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Use of bicycle sensors by Dutch municipalities

by
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Preface

I hereby present to you my final report of my Bachelor thesis on the use of bicycle sensors by Dutch municipalities. This report is submitted in partial fulfillment of the requirements for a Bachelor's degree in Civil Engineering at the TU Delft.

Even though I, as a Dutch person, benefit daily from bicycle sensors, it was not something I gave much thought to. However, since doing my research, I enjoy recognizing the sensors on bicycle paths and being able to understand what it is that they do. This experience has sparked my interest in traffic flows of active modes of transport, so much so that it has persuaded me to stay in Civil Engineering and continue my education by doing a Masters degree in Transport & Planning.

I would like to thank Maria Salomons and Yufei Yuan for all their time and effort to enhance this research. I would also like to give my appreciation to Giulia Reggiani for her expertise and dedication to this project, coming up with new ideas or questions and contributing her time to me. Additionally, I would like to express gratitude to my peers in Group 1, for reviewing my (intermediary) reports and giving valuable remarks.

Merel Sterk
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Summary

The Netherlands is a special country when it comes to cycling and especially when it comes to the use of traffic sensors adjusted to sense cyclists. Literature shows that loop sensors are used by the Dutch at almost every signalized intersection and that they work a lot with automatic traffic control: adjusting green light time by demand, creating a "green wave" and anticipating on coming cyclists for example.

In this report, the research on the use of bicycle sensors by Dutch municipalities was investigated. Three main matters were looked at: the current use of bicycle sensors, the current knowledge on bicycle sensors and future use and views on bicycle sensors. This was done to make information available to different stakeholders and get insight into the use of bicycle sensors by Dutch municipalities. To do so, a literature study as well as a survey-based research were conducted. The literature study informed about currently used sensors, what they can measure and how they work. Next to that, literature on the current situation was found in government- and municipality reports. The survey was conducted among experts on bicycle sensor use by Dutch municipalities, in order to learn about how these municipalities use the sensors, how much they use them and what they expect from sensors in the future.

The results from the literature study show a difference between sensors in term of what variables they can estimate. Furthermore, there is little availability of information in government- or municipality-reports on how sensors (data) are used. The results from the survey showed that every responding municipality uses push buttons and loop sensors at 81%-100% of the signalized intersections. However, they do not exploit these sensors to their full capability, even if they are aware of all their possibilities. There are some municipalities that are experimenting with newer sensors, but this is only done on a small scale. Most municipalities find it important to change and improve current sensors, even though some are completely satisfied with the status quo.

The conclusions drawn from this study are that:

1. Big municipalities in terms of number of inhabitants behave similar when it comes to bicycle sensors and have a common configuration of loop sensors and push buttons at signalized intersections that are used mostly for automatic traffic control; new sensor types are deployed and tested at only a few locations.
2. Knowledge on widely deployed sensor types is good, yet knowledge on newer sensor types, that give a higher degree of insight to bicycle traffic management, is limited and should be improved to enhance said management.
3. Responding municipalities find it important to change and improve sensors and the majority has future plans to incorporate mobile applications or other smart sensors at busy locations.

It is recommended to expand this research further and include more and diversified municipalities, to get a better representative of the whole of the Netherlands. It would also be beneficial to study which benefits newer sensor types have over the more traditional sensor types and how they can be implemented, to inform municipalities on this.

Contents

1 Introduction

The Netherlands are known for its unique cycling culture. Collectively, they cycle over 15 billion kilometers per year, make 25% of their trips on bicycles, own around 23 million bicycles and are in possession of 37 000 kilometers of bicycle paths [1]. Relatively, this is more than any other country in the world. Part of the reason for this is their long history and habit of cycling, as well as the country being densely populated and having mostly flat land [2]. To accommodate all these cyclists, the government agencies invest in the quality of cycle paths and fast cycle routes. Next to that, they spend money on monitoring and managing the bicycle flows. The latter is mostly done through traffic control installations. These installations depend on information gathered from certain sensors, meaning that they are vehicle actuated and dynamic. Besides this, the Dutch are also implementing intelligent traffic control installations (iVRI's) at a fast rate, with around 800 currently deployed. These installations give real time traffic data and green light time to traffic users via mobile applications [3]. It holds that loop sensors occur most often at the "older" traffic control installations and it is common knowledge that municipalities still install these at all signalized intersections. The Netherlands are known to use automatic traffic control installations at most big intersections. What differentiates them from other countries is that they use adjusted (loop) sensors to detect bicycles separately from cars at the respective bicycle path [4], [5].

1.1 Problem statement

The Dutch municipalities use and decide on the deployment of bicycle sensors. Bicycle sensors are sensors that detect bicycles on cycle paths and at intersections with automatic traffic control installations. Flow, queue, speed and waiting time are among the variables that can be estimated from the data [6]. There is no easy-accessible documentation of sensor deployment and usage: it is unknown which municipalities use what kind of sensors, at which location they use them and for what purpose they use them. It is also unknown what municipalities do with the data they are provided with, if they act on it and in what manner. This lack of documentation and knowledge is a shortcoming for different parties: Dutch municipalities, cyclists, non-Dutch countries and companies that develop bicycle sensors.

1.2 Stakeholders

Dutch municipalities could learn from each other and share what benefits they get from bicycle sensors. New sensors could be tested in a municipality and if they are deemed beneficial, be deployed in similar municipalities. Municipality employees, like traffic engineers that develop algorithms to estimate bicycle flows, should be able to get information and findings on sensors from each other. Moreover, there is still difference among Dutch municipalities when it comes to cycling. The Dutch Cycling Bond ranks municipalities based on a number of categories each year and selects the best scorer to become the Cycling City of the Year [7]. For other municipalities to do better, they should know what kind of sensors are deployed in the Cycling City of the Year and other top scorers, learn how this municipality earned that title and check if their techniques could be useful in their own area.

Furthermore, the Netherlands are one of the safest countries when it comes to cycling, partly due to the use of bicycle sensors [8]. They also know how to accommodate cyclists without causing too much extra congestion in cities [9]. Cycling safety is one of the main issues in other countries and restrain residents to cycle more [10]. In addition, cycling is becoming increasingly popular and numbers of cyclists, kilometers traveled by bike and share of bicycle trips for example are going up [11]. Subsequently, bicycle flows are increasing and non-Dutch countries need to learn how to cope with these rising quantities. The parties that are responsible for bicycle sensors in other countries, the government-agencies, can learn from the Dutch in this regard and increase their methods to detect cyclists. Apart from an increase in safety, this will decrease congestion and help to promote cycling.

In addition, cyclist themselves are beneficiaries of bicycle sensors. The aim of the municipalities by deploying bicycle sensors is to make the cycling experience as pleasant as possible. This could mean anything from safe cycling, to fast cycling, to less waiting time in front of traffic lights. When the sensors get better, cyclists will notice.

Lastly, the companies that develop bicycle sensors will profit from this information. With these insights, they can adjust their own products accordingly and meet the demands of their customers, the municipalities.

1.3 Research question and subgoals

This report reflects the process of answering the research question: *"What kind of bicycle sensors are used, and how much, by Dutch municipalities to detect cyclists for which monitoring purpose in current and future scenarios?"*. To answer this research question, subgoals were developed to guide the research. The three subgoals are:

- Determine the current situation regarding bicycle sensors in the municipalities
- Determine current knowledge of municipalities on bicycle sensors
- Determine future plans and future views on bicycle sensors

The first two subgoals are related to the current scenario part of the research question. The outcome is an overview of the current scenario and the current knowledge of the municipality. This is studied via a survey and literature research. The last subgoal will show the future trends in terms of bicycle sensors for Dutch municipalities. This is deduced mainly from the survey. The outcome is a description of the willingness to change the current situation of Dutch municipalities and what the general opinion is on what the change will look like.

This report first describes the literature and survey-based methodology used for the research. Next, the literature research is discussed and information about the researched sensors is given. Thereafter, the results from the survey are presented and discussed. Finally, a conclusion is drawn from the results and recommendations for further research are made.

2 Methodology

It was chosen to conduct a survey among experts on bicycle sensors to be able to answer the research question. To fully understand the bicycle sensors and see which information already was published, a literature research was done on these topics. This section first discusses how and which literature was researched and elaborates the methodology of the survey-based research afterwards.

2.1 Literature research

The literature research consisted of two parts. The first part embodied the research on different kind of bicycle sensors and shows which variables the sensors are able to estimate. The second part contained the search for literature that describes the current situation of deployment of the sensors and the plans government agencies have for the coming years.

2.1.1 Bicycle sensor types

Literature research was done on six types of bicycle sensors: push buttons, loop sensors, infrared sensors, WiFi/Bluetooth sensors, mobile applications that can track cyclists and smart cameras. There are many more bicycle sensor types in use in the Netherlands and outside, however the first three sensors were chosen to look into because they are considered to be the among the most common bicycle sensors used in the Netherlands [12]. The last three sensors were chosen to investigate because they belong to the group of new and innovative sensors, that have potential to become more common in the future and are occurring in the Netherlands [13]. It was determined how these sensors work, in which configurations they occur and what variables can be estimated from the data that they collect.

2.1.2 Current situation regarding bicycle sensors from government- and municipality-reports

Reports of government-agencies were looked into, to get an overview of the current situation of deployment of bicycle sensors in the different municipalities. Most of these reports are on the future: they state goals the government agencies want to reach and how they plan to do so. Next to this, information about the government agencies that responded to the survey was looked up, such as number of inhabitants, size and other characteristics of the area.

These mentioned reports are considered "grey literature". They are unpublished studies, outside widely available journals. They normally do not employ peer review and therefore their validity can be questioned [14]. Consequently, it was very important to determine the source of the research material and the date it was published. Verified government- and municipality-sources were considered to be valid. Reports that describe the situation or plans from 2019 onward, were included in the study. These reports were published up to six years ago, since most provinces and municipalities have a "Traffic- and Transport plan" that is updated around every five years, as stated in the Dutch Law on Planning of Traffic and Transport (*"Planwet Verkeer en Vervoer"*) [15]. Older reports were judged to be irrelevant to the current scenario, considering the plan was intended for a time-period that had already ended.

