The effect on traffic delay because of the ViNotion system for cyclists at Poortlandplein, Delft

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The effect on traffic delay because of the ViNotion system for cyclists at Poortlandplein, Delft

Analysis of provided data for the Poortlandplein intersection in Delft, which gives an insight on traffic influences because of the ViNotion system.

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Figure on cover: (ViNotion, 2024)

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Preface

This report contains the Bachelor End Project of Casper Polet for the course CTB3000-16 during Q4 of 2023-2024. This report lies in the category of Transport Planning, which is one of the main topics in the bachelor of Civil Engineering in Delft University of Technology. As a cyclist, I am a frequent road user that often experience delays when training with my bike. I often wonder why a lot of people say that cycling has to be a huge priority in traffic, whilst it is difficult to experience in reality. Hence why this is a great opportunity to delve deeper into this subject.

This report consists of a multiple-week research, in which the intersection of Poortlandplein in Delft is analyzed using data. Chapter 1 covers the Introduction, and the literature review is provided in Chapter 2. Chapter 3 covers the Methodology part. Chapter 4 covers the Data Analysis part, which is especially relevant for people who want to improve the ViNotion system. From here, the Discussions, Conclusions and Recommendations will be provided. These Chapters are of interest for people who want to see what the impact of ViNotion is on the Poortlandplein intersection.

I want to give many thanks to Dr.ir. A.M. (Maria) Salomons for helping me with the startup of this course. I want to thank my examiners and supervisors Dr. Y. (Yufei) Yuan, Dr. S. (Shadi) Sharif Azadeh and K. (Kuldeep) Kavta for helping me through this project. I also want to thank Peter Broekhuijsen from the municipality of Delft for providing me with the right data, and for helping me to get familiar with YAVV. Lastly, I want to thank my group members D. van den Brug, J. Jorritsma, M. el Aazizi and B. Nauta for providing me with feedback every week.

Katwijk, May 2024
Casper Polet

Summary

Delft is a city in the Netherlands that wants to promote the use of bikes as much as possible, as cycling to work or university is more environmentally friendly and requires less space in traffic then cars. One way to make cycling more appealing is to reduce the travel delay at signalized intersections. Therefore, the municipality in Delft has implemented a detection system called ViNotion at the Poortlandplein intersection. This system gives priority to groups of at least five cyclists travelling southwards, mainly to the campus of the Delft University of Technology.

This report focusses on the following main question: “What is the effect of the ViNotion system at the Poortlandplein intersection on travel delay for cyclists and what lessons can be learned to improve the system?”

VLOG-data from relevant working days in April 2023 and 2024 have been read with YAVV. The following variables have been used for this report: waiting time for first cyclist at intersection; traffic flow for cyclists in every direction and the number of times the ViNotion system has given priority of cyclists. The dataset consists of over 200 datapoints per year. The Student’s t-test is performed to have a clear idea about the effect of ViNotion on the travel delay. Note that the change in traffic flow, which means a busier intersection and thus potentially longer waiting times, has not been taken into consideration in this report. Also, there has been no research for the travel delay for cars.

After performing the T-test, it became clear that the ViNotion system has a significant impact on the waiting time. As can be seen in Figure 1, the median of the waiting time for the first cyclist coming up to a red light at the intersection dropped by 3 seconds, despite the increase of the flow of both cars and cyclists. It can be stated that other legs of the intersection saw an increase of waiting time, but given that the traffic flow here is way smaller, the total waiting time for every cyclist will still be reduced.

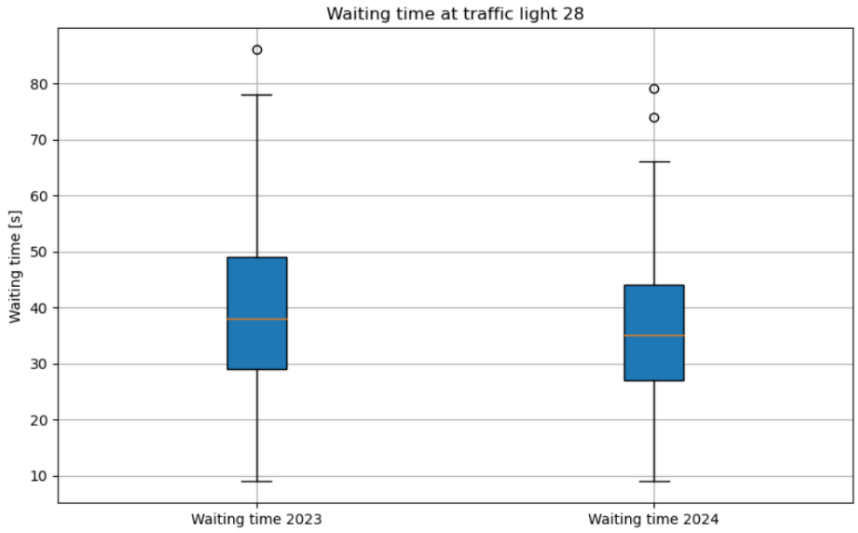

Figure 1: boxplot of the waiting times at traffic light 28

ViNotion has a positive impact on the Poortlandplein-intersection. Within a year, a 28.5% increase in cyclists using the intersection has been measured. Despite the intersection getting busier, the travel delay has been reduced. Further research is recommended tough, as the travel delay for cars has not been taken into consideration in this report and thus is not known.

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1. Introduction

The bike is a great way to commute to work, university or to a spare time activity. The bike requires less space in traffic and is also more ecologically friendly compared to taking the car. This is the reason why municipalities want to make it more attractive for people to use their bikes. One of the ways to do this is to make commuting by bike faster by limiting the travel delay. The municipality of Delft is using a special camera that gives priority to cyclists at the traffic light at the Poortlandplein intersection (see Figure 2) when going from Julianalaan to Schoenmakersstraat. This camera is called the ViNotion camera and makes use of a special software that receives data. 'ViNotion empowers governments, institutions, organizations, and commercial companies with state-of-the-art video analytics and smart camera technologies for data-driven decision-making and planning (ViNotion, 2024).' This so-called CAM-messages are then processed and, if five or more cyclists enter the traffic light, priority is given. This module is called the "Fiets Peloton Module", or FPM (Broekhuijsen, 2024). Which is the translation of Bike Peloton Module in Dutch.

Figure 2: Overview of the Poortlandplein-intersection (Maps, 2024)

The intersection is an important node in the city of Delft, which is known for its big university and innovative ways of solving problems. The campus of the university is lying southwards of the intersection. Students mostly live in the northern part of the intersection, and thus travel from Julianalaan to Mijnbouwstraat or Schoenmakersstraat. Figure 3 shows a bigger map in

which the intersection is shown, and the position of the intersection is visible compared to the entire city of Delft.

