar-vervoer-nederland/about

ANNEX VI - QUESTIONNAIRE WORKSHOP

Doel van deze enquête

Het doel van deze enquête is om op een overzichtelijke manier inzicht te krijgen van de ervaringen van deelnemers aan de workshop. Op deze manier is het mogelijk om antwoorden te vergelijken, en hier conclusies aan te verbinden. Deelname aan de workshop en het invullen van de enquête zijn volledig anoniem, en zullen dan ook met niemand gedeeld worden.

Verzamelde data

- In deze enquête wordt niet gevraagd naar persoonlijke informatie die terug kan leiden naar de deelnemer.
- De deelnemer heeft altijd recht om verzamelde informatie in te zien, en eventuele verwijdering aan te vragen.
- Alle verzamelde informatie wordt opgeslagen in een beveiligde omgeving van de universiteit, en hiertoe hebben geen andere personen toegang behalve de onderzoeker.
- De deelnemer ontvangt, zodra het onderzoek is afgesloten, een digitale kopie van het eindresultaat.

Ik heb eerder een vergelijkbare tool gebruikt. *I have used a similar type of tool before.*	○Ja ○Nee
Ik heb ervaring met het discussiëren in een participatieve setting. *I have been involved in a participatory setting before.*	○Ja ○Nee
Ik vond het leerzaam om een ruimtelijk vraagstuk te bespreken in een participatieve setting met de ondersteuning van een tool. *I enjoyed being part of a participatory setting with the use of a geo-information tool..*	Oneens ○○○○○ Eens

Effectiveness of Tool

Perceived completeness

De gebruikte indicatoren zijn compleet. *The indicators used in the tool were complete.*	Oneens ○○○○○ Eens
Welke indicatoren zou u graag nog toevoegen? *What indicator(s) would you like to add?*	
De gebruikte functies van de tool zijn compleet. *The functions of the tool were complete.*	Oneens ○○○○○ Eens
Welke functie(s) zou u graag nog toevoegen? *What function(s) would you like to add?*	

De aannames in het onderliggende model waren voor mij duidelijk. *The assumptions of the underlying models were clear to me.*	Oneens ○○○○○ Eens

Easy contribution to the discussion

Het was gemakkelijk om mee te doen aan de discussie. *It was easy to contribute to the discussion.*	Oneens ○○○○○ Eens
Het doel van de workshop was duidelijk. *The goal of the exercise was clear to me.*	Oneens ○○○○○ Eens
De tool ondersteunde de discussie over: 1. Het ruimtelijke probleem; 2. Over strategieën om met het probleem om te gaan. *The tool helped structure the discussion:* *1. About the problem.* *2. About strategies.*	1. Oneens ○○○○○ Eens 2. Oneens ○○○○○ Eens

Efficiency of Tool

Perceived ease of use

Ik begreep de functies van de tool snel. *I understood the functions of the tool quickly.*	Oneens ○○○○○ Eens
De software die gebruikt werd heeft een duidelijke interface. *The software that was used had a clear interface.*	Oneens ○○○○○ Eens
De knoppen om de weging aan te passen waren gemakkelijk te gebruiken. *The buttons to change the weight of indicators were easy to use.*	Oneens ○○○○○ Eens
De knoppen om de indicatoren te wijzigen waren gemakkelijk te gebruiken. *The buttons to change the input indicators were easy to use.*	Oneens ○○○○○ Eens

Satisfaction of use

Ik ben tevreden met het gebruik van de tool. *I am satisfied with the use of the tool.*	Oneens ○○○○○ Eens
De tool heeft voldoende focus. *The focus of the tool was sufficient.*	Oneens ○○○○○ Eens
De tool laat voldoende detail zien. *The level of detail was sufficient.*	Oneens ○○○○○ Eens

Satisfaction of output

De kaart die met behulp van de tool gecreëerd is, geeft nieuwe inzichten. *The map that was created with the help of the tool is insightful.*	Oneens ○○○○○ Eens
De kaart die met behulp van de tool gecreëerd is, is duidelijk. *The map that was created with the help of the tool is clear.*	Oneens ○○○○○ Eens
De kaart die met behulp van de tool gecreëerd is, is geloofwaardig. *The map that was created with the help of the tool is credible.*	Oneens ○○○○○ Eens

Overige opmerkingen

Wat zijn de sterkste punten van de tool? En wat zou er verbeterd kunnen worden?
What are the tools' strongest points? And what could be improved?

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Hartelijk dank voor het invullen en voor uw deelname!