2.2 Survey-based research

Next to the literature research, a survey-based research approach was chosen. The survey-based research conducted consisted of three basic steps: (1) designing a questionnaire survey, (2) conducting the survey and (3) analyzing the survey results.

2.2.1 Designing the survey

A survey is a method of collecting information or data from individuals [16]. Different survey methods exist. In this study a questionnaire survey method was used. With the subgoals that were mentioned in Section 1 in mind, questions were designed. Each question was attributed to a subgoal, in order to fulfill this goal. The questionnaire was designed with both open and closed questions. In this way, some questions got quantifiable answers, while others were answered in a qualitative way.

When designing a survey, it is important to avoid ambiguity and to be very clear and precise. The questionnaire was therefore reviewed by peers, experts and supervisors before it was sent out. Questions were based on literature on survey design [17]. The complete survey can be found in Appendix A.

2.2.2 Conducting the survey

The questionnaire was conducted via the internet using Google Forms. It was decided this was the best method available after trying multiple survey-websites and comparing them. The comparison was made based on the type of questions the survey-website allowed to be asked, the number of questions that was allowed, the costs of conducting the survey, the way in which gathered answers were presented and on personal preference. The survey was only intended for experts that work with and have knowledge on the use of bicycle sensors by Dutch municipalities. That constrained the respondent selection to Dutch municipality employees and consultants who work with and advise Dutch municipalities. The survey was directly send to the members of Contactgroep Verkeersregeltechnici Nederland (CVN) and Initiatiefgroep Verkeersregeltechnici (IVER) and to some employees of SWECO on the 19th of May, 2020. Next to this, the survey was posted to the LinkedIn-page of Maria Salomons (supervisor on project), Giulia Reggiani (expert on project) and Merel Sterk (project undertaker), to attract expert respondents outside of these groups. Additionally, a search on LinkedIn was executed, to directly approach people who were considered to have sufficient knowledge to participate in the survey. The survey closed on the 9th of June, 2020, having collected fifteen responses in 21 days. It was not possible to determine the response rate, since LinkedIn does not tell you how many people were reached by your post. All the members, employees and people from the approached groups were within the constrained respondent selection. These experts filled out the survey from the perspective of a specific municipality or consultancy that advises municipalities. Thereafter, each response was considered to be from a specific municipality or area. In this way, the following parties responded:

- Municipality of Eindhoven
- Municipality of Delft
- Municipality of Haarlemmermeer
- Municipality of Leiden
- Municipality of Almere
- Municipality of 's-Hertogenbosch
- Municipality of Den Haag
- Municipality of Utrecht
- Municipality of Amsterdam
- Municipality of Enschede
- Municipality of Haarlem
- Province of Overijssel
- Rijkswaterstaat: Traffic Control Center of the South-West of the Netherlands
- Consultancy Vialis (from the perspective of multiple municipalities)
- Consultancy Witteveen+Bos (from the perspective of multiple municipalities)

In Section 3.3.1 , Table 4, information about these municipalities can be found, including their number of inhabitants, kilometer of bicycle paths and how much money they spend on bicycle traffic management. In Figure 1 the location of the municipalities that participated can be seen. Together, the municipalities that responded are 3.7% of all Dutch municipalities, yet they represent 17.8% (3 006 375 residents) of total Dutch inhabitants and their combined surface area is 2.9% (1222.87 km^2) of the total surface area of the Netherlands . All the municipalities are considered to be "big" municipalities, having over 100 000 inhabitants and thus having bigger bicycle flows. They make up 37.5 % of the big municipalities in the Netherlands.

The respondents are considered being representative of the big municipalities, with greater bicycle flows and more signalized intersections. A limitation of the survey sample is that it can not represent the Netherlands as a whole, since no specific smaller municipalities are in the survey sample. Within the province of Overijssel and the South-West of the Netherlands (Rijkswaterstaat), there are smaller municipalities, yet those responses are too generic to attribute these results to smaller municipalities. Conclusions based on the survey therefore were drawn with caution and with respect to the survey sample.

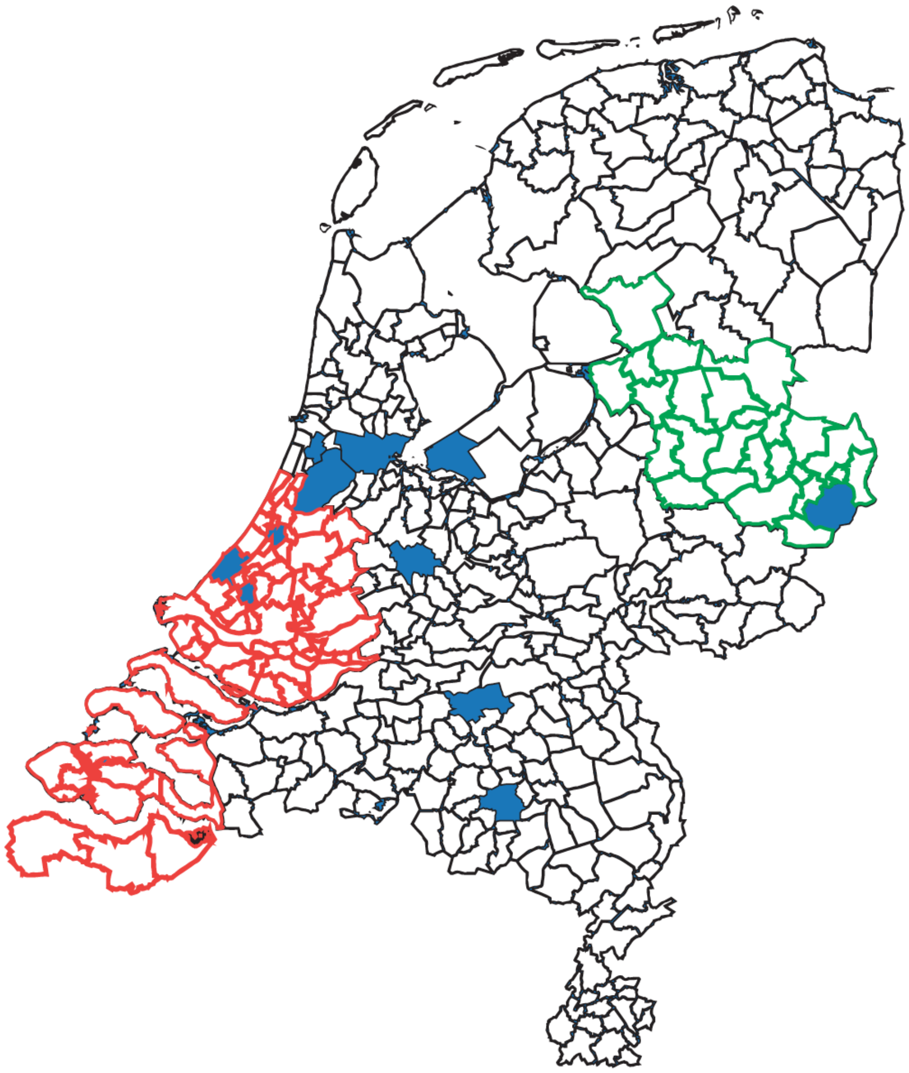


Figure 1: A map with the location of the municipalities within the Netherlands that responded to the survey highlighted in blue. The green outline is the area of the province of Overijssel. The red outline is the area of the South-West of the Netherlands [18].

2.2.3 Analyzing the results

From Google Form both quantitative (percentages, amounts) and qualitative (actions, knowledge) answers were collected. The answers to questions 1 and 2 were general questions to be able to match a response with a municipality. The remaining answers were divided into three groups, as seen in Table 1.

Group	**Related subgoal**	**Related survey questions**
1	Determining the current situation regarding bicycle sensors in municipalities	3, 4, 5, 7
2	Determining the current knowledge of municipalities on bicycle sensors	6, 8, 9, 10
3	Determining future plans and views on bicycle sensors	11, 12, 13, 14, 15

Table 1: Overview of subgoals and corresponding survey questions.

The quantitative answers were chosen to be displayed graphically. Graphs were made using Jupyter Python. For the qualitative results the choice was made to give either a text summary or to group certain common answers together and display them graphically as well. After displaying the results, they were analyzed, to see if there were remarkable similarities or differences between literature- and survey results. In addition, it was examined if municipality characteristics that were found in literature, like budget, size or number of inhabitants, could be attributed to specific bicycle sensor use. This was done to see if there was any correlation between these two factors and to be able to compare the municipalities on their bicycle sensor use.

3 Literature Research

Literature research was done on different bicycle sensors and on reports from government-agencies. Most of the literature that was used, was specifically applicable to and focused on Dutch areas, since the Netherlands have a very distinct cycling culture [2], as explained in Section 1. This section reports the findings from literature.

3.1 Bicycle sensor description

The six types of sensors that were researched are push buttons, loop sensors, infrared sensors, WiFi/Bluetooth sensors, mobile applications that can track cyclists and smart cameras. For each sensor type it is explained how the sensor works, what data is logged on cyclists and what kind of information the sensor can provide to the municipalities.

Push buttons

Push buttons, seen in Figure 2, are active sensors that are located at signalized intersections. They are active sensors because a cyclists needs to push a button manually. They consist of a mechanical switch that is activated when the button is pushed. Inductive push buttons work in the same manner, they consist of a flat surface that will indicate detection after it is touched with a hand. They are very often combined with loop sensors [12].

Some argue that push buttons are superfluous and are only installed to give the cyclists a sense of control when they are waiting, because the loop sensor has already detected the cyclist. However, loop sensors can miss a cyclist, especially when they do not have a metal bicycle [19]. When these sensors are combined and when the button is pushed, the cyclist is ensured that he will be detected, regardless of the sensitivity of the loop sensor. Once the switch is activated after the push, the presence of a cyclist is detected. This can be used to activate the green light for their direction [20]. The push button can estimate waiting time of the first cyclist that presses the button as well, if a log of the timing of the traffic light is kept.

(a) A mechanical push button

(b) An inductive push button

Figure 2: Different kind of push buttons at a signalized intersection [21].