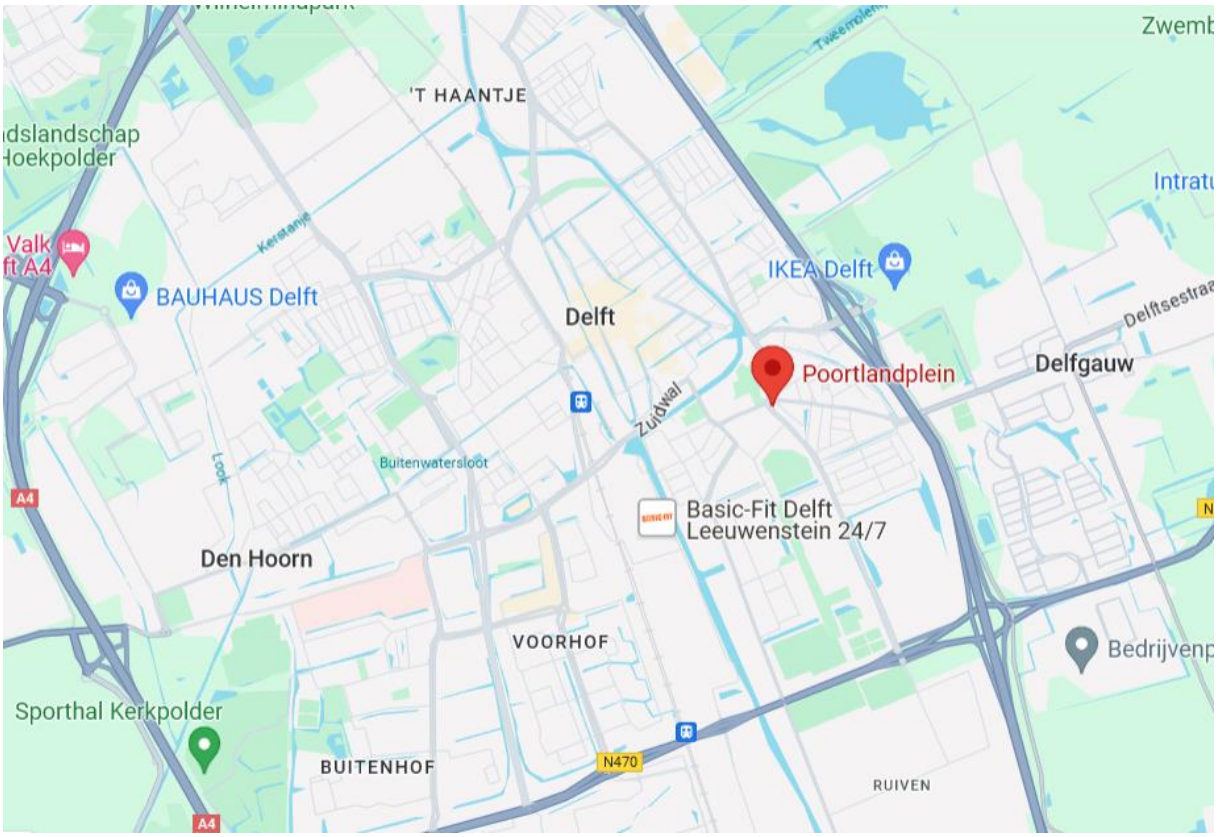


Figure 3: Poortlandplein shown on the map of Delft (Maps, 2024)

1.1 Motivation

In the Netherlands, the number of cyclists on the road is very significant. There are multiple benefits of having a lot of cyclists on the road. Cyclists do not take a lot of space in the traffic, which is especially beneficial in urban areas. Also, using bikes for transportation contributes to a greener world. The municipality of Delft wants to stimulate as many people as possible to use their bikes to work, school, studies etc. Therefore, it is necessary to make the use of bikes as appealing as possible without, if possible, negatively impacting the travel time of cars.

One of the potential possibilities to make cycling more appealing, is making sure that cyclists have to stop less. This impacts the comfort of the cyclists, as they do not have to use their brakes and come to a stop. It is also worth noting that the travel time of the cyclists will go down because of this. Looking at when cyclists come to a stop, it is mostly at intersections to give priority to a car, shows a study at Linköping University. ‘Faster cyclists were delayed more when the infrastructure required a stop regardless of the traffic situation, like at a red traffic light or a stop sign. The members of the so-called ‘comfort cyclists’ group were delayed the most in a roundabout with mixed traffic, where many chose to get off their bike and walk (Kircher, 2018).’

In the Mobility program in Delft for 2040, published by the municipality of Delft, it is clear that the traffic flows are getting bigger and bigger, and that this might lead to more congestion in the future. This is one of the reasons to try and get people to use their bikes more, as a cyclist needs 28 times less space than cars driving at 50 km/h. In Figure 4, a graphical

display is provided. This figure shows the big difference in used space between a moving bicycle and car.

It is also stated that the city of Delft wants to improve itself by making traffic more environmentally friendly, as well as reducing noise. Cycling can have an important role in fulfilling these goals, as cycling is good for the environment. Therefore, the municipality wants to look how they can improve the comfort, safety and travel time for cyclists. As 50% of road users in the city are already cyclists and Delft has an average of 0,5 cars per household compared to an average of 1.0 in the Netherlands (Delft, 2024), this seems like quite a big challenge that needs innovative solutions, but at the same time there is a huge potential to develop the city even more.

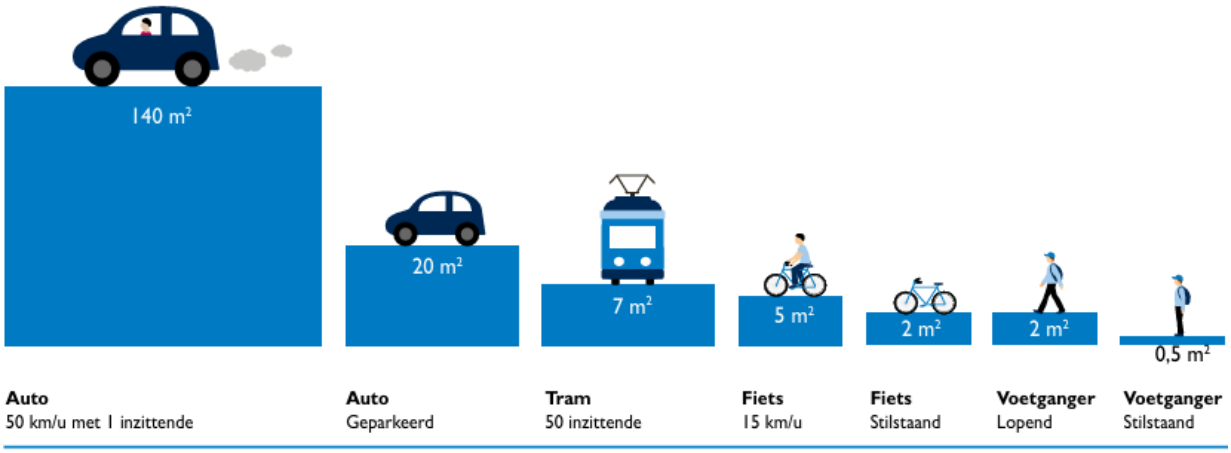


Figure 4: Graph of area per used vehicle (Delft, 2024)

1.2 Problem Analysis

Especially on workdays between 8:00 and 9:00, there are a lot of students on the road that use their bikes to go to campus. On working days, it is common that more than 500 cyclists make use of the Poortlandplein intersection between 8:00 and 9:00 only. Especially at Poortlandplein, there are a lot of cyclists at the intersection, travelling from Julianalaan to Schoenmakersstraat. A lot of times, there are many students waiting for the traffic lights. Sometimes, the number of cyclists waiting for the traffic lights is way bigger than the number of cars passing through. This feels unfair, as Delft wants to prioritize cycling over cars. This is where the ViNotion system comes into play. With the use of the ViNotion camera, the number of cyclists approaching the traffic light can be determined. Also, the speed of the cyclist can be determined. Because of this technology, cyclists can be given priority when they are approaching the traffic light. This leads to less travel time for cyclists. But of course, giving priority to cyclists means there will be a delay in travel time for cars.