ANNEX VII - WORKSHOP SET-UP

Activity	**Time**
Start	**15:30**
Before we start: who-is-who?	
Introduction to the planning problem and thesis scope	**15:35**
• Welcome • What is the thesis about? • 30 is the new 50 • Distinction between GOW50, ETW30, and the new GOW30 • Oral informed consent; the session will be recorded (screen and audio), is that okay with the participants?	
What are we going to do today? What will you learn? Goal.	
• Importance of participation in planning (generate knowledge and common understanding): does the tool support this? • You will learn how to use a geo-information tool in a participatory setting. • Tool calculates suitability for a speed limit of 30 km/h, and additional information layers could potentially aid in a discussion on the type of 30.	
Introduction to the tool	**15:40**
• Different Tasks: what are the goals? • Discuss **where** 30 km/h (network level). What are suitable locations for 30 km/h? • Discuss **how** 30 km/h (road level).	
Explain input layers	
• Base layers (luchtfoto, landgebruik, hulpdiensten) • Road characteristics (huidig snelheidslimiet, netwerken, fietsinfrastructuur) • Environmental characteristics (omgevingskenmerken) ► show zooming in/out	
Practice exercise to understand the tool	
• Find the ITC building in Enschede/find your home/find a familiar place • Zoom in/zoom out • Use the pan option • Turn some layers on/off	
Exercise on *network level*	**15:50**
Which road is suitable for a speed limit of 30 km/h (necessity to change)? Goal: Map a few locations that might be suitable for 30 km/h.	
• Select indicators that you find important for determining suitability for 30 km/h. • Do all indicators have the same relevance?	

• If not, change weights and see what will happen with suitability. • Does this suitability image match with what you would expect to see? • If no, what could be the determining factor? • Does changing the indicators and/or weight influence this output?	
Break	***16:15***
Exercise on *road level*	**16:25**
Goal: Get a better understanding of the current situation, and should this change?	
• Introduce StreetView • Agree on a location from the previous exercise that you are interested in exploring, would it be suitable for changing the speed limit (or if already 30 km/h, could potentially become GOW30). • Look at the current situation from a few angles. • Turn some layers on/off to provide additional information. • Does the typical design match the real situation? • What would you do, should it change? • Is there any data missing to make an informed decision?	
Fill in questionnaire	**16:50**
Round of discussion	
• What was your experience using the tool? • What could be improved, or what were good points? • Do you see yourself using such a tool in 'real life' situations?	
Any feedback? Thank you	
End	**17:00**