Loop sensors

Loop sensors, seen in Figure 3, are electromagnetic sensors. They consist of a copper wire, embedded in the road, that is connected to an electronic unit. The wire, together with the electronic unite, create a magnetic field around the loop. The resonant frequency of this magnetic field is altered when a metal object is placed above the loop. Hence they cannot detect bicycles that are not made of metal, like carbon racing bicycles. This change in frequency is detected through the electronic unit and is converted into a signal [12]. How much the frequency

Figure 3: A loop sensor at a signalized intersection [26].

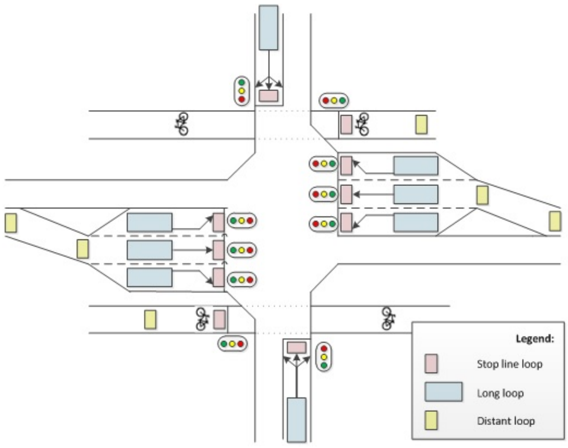


Figure 4: Configuration of a loop sensor at a signalized intersection [20].

changes is dependent on the type of vehicle placed on the loop (for example a truck, car, motor cycle or bicycle), and the sensor should be adjusted accordingly to detect the right vehicle.

Loop sensors can be present in different shapes and configurations, with a different number of loops per direction. How easily the cyclist is detected is dependent on the shape of the loop (for example quadruple loop, dipole loop) and where the cyclist has positioned himself [22],[23]. The configuration, how many loops there are per direction, determines which variables can be estimated. An example of a two-loops per direction configuration can be seen in Figure 4, with an upstream loop (distant loop) and a downstream loop (stop line loop). For signalized intersections it holds that the downstream loop is placed directly at the stop line of the traffic light. The upstream loop is placed at around fifteen meters ahead of the downstream loop [24]. For detecting bicycles, no more than three loops per direction are generally used [12].

A pass over the loop sensor will detect presence of a cyclist. The waiting time of a single cyclist can be derived from the duration of the down stream sensor being activated. Speed can be estimated if there are at least two loops present, with the time between the pass over the upstream loop and the pass over the downstream loop being recorded. The distance between these two loops then needs to be known, from which the speed can be derived. The queue in front of a red light can be estimated as well with two loops. This is done by counting the number of passes over the upstream loop, while the downstream loop is detecting a present cyclist. It is dependent on where the upstream loop is placed and if there is a possibility for cyclist to take a turn after passing the upstream loop. Flow can be measured if the passes over the loop are counted and this count is set within a time frame [25]. The contingent third loop upstream is used to time the green light time accordingly.

Infrared sensors

Infrared sensors can either be passive or active sensors. Both sensors are standalone: one sensor is used for a section of road, not multiple. Passive sensors measure the electromagnetic waves that people emit naturally and detect the person that is sending out this radiation. It is not possible to make a distinction between cyclists or pedestrians with this sensor, however, if directed properly, it can be constrained to only detecting the bicycle path without the sidewalk.

Active sensors emit their own radiation that is being reflected by the road surface. If the sent signal is reflected by a bike, it is returned quicker than when it was reflected by the road and therefore the bike is detected [12]. This sensor can classify traffic users. The distance from which they can detect a cyclist is dependent on their form. Active sensors can detect a cyclist only at the location where it is aimed at. The range of infrared sensors is dependent on the frequency that emit or can pick up on, as well as the thermal background noise. Ranges up to 50 meters are possible [27]. One big disadvantage of infrared sensors is that they are sensitive to bad weather . The sensors can detect presence of a cyclist and estimate speed of a cyclist (through approaching velocity), waiting time (how long radiation is received if the sensor is aimed at the stop line) and flow (from counting the passing cyclist and their respective timestamps) [9].

WiFi/Bluetooth sensors

Many of the devices that people carry with them nowadays are embedded with Bluetooth and WiFi, both radio modules. This allows the communication between devices without being physically connected by a cable, having a range up to 100 meters dependent on the class of the sensor [9]. Mobile phones are carried by cyclists and nowadays almost all phones are equipped with both Bluetooth and WiFi. WiFi and Bluetooth sensors are in an inquiry mode when they establish a link with the responding device. Once they are paired, the responding device (the mobile phone of the cyclist) can be continuously tracked, instead of on one, sole location like the previously mentioned sensors do. This allows the sensors to deduct more data on the cyclist and estimate further variables. The cyclist only has to enable his discovery mode to allow the WiFi or Bluetooth sensor to track him [28]. From the continuous tracking, they can detect if a cyclist is present and they can measure waiting time, speed, flow, routes and travel time of a single cyclist. The occupancy rate of the network can be estimated as well, if the sensors are installed at multiple locations covering the municipality. Queues can be estimated properly if enough cyclists allow themselves to be detected by enabling their discovery mode.

Mobile applications that can track cyclists

Mobile application that can track cyclists, as seen in Figure 5, work in a similar way as WiFi/Bluetooth sensors. They connect to mobile devices via WiFi or Bluetooth and extract data on the cyclists in this way, by continuously tracking them. The main difference is that the cyclists need to have the mobile application installed on their phone for it to work. The application can be connected with traffic lights and can adjust green-light time of the traffic light if needed. Special infrastructure (a sensor) is thus needed at the traffic control installation. Applications like Schwung and Talking Bikes are deployed in some Dutch areas [29].

Another way of tracking via mobile applications is making use of the GPS receivers that are installed at most mobile phones. They do not need a physical sensor, because the GPS data is send wireless to a receiver data point via 3G/4G/WLAN. The received data is the GPS data from the mobile phone, which gives the variables of speed, waiting time of a cyclist, flow, routes, travel time, occupancy of the network. The goal is to provide real time guidance to the cyclist, based on predicting algorithms that work with the GPS data. Then real-time information is needed and communication needs to be possible. The main challenge for these applications is the security and privacy of the users, so security algorithms need to be integrated. These kind of applications are still under development and not yet officially deployed [30].

Figure 5: A visualization of a mobile application that can track cyclists [31].

Smart cameras
Smart cameras work as normal cameras do, combined with artificial intelligence. They are equipped with intelligent image processing techniques and pattern recognition algorithms, based on images or video sequences they receive. Because of this they are able to estimate a lot of, and various variables, when it is correctly coded in the algorithm. The smart cameras consist of a sensor, a processing and a communication unit, with special requirements for each unit [32]. They can be used to detect cyclists with a certain accuracy for example, as seen in Figure 6. Another possibility is detecting certain points of the face to measure the level of 'smiliness' and determine the mood of cyclist [33]. Next to this they can estimate waiting time of cyclist, speed, flow, queue and demographics like gender or age.

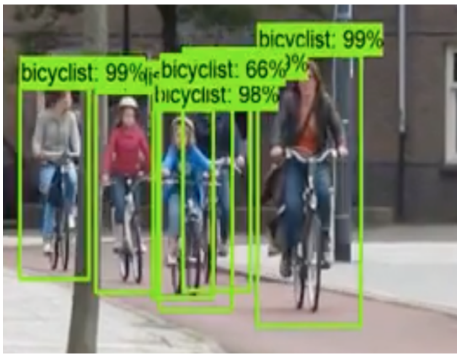


Figure 6: A smart camera image that estimates if cyclists are present [34].

3.2 Overview of bicycle sensor and variables

Each sensor collects certain data, the data that can be collected differing from sensor to sensor. With certain processing techniques the data are turned into estimates of different variables, to be able to monitor the cyclists. Which data are needed to estimate certain variables can be seen in Table 2. This can be linked to Table 3, that shows which variables a certain sensor can estimate. These tables together tell which data a certain sensor logs, from seeing which data are needed for the certain sensor to estimate the specific variable.

It is important to maintain a specific definition of the variables, to properly understand what is meant. For the variables in the tables, the definition are as follows:

- **Presence:** presence of a cyclist at a certain location.
- **Waiting time:** time from which a cyclists stops in front of a signalized intersection until the moment he manages to cross the intersection.
- **Speed:** average speed of a cyclist between two certain locations.
- **Queue:** the number of cyclists waiting for a traffic light to turn green
- **Flow:** the number of cyclists that cross a certain location per time unit.
- **Routes:** the road taken in getting from a starting point to a destination.
- **Travel time:** time employed by a cyclist to travel between two locations.
- **Occupancy of network:** how many cyclists are present in a certain network area.
- **Demographics:** age of cyclists, gender of cyclists.
- **Mood:** 'smiliness'-level of cyclists.

Data \ Variable	Presence	Waiting time	Speed	Queue	Flow	Routes	Travel time	Occupancy of network	Demo-graphics	Mood
Timestamp sensor activated	■	▲	□	▲	□	□	□	■	□	□
Duration sensor active	□	■	□	□	□	□	□	□	□	□
Difference in timestamp between two sensors	□	□	▲	□	□	□	□	□	□	□
Distance between two sensors	□	□	▲	□	□	□	□	□	□	□
Approaching velocity	□	□	■	□	□	□	□	□	□	□
Number of passes	□	□	□	▲	■	□	□	■	□	□
Time stamp green light time of traffic light	□	▲	□	▲	□	□	□	□	□	□
GPS data (longitude and latitude)	■	■	■	□	■	■	■	■	□	□
Camera imagery	■	■	■	■	■	□	□	□	■	■

Table 2: An overview of which data is needed to estimate a variable. A filled out square means that the data in that row is needed to estimate the variable of the column. Filled out triangles in a column mean that the data from all their respective rows with a triangle as well is needed together in order to estimate the variable.