Currently, the ViNotion system only gives priority to groups of cyclists. When the camera sees 5 or more cyclists in a group, they will get priority and the traffic light will be green. There are a few problems with this system. One of which is that a group of 4 cyclists do not get priority at the traffic lights. Also, when another group of four cyclists approach the traffic lights a few seconds later, then there might be a group of eight cyclists waiting for the traffic light without getting priority. The criteria are that the camera needs to detect five or more cyclists on the exact same time. The detection area in which these five cyclists need to be, is approximately 100 metres long. Note that there always need to be at least five cyclists within this area to give priority. If four cyclists go through and later on, a few more enter, the detection system will not give priority.

1.3 Objective and research questions

This report aims to analyze the data at the Poortlandplein intersection. The objective of this report is to get an idea of the effect of ViNotion on the travel delay for cyclists at every leg of the intersection. After this, recommendations will be provided as to how to optimize this system even more. Please note that there were only eight weeks to create this report, and thus it is highly likely that extra research is needed to get a more complete overview of this intersection. For example, the travel delay for cars is left out of this report, as this was going to take to much time to develop.

The following **research question** will be answered in this report:

“What is the effect of the ViNotion system at the Poortlandplein intersection on travel delay for cyclists?”

Furthermore, the following **sub questions** will be answered:

“Which analysis method can be used to see if the same parameters, received from different dates, show any significant differences?”

It is already clear that data will be collected and analyzed from before and after the implementation of the ViNotion system. This sub question will help to find a proper way to test the difference in the analyzed dataset. This method will then be used in the report. This sub question will be answered in the Methodology Chapter of this report.

"Which variables have to be considered when analyzing the difference in travel delay before and after ViNotion for cyclists on Poortlandplein?"

When wanting to have a clear vision on the difference in travel delay for cyclists, it is important to understand which variables can give valuable information about this. In the Methodology part, the goal is to answer this sub question to have a clear view about what part of the data has to be analyzed to eventually answer the research question.

"What is the difference in waiting time at every traffic light for cyclists on Poortlandplein, when looking at before and after the implementation of the ViNotion system?"

This sub question will be answered during the Data Analysis chapter in this report. It is important to dive deep into the situation before and after the ViNotion system, and see what the differences are in the data that is collected during the Data Collection part.

"What lessons can be learned about the results obtained from the data analysis for future use/improvements of the ViNotion system?"

After analyzing the data, there should be a clear vision on lessons that can be learned to make the ViNotion system even better in the future. This sub question will be answered in the Discussion Chapter and helps answering the research question by providing clear ways to improve the system.

1.4 Definitions of Key Concepts

During the course of this report, a few key concepts are used that have to be defined. These keywords are mostly concepts used when processing the information that the ViNotion camera receives. This information has to be converted into readable numbers, so that a proper analysis can be done.

1.4.1 CAM-data

CAM is an abbreviation for Cooperative Awareness Messages. These CAM messages are exchanged in the ITS Network between ITS-stations to create and maintain awareness and to support cooperative performance of vehicles using the road network (CROW, 2018). The ITS-station becomes aware of the presence, type and status of the information and can convert this information in multiple ways. There are several applications of ITS. One of which is VLOG-data, which is explained in Chapter 1.4.2.

1.4.2 VLOG-data

CAM-messages will be received by an ITS-station and will then be converted to VLOG-data. VLOG-data is data that is taken from a VRI. VRI stands for "Verkeers Regel Installatie", which means "Traffic Control Installation". VLOG stands for VRI-Logging Data. VLOG-data is the most complete information one can get to analyze traffic data (Wegverkeer, sd). Apart from achieving VLOG-data, it is also important to have an application that can read the data and convert it into graphs and clear tables, so it is easy to understand for humans.

1.4.3 YAVV

VLOG-data is hard to read by itself. Therefore, software is made to make it easier to read the data and analyse it. The software used for this report is YAVV. YAVV stands for Yet Another VLOG Viewer and is also provided with a wiki, in which a lot of information is given about this program (CodingConnected, 2024). This wiki has been used multiple times during this report to get a clear idea about how to use the YAVV in its best way.

1.5 Reading Guide

The structure of the report is as follows: Chapter 1 covers the Introduction to the report. The introduction gives the Motivation, Problem Analysis and the Objective. Also, a definition of key concepts is provided. Chapter 2 is a Literature Review, where case studies will give more of an insight for this report. Chapter 3 covers the Methodology. Here, it is described how the research of this report will be done. Chapter 5 covers the Data Analysis part. After this, Chapter 6 will cover the Statistical Test. In Chapter 7, the Discussion will be covered in which the lessons that can be learned will be stated. Chapter 8 is about the Conclusion of the research- and sub-questions where recommendations will also be noted.

2. Literature Review

This chapter covers the Literature Review. As far as known, there has been no research that lies exactly in the scope of this project. But it is still beneficial to study the behavior of cyclists at an intersection, in order to get an idea of making the signalized intersection more effective. After all, it is important to make sure that the cyclists are happy about the intersection, and thus it is necessary to get an idea of the aspects that contribute to this happiness. This is also the demand from the municipality of Delft, in order to get more people in the Netherlands to use their bikes (Delft, 2024).

2.1 Cyclists pushing the button

An article has been published by Maria Salomons about behavior of cyclists at intersection when it comes to pushing buttons. It turns out that 77% of the social media posts expressed negative opinions towards traffic signals. 52% of the people believe that pushing buttons at intersections is ineffective. The main reasons for criticism were about hygienic reasons, long waiting times or safety issues. After using data provided by the municipality of the Hague, it can be concluded that 99,3% of the time, the detector detects the cyclists and thus the use of the button becomes unnecessary. The button is touched 85% of the time, tough. There is no correlation seen to the maximum waiting time and the number of times the button is pushed. It can be concluded that the negative comments on social media do not reflect what is seen in real life. Cyclists keep using the traffic lights. The negative comments might be because of covid or other concerns such as hygiene. It is advised to take these concerns seriously and give information to the people (Salomons).

This study shows that, whilst there is a negative view on signalized intersections by cyclists, the intersection will still be used. The type of button does not seem to matter a lot. But, given that there is such a negative view on social media, it can be stated that there lies an opportunity to change the viewpoint of the cyclists and make them more satisfied with the intersection. As one of the major concerns is the long waiting time, this has to be changed. The study of Salomons shows that ViNotion can not only be used to get cyclists from A to B faster, it can also be stated that the cyclists will be more satisfied. This may lead to more people using their bikes on their way to work, university etc.

For the Poortlandplein intersection (and thus this report), this means that reducing the waiting time of the intersection leads to more positivity towards using the bike for transportation. A positive view may eventually lead to more happy cyclists, and thus a higher usage of bicycles, which leads to a more environmentally friendly way of transportation in Delft. As the study shows that the type of push button does not contribute to waiting times or a positive view of the intersection, it can be stated that the type of push buttons at Poortlandplein do not have to be taken into account.

2.2 Delay at intersections

An article published by Gent University studied the delay of cyclists at multiple intersections using GPS. Whilst the real scope of the article was about the GPS, the interesting point of the study for this report is the measured travel delays and the day it is calculated.

The travel delay can be calculated with the following formula:

$$\mathrm{tw} = \Delta\mathrm{t} - \mathrm{tc}$$

with:

tw = the additional delay
$\Delta t = \text{the extra time needed to travel}$
tc = the ideal cycling time to pass the junction.

