‘Green wave’-apps for cyclists

A thesis about apps that influence the green phase of bicycle traffic signals at intersections

R. C. Verbeeke

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Delft

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Challenge the future

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A thesis about apps that influence the green phase of bicycle traffic signals at intersections.

by

R. C. Verbeeke

Faculty of Civil Engineering and Geosciences
Civil Engineering Bachelor Thesis

Delft University of Technology,
Stevinweg 1, 2628 CN Delft

Student number:	4726472	
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Supervisors:	Dr. ir. A. M. Salomons,	TU Delft
	Dr. ir. W. J. Schakel,	TU Delft

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TU Delft

Preface

In this thesis, I aimed to determine how innovative 'green wave'-apps can contribute to the cycling experience by analyzing the existing apps and interviewing stakeholders. This thesis is the final project of my bachelor of civil engineering at Delft University of Technology. My interest in transport and planning and in the special cycling-culture of the Netherlands made doing this research both interesting and enjoyable.

I would like to thank my supervisors, Maria Salomons and Wouter Schakel, for their valuable feedback and guidance during this project and for the inspiration for this subject in the first place. Next, I would like to thank all contacts at municipalities and app manufacturers who answered my many questions and gave me interesting insights in the existing 'green wave'-apps and how they work. Lastly, I would like to thank Peter Veringmeier and Maria Salomons for using their networks to help me find these contacts.

Ruben Verbeeke
Delft, June 15, 2020

Abstract

Many municipalities try to encourage cycling in their cities to increase the use of sustainable modes of transport and decrease congestion. They therefore implement innovative traffic solutions such as ‘green wave’-apps for cyclists. These ‘green wave’-apps have already been implemented in several municipalities in the Netherlands and Germany, but not much research has been done into this kind of apps. The goal of this thesis was to determine how these apps can contribute to the cycling experience and benefit both cyclists and municipalities. Therefore the research question was: How can the existing smartphone apps that influence the green phase of cyclist traffic signals contribute to the cycling experience at signalized intersections? These ‘green wave’-apps influence the green phase of traffic lights by requesting a green light earlier than conventional detectors would.

Literature was reviewed to determine the problems that the existing ‘green wave’-apps for cyclists aim to solve, the way that these apps work and any known results of the use of these apps. Theoretical results of the use of ‘green wave’-apps were calculated in two case studies. Interviews with employees of municipalities and app developers and a small survey conducted among users of the apps were used to analyze the experiences of stakeholders.

The ‘green wave’-apps for cyclists all aim to reduce waiting times and the number of stops the cyclists have to make, two important factors for the convenience of cycling. They therefore detect when the user is approaching a traffic signal and then request a green light before the cyclist has reached the intersection. Of the four existing ‘green wave’-apps for cyclists, Schwung and SMART work with a route prediction based on the users’ travel history, SiBike lets users plan their routes in the app and CrossCycle only works with live GPS-tracking and certain ‘trigger points’ close to traffic signals.

This research showed that when the request of a green light can be granted immediately, the use of a ‘green wave’-app can decrease the travel time of an average cyclist with up to 4.4 seconds per intersection. When an intersection already has more than one detection loop for cyclists, the advantages of using a ‘green wave’-app are more noticeable for the faster cyclists. Interviews with municipalities showed that the few reactions they got from users of the apps were mainly positive, but for most cities, specific results of the apps are not yet known due to a low number of users and a lack of research. Only in Enschede and in Marburg (Germany), a decrease in average waiting times for cyclists seemed to be found by research.

The users that responded to the survey showed mixed experiences, which was in line with the results of a survey conducted in Enschede. Some respondents did not experience benefits from using a ‘green wave’-app and therefore stopped using the app. The respondents who used the app more frequently in their everyday cycling, more often seemed to experience an increase in the number of times they got an early green light while using the app. Suggestions from respondents for possible improvements of the apps were mainly about the implementation at more intersections. Municipalities saw possible improvements in the feedback to the users in the app. More information about where and when a cyclist got an early green light while using the ‘green wave’-app could increase the transparency of the app and show users the benefits from using it.

The results indicate that the existing ‘green wave’-apps for cyclists can contribute positively to the experience of cycling and already seem to decrease waiting times for cyclists in some cities. This more positive cycling experience could theoretically contribute to the popularity of cycling as a sustainable mode of transport and help municipalities encouraging bike usage. However, the experiences of cyclists are currently only partly positive. The suggested improvements of the apps could help to further increase the number of users and develop the apps to further improve user experiences. Further research could simulate the impact of the use of these apps on traffic flows at intersections or look at the importance of the route prediction compared to only GPS-tracking.

Contents

1 Introduction

The Netherlands is a cycling nation. With a combined cycling distance of 15 billion kilometers per year, the Dutch take the bike for over 25% of the trips they make. (Fietsersbond, 2018) Although these numbers look great, many municipalities are still trying to increase this number. Many of them aim for the prestigious title of Best Cycling Town in the Netherlands. With big campaigns and municipal policies focused on bike usage, the municipalities take this competition rather seriously. The underlying reason often is the congestion of car traffic and the high usage of cars in (inner) cities, a factor that decreases the livability. With population growth and urbanisation increasing pressure on the road systems in cities, municipalities often have two options to prevent car traffic congestion; increasing the capacities of roads or decreasing the number of cars on the road. A good way to decrease the number of cars on the road is by decreasing the share of car users in the overall trips. Fishman stated in his study in 2016 that worldwide interest in cycling as transport is increasing. Cycling is often a good alternative to using the car for a trip in an urban area, so encouraging cycling can make a real difference in the number of cars on the road.

1.1. Topic description

In order to motivate people to take the bike instead of the car, the trip on the bike has to be convenient and comfortable. For cyclists, a signalized intersection can cause delays and discomfort. When the cyclist has to stop and wait for the light to turn green at many intersections, the overall travel time will go up. This may discourage people to take the bike. Another inconvenience of having to stop at intersections is the energy it takes to accelerate to the normal speed when the light turns green. This inconvenience especially applies to elderly because of balance problems.

Because of the reasons above, having to stop at a red light can be annoying for cyclists. This especially applies in the cases in which a traffic signal turns red just before the cyclist reaches the intersection or when the light turns green when the cyclist has just completely stopped. In these cases, a small adjustment in the green phase of the traffic signal could have prevented that the cyclist had to stop. The green phase should have been extended for a couple of seconds (in the first case) or it should have started a couple of seconds earlier (in the second case). With these small adjustments, the cyclist could have continued his trip without the inconvenience of having to stop.

Multiple companies and organizations have done experiments with apps for cyclists that influence the green phase of the traffic signal. The goal of those apps is to detect the cyclists in time to adjust the traffic signals in order to make sure that the light is green when the cyclist reaches the intersection. At the time of writing, four different apps have been tested or are already being used in the Netherlands and Germany. These apps, Schwung, SMART, CrossCycle and Sitraffic SiBike, are the kind of apps this research is about and they are used as reference projects in this thesis. Three of these apps are already implemented in some municipalities in the Netherlands and can be used at certain intersections. Schwung, for example, can already be used in 10 municipalities throughout the Netherlands. (Schwung, s.d.) However, none of the apps are currently used on a big scale.

1.2. Research goals

The use of smartphone apps to adjust the green phase for cyclists is the topic of this thesis. Up to now, not much research has been done into this specific use of technology. The goal of this research is determining how cyclists and municipalities can benefit from the existing 'green wave'-apps. The main research question therefore is:

> How can the existing smartphone apps that influence the green phase of cyclist traffic signals contribute to the cycling experience at signalized intersections?

The research question of this thesis can be split up into different sub-questions.

- What are current problems and issues for stakeholders like cyclists and municipalities that this kind of apps aim to solve?
- Which apps already exist and how do these apps work?
- What are the (theoretical) results of the use of such apps?
- What are the experiences of stakeholders with the existing apps?
- What are possible improvements of the existing apps?

The goal of this research is to find an answer to the main research question. The sub-questions will be answered to form a solid basis for the answer on the main research question.

1.3. Methodology

This research is split into three parts. The first part is the analysis of the stakeholders and their problems that the cyclist apps are meant to solve. Secondly, the existing apps and their results are analyzed. The last part of this research is the evaluation of the existing apps and the determination of their shortcomings and possible improvements based on the feedback from stakeholders.

1.3.1. Analysis of stakeholders and problems

The first part of this research consists of analyzing the problems that the apps aim to solve and the stakeholders that are involved. The first step is therefore to find the stakeholders for this subject. Their interest and influence on the use of the apps are determined by a combination of literature study and interviews with stakeholders. These interviews are conducted by email with employees of the Dutch municipalities of Breda, Eindhoven, Enschede, 's-Hertogenbosch and Tilburg (all currently using one of the four cyclist apps) and employees of Mobidot and Vialis (developers of respectively the SMART app and the Schwung app).

The second step is to analyze the problems and inconveniences that the cyclist apps aim to solve. The point of view of every stakeholder is taken into account. This analysis is partly based on the conducted interviews and partly on literature study.

1.3.2. Analysis of existing apps

In the second part of this research, the existing apps and their results are analyzed. At first, an overview is given of existing apps and systems that are build to solve the problems found in the first part of this research. This is based on literature study. The second step is the further discussion of the four reference projects; Schwung, SMART, CrossCycle and SiBike. These four apps are found in an early literature study to be the best examples of the thesis subject in the Netherlands and Germany as these are the only apps for cyclists that can influence the green phase of traffic signals. To analyze the working of these apps, the interviews with employees of the app developers and municipalities are used, combined with the information about this that is available online.

The next step is to look into the results these apps have. Not much information about results of the four reference projects is publicly available. The available literature is used to describe the results and is completed by information from the conducted interviews. Potential results of these apps are described based on a theoretical analysis of the impact of a cyclist app. Speeds and travel times of cyclists are calculated in two case studies to compare cyclists who use the app with cyclists who do not use the app. The first case is an intersection with only one detection loop for cyclists and the second case is an intersection with also a second detection loop. In this way, the results of the use of a ‘green wave’-app are analyzed at two different intersections with the most usual detection loop configurations. The many assumptions that are made are based on available literature. The exact method of this analysis can be found in chapter 4 of this thesis.

1.3.3. Evaluating existing apps

The last part of this research consists of evaluating existing apps. The first step is to describe the feedback from the stakeholders. This is partly based on the analysis of the stakeholders, partly on extra results from interviews with stakeholders and partly on a small survey for users of ‘green wave’-apps for cyclists. The survey was published in 16 local Facebook groups in the cities where cyclist apps are used. The survey asked the respondents about their experiences with the app and how much they use(d) it. The questions of this survey can be found in appendix A of this report. Most questions were multiple choice questions and the few open questions were not mandatory to answer. This is done to keep the effort of answering low and to prevent people from stopping halfway the survey. Because of a low number of respondents, the survey is not meant to display an accurate representation of all of the users. This low response is due to the users being a very specific target audience because of the low user numbers of the apps. The answers can however, give an indication of the experiences of some of the users.

The second step is to evaluate existing apps on several criteria. The criteria are based on the previous chapters and aim to cover all aspects that have been discussed in the research into these apps. All four reference projects are evaluated qualitatively to determine to what extent they satisfy the needs and wishes of the stakeholders. The possible improvements that are concluded from the feedback from stakeholders are also discussed here.