Variable \ Sensors	Push button	Loop sensor	Infrared sensor	WiFi/Bluetooth sensor	Mobile application	Smart camera
Presence	■	■	■	■	■	■
Waiting time	■	■	■	■	■	■
Speed	□	■	■	■	■	■
Queue	□	■	□	■	□	■
Flow	□	■	■	■	■	■
Routes	□	□	□	■	■	□
Travel time	□	□	□	■	■	□
Occupancy	□	□	□	■	■	□
Demographics	□	□	□	□	□	■
Mood	□	□	□	□	□	■

Table 3: An overview of which sensor can estimate what variables after processing its data. A filled out square means that the sensor in that column can estimate the variable from that row after processing.

3.3 Municipality information & plans from government-reports

Characteristics from the municipalities and areas that responded are given. Moreover, the plans and views from a few of these municipalities are discussed.

3.3.1 Municipality information

Table 4 shows the information found on the municipalities that responded to the survey. It is important to note that kilometer of bicycle path in a municipality only takes so-called free-lying bicycle paths into account; bicycle lanes that are not physically separated from the car traffic are not included. This information is not registered for a lot of municipalities.

It was tried to find the budget of each municipality when it comes to bicycle traffic. However, municipalities report this in different ways, do not attribute the same categories to bicycle traffic and often only publish the total budget of transport and mobility in the municipality, where infrastructure for cars and pedestrians are included too. It was decided that the numbers would not give an accurate representation of the real situation, that comparisons or conclusions based on these numbers could be incorrect and it was thus chosen not to report them. The total budget related to mobility, including public transport and car traffic, was found for most municipalities and reported, to give a sense of how much money the municipalities spend on this category in 2020.

Other information was gathered from the Fietserbond, the Dutch Cycling Bond. As mentioned in Section 1, the Dutch Cycling Bond represents the interest of cyclists and they initiate a lot of research on the use of bicycles in the Netherlands. As mentioned before, each year they announce the Cycling City of the Year, based on subjective and objective data (e.g. infrastructure, maintenance and the experience of cycling within the municipality). The score of the municipalities according to the Cycling City of the Year 2020 is given in the table, on a scale of 1 to 5, with 5 being the highest. The highest score of that year, a 4.43, was given to Houten. The average score was a 3.4.

Municipality or area	Number of inhabitants	Surface area [km^2]	Kilometer of bicycle path [km]	Budget related to mobility [*x1000 €*]	Score Dutch Cycling Bond [*scale* 1 *to* 5]
Eindhoven	231 469	88.84	-	44 336	3.4
Delft	103 163	24.06	-	13 949	3.4
Haarlemmermeer	154 235	206.31	-	8 860	3.2
Leiden	124 899	23.27	-	26 947	3.4
Almere	207 904	248.77	440	151 240	3.4
's-Hertogenbosch	110 790	39.98	-	25 971	3.7
Den Haag	537 833	98.13	260	68 743	3.3
Utrecht	352 866	99.21	245	60 131	3.4
Amsterdam	862 965	219.49	767	648 100	2.9
Enschede	158 986	142.72	-	-	4.1
Haarlem	161 265	32.09	-	-	3.2
Overijssel (province)	1 156 431	3420.74	2800	-	-
Zuid-West NL (Rijkswaterstaat)	-	-	-	-	-

Table 4: Information about municipalities or areas that participated in the survey, information gathered from [7],[35],[36] and the respective municipality budget websites (municipality.budget-2020.nl).

3.3.2 Government-reports

Government-agencies produce multiple reports each year on numerous things. As mentioned in Section 2.1.2, most municipalities issue an "Traffic- and Transport plan" every five years or so. For this literature study, the Traffic- and Transport plans of Amsterdam, Den Haag, Utrecht and Eindhoven were looked at in depth. These municipalities are the biggest in terms of inhabitant number of the respondents and subsequently have the biggest bicycle flows. The Traffic- and Transport plan of Delft was looked at as well, since that is the smallest municipality of the respondents in terms of inhabitant number, to see if that makes Delft different from the big municipalities in their plans and views.

From these municipalities, Amsterdam is the one with the most inhabitants and the biggest total budget. Amsterdam calls itself the world-city of cycling, with more than two million kilometers being biked by the inhabitants per day, according to its multiple year plan for cyclists in the city, [37]. In their plan they state three goals: (1) Comfortable cycling, (2) Easy bicycle parking and (3) "The new cycling". The first and the third goal are related to the use of bicycle sensors. They state that they want to make cycling as comfortable as possible by reducing the waiting time at red lights and they want to promote the "new cycling" by enhancing cycling itself. Both measures are thus focused on green-light time of traffic lights and enhancing safety. As an innovative idea they thought of bicycles with incorporated chips: traffic lights will shorten the red light when a cyclist with such a bicycle is waiting in front of it. This is a new kind of sensor. Further use of sensors are not mentioned in their multiple year plan.

In the multiple-year plan for Den Haag, [38], it is stated that the most important aspect of cycling is ensuring that it is safe and in that way promoting the use of bicycles to get around the city. Next to that, they want to create a faster network within the city, by fixing missing links and increase flow. They explicitly mention creating enough space for the bicycles to align in front of the traffic light and the adjustment of traffic lights. It is not mentioned how they want to adjust the traffic lights.

Utrecht states in its multiple year plan, [39], that they want to become an world-city of cycling as well. They want to do so by creating fast cycle networks, increasing flow and safety, to get more people to use the bicycle. When it comes to creating fast cycle networks, they particularly want to reduce waiting time in front of traffic lights. To do so, they want to generate more green-waves, set the right adjustments for traffic lights and remove traffic lights at some locations. Especially for the first two goals, they need to use bicycle sensors to make sure that the optimum adjustment is found. They want to increase safety by reducing the time between green light time of traffic lights, to prevent cyclists from running a red light.

Eindhoven and the province of Noord-Brabant focus on fast cycling routes in their mobility plans [40],[41]. The (older) vision of the province is "sustainable accessibility within the area". Making sure that each destination can be reached with ease, without too much negative effects for others. The Traffic- and Transport plan of the municipality states that they want to make cycling self-evident and as comfortable as possible.

Delft, as the smallest municipality in regards to inhabitant size in the survey sample, has a Mobility Plan for 2040, [42], in which they state that they want to increase accessibility, liveability and sustainability. They want to do so by initiating a switch from cars to bicycles as much as possible. Making the bicycle network fine-meshed, safe and connected to the regional network will contribute to this. Later, they state that they want to increase the flow by using intelligent traffic systems (ITS). Mobile applications that increase green light time are explicitly mentioned. Since Delft houses the Delft University of Technology, they aim to include the university and share ideas or struggles with them.

It is noted that in general, these plans do not explicitly mention (the use of) bicycle sensors. It is stated what goals the municipalities have and a short section is dedicated to how they are going achieve this. No in-depth explanation or extensive plan is provided. When a new Traffic- and Transport plan is made, there is not necessarily a reflection on the old plan, to see what was accomplished. Therefore, there is no detailed explanation on how they achieved their goal, if certain sensors were of use in this or if data from sensors were used to make good or bad decisions.

4 Results

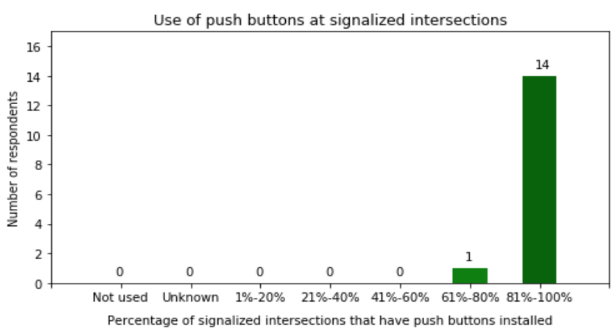
This section discusses the results and answers given in the survey. There was a total of fifteen responses to the survey. The responses can be found by clicking here (only available in Dutch and via a device with internet connection). The results of the seventeen-question survey were categorized into three main groups, as mentioned in Table 1. The groups were:

- Group 1, related to the first subgoal (determining the current situation regarding bicycle sensors in municipalities): survey questions 3, 4, 5 and 7.
- Group 2, related to the second subgoal (determining the current knowledge of municipalities on bicycle sensors): survey questions 6, 8, 9 and 10.
- Group 3, related to the third subgoal (determining future plans and views on bicycle sensors): survey questions 11, 12, 13, 14 and 15.

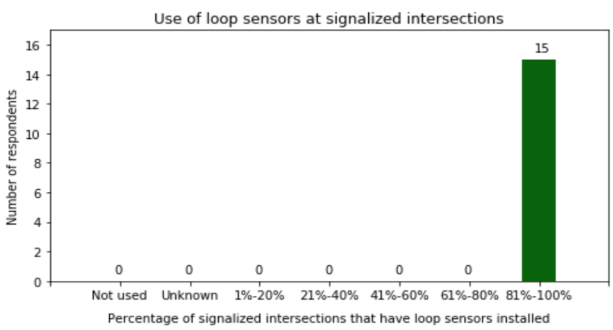
4.1 Group 1: Current situation regarding bicycle sensors in municipalities

The questions that give an overview on the current situation regarding bicycle sensors in municipalities are questions 3, 4, 5 and 7. Bicycle sensors can be used at signalized intersections or at bicycle paths, for different purposes.