The ideal cycling time tc can be estimated by taking the normal average speed of a cyclist in Belgium, which is 18 km/h (vc). The distance (d) is known because of the GPS-data, this means that the following formula can be applied.

$$tw = \Delta t - d/vc$$

The results of this report shows that the measured delay is the same at almost all GPS points, but of course it differs per leg and per intersection. The lowest value of the delay is measured at 15 s, whilst the highest value approaches 60 s.

The lesson that can be learned based on this report is that the travel delay might be different at different legs of the intersection. Therefore, it is important to analyze every leg of the intersection separately and consider what leg is the most important to take into account when willing to minimalize the travel delay (Gillis, 2020).

3. Methodology

This chapter covers the methodology of this report. Firstly, data before the use of the ViNotion and after the implementation of ViNotion will be collected and reviewed. The differences and similarities will be investigated and a decision as to what data is useful will be concluded. After this, data will be analyzed and reviewed using a statistical analysis. Finally, the data will be discussed and a conclusion will be formed.

3.1 Literature Review

Before the start of the data collection, a literature review will be conducted. There has never been research on the Poortlandplein intersection, but there have been other studies that looked int the behavior of cyclists at signalized intersections. These case studies can help to find useful information for the rest of this report. All the articles are taken from the scientific website Google Scholar. Y. Yuan also provided some handy reports to take a look at. The Literature Review part is handy to get background information, which helps to define the scope of the project better, and learns what the best approach is.

3.2 Data collection

Secondly, the data will be collected. The data will be provided by the municipality of Delft. This so-called VLOG-data will be read using YAVV (Yet Another VLOG Viewer). With YAVV, one can get an overview of the entire intersection and see when the traffic lights turn green, orange and red. YAVV also provides you with graphs and other statistics such as the cycle times, waiting times etc.

YAVV has two main ways to analyze the data. First of all, the phase log is provided. This phase log shows every traffic light and its color at every minute of the day. There is also information provided that are called “events”. One of these events is the event called “FPM_P1_PRI”. As can be seen in Figure 5, whenever the event happens or is true, a blue bar is provided. Note that the “FPM_P1_PRI” event has been moved to the upper part of the phase log for the purpose of the Figure.

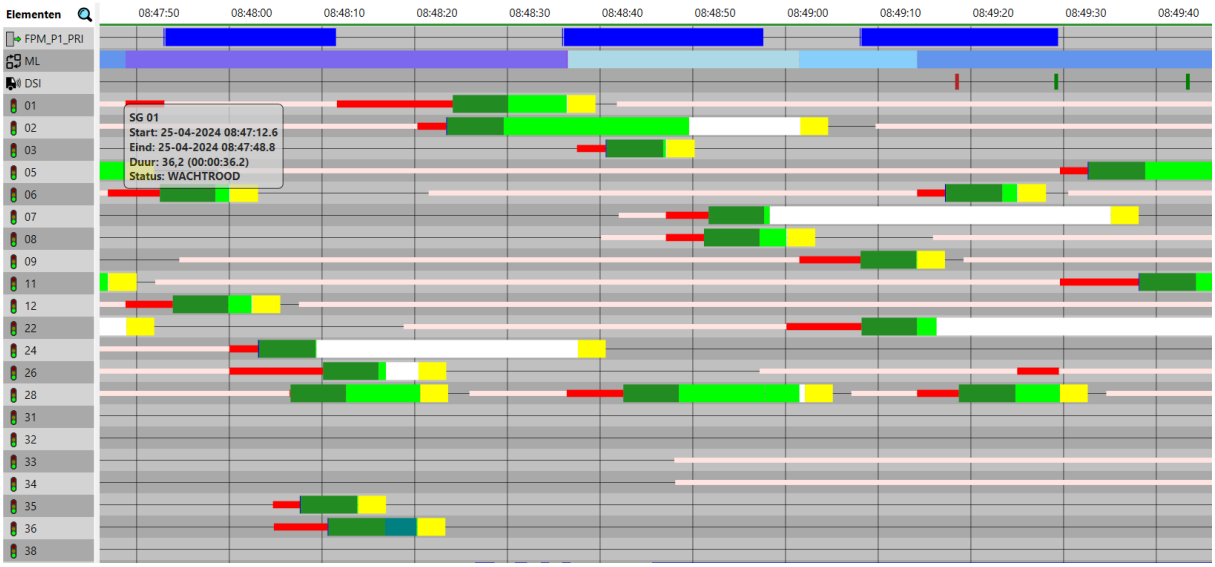
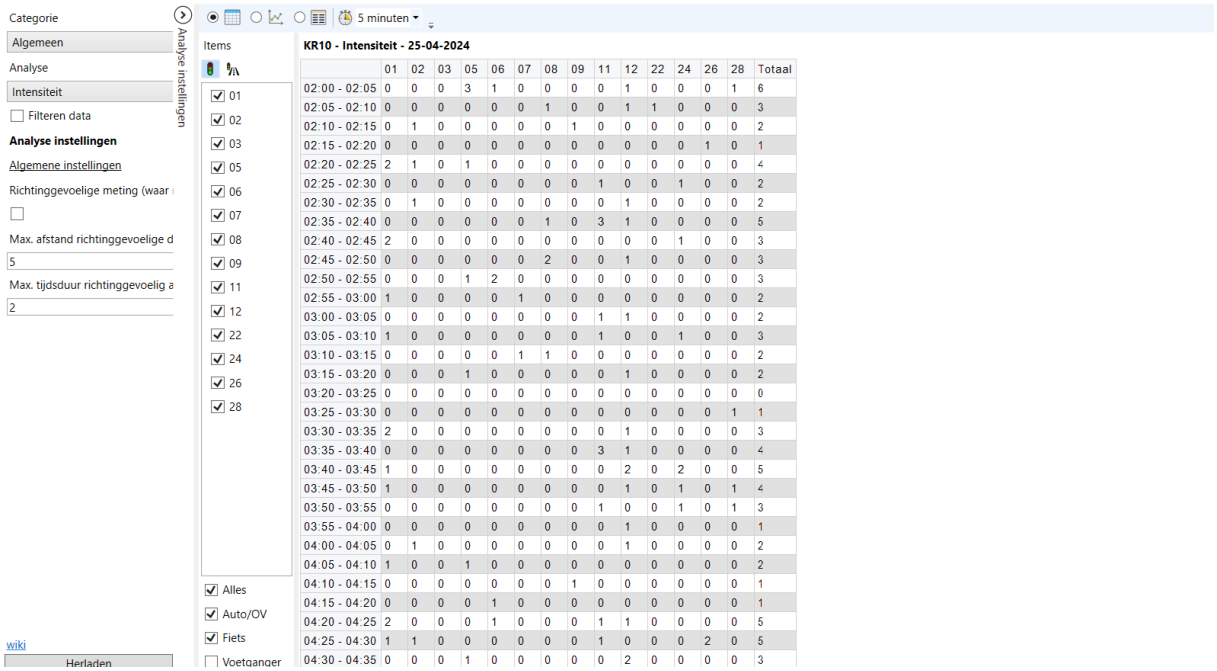


Figure 5: Phase-log of VLOG-data in YAVV

The second option is the analysis tab. Here, different variables are provided. All these variables are listed in Appendix B. Figure 6 shows an example of the analysis tab.