1.4. Report Structure

The analysis of stakeholders takes place in the first part of chapter 2. The second part of this chapter consists of the analysis of the problems that cyclist apps aim to solve. Chapter 3 displays the existing systems for improving cyclist traffic flow at intersections. In the second part of this chapter, the four most relevant apps for this thesis are further discussed. The results of the implementation of these four apps are discussed in chapter 4. At first, known results of the implementation of the apps are described. The second part of this chapter consists of the case studies with the theoretical results of these apps for cyclists. The 5th chapter is the evaluation of the four relevant apps. In the first section, the feedback of the stakeholders is described. In the second part of this chapter, the four apps are evaluated based on the criteria that are determined in chapter 5.2. Chapter 6 consists of the discussion of the results found in the research and in the 7th chapter, the conclusion and recommendations for further research are given.

2
Problem analysis

This chapter goes into detail about the reasons for the implementation of a 'green wave'-app for cyclists. The stakeholders and their interests are analyzed in the first part of this chapter. Secondly, problems that such apps could aim to solve are described.

2.1. Stakeholders

In order to understand the problems that the 'green wave'-apps for cyclists aim to solve, it is important to know which parties are stakeholders in the implementation and use of the apps. The three most obvious stakeholders are the app manufacturers, the municipalities that implement the app and of course the cyclists who are going to use the app. The other road users who do not use the 'green wave'-app are the last stakeholders in this thesis. The stakeholders are further described below.

2.1.1. Municipalities

At the time of writing, 12 different municipalities in the Netherlands have implemented some kind of 'green wave'-app for cyclists. An overview of these municipalities and the apps they use is given in table 2.1. The importance of municipalities as stakeholders can be seen in their role in the programming of traffic control systems. Municipalities are responsible for the maintenance and operation of the municipal roads in their cities. (Rijksoverheid, n.d.) This means that they are also responsible for the operation of the traffic signals at intersections and are able to reflect their policies regarding mobility in the way these traffic signals are programmed. Priority can be given to transport modes that the municipality wants to promote. Therefore, the influence of municipalities on the implementation of 'green wave'-apps for cyclists is big. This influence also comes with big interest as there are multiple reasons for municipalities to implement a cyclist app. These reasons are discussed in chapter 2.2.

2.1.2. App developers

Other stakeholders are the developers of the apps. In many cases, they have a facilitating role because they deliver the systems the municipalities need to implement a 'green wave'-app for cyclists. In the case of Enschede however, the SMART app was initiated by the municipality and developed in cooperation with a manufacturer. So developers can also help municipalities with the innovation they look for and with working towards their goals regarding mobility. The developers influence the availability of the apps and systems. Their interest is mainly economical. The potential of their apps being used on a big scale is economical appealing. This could happen when one app is already being used in many cities and other cities therefore choose to implement this specific app because cyclists might already be used to using this app. For now, the implementation of the technology is still in a starting phase. The interest of the developers might now be to improve their systems and get it implemented in more cities.

2.1.3. Cyclists

Cyclists are an obvious stakeholder. They are the ones who will use the app and who want to profit from its benefits. The implementation of 'green wave'-apps can result in cycling being more convenient

Table 2.1: Municipalities that use ‘green wave’-apps for cyclists

App	Developer	Municipalities
Schwung	Vialis Moop Mobility	Almere Breda Den Bosch Dordrecht Eindhoven Emmen Hilversum Lelystad Noordoostpolder
SMART	Mobidot	Enschede
CrossCycle	Dynniq	Tilburg
SiBike	Siemens	Marburg, Germany

for the cyclists and to less energy use and lower waiting times at intersections. These are the main interests for the cyclist and these interests are further discussed in chapter 2.2. An indirect interest for cyclists can be the data that the municipality gains because people use the app. The municipality can use this to invest in improvements to the cycling infrastructure and to improve the settings of traffic control systems so that important cycling routes are given priority at intersections. App users do not have a big influence on the implementation of apps, because this relies on the policy of the municipality. However, the cyclists do have an impact on the effectivity of the app as the goals of the municipality (increasing bike usage and gaining cycling data) can only be accomplished when many cyclists actually use the app.

2.1.4. Other road users

The last stakeholders are the other road users: cyclists who are not using the app, car drivers and public transport. They do not have much influence on the implementation of ‘green wave’-apps, but they might have interests regarding it. The implementation of an app could result in longer waiting times for road users like car drivers and public transport. This effect might be minor, but it should be taken into account when implementing an app for cyclists. The technology behind the ‘green wave’-apps can also be used in cars and this already happens on a limited scale. (Willemsen, 2019)

The cyclists who are not using the app can still benefit from it in certain situations. When the cyclist travels together with someone who does use the app, the app can still request a green light which both of them can benefit from. The cyclists who do not use the app can potentially also benefit from it in the long term. When municipalities get more cycling data and use that to improve the cycling infrastructure in the city, also people who did not use the app benefit from it.

2.2. Interests in ‘green wave’-apps

Now the stakeholders are known, their interests in using or implementing ‘green wave’-apps and their problems that can maybe be solved by the apps can be analyzed.

2.2.1. Municipalities

There are multiple possible reasons for municipalities to implement a ‘green wave’-app for cyclists. These reasons are often based on the problems regarding mobility in cities as stated in chapter 1. The three main reasons are discussed below.

Encourage cycling

Firstly, as described in chapter 1, many municipalities try to increase bike usage in their city. Whether this is their goal because of environmental reasons, public health reasons or just because they want to decrease congestion of car traffic, it results in the overall aim for an increase in bike usage. Convenience is an important factor for the choice of a mode of transport. This means that increasing the convenience of bicycle trips can potentially increase bike usage in the city. Municipal policies, like implementing ‘green wave’-apps, can be used for that. (Rietveld and Daniel, 2004) This reason also came up as the main reason in interviews with the municipalities of Breda[1], Eindhoven[2], Enschede[3], ‘s-Hertogenbosch[4] and Tilburg[5]. The effectivity of the implementation of such an app is not proven yet, but it is possible that this technology or a future version of it can contribute to their goal.

Cycling data

The second reason for implementing these apps is the data they can provide. Cycling traffic data can be valuable for municipalities as this can identify busy and important cycling routes. These routes can be taken into account when programming traffic control systems and when planning infrastructure investments and policies. This can make the investments of a municipality more effective and can increase the effectivity of policies regarding mobility. The available cycling traffic data for municipalities often is limited. Measurements using the data from detector loops near intersections are not very accurate because these loops are designed to detect cyclists, not to count how many there are. Especially at high cycling volumes these measurements can be inaccurate. (Gorter, 2016) Doing specialized measurements for determining the cycling traffic flows on the other hand can get expensive and requires many extra detectors. When a ‘green wave’-app for cyclist is implemented, the anonymized GPS-data of app users can serve as a more accurate data source. Improving the availability of cycling data is also the goal of the new ’Talking Bikes’ project in which the Dutch Ministry of Infrastructure and Water Management asks companies to come up with IT solutions that provide cycling data. (CROW, 2019)

Innovation

The third reason for municipalities to implement a ‘green wave’-app for cyclists is innovation. Municipalities want to stimulate innovation regarding mobility. This came up in correspondence with the municipalities of Enschede[3] and Eindhoven[2]. In many cases, innovation goes hand in hand with positive publicity for a municipality. The SMART app used in Enschede is developed together with the municipality and is also the showpiece of the campaign for best cycling town of 2020. The implementation of Schwung in Eindhoven was announced at the ITS conference that took place in the city in 2019. It was the showpiece of the municipality at this conference about innovative technology. (Eindhoven, 2019) The pilot with CrossCycle in Tilburg also started in the weekend of a cycling conference in the city. (Dynniq, 2017) The announcement of such measures for cyclists is positive publicity for the city and can be an example of the municipality’s focus on cycling.

2.2.2. Cyclists

Cyclists are very much influenced by waiting times and the number of stops on their trip. Long waiting times at intersections increase the overall travel time of cyclists and acceleration after a stop costs the cyclist a lot of energy. Other than with cars, this energy has to come from the driver himself. Both of these factors can decrease the convenience of the bike as a mode of transport.

Number of stops

A study by Fajans and Curry (2001) showed that cyclists preferred to cycle on a busy road with car traffic instead of a dedicated cycling route just because there were more stops on that dedicated cycling route. Every stop requires cyclists to accelerate again, which decreases the average speed or, when wanting to maintain the same average speed, increases the power they have to deliver. A study in Texas even concluded that cyclists are willing to increase their travel time to avoid intersections and traffic lights. (Sener et al., 2009) Adding to that, Rietveld and Daniel (2004) conclude with their study that an increase in bicycle usage of 4.9% is seen when the number of stops per kilometer is decreased by 0.3 stops. This means that decreasing the number of stops for cyclists increases cycling comfort and can increase the overall bicycle usage. The ‘green wave’-apps for cyclists aim to decrease this number of stops by decreasing the number of times a cyclist has to stop at traffic signals.

Waiting times

As said before, the overall travel time of a trip by bike is important for the convenience of the bike as a mode of transport. In 2004, Rietveld and Daniel stated that bicycle usage can go up by 3.4% when

[1](F. Van Holten, personal communication, May 19, 2020)
[2](L. Van den Biggelaar & B. Braakman, personal communication, May 12, 2020)
[3](B. Groenewolt, personal communication, May 12, 2020)
[4](E. Greweldinger, personal communication, June 4, 2020)
[5](M. Clijsen, personal communication, May 15, 2020)

a trip is 10% faster by bike than by car. This is a big difference when taking into account the speed differences between bicycles and cars, but especially in urban areas, cycling can be faster than going by car for trips up to approximately 5 kilometers. (Dekoster and Schollaert, 2000) Reducing the waiting times for cyclists at intersections can decrease the overall travel time. This is especially important when considering that the value of time[6] for cyclists is approximately 45% higher than for car drivers. This is mostly because of the inconvenience of cycling and applies best for areas with uncomfortable cycling infrastructure. (van Ginkel, 2014)

The use of ‘green wave’-apps could decrease overall waiting times. The ultimate result of these apps is to prevent cyclists from having to stop at all, but this is not always possible when taking into account the other traffic at the intersection. When the traffic light cannot be changed to green before the cyclist arrives, the cyclist can still benefit from the app. Because the app registers the cyclist going towards the traffic signals before conventional detectors could have detected the cyclist, the green light is requested earlier and can be given earlier when the traffic control cycle allows for that. This can decrease the waiting times for cyclists who, despite using the ‘green wave’-app, have to wait for a red light.

[6]The value of time tells how much the cyclist values the travel time on the bike. Saving travel time is worth a certain amount to the cyclist. This amount is the value of time.

3

Existing apps and systems

As mentioned in chapter 1, multiple systems have been come up with to increase the convenience of cycling at intersections. In this chapter, some of those systems are discussed. Then the four most relevant apps for this thesis are further discussed and the way they work is analyzed.

3.1. Existing systems that give cyclists a speed advice

This thesis is mainly about apps for cyclist that influence the green phase of the traffic signals. However, there are also other apps or systems that are worth mentioning when talking about the existing apps that improve bicycle flows in cities. These systems give cyclists an indication of the speed they have to maintain to catch a green light at the next intersection. Systems that work this way are not a part of the main focus of this thesis, but since they are innovative apps with the same goals as the 'green wave'-apps where this thesis is about, some examples will be briefly described below.

Trafficpilot is an app for car drivers and cyclists. It was first implemented in Dusseldorf, Germany, in July 2019 and has since been expanded to five other cities in Germany. The app, which can be used in the car but also on the bike, gets information about upcoming green lights from the traffic control system and calculates and displays the desired speed for vehicles to catch the green light. This helps users to get in a green wave and decreases the amount of stops bicyclists and car drivers have to make. When waiting for a red light, the user gets to see a countdown timer for the next green light. (TrafficPilot, 2020) A similar app was already implemented in Copenhagen in 2018. GreenCatch, developed by the Dutch tech-company Technolution, gives advisory speeds for bicycles, cars, public transport vehicles and trucks. (Fietsberaad, 2018) Figure 3.1 shows screenshots from the GreenCatch app.