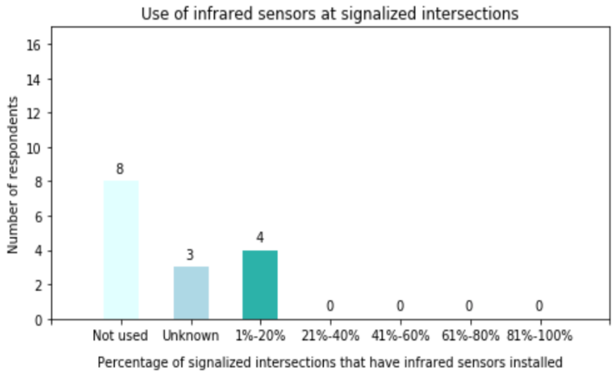
The graphs in Figure 7 show what kind of bicycle sensors are used and to what extent at signalized intersections. It is seen that almost all intersections of the responding municipalities have push buttons and loop sensors installed. Infrared sensors were used at 1%-20% of the signalized intersections by four municipalities (Amsterdam, Utrecht, Leiden, Haarlem). The WiFi/Bluetooth sensors are only used by Utrecht, at very few locations. Mobile applications were used at a few locations by Enschede and at every intersection by Almere and 's-Hertogenbosch. The fourth response comes from a consultant, from the perspective of multiple municipalities. An explanation for the responses of Almere and 's-Hertogenbosch could be that they use the mobile applications for which no sensors are necessary (data is transferred via 3G, 4G or WLAN), hence they can cover every location within those networks. However, these sensors are still in development. It was possible for the respondents to mention other sensors that they use but that were not listed. According to a consultant, radar sensors and LiDAR are used by municipalities as well. Den Haag and Haarlem also said that they used radar sensors. Even though Haarlemmermeer and Utrecht did not say they use other sensors in question 3, they responded to question 4 with 'Trafi-One' and 'Radar' respectively. Radar (Radio Detection and Ranging) sensors operate on the radio-frequency spectrum to detect the position and movement of objects [22], [43]. It does not only detect metal, but water (in a body) as well. LiDAR stands for Light/Laser Imaging Detection and Ranging and is similar to radar sensor, but uses short laser pulses instead of a radar. A Trafi-One is a thermal imaging sensor that can detect vehicles, bicycles and pedestrians [44].



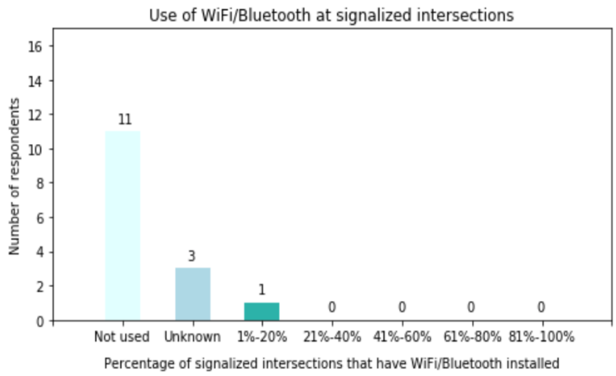
(a) Push buttons



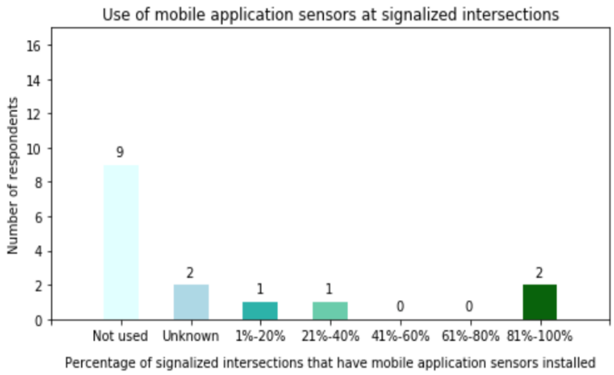
(b) Loop sensors



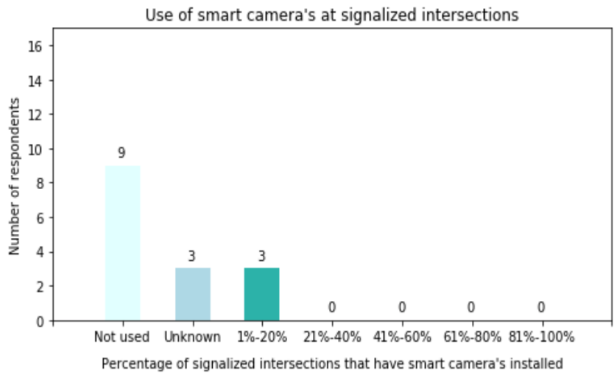
(c) Infrared sensors



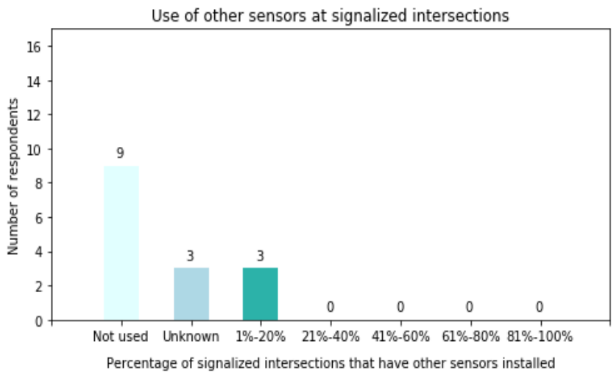
(d) WiFi/Bluetooth sensors



(e) Mobile applications



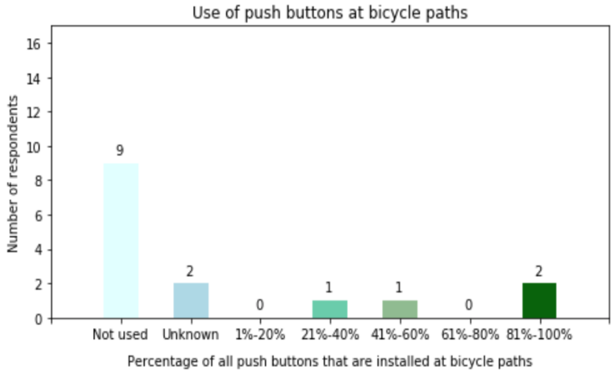
(f) Smart cameras



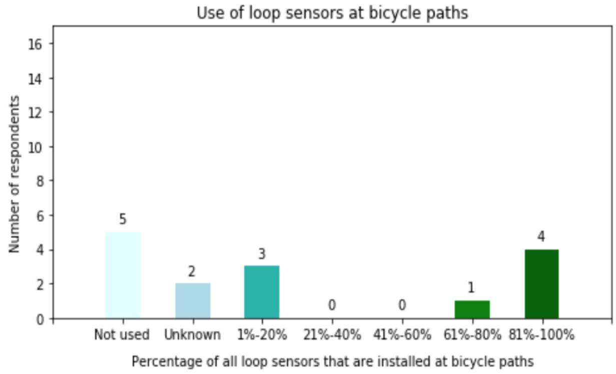
(g) Other sensors

Figure 7: Use of certain bicycle sensors at signalized intersections.

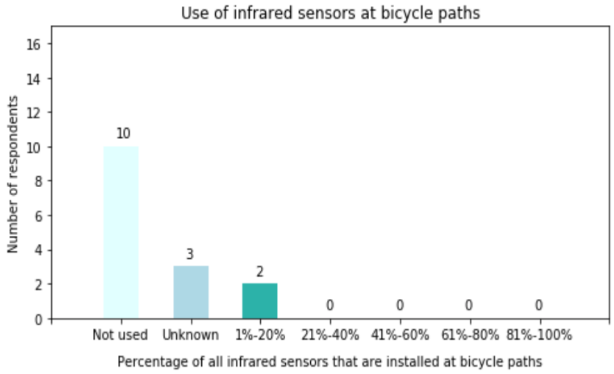
Figure 8 shows what percentage of the total amount of that sensor is placed on a bicycle path. Eindhoven, Enschede, the province of Overijssel and Utrecht stated that they use push buttons at bicycle paths, with the latter two stating that all their push buttons are located at bicycle paths. Loop sensors at bicycle paths are a bit more common, with eight out of fifteen stating that they use them for certain at bicycle paths. A loop upstream of a traffic light was considered to be at a bicycle path as well. 's-Hertogenbosch and Utrecht were the two municipalities that have a small percentage of infrared sensors installed at bicycle paths. A small part of mobile applications are used at bicycle paths according to Utrecht and a consultant. Enschede stated that the vast majority of mobile application sensors are used at bicycle paths. Den Haag and 's-Hertogenbosch are the two municipalities that say that they use smart cameras at bicycle paths. Den Haag and Amsterdam use other sensors than the ones listed at bicycle paths, but the survey did not allow them to elaborate on which sensors.



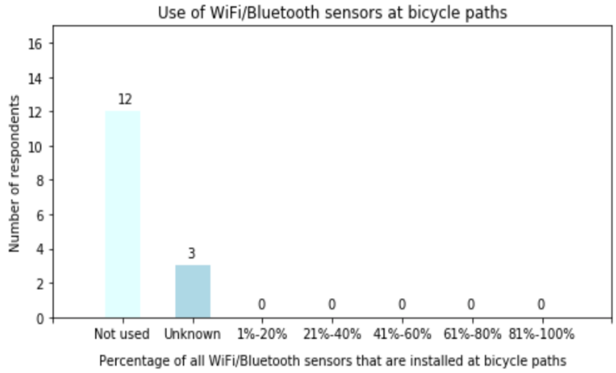
(a) Push buttons



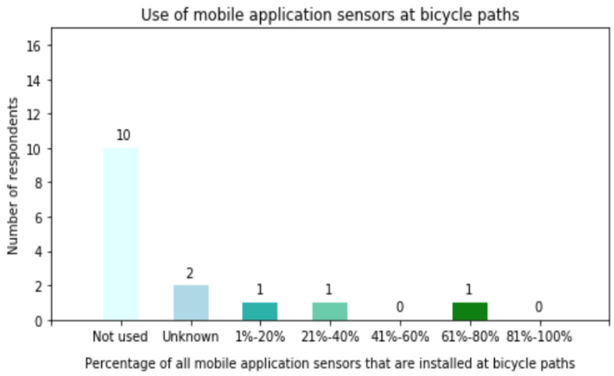
(b) Loop sensors



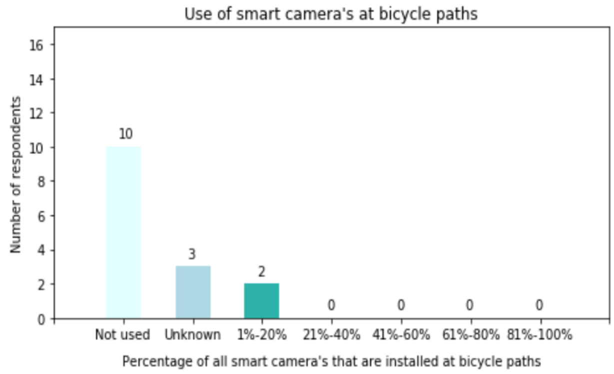
(c) Infrared sensors



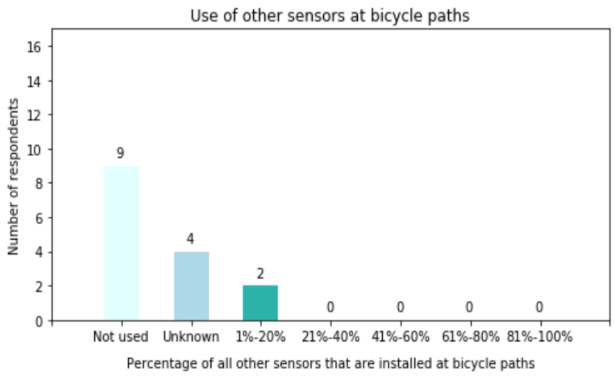
(d) WiFi/Bluetooth sensors



(e) Mobile applications



(f) Smart cameras



(g) Other sensors

Figure 8: Percentage of certain sensors that are located at bicycle paths.