	01	02	03	05	06	07	08	09	11	12	22	24	26	28	Totaal
02:00 - 02:05	0	0	0	3	1	0	0	0	0	1	0	0	0	1	6
02:05 - 02:10	0	0	0	0	0	0	1	0	0	1	1	0	0	0	3
02:10 - 02:15	0	1	0	0	0	0	0	1	0	0	0	0	0	0	2
02:15 - 02:20	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
02:20 - 02:25	2	1	0	1	0	0	0	0	0	0	0	0	0	0	4
02:25 - 02:30	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2
02:30 - 02:35	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2
02:35 - 02:40	0	0	0	0	0	0	1	0	3	1	0	0	0	0	5
02:40 - 02:45	2	0	0	0	0	0	0	0	0	0	0	1	0	0	3
02:45 - 02:50	0	0	0	0	0	0	2	0	0	1	0	0	0	0	3
02:50 - 02:55	0	0	0	1	2	0	0	0	0	0	0	0	0	0	3
02:55 - 03:00	1	0	0	0	0	1	0	0	0	0	0	0	0	0	2
03:00 - 03:05	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
03:05 - 03:10	1	0	0	0	0	0	0	0	1	0	0	1	0	0	3
03:10 - 03:15	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2
03:15 - 03:20	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
03:20 - 03:25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
03:25 - 03:30	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
03:30 - 03:35	2	0	0	0	0	0	0	0	0	1	0	0	0	0	3
03:35 - 03:40	0	0	0	0	0	0	0	0	3	1	0	0	0	0	4
03:40 - 03:45	1	0	0	0	0	0	0	0	0	2	0	2	0	0	5
03:45 - 03:50	1	0	0	0	0	0	0	0	0	1	0	1	0	1	4
03:50 - 03:55	0	0	0	0	0	0	0	0	1	0	0	1	0	1	3
03:55 - 04:00	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
04:00 - 04:05	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2
04:05 - 04:10	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
04:10 - 04:15	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
04:15 - 04:20	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
04:20 - 04:25	2	0	0	0	1	0	0	0	1	1	0	0	0	0	5
04:25 - 04:30	1	1	0	0	0	0	0	0	1	0	0	0	2	0	5
04:30 - 04:35	0	0	0	1	0	0	0	0	0	2	0	0	0	0	3

Figure 6: The analysis tab of YAVV

As the ViNotion system was implemented at November 2023, it is important to note that data from before and after implementation will be used. Therefore, data from the entire month of April 2023 and April 2024 will be collected.

As there is a ton of data available, it is important to make a decision as to what data is relevant to use for this report. Therefore, it is important to take a look at the intersection and when the busy moments (where ViNotion comes into play the most) occur. Because of the many students that have to go to campus, this is mainly on working days between 8:00 and 9:00 (Broekhuijsen, 2024). Therefore, an overview is made of working days in both April 2023 and April 2024, see Table 1. Note that in 2023, Easter and King's Day were both on working days. When taking a look at the data, these dates will not be relevant and thus be avoided. In April 2024, Easter Monday was on April 1st, whereas King's Day was on a Saturday, which isn't a working day at all. Note that therefore, April 2023 has 17 relevant days and April 2024 has 19 relevant days.

Workdays April 2023	Workdays April 2024
3-6 April	2-5 April
11-14 April	8-12 April
17-21 April	15-19 April
24-26 and 28 April	22-26 April

Table 1: Relevant (working) days in April 2023 and April 2024 in the Netherlands

Furthermore, a decision has to be made as to what data is relevant to use when researching the scope of this report. Both car traffic lights and cycling traffic lights are provided, but as this report focusses on cyclists only, the cycling traffic lights will be used. Table 2 gives an overview of all traffic lights that cover cyclists, whereas Appendix A shows the overview of the intersection with all numbered traffic lights.

Traffic light number:	Coming from:	Travelling to:
22	Nassaulaan	Mijnbouwstraat
24	Schoenmakersstraat	Julianalaan
26	Mijnbouwstraat	Nassaulaan
28	Julianalaan	Schoenmakersstraat

Table 2: Overview of all traffic lights for cyclists

3.2.1 Variables

Now that the relevant days and times of the day are known, the next step is to make a decision what variables are relevant. YAVV provides a lot of information, and as the research in this course can only take a couple of weeks, it is necessary to filter variables out if the relevancy for this report is limited. Appendix B shows the entire list of variables that are available in YAVV. Also, there is an option in YAVV that shows green times for every single traffic light, at every time of the day (see Appendix C). It is safe to say that the provided information is very detailed. Therefore, the decision is made to solely look at the provided variables listed in Appendix B. The relevant variables have been listed in Table 3.

Relevant data	Description
Traffic flow	Traffic flow is an important variable to take into account, as this tells how many cyclists enter the intersection on a specific. The traffic flow will be analyzed to find the correlation between this variable and the number of times the ViNotion system comes into play. Also, there might be a relation between the traffic flow and the waiting time. This datapoint will be taken for both the 2023 data as the 2024 data, and from all traffic lights for cyclists, so traffic lights 22, 24, 26 and 28.
Waiting time for first person	This variable shows the average waiting time for the first person coming up to the intersection. As this report focuses on waiting time for cyclists, it is easy to say that this variable is important to discuss, and that this variable will be analyzed. The question is whether the other variables will be influenced by this one or the other way around. This datapoint will be taken for both the 2023 data as the 2024 data, and from all traffic lights for cyclists, so traffic lights 22, 24, 26 and 28.
FPM_P1_PRI	The FPM_P1_PRI event statistic shows when the ViNotion system comes into play to give priority to cyclists. This variable is important to take into account, as this variable not only let other drivers go directly through, it will probably also increase the waiting time for cyclists on other traffic lights at the intersection. Note that this data is only available in the 2024 file, and thus will only be added there. As already mentioned, this data is only taken at traffic light 28.

Table 3: Variables used for this report

Both the traffic flow and waiting time for first person entering the intersection can be found in the analysis tab (see Figure 6 for an example). The analysis tab automatically provides these stats per 5 minutes. The stats can then be exported to Excel. The FPM_P1_PRI event has to be counted by hand, and will then be added to the Excel file. After doing so, a big Excel file will be made and exported as an csv-file. The data can then be imported in Python. The panda package of Python will be used to load in the data and to make different graphs.

3.3 Data Analysis

After the data is collected and filtered, it is time to analyze the data. Before focusing on cyclists, it is important to take a look at the flow of cars as well. If more cars enter the intersection means they will get more greentime and thus the waiting time of cyclists will go up. If there is an increase or decrease of more than 10%, this should be taken into account when analyzing the data. Furthermore, the data of the cyclists will be taken into Python, where a boxplot, scatter plot and bar graph will be made. These graphs give an insight to the differences in the datasets and also help the readability of this report. Note that, as mentioned in the data collection part, the differences in waiting time compared to traffic flow is taken. A higher traffic flow will lead to a more congested intersection, and thus it is expected that the traffic flow will influence the waiting time for cyclists. This will be done for all the trajectories of cyclists, as shown in Table 2. Also, a graphical overview of waiting time compared to the amount of ViNotion detections will be made for the 2024 data. These graphs will all be added to the report, and will also be reflected on.

3.3.1 Statistical Test

The rest of the data analysis will be in the form of a statistical test. The aim of the report is to find a difference in waiting time for cyclists for two different datasets, as defined above. As a result, the student's t-test is the best way to test this data. The student's t-test was designed by William Sealy Gosset. He published his design under the pseudonym of "Student", hence why it is still called the student t-test nowadays (Wikipedia, 2024). The aim of this t-test is to test whether the null-hypothesis is true or false. The t-test does so by calculating the p-value. If this value is lower than 0.05, the null-hypothesis can be rejected (Teacher, 2016).