The information about upcoming green lights that is needed to calculate the advisory speed is not always available far in advance. This is due to the fact that nowadays, most traffic control systems in the Netherlands (and also in Germany and Denmark where the previous apps were implemented) are vehicle actuated. Because of this, most of the time there is not a fixed cycle of green phases with fixed lengths. The lengths of the green phases and the order in which the traffic signals turn green depend on the present traffic. With several detectors, the presence of traffic is measured and green lights are granted and extended based on the amount of traffic and the type of traffic that is approaching the intersection. For example, a municipality might decide that public transport vehicles such as buses or trams should get priority above other traffic. When a bus is then approaching a certain traffic signal, this traffic signal is more likely to be the next to turn green. Of course this dynamic cycle of green phases is bound to certain limits set by the responsible road manager. Because of this dynamic cycle, the information about upcoming green phases and the calculated advisory speed can sometimes only be available on short-notice. In some situations this calculation of the advisory speed is not possible at all because the information from the traffic control system is not transmitted quickly enough. (TrafficPilot, 2020)

In the Netherlands, the company Springlab experimented with systems that give advisory speeds for cyclists to catch green lights. Their first prototype, the light companion, was tested in Utrecht in 2015 and consisted of an LED strip next to the cycle path. When a cyclist entered the test area, a green light in the LED-strip started moving towards the traffic signal and when the cyclist followed the

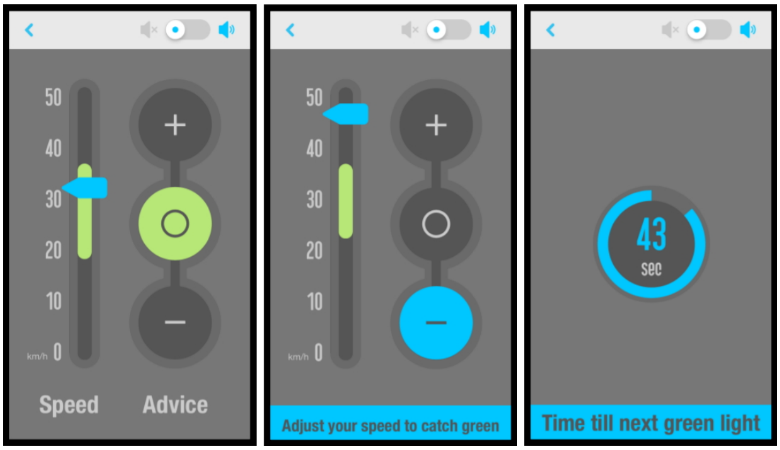

Figure 3.1: Screenshot of GreenCatch app (Araghi, 2016)

speed of that light, he reached the traffic signal just after it had turned green. (Fietsberaad, 2015) After testing this prototype, it turned out that cyclist were focusing too much on the LED-strip and less on the surrounding traffic. This resulted in the second prototype in 2017, Flo. Flo is placed next to a cycle path and calculates if cyclists have to increase or decrease speed in order to catch the green light at the intersection down the road. A picture of a hare or a turtle shows cyclists to increase or decrease their speed, a cow indicates that they will not be able to catch the green light. (Kruijff, 2017) The installation of Flo in Utrecht resulted in an overall increase of the number of cyclists catching the green light of 4%. This result was best noticeable during the off-peak hours where up to 8% more cyclists caught the green light. (Wilgenburg, 2017)

3.2. ‘Green wave’-apps that influence the traffic signal

There are currently four apps that serve as ‘green wave’-apps for cyclists by influencing green phases of traffic signals: Schwung, SMART, CrossCycle and SiBike. These apps have all been tested or implemented in some municipalities in the Netherlands and Germany. The municipalities where they work are displayed in figure 3.2 and can also be found in table 2.1. In essence, these apps all aim to do the same thing and the way they work is quite similar. The basics of these apps are discussed below and are followed by the differences or specific functions per app.

The app is installed on the smartphone of the cyclist and works in the background. The app automatically detects when a person starts cycling and when traffic signals (that work with the app) are approached. This prevents cyclists from having to take their phones out of their pockets to use them while on the bike. When a cyclist is approaching a traffic signal, the app detects this and automatically

Figure 3.2: Map of Dutch cities that use a ‘green wave’-app for cyclists

notifies the traffic control system via the internet connection of the smartphone. The notification is often sent between 40 and 60 meters away from the intersection, but this can differ per intersection.[1] With this notification, the traffic control system detected the cyclist and a request for a green light for the cyclist is made. When possible, this request can be granted and the traffic light can turn green before the cyclist even reached the crossing. When the light was already planned to turn green or the light was already green, the green phase can respectively be started early or be extended. In this way, the cyclist can benefit from the existing green phase of the traffic signal.

The notification that is sent to the traffic control system can contain the speed and position of the cyclist. In this way, an approximation can be made of the moment the cyclist will enter and exit the intersection. This can be used to better time the start and duration of the green light to the cyclist. The Talking Traffic partnership, consisting of the Dutch Ministry of Infrastructure and Water Management, 60 local and regional authorities and many private businesses, aims to improve traffic flows in urban area’s with innovative solutions. Turning regular traffic light controllers (Verkeersregelinstallatie or VRI in Dutch) into intelligent traffic light controllers (iTLC, iVRI in Dutch) is part of their plans for innovative solutions. These intelligent systems receive CAM data (Cooperative Awareness Message) from road users, for example from the ‘green wave’-apps. This CAM data is so called ’floating bike data’ because with this data, the location and speed of cyclists are almost continuously known when they approach the intersection. With ’floating bike data’, ’floating car data’ and possibly other data sources such as public transport vehicles and emergency services, the intelligent traffic light controller can optimize the cycle of green phases to minimize the overall waiting times at the intersection. (Talking Traffic, 2019)

This use of floating bike data, however, is a possible future use of ‘green wave’-apps as it requires intelligent traffic control systems. Approximately 800 out of all 5500 traffic control systems in the Netherlands are now ’intelligent’, but this does not mean that they all are already working with this floating bike data. (Talking Traffic, 2019) The advanced use of speed and location data of the cyclist is not yet implemented at most traffic control systems. In several municipalities, the notifications from the ‘green wave’-app are now treated like the activation of a regular detector loop, with the only difference being that this notification detected the cyclist earlier than the regular detector would do. If a traffic signal has a second or third detection loop further away from the stop bar, this is regularly at approximately 21 meters (in urban areas) to 35 meters (outside urban areas) from the intersection. (Goudappel Coffeng BV, 2018) The regular detection loop would detect the cyclist later than the ‘green wave’-apps, where the detection happens at 40 to 60 meters distance from the intersection.

3.2.1. Schwung

The Schwung app is currently used in ten municipalities in the Netherlands. It is developed by Vialis and Moop Mobility. A special function of this app is that it saves the routes that the users take on the bike and uses this to determine their regular routes. Based on this travel history, the app can predict where the cyclist is going and which traffic signals he is going to encounter. This increases the accuracy of the requests for green lights and reduces the amount of false requests. (Schwung, s.d.) False requests could occur when a cyclist approaches a traffic signal, but takes another route, preventing him from encountering the traffic signal. The fact that this app works with travel data and route predictions results in that the first couple of trips, the app is still gathering data. This means that it can happen that during the first trips with Schwung, the app does not request any green lights for the cyclist because it is not able to predict his route. (Hartman, 2020)

The travel history of the user is for privacy reasons only saved locally on the smartphone. Every trip, a new, anonymous ID is made for the user. This ID is used when the app makes the green light requests, so this request cannot be traced back to the individual user. Only anonymized data is shared with the municipality as general cycling data. The app has to detect that the user is cycling before it starts saving the data. Because the cycling is not immediately detected, the travel data that is shared with the municipality has a different starting point for every trip and can not be traced back to a specific house or address. (Vialis – Infoplaza, s.d.)

[1] With the SiBike app, this distance is approximately 60 meters. (Siemens, 2016) With Schwung and SMART, this distance is approximately 40 to 50 meters. (L. Misdom, personal communication, June 10, 2020) For the CrossCycle app, information about this distance could not be found.

3.2.2. SMART

The Self-Motivated And Rewarded Travelling app, or SMART app, was introduced in 2013 by the municipality of Enschede to motivate people to choose for a sustainable mode of transport. (VerkeersNet, 2013) The app saves the routes people travel and lets users complete challenges, alone or in a group with friends who also use the app. These challenges range from traveling a certain distance by bike to choosing public transport instead of the car for a longer trip. By completing challenges, the user earns credits which can be spent in the SMART web shop on discounts and gift cards. Later, in 2018, the SMART Green function was added to the app. This function makes the SMART app work as a 'green wave'-app. By implementing the Schwung technology in the existing app, the users would now experience permanent benefits from the app, next to the rewards. (Fietsstad, 2018) Because the technology of Schwung is used in the SMART app, this app works with the same route prediction and privacy measures as specified above.

3.2.3. CrossCycle

CrossCycle is a product of Dynniq, developed for a pilot in Tilburg. This app does not work with route predictions, but solely with live GPS-data to detect cyclists approaching traffic signals. The GPS-data is, however, saved and anonymously shared with the municipality. What this app does have is a special priority for big groups of cyclists, they can get priority above other traffic at intersections. (Dynniq, 2017)

3.2.4. SiBike

The Sitraffic SiBike system by Siemens is the only one of the four apps that is not used in the Netherlands. In the German city of Bamberg, the first pilot with this app took place in 2016. (Siemens, 2016) After this test, the app was implemented in Marburg, also in Germany. The SiBike app works like the basics described above. However, it is similar to the CrossCycle app, because it also does not use saved travel data for route predictions. The app is triggered by a certain GPS-point which is approximately 60 meters from the traffic signal. When the cyclist passes this point, the traffic control system is notified and a request for a green light is made. (Siemens, 2016) A visualization of the way SiBike works can be found in figure 3.3. What is different about the SiBike app is that this is the only one of the four apps where cyclists can plan their route in the app. By allowing cyclists to plan their routes in the app, the app can predict where the cyclist is going and can therefore request a green light for the right direction at an intersection. (VMZ Berlin, s.d.) This increases the accuracy of the green light requests.

Figure 3.3: Explanation of SiBike app by Siemens (Goed Op Weg, 2016)

4

Results of the use of existing apps

In this chapter, the available results of the use of the apps mentioned in chapter 3 will be described. First, the available results and literature will be mentioned. After that, two case studies are done to determine the results the use of a 'green wave'-app could theoretically have.

4.1. Results of tests and pilots

There is not much literature available about apps like these and very few statistics or results from the use of the apps are available online. However, for this thesis the available information is gathered to give an overview of the results that these apps have already had. Results of the SiBike app and the SMART app were found and are discussed below. Specific results of Schwung and CrossCycle could not be found online and are therefore not mentioned in this chapter.