In Figure 9 it can be seen in which configurations loop sensors occur. Most municipalities stated that they use two or three loops per direction, with the configuration of one loop per direction being mentioned by Haarlem, Delft, Amsterdam and Eindhoven. A consultant stated that it was strongly dependent on the situation and lay-out of the intersection.

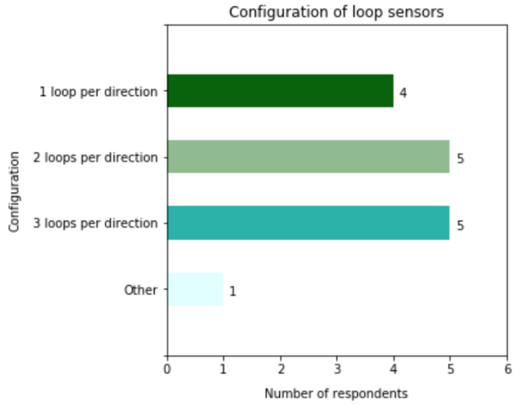


Figure 9: Configuration of loop sensors with number of loops per direction.

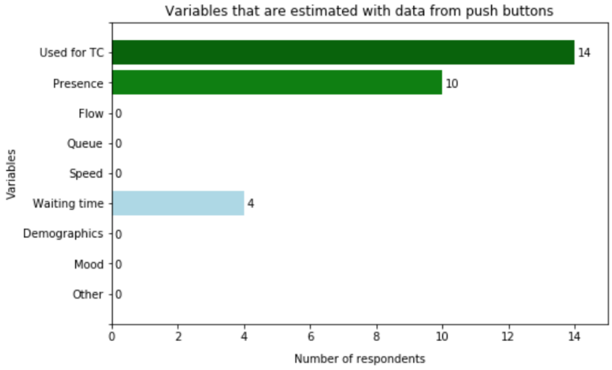
4.2 Group 2: Current knowledge of municipalities on bicycle sensors

The questions that give an overview on the current knowledge of municipalities are questions 6, 8, 9 and 10.

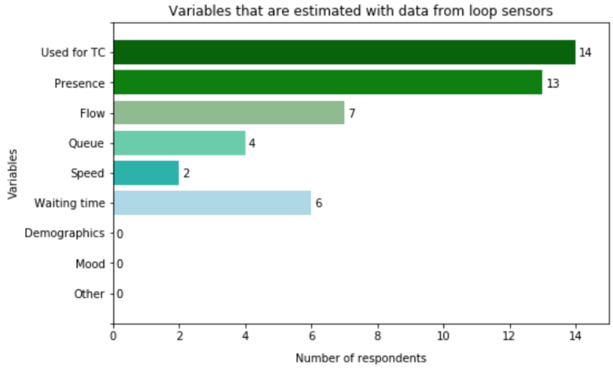
Figure 10 depicts which variables are currently estimated through the certain sensors. It is important to note that this question was a 'tick-box' question. That means that multiple variables could be ticked for one sensor, as can be clearly seen from Figure 10b. If the municipality did not use that sensor, they did not tick anything.

It can be easily seen that bicycle sensors are used mostly for automatic traffic control. This can mean adjusting green light time of the cyclists as well as adjusting green light time of other participants of the intersection (pedestrians, vehicles). Demographics, mood or other variables that were not listed are not estimated by any of the municipalities. Amsterdam, being the biggest municipality in terms of number of inhabitants, stated that their sensors are only used for automatic traffic control, detecting presence of a cyclist and loop sensors are used to estimate flow additionally. They did not express that they estimate any variables with the other sensors that they stated they use in question 5. Delft, having the smallest number of inhabitants in the sample size, only use their sensors for traffic control and detecting cyclists. 's-Hertogenbosch, Den Haag, Leiden and Utrecht are the municipalities that use the bicycle sensors to estimate the biggest number of variables, like flow, queue, speed and waiting time, next to the more normal uses of traffic control and detecting presence.

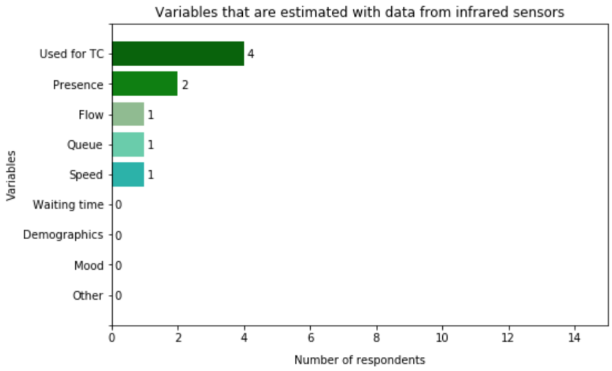
Question 8, in combination with question 9, asked if municipalities were aware of all processing techniques that can be applied to the data that the sensors collect to estimate variables, but that are currently not exploited. 33% of the responding municipalities said that they were not aware of such processing techniques. The other 66% voiced that they are aware of these techniques and mentioned most of the further variables that can be estimated. However, some knowledge of these municipalities was still lacking, especially for the mobile applications, WiFi/Bluetooth sensors and smart cameras. Den Haag expressed separately that they want to integrate a dynamic traffic control installation that acts depending on the type of weather.



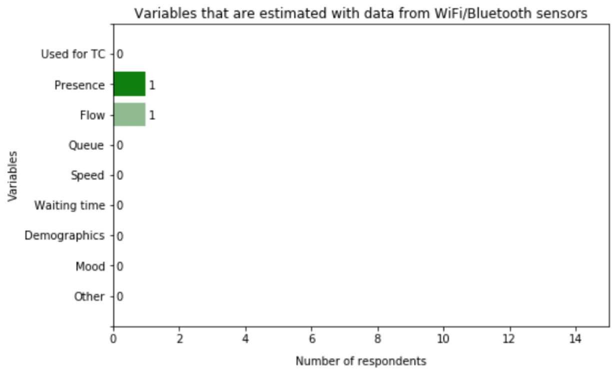
(a) Push buttons



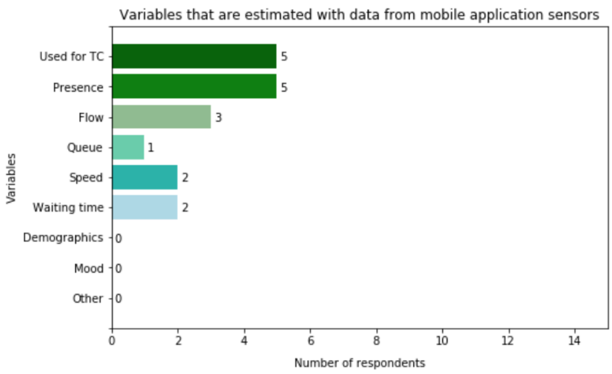
(b) Loop sensors



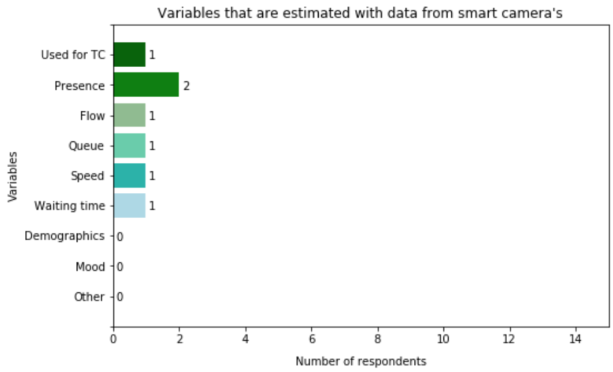
(c) Infrared sensors



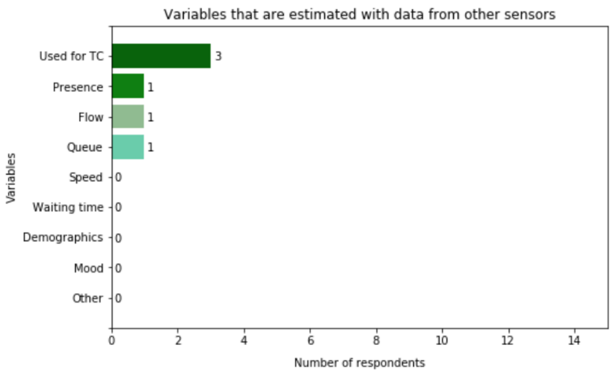
(d) WiFi/Bluetooth sensors



(e) Mobile applications



(f) Smart cameras



(g) Other sensors

Figure 10: Variables that are currently being deduced from certain sensor data.

In Figure 11 the actions that are taken based on the estimated variables are displayed. In line with Figure 10, most actions are automatic traffic control actions. One of the consultants stated that municipalities do collect data as well. Haarlemmermeer expressed that they do not undertake any action based on bicycle sensor data and Den Haag takes other actions, based on a new sensor module that they are experimenting with, next to the automatic traffic control actions.