The null-hypothesis H0 for the t-test is as follows: "The 2024 data shows the same waiting time for cyclists for the same flow". Based on the hypothesis, it can be stated that a two-tailed t-test will be performed. The test will be performed in Python, and thus a code will be written. The hypothesis will be rejected if the p-value is lower than 0.05, which would mean that the ViNotion camera has a significant influence on waiting time for cyclists at traffic light 28.

4. Data Analysis

This chapter covers the analysis of the provided data. In this chapter, the data that is collected and presented in Chapter 3 will be analyzed. Graphs will be provided. First of all, the relevant days from the provided data will be analyzed. After that, a number of different sorts of relevant data will all be stated and put into graphs with the help of Python.

4.1 Effect of traffic flow

The traffic flow of the Poortlandplein intersection influences the waiting time of the cyclists. The busier the intersection, the longer it will take in general to have a green light. This means that it is important to get an insight on the flow of cyclists and cars at the Poortlandplein intersection. Table 4 shows the total traffic flow between 8:00 and 9:00 of the cars in both April 2023 and April 2024. Note that only the relevant dates as mentioned in Table 2 are taken into account.

Date (2023)	Flow		Date (2024)	Flow
April 3rd	1515		April 2nd	1568
April 4th	1576		April 3rd	1616
April 5th	1544		April 4th	1728
April 6th	1590		April 5th	1398
April 11th	1580		April 8th	1499
April 12th	1609		April 9th	1483
April 13th	1653		April 10th	1427
April 14th	1532		April 11th	1590
April 17th	1641		April 12th	1410
April 18th	1525		April 15th	1636
April 19th	1575		April 16th	1974
April 20th	1618		April 17th	1553
April 21st	1395		April 18th	1644
April 24th	1391		April 19th	1626
April 25th	1311		April 22nd	1518
April 26th	1180		April 23rd	1508
April 28th	772		April 24th	1521
TOTAL	25007		TOTAL	26699
AVERAGE	1471		AVERAGE	1571

Table 4: Traffic flow of cars at Poortlandplein

There is a 6.79% increase in cars entering Poortlandplein intersection between 8:00 and 9:00. Despite this increase, the assumption will be made that this increase of cars does not have an influence on the waiting time for cyclists, when comparing 2023 and 2024. Therefore, the influence of cars on the intersection will not be used in this report. It is recommended, tough, to use this information when analyzing this intersection in a later stadium.

Now that the change of flow for cars is known, it is time to take a look at the flow from the cyclists. Table 5 shows the daily flow for cyclists. Over here, a 28,5% increase in flow is notified. Because of the assumption that the increase for cars is not taken into account, the increase for cyclists will not have an effect on the tests that will be performed. Again, for further research, it will be interesting to consider the change of flow for cyclists, and also answer the question why there is such a huge increase in flow for cyclists on Poortlandplein.

Date (2023)	Flow		Date (2024)	Flow
April 3rd	486		April 2nd	691
April 4th	548		April 3rd	574
April 5th	483		April 4th	545
April 6th	514		April 5th	547
April 11th	555		April 8th	693
April 12th	484		April 9th	714
April 13th	524		April 10th	665
April 14th	535		April 11th	633
April 17th	613		April 12th	625
April 18th	554		April 15th	722
April 19th	573		April 16th	626
April 20th	498		April 17th	604
April 21st	473		April 18th	645
April 24th	439		April 19th	456
April 25th	507		April 22nd	769
April 26th	425		April 23rd	789
April 28th	273		April 24th	612
TOTAL	8484		TOTAL	10910
AVERAGE	499		AVERAGE	642

Table 5: Traffic flow of cyclists at Poortlandplein

4.2 Datapoints

In total, 408 datapoints have been used in this report. Each datapoint is taken over 5 minutes of time. Appendix C shows the data from 2023, that has been converted into a csv file and has then been imported in Python. Appendix D shows the data of 2024. Figure 7 shows a scatter plot of all the datapoints, where the y-axis is the waiting time and the x-axis is the flow. The scatter plot gives a clear overview of all the datapoints, and shows that a higher traffic flow in 2024 usually means a relatively low waiting time compared to 2023.

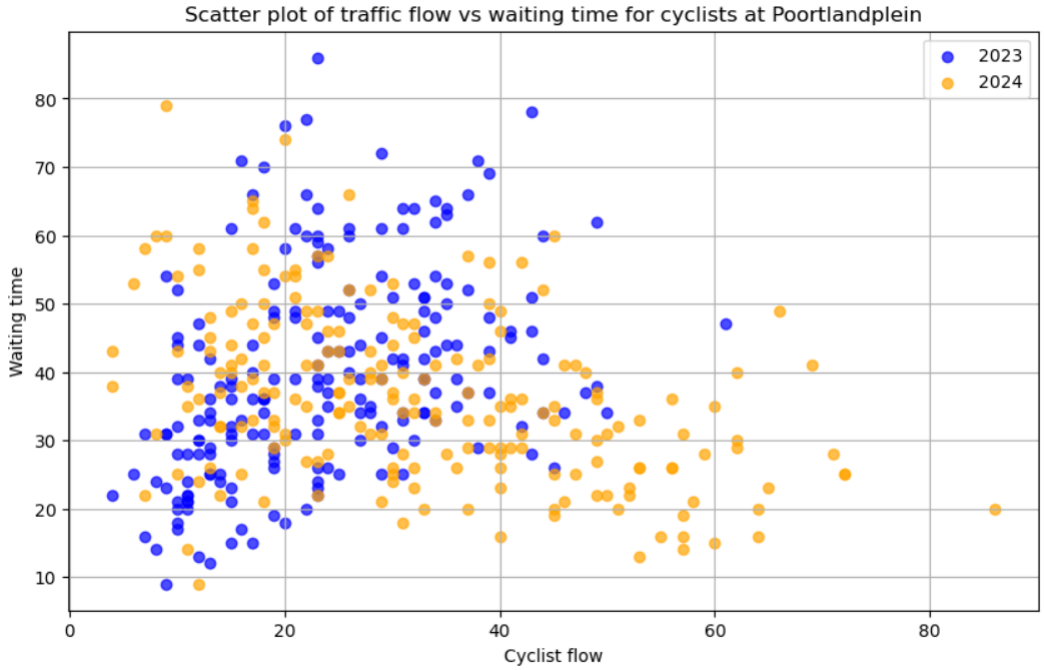


Figure 7: scatter plot of all the datapoints

4.3 Waiting time 2023 vs Waiting Time 2024

Figure 8 shows a boxplot of the waiting time for both 2023 and 2024 at traffic light 28, this is the traffic light where ViNotion is implemented. The orange line is the median of the data. The median is the middle number of the dataset. The blue box covers the first and third quartile. If one orders all the numbers in the data from low to high, then the blue box covers the range of 25%-75% of the data. The black lines cover de smallest and biggest datapoint, where the dots are outliers. The waiting times for the other legs of the intersection (traffic light 22, 24 and 26) are shown in Appendix E.