4.1.1. Results of SiBike in Marburg

The best example of a scientific research into the results of 'green wave'-apps for cyclists is the experiment with the SiBike app in Marburg, Germany. The SiBike app by Siemens was implemented at six intersections on a busy cycling route between university buildings. Researchers of the TU Munich had cyclists drive up and down this route to test the results of the SiBike app. They measured the number of stops of the cyclists, their travel time by GPS-tracking and the travel time of other road users on the same route by the use of license plate detectors. The measurements took place in three different traffic situations:

1. Existing programming of traffic control system, not using the SiBike app
2. Programming of traffic control system optimized for cyclists, not using the SiBike app
3. Improved programming of traffic control system and using the SiBike app

The measurements of all three traffic situations are then compared in order to say something about the impact of the new traffic situations. (Grigoropoulos et al., 2018) The difference between the second and the third situation is the most relevant for this thesis as this shows the impact of the implementation of the SiBike app.

Cyclists

The researchers of the TU Munich found changes in the average amount of stops that cyclists had to make on the test route. These changes can be found in table 4.1. The changes in average travel time for the cyclists can be found in table 4.2. Note that in both tables, only the changes in the east-west direction where big enough to be significant according to the Tukey-Kramer-test.[1] The article compares differences between all three traffic situation and the changes in these tables are between traffic situation two and three. This means that the changes in the amount of stops and average travel times for cyclists are caused by the implementation of the SiBike app. As can be seen in the tables

[1] Tukey procedure for unequal sample sizes (NIST/SEMATECH, 2012)

Table 4.1: Changes in average amount of stops after implementing SiBike (Grigoropoulos et al., 2018)

Direction	Difference	Significant?
Off-peak hours		
East - west	-43,2%	Yes
West - east	+7,5%	No
Peak hours		
East - west	-37,3%	Yes
West - east	-1,3%	No

Table 4.2: Changes in average travel time for cyclists after implementing SiBike (Grigoropoulos et al., 2018)

Direction	Difference	Significant?
Off-peak hours		
East - west	-24,0%	Yes
West - east	-3,7%	No
Peak hours		
East - west	-15,6%	Yes
West - east	-10,4%	No

Table 4.3: Aggregated changes in average travel time for cars (Grigoropoulos et al., 2018)

Direction	Difference	Significant?
Off-peak hours		
East - west	-16,8%	Yes
West - east	+8,5%	No
Peak hours		
East - west	-0,7%	No
West - east	-13,3%	No

below, the biggest improvements are found in the off-peak hours, but even during peak hours, the cyclists' average travel times have decreased.

Other road users

To get a complete overview of the impact of the SiBike app, the researchers also looked at the changes in average travel times for the other road users. These changes for car drivers can be found in table 4.3. Note that these are average changes over the whole stretch of road and because the car traffic varies over the length of the road, the changes in travel time vary a lot over the length of the road too. At certain points on the route, bigger changes up to a decrease of 28,5% are found. (Grigoropoulos et al., 2018) From these results, can be concluded that there is no major increase in travel times for cars after implementing the SiBike app. It looks like there is actually a decrease in travel time and this decrease is locally even higher than the values in table 4.3.

Some bus lines followed (part of) the test route. Because of this, the changes in travel times for the public transport vehicles were also analyzed in the article. However, a low number of buses was detected, which resulted in a too small sample group to give statistically significant results about the travel times for public transport. The little data that the researchers did find, did not seem to show a major increase in travel time for the buses.

4.1.2. Results of the SMART app in Enschede

In 2019, a research into the measures of the municipality of Enschede for cyclists was conducted. In this research, the SMART app was also mentioned and the waiting times for cyclists at the intersections where the SMART app is working were compared with the situation without the app. (Hamme, 2019) The analyzed traffic signals can be found in figure 4.1. The SMART app is connected to several traffic signals in the city of Enschede. (Light blue in figure 4.1)

By comparing the average waiting times for cyclists at these intersections with the same intersections in the year 2011, Hamme wants to find out the impact of the SMART app on the average waiting times. Overall, the waiting times for cyclists at intersections in Enschede decreased by 5% between 2011 and 2018. At the traffic signals where the SMART app was introduced however, an average decrease of 17% was found. The share of cyclists at these intersections who use the SMART app is substantial, 10.8% on average. With these result however, some remarks have to be made. The share of SMART app users at two intersections was significantly higher than at other intersections, which can point at measurement errors. At one intersection, the waiting times could be inaccurate due to construction works during the measurements in 2011 and at two others, the decrease in waiting times is significantly higher than at others, which raises doubts about the accuracy of these two measurements. (Hamme, 2019) Despite these remarks, the decrease in waiting times at intersections with the SMART

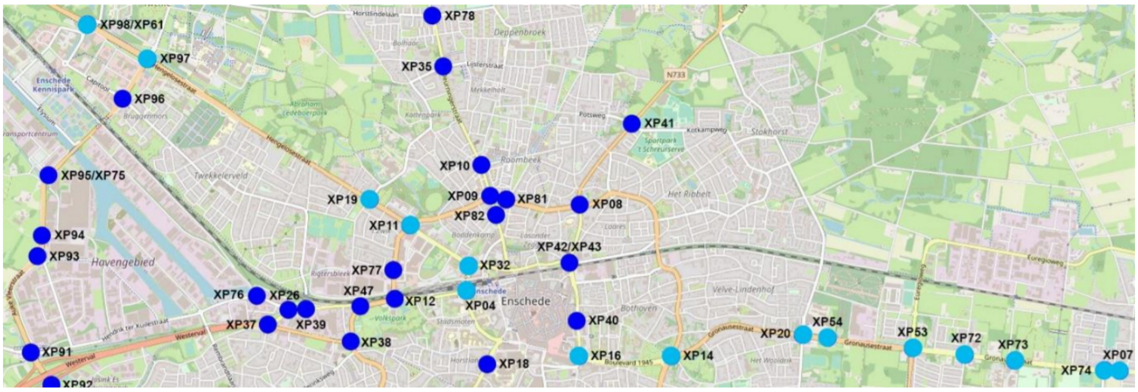

Figure 4.1: Traffic signals included in the analysis of waiting times. (Traffic signals with SMART app in light blue) (Hamme, 2019)

app is still more than the average 5% decrease at all signalized intersections in the city. This seems like a significant impact of the implementation of the SMART app.

Survey

In March 2019, students of the University of Twente conducted a survey among 50 users of the SMART app asking them about their experiences with SMART as a ‘green wave’-app. The results of this survey were provided by the municipality of Enschede[2] during the interviews with stakeholders. The answer possibilities of questions about whether the respondents experienced getting green lights faster while using the app are given a certain score. ‘Yes’, ‘maybe’ and ‘no’ respectively equal a score of 1, 2 and 3. In this way, a mean score and standard deviation can be calculated. The results of these experiences of getting green lights faster in rush hours and in off-peak hours can be found in table 4.4.

Table 4.4: Answers of users of the SMART app about whether they experience getting green lights faster while using the SMART app. (Yes is 1, maybe is 2, no is 3)

Reference period	Yes	Maybe	No	Mean	Standard deviation
Morning rush hour	8.33%	35.42%	56.25%	2.31	0.79
Evening rush hour	10.42%	37.50%	52.08%	2.48	0.65
Off-peak hour	37.50%	37.50%	25.00%	1.88	0.78

What can be seen in these results is that during rush hours, the users tend to experience the impact of using the app significantly less than during off-peak hours. During rush hours, most users do not experience shorter waiting times while using the app. When asked if the use of the SMART app led to a feeling that they could reach their destinations faster, most responses were negative, resulting in a mean score of 2.31. Despite these many negative answers, 38% of the respondents answered that they would probably or definitely continue using the app. 28% was not sure about this yet.

4.2. Theoretical results: case studies

In this section, the potential results of the implementation of a ‘green wave’-app for cyclists on real life situations are analyzed in two case studies. These case studies are done to determine some requirements for an app to work and to determine what the implementation of an app could result in for cyclists. In the cases is assumed that there is no other traffic at the intersection. This means that a request or a green light by a ‘green wave’-app can be granted without significant delays. Calculations of the impact of a ‘green wave’-app on an intersection with other traffic are outside of the scope of this thesis.

Cyclist characteristics

In the Netherlands, the average speed of a cyclist is $18km/h$, which translates to $5m/s$. When decelerating, a comfortable deceleration rate is $1,5m/s^2$, but in case of an emergency brake, this rate

[2](B. Groenewolt, personal communication, May 25, 2020)

can increase up to $2,6 m/s^2$. Acceleration rates range between $0,8 m/s^2$ and $1,2 m/s^2$, so for these calculations, the average acceleration rate of $1 m/s^2$ will be used. The average length of a bicycle is $1,8 m$. (CROW, 2015) The first, more comfortable, deceleration rate will be used in the cases below. This deceleration suits a cyclist who is approaching a well visible, signalized intersection and starts braking well in time. The assumption is made that the deceleration happens linearly and cyclist time their braking so that they stop just before they reach the intersection. The average breaking distance is therefore calculated with equation 4.1. (AASHTO, 2012) The time it takes for the cyclist to go from the initial speed to a standstill is calculated in 4.2. The perception and reaction time of cyclists is $1s$. (AASHTO, 2012) It has to be noted that cyclists often slightly decrease their speed earlier by stopping paddling. However, for these calculations, this will not be taken into account.

$$BD = RT * v_0 + \frac{v_0^2}{2 * a} = 1 * 5 + \frac{5^2}{2 * 1,5} = 13,3m \tag{4.1}$$

$$BT = RT + \frac{v_0}{a} = 1 + \frac{5}{1,5} = 4,3s \tag{4.2}$$

where:
- BD = Braking distance $[m]$
- BT = Braking time $[s]$
- RT = Reaction time $[s]$
- v_0 = Initial speed $[m/s]$
- a = Deceleration rate $[m/s^2]$

Traffic signal characteristics

Some traffic signals are green when no conflicting traffic is approaching, but in that case the cyclist could continue without waiting and there is no need for a ‘green wave’-app. That is why in these case studies, the assumption is made that the traffic signal is red when the cyclist approaches it. The green phase for cyclist at most intersections consists of a standard green time which can be extended when approaching cyclists are detected. This standard green time for cyclists is 3 to 4 seconds. (CROW, 2014) In these case studies, the standard green time will be assumed to be 4 seconds. Another assumption for these case studies is that there is no other traffic, so the standard green time will not be extended. When not extended, the traffic signal will go to the yellow phase after the standard green time. For cyclists paths, this yellow phase is 2 seconds. (Goudappel Coffeng BV, 2016) After the yellow phase, the traffic signal turns red again.

4.2.1. Case 1: Intersection with one detector

The first case is an intersection of the Goverwellesingel and the Middenmolenlaan in the city of Gouda. Coming from the north-east direction, there is currently only one detective loop for cyclists. (Figure 4.2) This loop is situated near the stop bar and therefore does not detect approaching cyclists before they have already decelerated. In the Netherlands, there are already a lot of cyclist traffic signals with two or even three detectors in the ground. This is one of the ways in which municipalities try to improve cycling comfort and reduce waiting times. However, there are still many traffic signals with only one detector, like this particular one in Gouda.

In this case, the cyclist is followed from 20 meters in front of the stop bar, until 30 meters after the stop bar. In the speed profile, $t = 0s$ is when the front of the bicycle is 20 meters away from the stop bar. The detector is situated approximately $0,5m$ in front of the stop bar and the width of the intersection is $19m$. With the length of the bike and the stop bar taken into account, the cyclist leaves the intersection when he has driven $41m$. ($20m$ before stop bar, $0,2m$ stop bar length, $19m$ intersection width and $1,8m$ bicycle length.)