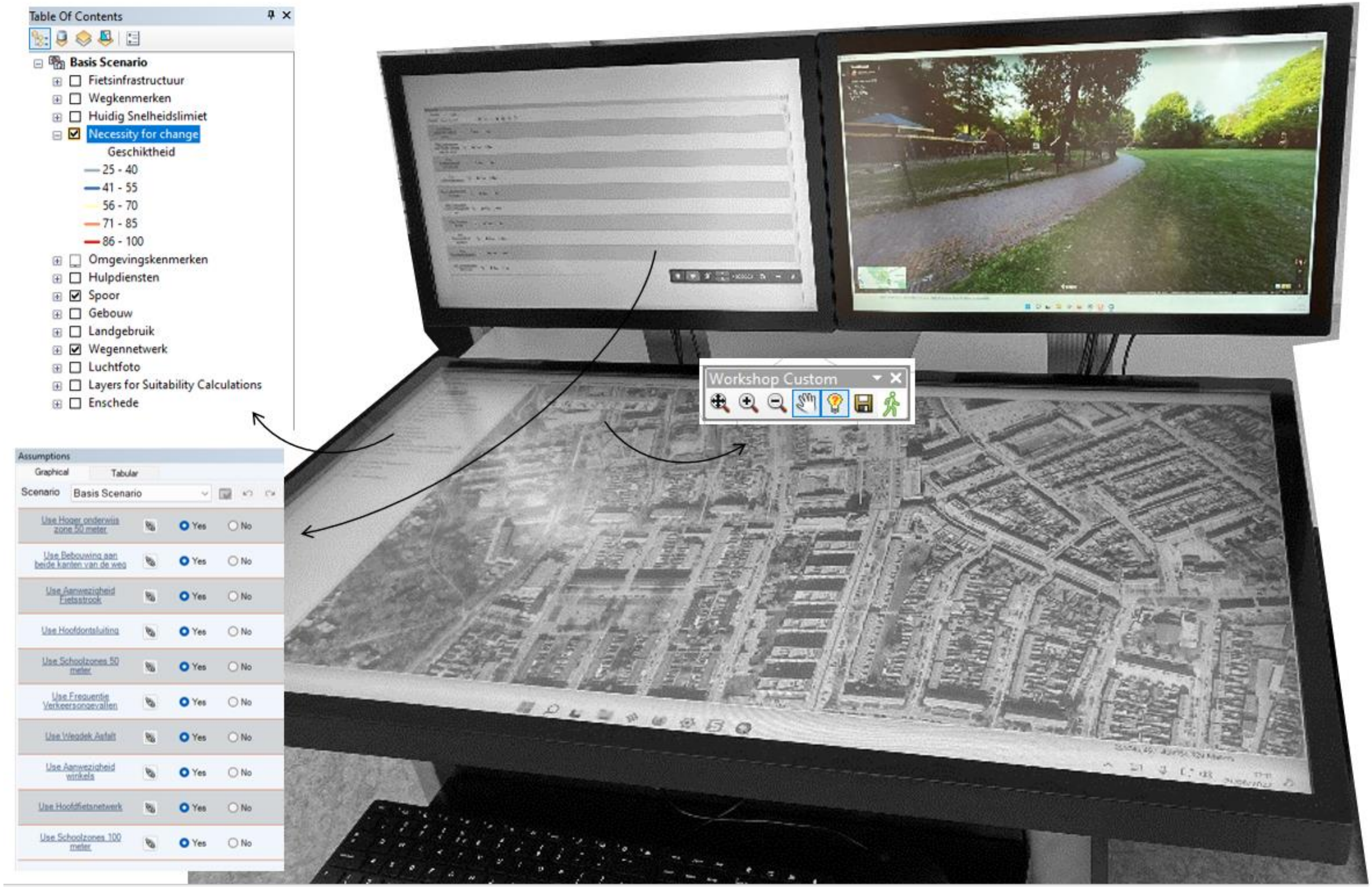

Figure 16: The interface of the tool in ArcMap, with the table of contents and the assumptions window on the left, the toolbar in the middle, and at the right the Google Street View window.

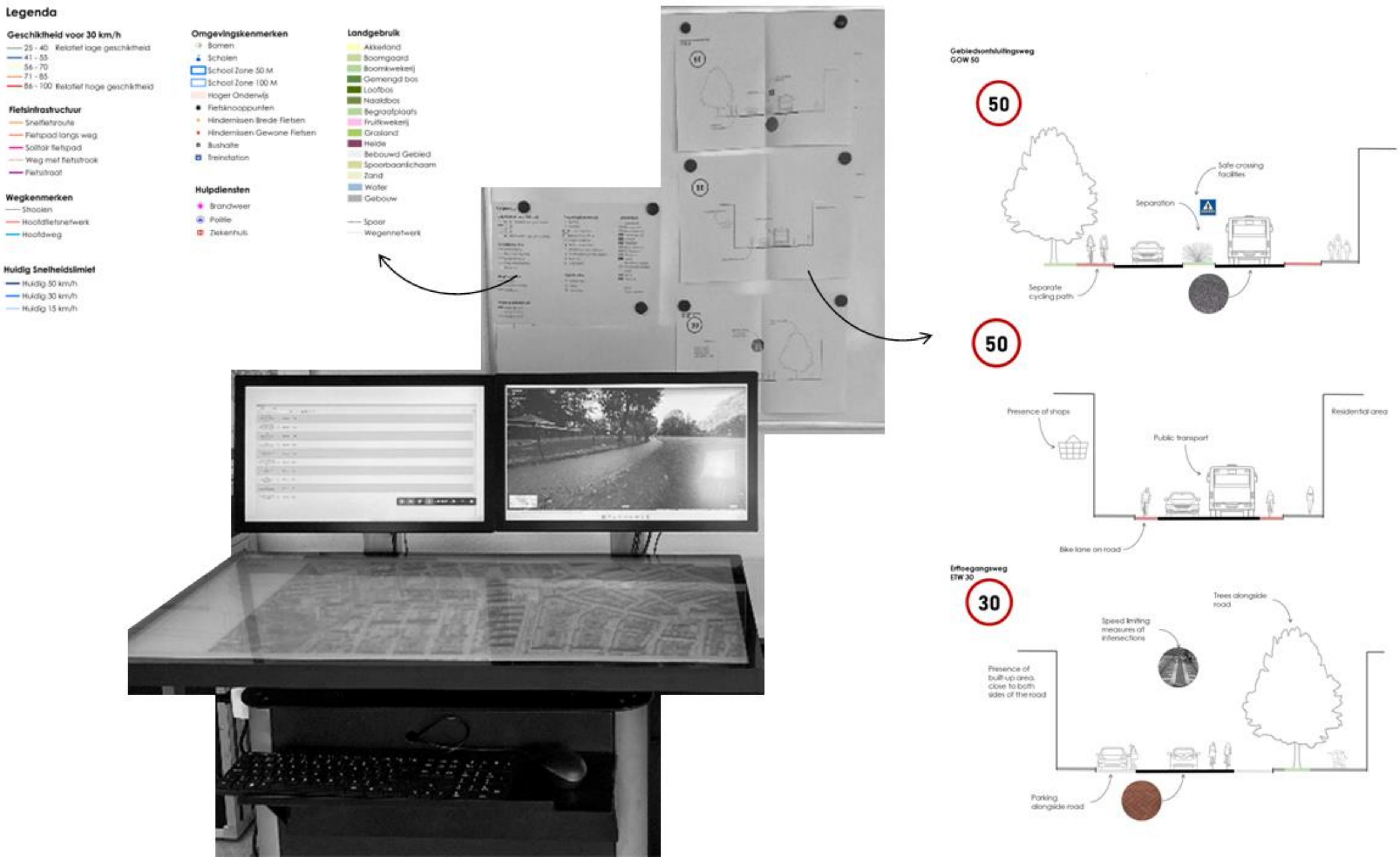

Figure 17: Workshop set-up with above the MapTable a printed legend of all the layers in the tool, and the typical road designs of GOW50 and ETW30.