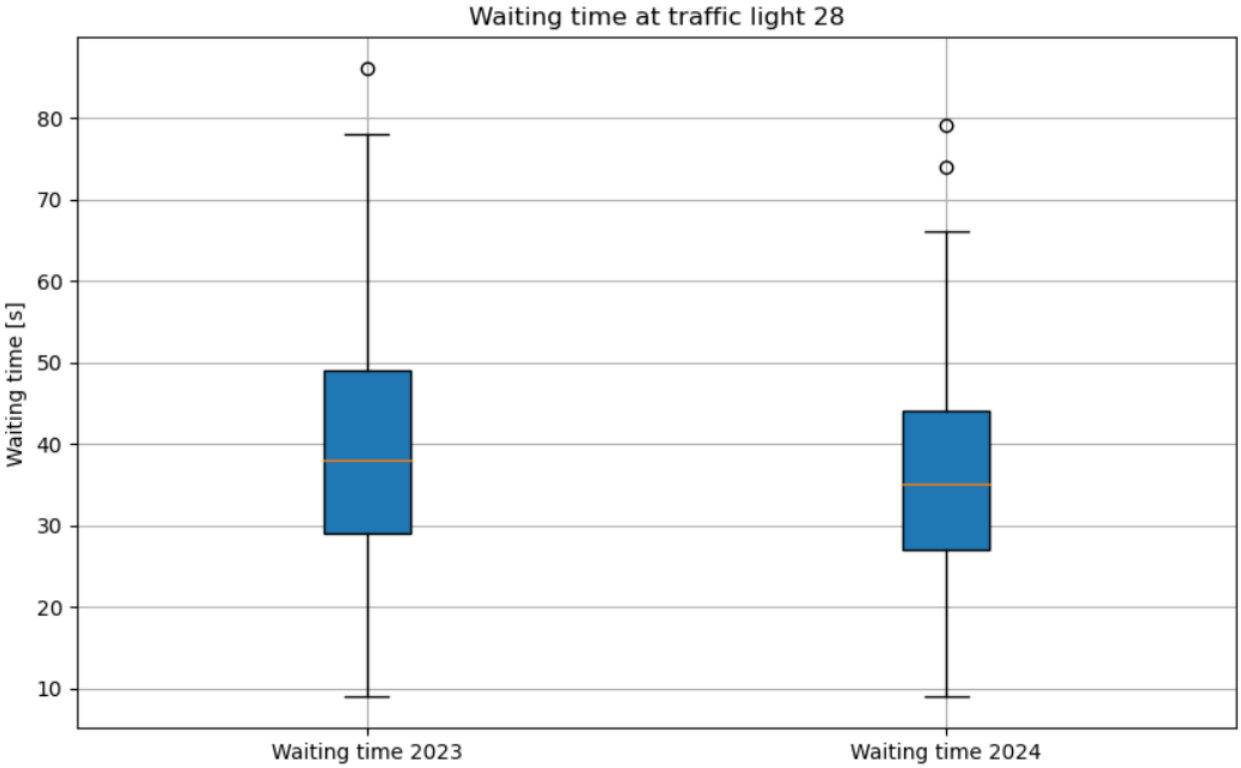


Figure 8: boxplot of waiting times at traffic light 28

As explained in the Methodology Chapter, traffic flow influences the waiting time and therefore it is interesting to take this information into consideration as well. Figure 9 shows the waiting time for the first cyclist on the y-axis, and states the traffic flow at the x-axis.

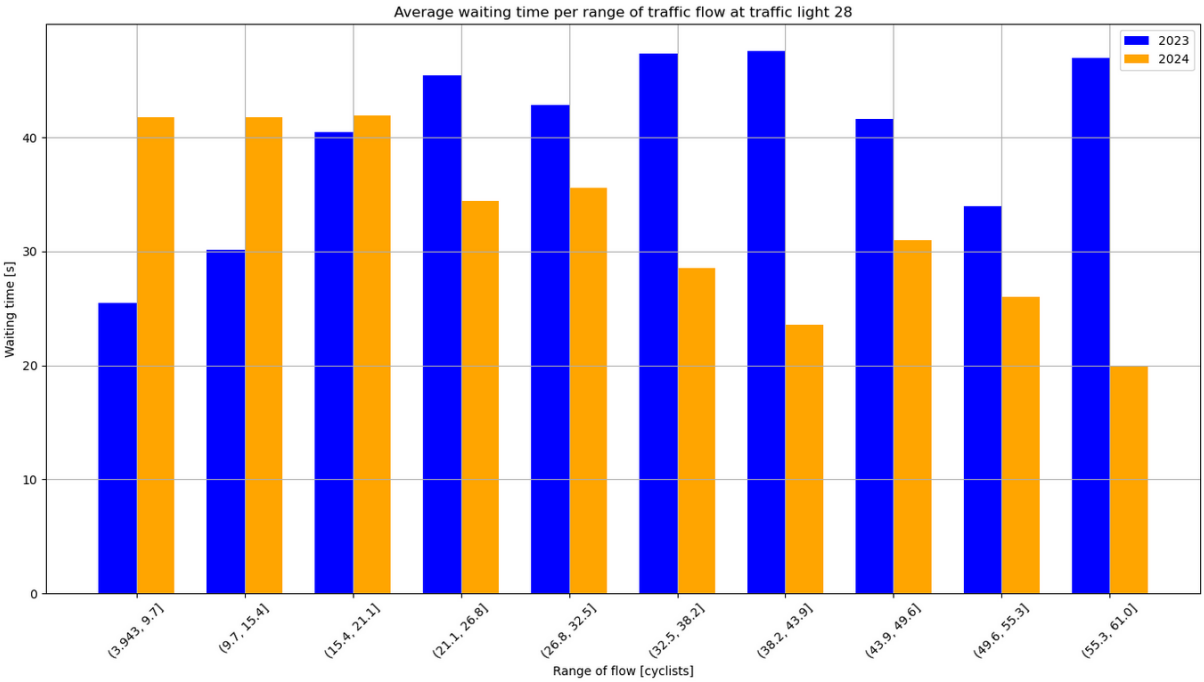


Figure 9: Traffic flow vs waiting time for traffic light 28

4.4 The effect of ViNotion

To get an idea of the effect of ViNotion on the waiting times in 2024, a barplot is made (see Figure 10). Here, the y-axis states the number of times that ViNotion has given in a 5-minute interval, whereas the x-axis is the average waiting time in this same interval.