Without a ’green-wave’-app

The cyclist approaches the traffic signal when the light is red. The braking distance is $13,3$ meters (Equation 4.1), but this accounted for one second perception and reaction time. This reaction time is here considered not necessary because of the long approaching distance and the clear view of the traffic signal. With the average speed of $5m/s$, the braking distance without the $1s$ reaction time is $8,3m$. The cyclist starts braking with a constant deceleration rate of $1,5m/s^2$ until he has come to a

Figure 4.2: Case study 1: Intersection Goverwellesingel and Middenmolenlaan in Gouda (Google, 2019)

standstill. This can be seen in figure 4.3. Approximately $0,5m$ before the stop bar, the cyclist is detected by the loop in the ground and is granted a green light almost instantaneously. This is $19,5m$ after the start of the measurement. In the traveled distance graph (figure 4.4) can be determined that the cyclist gets a green light at $t = 4,9s$.

From the moment the light turns green, there is one second perception and reaction time before the cyclist starts accelerating again. This acceleration is done with a constant acceleration rate of $1,0m/s^2$ until the initial speed of $5m/s$ is reached. Then the cyclist continues with this average speed. At $t = 6.2s$, the cyclist has accelerated a little bit and enters the intersection. The cyclist exits the intersection at $t = 12,6$ (when $41m$ has passed) and reaches $50m$ from the starting point in $14,4$ seconds. The fact that the traffic light is red before the cyclist has exited the intersection should not be a problem as traffic control systems take into account the time it takes to cross the intersection when giving another traffic flow a green light.

With a 'green-wave'-app

In this case, a 'green wave'-app could be beneficial for the cyclist. The app could prevent the cyclist from having to decelerate and having to stop. As the assumption is that there is no other traffic at the intersection, the cyclist can get a green light at the moment that he or she is detected. The traffic light

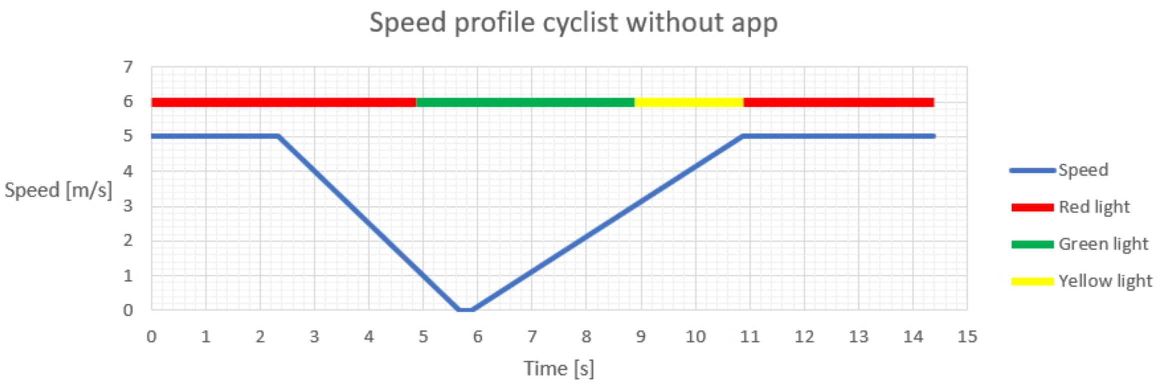

Figure 4.3: Speed profile of cyclist without 'green wave'-app

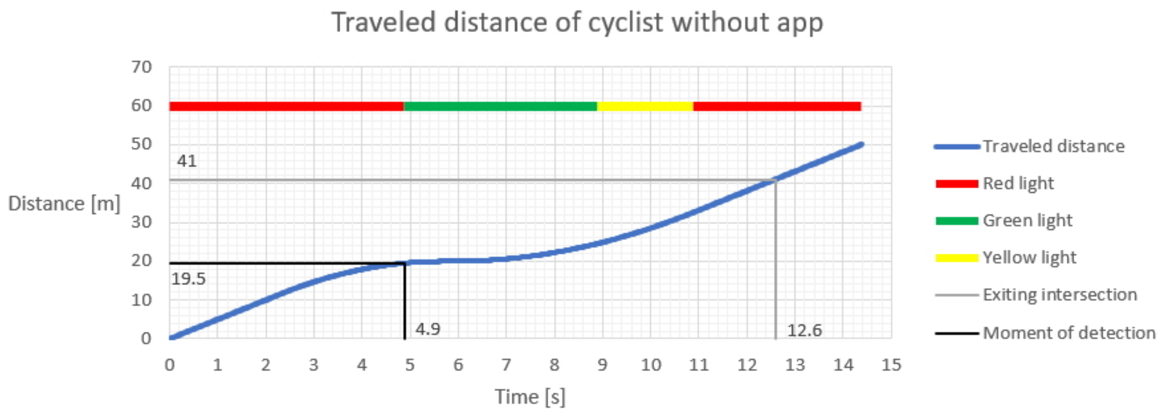

Figure 4.4: Graph of traveled distance of cyclist without ‘green wave’-app

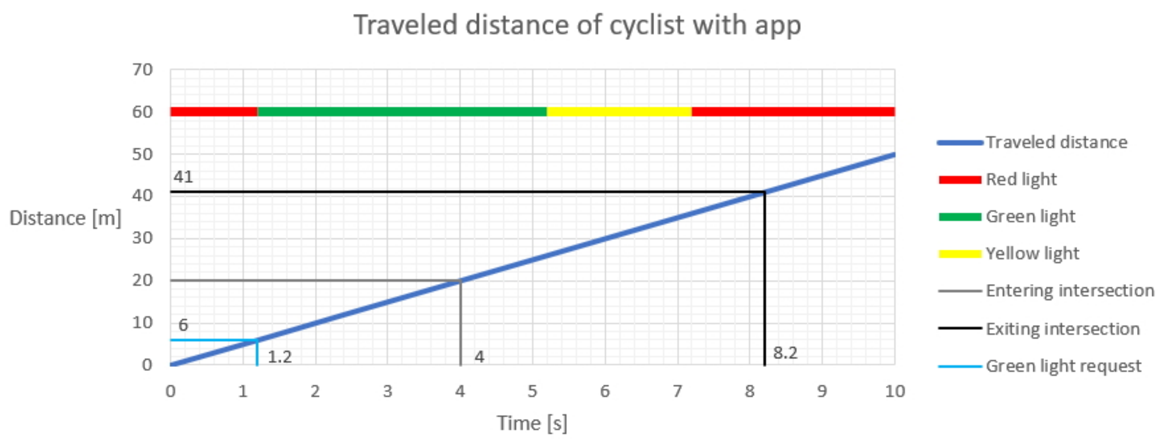

Figure 4.5: Graph of traveled distance of a cyclist who uses a ‘green wave’-app

has to turn green before the cyclist starts decelerating. With an average braking time of $4,3$ seconds (including reaction time) and an average braking distance of $13,3$ meters, the ‘green wave’-app should request a green light at least 14 meters away from the traffic signal. This only applies for situations where the request is granted immediately. The municipality should look into the cycling speeds that they want to design for because faster cyclist require earlier detection. Also the delay between the app sending a green light request and the traffic light actually turning green should be determined in order to check if this really is negligible as is assumed in this case study.

The speed profile for this situation with an app is not very interesting as this is a horizontal line at a constant speed of $5m/s$. In the traveled distance graph can be seen that the traffic light turns green when the cyclist has traveled $6m$ or $1.2s$. (Figure 4.5) Also in this graph can be found that the cyclist enters the intersection at $t = 4s$ and exits it at $t = 8,2s$. The traffic signal still only has a standard green phase and a yellow phase, because there is no other traffic to extend the green phase.

Comparison

In table 4.5, a comparison is made of several factors of the cyclist who uses a ‘green wave’-app and the cyclist who does not use an app. The cyclist with the ‘green wave’-app maintains a higher average speed and has a shorter overall travel time. The total green time given to the cyclist is the same for both cyclists, but the cyclist with the app occupies the intersection for a shorter period of time. Because of their higher speed, the green time for users of a ‘green wave’-app can, in this situation, potentially be a bit shorter than for cyclist who do not use the app. Note that for this to work, the cyclist has to use the ‘green wave’-app and cyclists without the app should still get the normal amount of green time.

In this situation, the user of the app gets the confirmation that he will get a green light by the traffic light already turning green. This despite of the fact that he does not use the green phase for another

Table 4.5: Differences between cycling with and without ‘green wave’-app in case 1

Factor	Without app	With app	Change
Overall travel time over the 50 meter section [s]	$14,4$	10	$-30,6\%$
Time between entering and exiting the intersection [s]	$6,4$	$4,2$	$-34,4\%$
Average speed [m/s]	$3,5$	5	$+42,9\%$

2,8 seconds. The green phase for this cyclist could be even more reduced if the traffic light only turns green when the cyclist is closer to the intersection. However, the cyclist should still be notified that the light will turn green in time to make sure he will not decrease his speed. Important to note is that the green phase has to be guaranteed when this notification is given to the cyclist. Otherwise, the cyclist will get to the intersection at a high speed and does not have enough time to stop for the red light. One option of notifying the cyclist is a waiting time indicator placed next to the traffic signal. Turning on that indicator can serve as a notification to the cyclist that he is detected and will get a green light. These countdown timers have to be further developed to serve as feedback of the granted green light to cyclists because the existing waiting time indicators tend to not be very accurate. The countdown should be consistent to give the cyclist an accurate indication of when the light will turn green. Next to being more accurate, the waiting time indicator should also be well visible for the cyclist. It should be visible from the distance where the cyclist would otherwise decide to brake.

Another option is to give feedback to the cyclist in the app and notify the cyclist in this way of the green light that is coming up for him. Because it is not allowed in the Netherlands to use a (smart)phone while riding a bike, this notification has to be showed to the cyclist in another way. Possible is mounting the phone to the steering bar, or giving notifications using sound or vibrations. The developers of Schwung are also looking into possibilities of using the display of electric bikes to notify the cyclist or connecting the app to a bicycle bell that lights up when the green light request is granted. (Van Dijk, 2019)

In this case study is shown that the use of a ‘green wave’-app at intersections, where there is only one detection loop near the stop bar, can result in higher average speed and shorter travel time for the cyclist. The use of an app can also result in a reduction of the needed green time. This could be beneficial for the municipality as this saved time can be used for other traffic. However, as this case study is based on many assumptions, the effects of the use of a ‘green wave’-app have to be further researched before such changes in green time can be made.