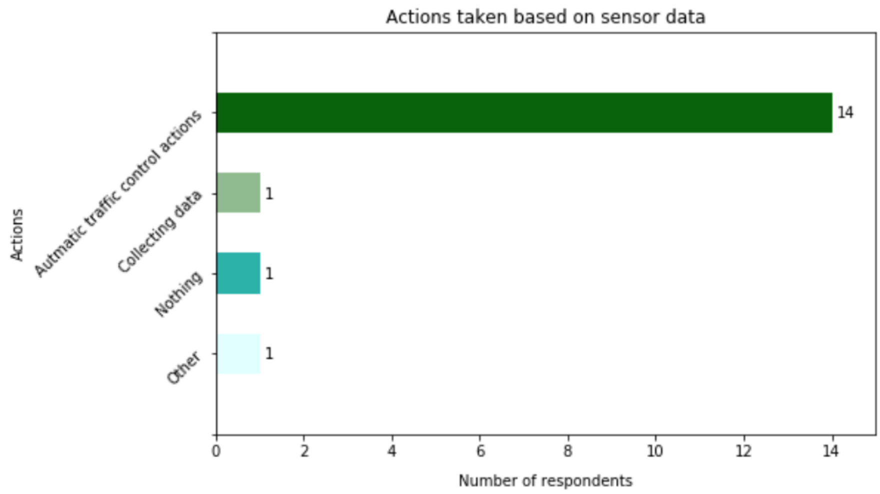


Figure 11: Actions that are being taken based on the sensor data. It was possible to select multiple options.

4.3 Group 3: Future plans and views on bicycle sensors

The questions that give an overview on future plans and views on bicycle sensors of municipalities are questions 11, 12, 13, 14 and 15.

When asked what variables municipalities would like to know, in addition to the ones that they already estimate, responses were intensity (Eindhoven), speed (Enschede, consultant, Amsterdam) counting the number of cyclists to adjust green light time (Haarlemmermeer, Haarlem, Amsterdam), detecting the type of bicycle (Enschede), queue and waiting time (Rijkswaterstaat) and the positioning of cyclists in front of stop lines (Amsterdam).

The answers to question 12 showed that there are currently not many municipality-plans to bring changes to the bicycle sensors that are installed. Quite a few municipalities (Delft, Almere, Utrecht, Rijkswaterstaat, Amsterdam and a consultant stated it as well) are working with mobile applications and implementing them into their bicycle networks. Next to that, Utrecht is experimenting with thermal cameras and Den Haag with smart cameras for cyclists.

Question 13 asked the municipalities when they would install loop sensors and at which location. All the municipalities that participated stated that they would always install loop sensors at signalized intersections. They maintain this when a new intersection is constructed and when older intersections are updated, provided that there is enough budget. A reason is that it is the best proven detection sensor so far, according to 's-Hertogenbosch. When the same question was asked for smart sensors, some say that these kind of sensors first need to be developed (Eindhoven) or that there is no necessity for these kind of sensors (consultant, Leiden). Others would use them if the budget allowed them to and they would place them at busier areas within their municipality, like main cycling routes and crowded cycle locations.

In Figure 12 the opinion on importance to change or improve bicycle sensors of the municipalities can be seen. Most municipalities find it quite to very important (score 3-5), with two (Eindhoven and Leiden) of the fifteen respondents finding it not important at all. The average score was a 3.5, just above 'some importance'.

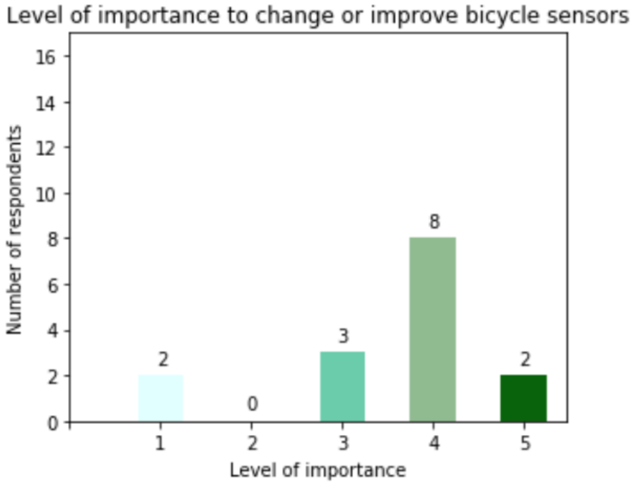


Figure 12: Opinion on the importance of changing or bettering the current bicycle sensors, with 1 finding it not important and 5 finding it very important.

5 Discussion

The results are discussed in terms of accuracy, reliability, interpretation and value.

Understanding of questions by the respondents and accuracy of responses
When conducting a survey, the posed questions are always subject to interpretation. Hence, this survey was no exception. Some of the answers given to questions 2, 5, 7 and 10 were unexpected, to the extent of questioning the interpretation from the respondents. For question 2, from which perspective the respondent filled out the survey, this did not matter much, since the answer could always then be deduced from question 1. Question 5 was about what percentage of a certain sensor was placed at bicycle paths. However, four responses stated that they use push buttons at bicycle paths, which is highly unlikely. This response threatens the validity of all the responses to that particular question, since the posed question is considered unclear and could be misleading. To prevent this as much as possible, all questions should have examples on what answers could look like, to enhance the interpretations. The majority (71%) of the respondents stated that they use loop sensors configured with two or more loops per direction. This answer was remarkable as well, since the answer of one loop per direction was expected to be the common answer, based on literature and expert experience. This contradiction between the results and experience, raises the question if the survey question was properly understood.

Next to that, the answers that were given by the respondents can not considered to be facts. It is based on the knowledge of one sole expert on bicycle sensor use in their specific municipality and no other sources were asked. For example: Amsterdam responded to the survey that they only make use of push buttons, loop sensors and infrared sensors, whilst they stated in their Cycling Plan that chip sensors (that use WiFi or Bluetooth) are also used. This is a clear discrepancy and questions the reliability of the results. Conclusions from the answers should therefore be drawn with caution, because the margin of error on the given answers to the survey is unknown.

Survey sample size
As stated prior in the methodology section, this survey can not be considered representative of the whole of the Netherlands with merely 3.7% of all municipalities of the Netherlands participating. Moreover, diversity in the survey sample is lacking. All municipalities are considered big municipalities in terms of number of inhabitants. Even more so, all the municipalities that responded are comprised of a bigger city and its surroundings, no municipality consisted of villages only for example. It could be argued that in these bigger municipalities innovation takes off because of bigger budgets, bigger flows and since innovation is often initiated in cities. This, however, can not be concluded from this research with this survey sample, because there is no way to draw comparisons with rural municipalities and see the differences between these two. For further research, it is recommended to include more municipalities in the research and have a more diversified sample.

Interpretation of the results
To get real insight into the use of bicycle sensors, it would be good to identify trends within similar municipalities and compare their bicycle sensor use. From the results no clear relations can be found between the municipality characteristics from Table 4 and the survey responses. It would be very interesting to see if municipalities behave differently if their population density and budget are different from each other. A hypothesis could be that municipalities with bigger budgets and more congestion due to population density, try and explore the more innovative sensor types. However, the sensors that were considered newer types of sensors,

WiFi/Bluetooth sensors, mobile applications that track cyclists and smart cameras are not used according to the responses by Eindhoven, province of Overijssel, Utrecht, Rijkswaterstaat, Amsterdam. Even though these municipalities have the biggest total mobility budget and are among the biggest municipalities in the survey sample in terms of number of inhabitants. Amsterdam, having the biggest budget, is doing nothing that is very different from the other participating municipalities, according to their answers to the survey. Moreover, most of the participating municipalities are behaving in a similar way: they have mostly push buttons and loop sensors installed at intersections and are trying newer sensor types at some locations, to test them.

When looking at the scores given by the Dutch Cycling Bond, all scores are around the average national score, except outliers Amsterdam (2.9) and Enschede (4.1). They have given very similar answers to the survey however and the reason for their score difference can not be deduced from this. There is, of course, a big difference in terms of the size of the bicycle flows between Enschede and Amsterdam, with Amsterdam being much more dense and busy, what could attribute to their lower score. Nevertheless, all these results mentioned do not provide proof to draw conclusions with enough scientific support.

Value to other parties

In Section 1, the introduction, it was stated that results from the research could be valuable to different parties, one being non-Dutch countries. It should be taken into account that non-Dutch countries may use a different traffic control system than the Netherlands. The Netherlands mostly uses dynamic and vehicle actuated traffic control systems, for cyclists as well. Another system is a static system, where a green light for example occurs at a set time. Both systems have benefits and disadvantages, but when one wants to learn from and implement the Dutch way, it is important to note whether it is possible to apply this mostly dynamic system into their current system. For further research it would be very interesting to study which intersection design would be best judged on certain intersection design characteristics, like time-saving, safety and clarity.

6 Conclusion

The goal of the research was to answer the research question: *"What kind of bicycle sensors are used, and how much, by Dutch municipalities to detect cyclists for which monitoring purpose in current and future scenarios?"* The conclusion from the research and the answer to this question is discussed according to the subgoals.

Current situation in municipalities regarding bicycle sensors
37% of the big municipalities of the Netherlands behave similar when it comes to bicycle sensors. They use loop sensors and push buttons at 81%-100% of signalized intersections. Newer types of sensors are deployed by some of the municipalities that responded to the survey, but only at few locations and in different ways. From the new type of sensors, mobile applications are deployed most. They are used to enhance the flow of the cyclist using the application and to lower his waiting time in front of red traffic lights.

Bicycle sensors are mostly installed at signalized intersections: bicycle paths only have a small share of sensors installed, with the loop sensor being the most common. These loop sensors at bicycle paths are often part of a two loops per direction configuration shortly upstream of a traffic light, giving information that the intersection downstream uses. The monitoring purpose of the bicycle sensors is mainly automatic traffic control. Each sensor is used for at least this activity according to the responding municipalities, with some participating municipalities estimating other variables (presence of a cyclist, speed, waiting time, flow and queue) as well. Unfortunately, no correlation between municipality characteristics and current bicycle sensor use could be deduced when combining literature research and the survey.