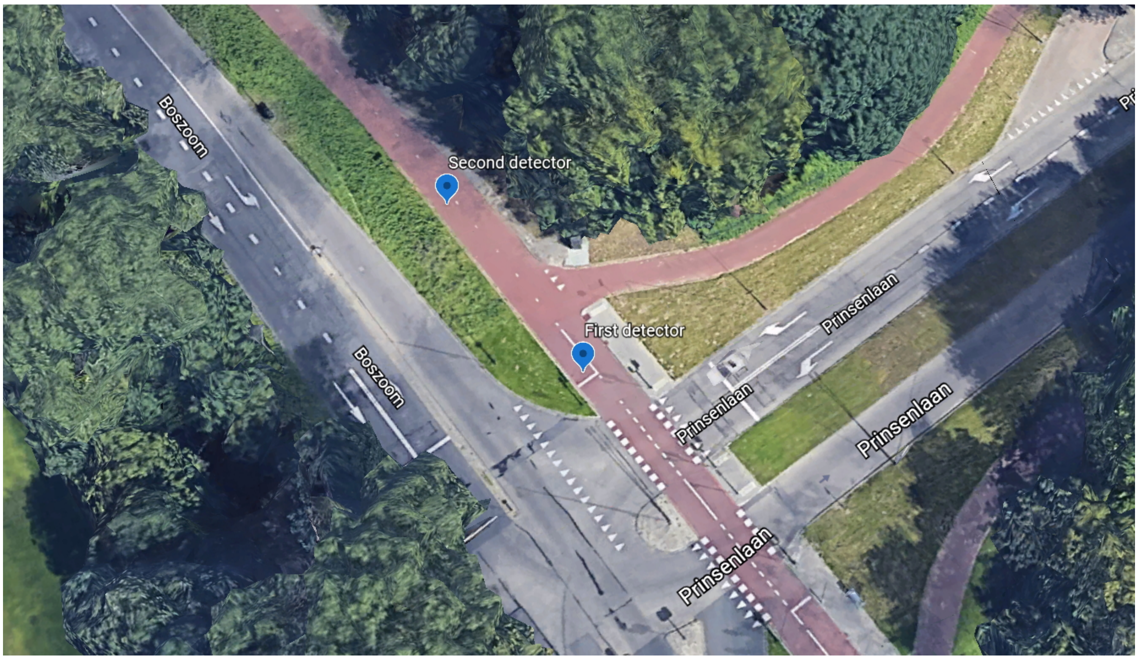

Figure 4.6: Case study 2: Intersection of Boszoom and Prinsenlaan in Rotterdam (Google Earth)

4.2.2. Case 2: Intersection with two detectors

The intersection for this case is the intersection of the Boszoom and the Prinsenlaan in Rotterdam. (Figure 4.6) Coming from the Boszoom, there are two detectors for cyclists, one near the stop bar and one approximately $21,5m$ in front of the stop bar. In a case with no other traffic, a green light can be granted immediately. Assuming the same, comfortable deceleration rate as before, cyclists with speeds of up to $24km/h$ are detected in time to prevent them from starting to brake. (Equation 4.3)

$$\begin{gathered} RT * v_0 + \frac{v_0^2}{2 * a} = BD \\ v_0^2 + 2 * a{*}RT * v_0 - BD * 2 * a = 0 \end{gathered} \tag{4.3}$$

With:
- BD = $21,5m$ (Braking distance)
- RT = $1s$ (Reaction time)
- a = $1,5m/s^2$ (Deceleration rate)
- v_0 = Initial speed $[m/s]$

$$\begin{gathered} v_0^2 + 2 * 1,5 * 1 * v_0 - 21,5 * 2 * 1 = 0 \\ v_0 = 6,67m/s \quad (24km/h) \end{gathered}$$

This maximum speed of $24km/h$ is fine for most cyclists, but because the road approaching the intersection is straight, faster cyclists can reach higher speeds. Especially people on sports bikes and e-bikes will not be detected in time to prevent them from having to decelerate. A ‘green wave’-app could help to also detect the faster cyclists in time in this situation. In a situation where there is conflicting car traffic as well, the green light cannot be given right away. In that situation, the request has to be made even earlier in order to give the cyclist a green light in time. Just like in case one, a confirmation of the granted green light can be given to the cyclist instead of turning the light green while the cyclist is approaching the intersection. This could reduce the needed green time to make the cyclist continue without having to stop.

Another advantage of using a ‘green wave’-app in this case is the way that some of the apps, like Schwung, use travel data from the past to predict which way the cyclist is going. Without using an app, a cyclist who comes from the Boszoom can be detected by the second detector and then still turn left before he reaches the intersection. When a green light is then granted based on the detection, the green time is wasted as the cyclist does not cross the intersection. With route prediction by a ‘green wave’-app, the app can predict that the cyclist is not turning left and can request a green light with more certainty that it is going to be used. When the app predicts that the cyclist will turn left, it will not request a green light.

Cyclists coming from the Prinsenlaan and wanting to turn left to cross the road are now only detected by the first detector just in front of the stop bar. If they use a ‘green wave’-app, they can be detected earlier and can experience benefits as described in case one (section 4.2.1). They still have to slow down because of the sharp turn, but when the green light is granted in time, they will not have to come to a complete stop. Accelerating from half of the initial speed to the initial speed still costs approximately 25% less energy than accelerating to the initial speed from a complete stop. (Fajans and Curry, 2001)

This case study showed that even when there is already a second detector for cyclists at an intersection, there are still benefits from using a ‘green wave’-app. Further research has to point out the exact results of using an app in combination with other traffic. However, the results from this case look promising, especially for the faster cyclists.

5

Evaluation of existing apps

In this chapter, the four existing apps are evaluated. Several criteria are selected based on the experiences of stakeholders and the results of the previous chapters. The four existing apps are then evaluated on each of these criteria.

5.1. Experiences of stakeholders

The experiences of stakeholders are important factors to take into account when determining the aspects based on what the existing apps have to be evaluated. In this section, the results of interviews with municipalities and the survey for users of the 'green wave'-apps are described.

5.1.1. Municipalities

Several municipalities that have implemented a 'green wave'-app for cyclists were contacted during this research. They were asked about their experiences with these apps and their motivation to implement them. The municipalities of Breda[1], Eindhoven[2], Enschede[3], 's-Hertogenbosch[4] and Tilburg[5] have responded to these questions.

Decisions regarding the implementation of a 'green wave'-app

All respondents mentioned that they had implemented the app to encourage bike usage. In the case of Enschede and Eindhoven, their wish for innovation was an extra motivation to implement it. The way they implemented the apps does differ a bit per municipality. The municipalities of Breda and Tilburg started with implementing the app at a small number of intersections and are now considering expanding this to more intersections. Eindhoven implemented Schwung at all of the approximately 90 intersections that were technically ready for it. Enschede and Tilburg both looked at busy cycling routes to implement the 'green wave'-app the first. After a pilot at one intersection, the municipality of 's-Hertogenbosch decided to implement the app at all intersections for cyclists in the city to provide the most benefits for the cyclists.

Does the app meet the expectations?

Overall, the municipalities do not have many specific results as research into this has not been done yet and user numbers are relatively low. However, the reactions that they get from users are mainly positive, so for now, the apps meet the expectations of the municipalities. The municipality of Enschede had a survey done by students of the University of Twente among 50 users of their SMART app. This survey showed mainly positive reactions of respondents. (See chapter 4.1.2.) Looking at the technology, the apps do their job and are all successfully installed. The municipality of Tilburg wants to look a bit more into the accuracy of the GPS-locations of users of CrossCycle and into the security of the cyclists' travel data.

[1] (F. Van Holten, personal communication, May 19, 2020)
[2] (L. Van den Biggelaar & B. Braakman, personal communication, May 12, 2020)
[3] (B. Groenewolt, personal communication, May 12, 2020)
[4] (E. Greweldinger, personal communication, June 4, 2020)
[5] (M. Clijsen, personal communication, May 15, 2020)

Does the apps lack any functions?

The municipalities of Breda, Eindhoven, Enschede, ’s-Hertogenbosch and Tilburg all responded that they would like to see some extra feedback to the users. Schwung already shows how many times the cyclist is ‘seen’ by a traffic signal with Schwung, but there are no statistics about how many times the user got a green light as a result of using the app. Some municipalities also suggest extra information for users such as where on their routes they got priority at the intersection and how much time they saved by using the app. Also more information for the municipality like a better insight in the bike traffic data and in the waiting times for cyclists were mentioned by respectively Breda and Enschede as possible improvements. The municipality of Eindhoven was considering experimenting with giving Schwung-users extra priority at traffic signals, instead of handling a green light request from the app like any other regular detector. Extra priority for cyclists with Schwung above other traffic should then be programmed in the traffic control system.

5.1.2. Users

The survey for users of ‘green wave’-apps was shared in local Facebook groups of the cities that have implemented a ‘green wave’-app for cyclists. The survey got 9 responses. The full questions and answer possibilities can be found in appendix A. Of all nine respondents, 5 are still using the app they tried. Most of the respondents used Schwung, 5 of them in Breda and 2 of them in ’s Hertogenbosch. The other two used SMART and CrossCycle. An overview of all the responses can be found in appendix B.

Comparison between users and ex-users

In the responses, a difference can be seen between the people who use the app and people who stopped using the app. In figure 5.1 can be seen that people who do not use the app anymore did not use the app as frequent as the people who still use it. Figure 5.2 confirms this as there can be seen that the people who still use the app used the app more in their everyday cycling and their standard routes. Figure 5.3 shows the respondents’ experiences of how much more they can continue their trip without having to stop for a red light compared to before they started using the app. It seems like people who still use the app have better experiences with it and more often experience an increase in the number of times they get a green light. In figure 5.2 was already shown that the respondents who still use the app use the app more often on their daily routes than people who do not use the app anymore. Therefore it seems like respondents who use the app more on their daily routes, more often experience an increase in the number of times they can continue their trip without having to stop for a red light.

Most (8 out of 9) of these responses are from users of Schwung and SMART, apps that use travel data of the past to predict the route of the user and request green lights based on that prediction. This could explain the relation of how frequent the app is used and how much the respondents experience an increase in green lights. When used on a daily basis, Schwung and SMART should theoretically predict the route of the cyclist more accurately and request the right green lights more often. However, as this relation is based on only 9 responses, this might not be accurate for all users.

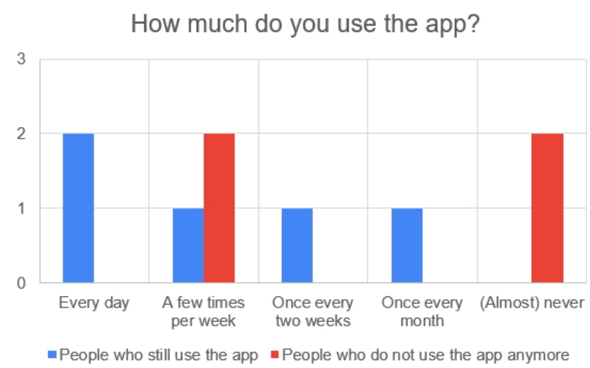

Figure 5.1: Frequency in which people use(d) the app (y-axis displays the number of times that answer was given)

Other feedback from users

When asked if the use of the app made the user choose to take the bike more often, all of the respondents answered negative, the use of the app did not change this. The responses to the question about privacy were more varied. 4 out of 9 respondents were somewhat concerned about their privacy. Five out of nine respondents added to the survey that they want the municipality to implement the app at more intersections. This was the only given answer on the question if the respondents had ideas for improvements for the app they used.

Figure 5.2: Description of the way respondents use(d) the app (y-axis displays the number of times that answer was given)

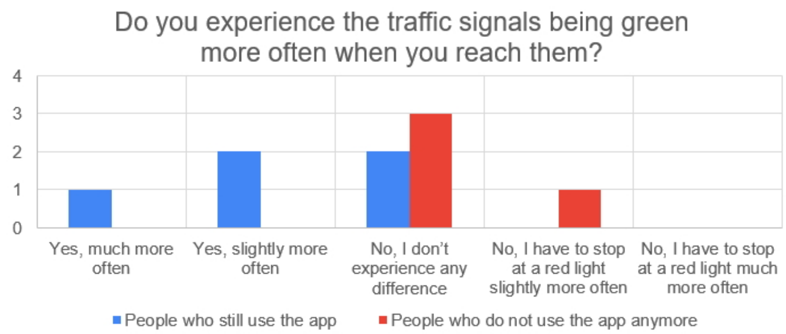

Figure 5.3: Experiences of how much extra green lights users get (y-axis displays the number of times that answer was given)

5.2. Qualitative evaluation of the apps

Based on chapters 2 and 4 and the experiences of the stakeholders described above, five criteria are selected based on which the existing four apps will be evaluated. These criteria are selected because when an app is evaluated on all five criteria, it should give a rather complete overview of the performance app.

- Bicycle traffic data
- User experience
- Privacy
- Innovation
- Future perspective

In the criterion ‘Bicycle traffic data’, the apps are evaluated on the data they generate for the municipality. The privacy of the users regarding this data is the second criterion. The user experience is evaluated next. Here mainly the feedback from users and municipalities is used to describe the results of the apps and experiences of users. The innovation criterion evaluates the apps on the aspect of added value and innovation compared to existing detectors for cyclists. At last, the future perspective of the apps is discussed. Each app is mentioned and compared with the other apps. The extent to which these apps can help municipalities reach their goals regarding bike usage can not specifically be evaluated based on this thesis. However, one can assume that a high number of users is one of the requirements to make these apps contribute to the goals of the municipality. In that case, an app that performs the best on the ‘user experience’ criterion can potentially also contribute the most towards the goals of the municipality.

5.2.1. Evaluation

Bicycle traffic data

The municipalities that were consulted for this thesis did not specify the need for bicycle travel data as one of the motivations for implementing a ‘green wave’-app. However, in the national Talking Traffic partnership, this data is of high value. From what is known about the apps, Schwung, SMART and CrossCycle are able to deliver this bicycle traffic data. Gathering this data is not explicitly described as one of the possibilities of SiBike on the website of Siemens. However, this is possible to integrate in the app as it already tracks the cyclist continuously. Siemens is, just like the developers of the other ‘green wave’-apps, one of the partners of the Talking Traffic partnership and is therefore involved with the development of the intelligent traffic light controllers and the use of bicycle data. Therefore it is likely that all four apps are able to provide the municipalities with cycling data or will be in the future.

User experience

As shown in chapter 4, the use of any ‘green wave’-app can result in a faster green light for the cyclist and a decrease in travel and waiting time. This is also what part of the respondents of the survey experienced. However, not every user had the feeling that the app worked. This is where the apps do all lack a certain transparency. As several municipalities stated, more feedback to the users would be a good function to add to the apps. Only in Schwung, there is some feedback to the user that shows how many ’Schwung-intersections’ the cyclist has passed and how many times the cyclist was ’seen’ by Schwung. It does not show when and where the use of the app paid off by an earlier green light.

The transparency could further be enhanced by the implementation of the ‘green wave’-apps at more (if not all) intersections in a city. This wish was found in the responses on the survey and was also the motivation of the municipality of ’s-Hertogenbosch to implement Schwung at all intersections in the city. When the app can be used throughout a whole city, users might experience the results of the app more. Traffic signals that work with the app will also be the routes of more cyclists, so more cyclists can use the app.

What adds to the user experience of SMART is the reward scheme where users can earn credits for taking the bike or public transport. Schwung is the only app that gives at least some feedback to the users. These factors make these two aps score better on this criterion than CrossCycle and SiBike.

Privacy

As found in the responses on the survey, users of the app are sometimes concerned about their privacy. It is therefore important that the apps do their job while guaranteeing the privacy of the users. This is a challenge that is faced in many innovative applications. The individual travel history in the Schwung app is stored on the users’ smartphone. Every trip, a new, anonymous ID is created to do the requests for green lights and to share the GPS-location with the municipality. Because of this anonymous ID, the privacy of the user is guaranteed. As the SMART app works with the Schwung technology, this privacy also applies for SMART app users. CrossCycle also generates anonymous GPS-data for the municipality. For the SiBike app, this is not known.

Innovation

All apps add a new technology to the detection of cyclists at intersections. CrossCycle and SiBike work similar to a second detector at intersections. The difference is that with these apps, the location of the virtual detector can be set and changed later by the municipality or developer. Another difference is that the municipality can give special priorities to the users of the apps or to groups of app users when these are detected. SiBike is somewhat more innovative than CrossCycle as users can plan their route in this app and can also see information such as available bicycle parking spots. (VMZ Berlin, s.d.)

The innovation of Schwung and SMART goes a bit further. By using route prediction, more accurate green requests can be made, without users having to plan their route in the app. These predictions can often not be made by regular detector loops at intersections. The conventional detector only detects that a cyclist is present, but it does not know anything about the route the cyclist is taking. Especially the possible future applications of the 'green wave'-apps for cyclists are innovative. The detection and prioritization of groups of cyclists and the data that the apps gather are big improvements compared to the conventional detectors.

Future perspective

The apps are all still being developed and tested. When more specific results of the apps become available and these results are positive, more municipalities might want to implement them. The municipalities that are already using one of the apps could decide to implement it at more intersections. The advantage of Schwung and CrossCycle is that the technology of the apps can also be implemented in existing apps. This increases the possibilities of the apps to gain more users. An example of this is the SMART app where the technology of Schwung is used. The Schwung app itself has approximately 5000 downloads in the Google Playstore and can be used in ten cities, while the SMART app can only be used in Enschede and has over 18000 downloads (Android and iOS combined). This can be explained by the fact that the SMART app already existed and already had many users when the Schwung technology was added to the app. The SMART app demonstrates that the option of implementing the technology of Schwung and CrossCycle in other apps can indirectly gain these apps many new users. This gives these two apps an advantage above the other apps.

Overview of evaluation

In table 5.1, the performance of each app on the five criteria is visualized with scores. A '0' means that the app did not perform significantly higher than the other apps. Apps that are performing better than an app with '0' get a '+' and apps that perform even better on a criterion get '++'. As can be seen in the table, Schwung performs the best in this evaluation. This is mainly because of the innovative route prediction and the possibility of implementation in an existing app. Note that the low score of the SiBike app is partly caused by a lack of information about the gathering of bicycle traffic data and privacy.

Table 5.1: Evaluation of existing apps

App	Traffic data	User experience	Privacy	Innovation	Future perspective
Schwung	+	+	++	++	+
SMART	+	+	++	++	0
CrossCycle	+	0	+	0	+
SiBike	0	0	0	+	0

6
Discussion

The goal of this research was to determine how the ‘green wave’-apps for cyclists can contribute to the cycling experience at intersections. In this chapter, the interesting results and findings of this research are discussed and possible limitations of the results are mentioned.

Case studies

The case studies in this thesis seem to find positive impact of the implementation of a ‘green wave’-app, which is in line with the results of the implementations of apps in Marburg and Enschede. The impact for cyclists on an intersection with only one detection loop is the best noticeable with a saved travel time of up to 4.4s, but cyclists can benefit from a ‘green wave’-app on intersections with more detection loops as well. This shows that the apps can have a positive impact for cyclists on most of the signalized intersections in the Netherlands, not only on the ones that do not yet have second or third detectors. Note that when intersections already have more than one detector for cyclists, the actual benefits from using a ‘green wave’-app might be less and mainly apply to faster cyclists.

An interesting result of the case studies is that the green time for the user of the app can be shorter than the green time for regular cyclists because less time is wasted by accelerating or decelerating when a ‘green wave’-app is used. The cyclist should, however, be notified of the granted green light well in advance, but not by already turning the light green as this would increase the required green time. This is where the other apps and systems described in chapter 3.1 become relevant. A combination of the ‘green wave’-apps to send the green light request and the other systems to give information to the cyclist about the granted green light request and the advised speed could be a solution. Further research and development has to be done to look into these possibilities and to determine the best way of notifying the cyclist of the granted green light.

The case studies are based on many assumptions. At first, the assumption is made that there is no other traffic at the intersection. Secondly, the speed and the acceleration and deceleration rate are based on average values. These assumptions make that the results of the case studies are only accurate for this traffic situation and for this average cyclist. However, when other traffic is present and a green light cannot be granted immediately, the ‘green wave’-app could potentially still benefit the cyclist when the green light request is made early enough. Further research could determine the results of the use of a ‘green wave’-app in other traffic situations, but in a situation without other traffic, these case studies already show the potential results for the average cyclist.

Results of the survey

With half of the respondents to the survey answering that they do not use the app anymore, it can be stated that the experiences with the apps are not all positive. An interesting result is that none of the respondents said to take the bike more often because of the app. This implies that the implementation of ‘green wave’-apps would not significantly contribute to the goal of the municipalities of increasing bike usage. At the current stage of implementation, with low user numbers for all of the ‘green wave’-apps, a significant impact of these apps on bike usage does indeed seem unlikely. However, it must be noted that most of the respondents also commented that they want the municipality to implement the app at more intersections. Implementing the app at more intersections might increase the user numbers and the positive experiences of users and might therefore increase the impact of the app on bike usage. Research has to be done into the effect of this further implementation of the ‘green wave’-apps on bike usage to determine if this assumption is right.

Another interesting result is the relation between the frequency of use and the positivity of the experiences with the app. It seems like the people who used the app more frequently on their everyday trips, more often experienced an increase in green lights. This could be explained with the self-learning route prediction of Schwung and SMART that can request more accurate green lights when the standard and everyday routes of the user are known.

The low number of respondents could make the results of the survey not applicable on all users of the ‘green wave’-apps. Because of this, the relation described above could also be partly coincidental. With Schwung, SMART, CrossCycle and SiBike being used by respectively 7, 1, 1 and 0 respondents, the survey cannot show significant differences between apps. A survey with more responses could be conducted to confirm the results of the survey conducted in this research. This more widespread survey could also show accurate statistics of users and could determine any differences in user experiences between the different apps.

Evaluation of the existing apps

In table 5.1 can be seen that most apps seem to satisfy the criteria of bicycle traffic data and privacy. Where the apps differ more in their performance in the other criteria, Schwung seems to satisfy most of them. Especially the innovative route prediction and the possibility of implementing its technology in other apps make this app stand out.

This evaluation is based on the results found in this thesis. As there is some information missing from some apps (like the data collection or the privacy policy of SiBike and more experiences of users of CrossCycle, SiBike and SMART), the outcome of this evaluation might be somewhat biased against these apps. However, this evaluation is based on all information available online, completed with the survey and stakeholder interviews. Improving the objectivity of this evaluation therefore requires a survey with more respondents, more information provided by the app developers, or preferably both.

Interesting are the improvements suggested by the municipalities and the respondents of the survey. More feedback in the apps about the results and accomplishments of the app makes it more clear for the user what the benefits are from using the app. Implementing the app at more intersections (and when possible at all of them) makes it more clear for app users where the app can work. Both of these suggested improvements seem to imply a lack of clarity about the way these apps work and how much users can actually benefit from them. This is in line with the responses on the survey where 6 of the 9 respondents did not experience any results of the use of a ‘green wave’-app and one of the respondents even deleted the app because he thought it was an April fools joke.

These suggested improvements are of course based on a limited number of stakeholders, so they might not speak for every stakeholder, but they do point out a logical problem. When people do not experience any impact of the use of an app, but they are somewhat concerned about their privacy, they tend to stop using the app. This was the exact answer of one of the respondents of the survey when asked about his privacy concerns.

7 Conclusion

By analyzing the existing 'green wave'-apps, the problems they aim to solve, their results and the experiences of stakeholders, this thesis has shown how the existing 'green wave'-apps that influence the green phase of traffic signals for cyclists can contribute positively to the experience of cycling. Both cyclists and municipalities can benefit from the use of these apps.

The results of the case studies, as well as the results of the 'green wave'-apps in Marburg and in Enschede, showed that the apps can have a positive impact on waiting times and the energy use of cyclists, two factors that in the literature study were found to be important for the convenience of cycling. This positive impact can apply to intersections with all kinds of detector configurations, but the biggest impact can be found at intersections that currently only have one detection loop for cyclists. The impact of the implementation of a 'green wave'-app at intersections that currently have two or more detection loops is mainly visible in the detection of the faster cyclists. Without a 'green wave'-app, they are often not being detected early enough by conventional detection loops.