Current knowledge of municipalities on bicycle sensors
Knowledge of bigger municipalities can be considered to be up-to-date when it comes to widely-deployed bicycle sensors and their current possibilities. Not all questioned municipalities estimate all variables that their sensors are capable of estimating, yet at least 66% know that their sensor have the ability to do so. Knowledge on the newer type of sensors (WiFi/Bluetooth sensors, mobile applications and smart cameras) is considered to be less than on the most common sensor types. The new sensor types are not exploited to the fullest and not all possibilities are known.

Future plans and views on sensors
In terms of future plans, the majority of the responding municipalities are implementing mobile applications and leaving the current bicycle sensors that are already installed as they are. Variables that they would like to be able to estimate in the future, are mostly variables that can already be estimated with existing bicycle sensors. Some new variables, like positioning and determining the bicycle-type, were of interest as well. In the future, loop sensors will still be installed at all renovated and new signalized intersections in the responding municipalities. Smart sensors will be implemented as well, only at busier locations, as long as budgets allow that. Participating municipalities found it on average important to improve or change the current bicycle sensors. That is supported by the current plans that they have on implementing newer sensors. However, the new sensor types are only in addition to the traditional sensor types and do not act as a replacement.

7 Recommendations

As for further research, a lot of topics are of interest. The ones most of current interest are:

- Enlarge the sample of municipalities and diversify this sample, to assess if municipality characteristics can be attributed to certain bicycle sensor use.
- Assess which benefits newer sensor types have over the more traditional sensor types and how these can be implemented.
- Assess if cyclist are content and satisfied with intersection arrangement and if they want change brought to bicycle sensors and if so, to what extent.
- Assess what change and improvement municipalities want when it comes to bicycle sensors.
- Assess which sensor data are used for automatic traffic control and to what extent bicycle sensors contribute to this.
- Assess different types of intersection designs, classify them based on their characteristics and determine which type would be best in what situation.

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Appendix A Google Form Survey

Delft University of Technology

Questionnaire Bicycle Sensor use in Municipalities

Thank you for participating in this questionnaire to contribute to the research on the use of bicycle sensors in Dutch municipalities.
This research is done on behalf of the TU Delft, department Transport & Planning at the active mode lab, for the Bachelor Final Project of Merel Sterk, under supervision of Maria Salomons and Giulia Reggiani. Biking and walking are active modes of transportation. The goal is to determine how many and what kind of bicycle sensors are being used and what is being monitored using these detectors by different municipalities.

PLEASE NOTE: We are only interested in bicycle sensors that measure bicycles that are on the road, not the sensors that measure parked bicycles.

If there are any remarks or questions of any kind you can send an email to merelsterk@hotmail.com

It will take approximately 10 to 15 minutes to fill out the questionnaire.

If you want to complete the questionnaire fully anonymous, use the Google account specially created for this research, instead of your own personal Google account: surveybikesensors@gmail.com // password: Surveybikesensors2020

TU Delft department of Transport & Planning:
https://www.tudelft.nl/en/ceg/about-faculty/departments/transport-planning/
Active mode lab of Transport & Planning:
https://www.tudelft.nl/citg/over-faculteit/afdelingen/transport-planning/research/labs/active-mode-lab/

De naam en foto die zijn gekoppeld aan je Google-account, worden geregistreerd wanneer je bestanden uploadt en dit formulier indient. Ben je niet **merelsterk@gmail.com**? Account wijzigen

*Vereist

1. For which municipality or company do you work? *

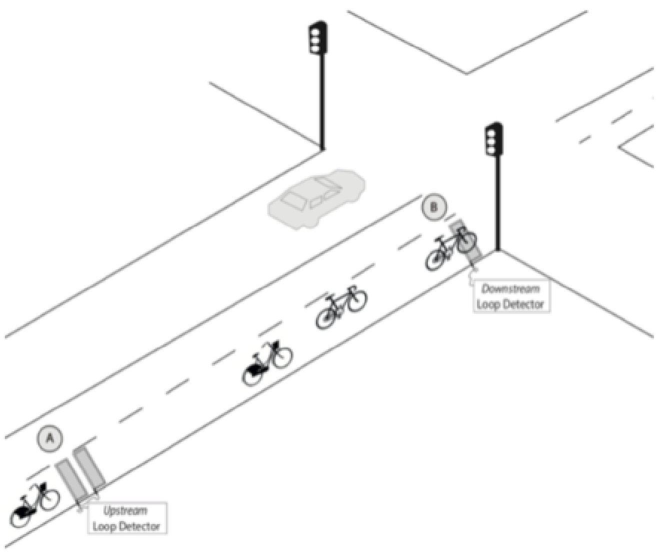
Jouw antwoord

2. From the perspective of which municipality are you filling out this questionnaire? *

Jouw antwoord

Sensors
Sensors are used to determine presence or absence of a cyclists, among other things. Multiple sensors can be installed to measure only one direction, as seen in Figure 1. For this research, if we ask about sensors at intersections, we only mean sensors at place B (downstream loop detector) in Figure 1. If we ask about sensors on bicycle roads, we only mean sensors at place A (upstream loop detector) or similar to place A in Figure 1, not necessarily close to an intersection, just on the bicycle road.

Figure 1



3. What is the percentage of signalised intersections that have specific bicycle sensors installed? For example: at 21%-40% of all the signalised intersections loop sensors are used. *

	We do not use this sensor at intersections	I don't know	1% - 20%	21%-40%	41%-60%	61%-8
Push buttons	○	○	○	○	○	○
Loop sensors	○	○	○	○	○	○
Infrared sensors	○	○	○	○	○	○
Wifi/bluetooth sensors	○	○	○	○	○	○
Smart camera's	○	○	○	○	○	○
Mobile application tracking sensors	○	○	○	○	○	○
Other sensors	○	○	○	○	○	○

4. If you ticked 'Other sensors' in question 3, which kind of sensors do you refer to?

Jouw antwoord

5. What percentage of the total amount of sensors are installed on bicycle roads? For example: 1%-20% of all infrared sensors are installed on bicycle roads. *

	We do not use this sensor on bicycle roads	I don't know	1% - 20%	21% - 40%	41% - 60%	61% - 80%	81% - 100%
Push buttons	○	○	○	○	○	○	○
Loop sensors	○	○	○	○	○	○	○
Infrared sensors	○	○	○	○	○	○	○
Wifi/bluetooth sensors	○	○	○	○	○	○	○
Smart camera's	○	○	○	○	○	○	○
Mobile application tracking sensors	○	○	○	○	○	○	○
Other sensors	○	○	○	○	○	○	○

Smart sensors

Smart sensors are sensors that can measure a lot more/different things than traditional sensors. For example smart camera's: they can detect certain points of the face, that can be combined to determine the mood (smiling/frowning/etc) of the cyclists. They can also determine gender and estimate age. This is a relatively new development in bicycle use and we want to find out how common it is in The Netherlands. Are you already using these new kind of sensors, or do you want to use them? Please let us know by filling out the questions below, keeping this knowledge in mind.

6. What is being monitored with the bicycle sensors in your municipality?

	Used for traffic control	Presence/absence of cyclist	Flow (#cyclists/time unit)	Queue (#cyclists in queue)
Push buttons	☐	☐	☐	☐
Loop sensors	☐	☐	☐	☐
Infrared sensors	☐	☐	☐	☐
Wifi/bluetooth sensors	☐	☐	☐	☐
Smart camera's	☐	☐	☐	☐
Mobile application tracking sensors	☐	☐	☐	☐

7. Loopsensors can be configured in different ways, dependent on the number of loops per direction. What is the most common configuration for loopsensors that is used in the municipality? *

- ◯ 1 loop per direction
- ◯ 2 loops per direction
- ◯ 3 loops per direction
- ◯ We do not use loopsensors
- ◯ Anders: ____________

8. Extra information can be gained from certain sensor data, by using specific processing techniques. For example: estimating the bicycle queue length based on certain data. Are you familiar with processing techniques that are not applied in your municipality, despite available data, for whatever reason (too expensive, too laborious, not necessary)? *

- ◯ Yes [please fill out question 9]
- ◯ No [please go to question 10]

9. If so, which kind of processing techniques?

Jouw antwoord ____________

10. What actions are taken based on the information you get from the sensors? For example: based on queue, the green light time is adjusted. *

- ◯ No actions are taken
- ◯ Only automatic traffic control actions are taken
- ◯ Anders: ____________

11. Is there information that you do not know how to extract, but do like to know? For example: knowing the type of bicycles that cyclists use (electric, speed bikes, etc). *

Jouw antwoord ____________

12. Are there active plans in development to make changes in the (near) future to the bicycle sensors? If so, could you explain what the changes will entail? *

- ◯ No
- ◯ Anders: ____________

13. Under which circumstances would the municipality install loop sensors and in which location? *

Jouw antwoord

14. Under which circumstances would the municipality install smart sensors and in which location? If you would never install cameras, for which reasons? *

Jouw antwoord

15. In your opinion, how important is it to change or improve sensors to detect bicycles? *

	1	2	3	4	5	
Not important	○	○	○	○	○	Very important

16. Do you have any kind of document/report from your municipality that provides (further) information on the use of bike sensors? Please upload (can be anonymous with Google account mentioned in introduction) or send it to merelsterk@hotmail.com

Bestand toevoegen

Talking Bikes
The project Talking Bikes (commissioned by the Ministerie van Infrastructuur en Waterstaat) aims to buy bicycle data from parties that already provide all kinds of services to cyclists: think navigation, monitoring bicycle performance, etc. A boundary condition for supplying data to Talking Bikes is that these already-supplying parties include the newly available services for intelligent traffic control in their applications. Information about for example time-to-green and time-to-red will be available within the applications and approaching cyclists can be automatically identified for a smoother flow.

https://www.ndw.nu/nieuws/bekijk/426/talking_bikes/

17. Is your municipality participating in project Talking Bikes, or have you heard about the project? If so, what is happening at the moment? *

Jouw antwoord

Do you have any other contacts associated with a different municipality that could be of help for this research? Please fill out their email address.

Jouw antwoord