Municipalities are mainly positive about the existing 'green wave'-apps as the implementation of the apps is a way of supporting innovation and supporting bike usage. However, the low numbers of users and the results of the survey conducted during this research do suggest that in the current state of implementation, a big impact on bike usage is unlikely. Therefore, based on this research, it cannot be stated that the implementation of these apps currently significantly contributes to this goal.

The survey conducted during this research showed that not all respondents experienced an increase in the number of times they got an early green light while using a 'green wave'-app. While this is based on a low number of respondents, it is in line with the results of the survey from Enschede. The more frequent users of the apps seemed to experience this increase in early green lights more often than respondents who occasionally used the app. Most of the respondents that did not experience this increase, stopped using the app because of this.

With the route prediction of Schwung and SMART being a more innovative solution than the route planner in the SiBike app and the live GPS-tracking of CrossCycle, there are some differences between the apps. However, all four analyzed 'green wave'-apps have the same main function, requesting a green light earlier than conventional detectors. Possible improvements of the apps should be focused on improving the experience of users. The implementation of the apps at more intersections should give cyclists more incentive to use the app. This could be combined with more feedback in the app about when and where the cyclist got an earlier green light as a result of the request made by the 'green wave'-app. With this feedback, users can see the benefits of using the app more clearly, which might increase user satisfaction.

Based on the results of this thesis, some recommendations for further research can be made. For example, a micro-simulation could be used to determine the impact of 'green wave'-apps on traffic flows and capacities of intersections in different traffic situations. This could lead to more insights about the impact of the apps on other traffic and could also show the effect of high numbers of cyclists using a 'green wave'-app. Further insights in user experiences and differences in experiences between users of different apps could be obtained from conducting a new survey. This survey should have responses of users of each of the four existing apps (and any new ‘green wave’-apps that might be developed in the future) and preferably have a significant number of respondents.

Future studies could look at the importance of the use of route predictions or route planners in apps for requesting green lights. Do apps with these technologies have significant advantages over apps with only live GPS-tracking? Another interesting study could be to look at the way the cyclist is notified of the granted green light. Can this be done without already turning the light green far in advance and is a speed advice to the cyclist important for catching the green light? These questions could not be answered in the given time frame of this thesis, but they are relevant to the further development of ‘green wave’-apps for cyclists.

This thesis was one of the first to be written about this innovative use of technology for cyclists. It showed that the existing ‘green wave’-apps for cyclists theoretically can contribute positively to the experience of cycling and already seem to decrease waiting times for cyclists in some cities. An increased convenience of cycling could contribute to the popularity of cycling as a sustainable mode of transport. However, the experiences of cyclists are currently only partly positive. The suggested improvements of the apps could help to increase the number of users and to further improve user experiences.

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A

Survey for users of ‘green wave’-apps for cyclists

A.1. Dutch questions

1. Welke ‘sneller groen’-app voor fietsers heeft u al eens gebruikt?

- Schwung
- SMART
- CrossCycle
- SiBike
- Andere, namelijk:

2. Gebruikt u de app nog steeds?

- Ja
- Nee

Wanneer u de app niet meer gebruikt, vul dan de volgende meerkeuzevragen in over de tijd waarin u de app wel gebruikte.

3. In welke gemeente gebruikt u deze app?

- Almere
- Breda
- Den Bosch
- Dordrecht
- Eindhoven
- Emmen
- Enschede
- Hilversum
- Lelystad
- Noordoostpolder
- Tilburg
- Anders, namelijk:

4. Hoe vaak fietst u met de app in gebruik?

- Elke dag
- Een paar keer per week
- Eens in de twee weken
- Een keer per maand
- (Bijna) nooit

5. Welke zin beschrijft het best hoe u de app gebruikt? (Meerdere antwoorden mogelijk)

- Ik gebruik de app (bijna) elke dag
- Ik gebruik de app voornamelijk op mijn vaste routes (naar werk/school)
- Ik gebruik de app voornamelijk wanneer ik haast heb
- Ik gebruik de app voornamelijk wanneer ik voor mijn plezier ga fietsen
- Ik vergeet de app vaak te activeren
- Anders, namelijk:

6. Merkt u dat u vaker kunt doorrijden bij verkeerslichten dan voordat u de app gebruikte?

- Ja, ik kan nu veel vaker doorrijden bij het verkeerslicht
- Ja, ik kan iets vaker doorrijden bij het verkeerslicht
- Nee, ik merk geen verschil
- Nee, ik moet juist vaker stoppen voor een rood verkeerslicht
- Anders, namelijk:

7. Verandert het gebruik van de app hoe vaak u kiest voor de fiets als vervoersmiddel in plaats van bijvoorbeeld het openbaar vervoer of de auto?

- Ja, ik kies nu veel vaker voor de fiets
- Ja, ik kies nu iets vaker voor de fiets
- Nee, ik kies even vaak voor de fiets als voordat ik de app gebruikte
- Nee, ik kies minder vaak voor de fiets
- Anders, namelijk:

8. Wat motiveert u om de app te gebruiken? Of waarom bent u met het gebruiken van de app gestopt?

(open vraag)

9. Zijn er functies die u graag toegevoegd zou willen hebben aan de app die u gebruikt?

(open vraag)

10. Maakt u zich zorgen om uw privacy wat betreft uw locatie gegevens die de app gebruikt?

- Ik maak mij ernstig zorgen
- Ik maak mij enigszins zorgen
- Ik maak mij niet echt zorgen
- Ik maak mij totaal geen zorgen
- Anders, namelijk:

11. In hoeverre zou u anderen aanraden om ook de app te gaan gebruiken?

- Ik zou dit sterk aanraden
- Ik zou dit aanraden
- Geen mening
- Ik zou dit afraden
- Ik zou dit sterk afraden

A.2. English questions

1. Which ‘green wave’-app for cyclists have you used before?

- Schwung
- SMART
- CrossCycle
- SiBike
- Other,...

2. Do you still use the app?

- Yes
- No

If you do not use the app anymore, please fill in the following questions with the time you did use it in mind.

3. In which municipality do you use the app? (You can tick multiple boxes)
• Almere
• Breda
• Den Bosch
• Dordrecht
• Eindhoven
• Emmen
• Enschede
• Hilversum
• Lelystad
• Noordoostpolder
• Tilburg
• Other,...

4. How often do you cycle with the app?
• Every day
• A few times per week
• Once every two weeks
• Once a month
• Hardly ever

5. Which sentence describes the way you use the app the best? (You can tick multiple boxes)
• I use the app (almost) every time I cycle
• I use the app mainly on my everyday routes (going to work/school)
• I use the app mainly when I am in a hurry
• I use the app mainly when I cycle around for fun
• I often forget to switch the app on
• Other,...

6. Do you experience that the traffic signals are green more often at the moment that you reach them? (Compared tot he time before you started using the app)
• Yes, much more often
• Yes, slightly more often
• No, I don't experience any difference
• No, I have to stop at a red light slightly more often
• No, I have to stop at a red light much more often
• Other,...

7. Does the use of the app make you choose the bike above another mode of transport more often? (Compared to before you used the app.)
• Yes, I choose the bike much more often
• Yes, I choose the bike slightly more often
• No, the use of the app did not make a difference
• No, I choose the bike slightly less often.
• No, I choose the bike much less often.
• Other,...

8. Are you concerned about your privacy regarding the GPS-data that the app uses?
• Yes, I am highly concerned
• Yes, I am slightly concerned
• No, I am not really concerned
• No, I am not concerned at all

• Other,...

9. What is your motivation to use the app? Or, in case you do not use the app anymore, why did you stop using the app?
(open question)

10. Are there any other functions that you would like the app to have? Or do you have any other comments on the app?
(open question)

11. Would you recommend others to use the app?
• I would highly recommend it
• I would recommend it
• No opinion
• I would not really recommend it
• I would definitely not recommend it

B
Responses to survey for users of ‘green wave’-apps for cyclists

The answers to the survey are in Dutch because this is the language that all of the respondents preferred.

Figure B.1: Question 1

Figure B.2: Question 2

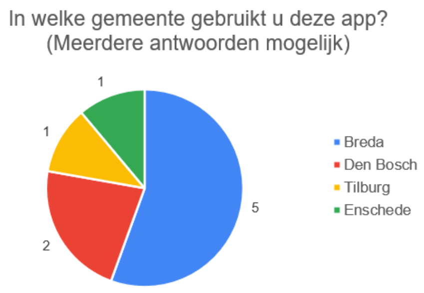

Figure B.3: Question 3

Figure B.4: Question 4

Figure B.5: Question 5

Figure B.6: Question 6

Figure B.7: Question 7

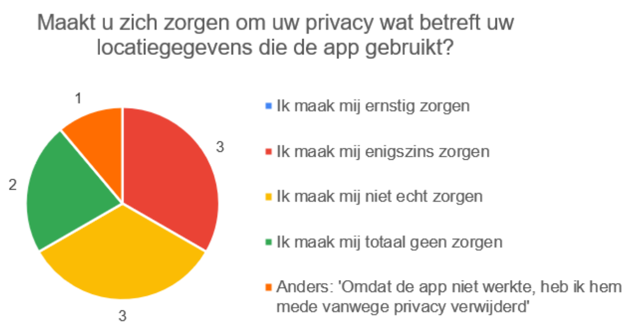

Figure B.8: Question 8

Question 9

Wat motiveert u om de app te gebruiken? Of waarom bent u met het gebruiken van de app gestopt?

- De app gaf in Breda geen data meer dus ik heb de app verwijderd. De app heeft het wel gedaan maar stopte naar verloop van tijd.
- Ik dacht meer groen dus doorfietsen
- Werkte niet
- Merk geen verschil met of zonder app
- De app werkte niet en het was maar bij 1 stoplicht in tilburg (gasthuisring)
- De verkeerslichten die in het systeem zitten, liggen precies op mijn fietsroute, vandaar dat het interessant is om deze app te gebruiken
- Breda heeft veel (ook nog slecht afgestelde) verkeerslichten. Als fietser kan je daardoor niet doorfietsen. Ik hoopte met Schwung een verbetering te krijgen. Maar helaas is daar weinig van te merken.
- De beloningen

Question 10

Zijn er functies die u graag toegevoegd zou willen zien worden aan de app die u gebruikt? Of heeft u nog andere opmerkingen over de app?

- Meer locaties svp
- Het is een best beperkte app toen ik het had.
- Ja meer stoplichten toevoegen in Breda
- Meer stoplichten!
- Meer verkeerslichten aansluiten
- ”Er zijn nu maar 4 verkeerslichten in Breda waarbij Schwung werkt. Graag dit uitbreiden.
- Het zou ook leuk zijn om te zien hoe vaak de Schwung-app sneller groen heeft gegeven; nu zie je het alleen voor vandaag.”
- Nee

Figure B.9: Question 11

Figure B.10: Question 12

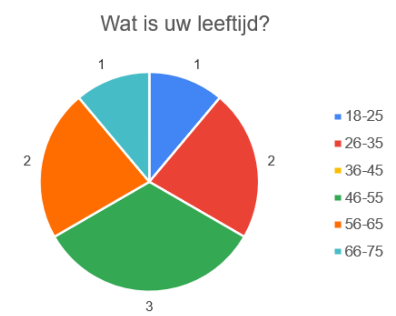

Figure B.11: Question 13