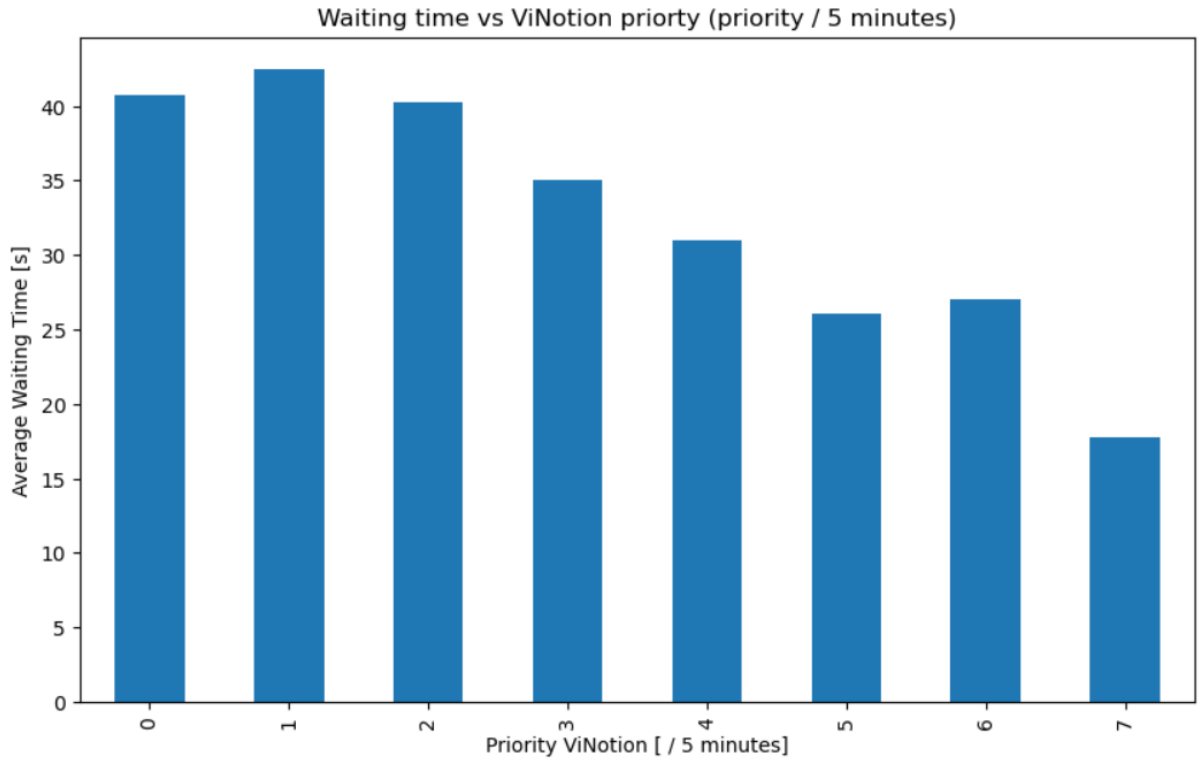


Figure 10: Average waiting time vs Priority ViNotion

It is also of interest to see what happens to the amount of times priority is given by ViNotion compared to the traffic flow at traffic light 28. This bar graph is shown in Figure 11. It can be seen that, when the traffic flow goes up, ViNotion gives more priority to cyclists. This statement is not true for more than 5 times priority given.

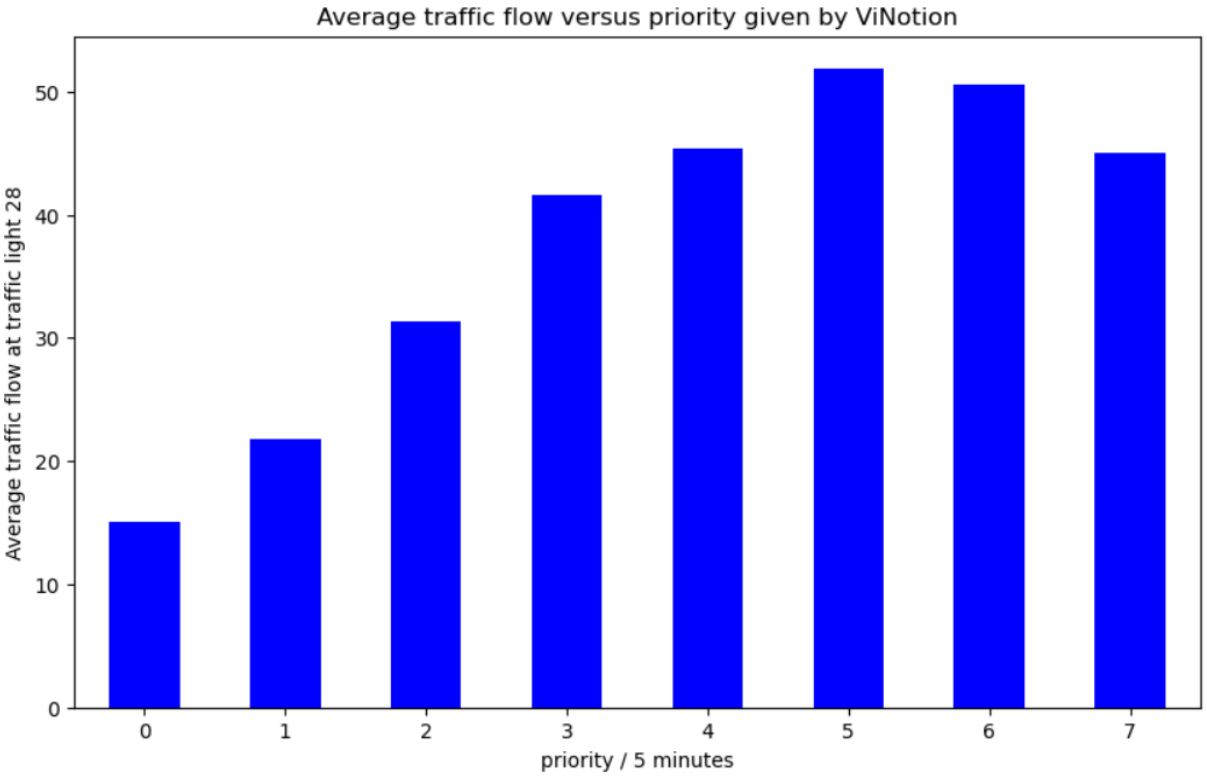


Figure 11: average traffic flow plotted against the amount of times priority is given

4.5 T-test

After plotting the data, it is time to check if the two datasets show a significant difference. In order to do this, a Student's T-test has been performed. Appendix F shows the Python code that is used for doing this T-test. The waiting times at traffic light 28 in 2023 and 2024 have been tested, with the following results:

t-statisctic	2.33
p-value	0.01

Table 6: results of T-test

A larger t value shows that the difference between the group and the mean is greater than the pooled standard error, indicating a more significant difference between the groups. The p-value is the probability that you see a t-value as large as this by one chance. A p-value less than 0.05 means that the null hypothesis can be rejected, which is the case in this situation. This means that there is a significant difference between the dataset of 2023 and 2024.

5. Discussions

This Chapter covers the discussion. In the previous chapter, a lot of graphs have been provided. The Discussions give more information about these graphs and discusses the effect of ViNotion on Poortlandplein.

5.1 Traffic flow

There is a significant increase in the traffic flow for cyclists at the entire intersection. There are a lot of potential reasons why this is. The weather could have been better in 2024, which lead to a lot of people taking the car in 2023 and take the bike a year later. Another potential reason is that people may have worked more at home or went to work later. As this project focusses solely on Poortlandplein, it is also unknown if there may have been a deviation which led to the increase. Also, there are no other intersections where information is available, thus it can not be researched if the increase in traffic is solely for the Poortlandplein intersection.

ViNotion may have also been the reason why. It is known that the happiness of cyclists is mainly based on the waiting time (see Literature Review). This means that a reduction of waiting time may lead to a more pleasant journey, which makes people keener on cycling to work or university. To check if this is indeed a potential reason, research has been done to every leg of the intersection. Table 6 shows the table with traffic increase per year. Note that there are three legs of the intersection without ViNotion (22, 24 and 26) and one leg with ViNotion (28).

	Avg. traffic flow 2023	Avg. traffic flow 2024	Increase (%)
22	1529	1718	12.36
24	1338	1524	13.90
26	741	1110	49.80
28	4876	6588	35.11
total	8484	10940	28.95

Table 6: Increase in traffic flow for cyclists per leg of intersection

The table shows that the increase at traffic light 28 is a bit above average. This means that ViNotion might be the reason of this increase, but it is hard to state that this is true or plausible. It is noticeable that there is a massive increase at traffic light 26 where no ViNotion is implemented. There is a big chance that the increase in traffic flow at traffic light 28 is due to other reasons, but further research will be needed to see if this is indeed true. For now, it can be concluded that there is no clear reason that ViNotion itself has led to a higher traffic flow.

5.2 Waiting time for cyclists

In the Data Analysis, information on waiting time, traffic flow and amount of times that priority is given by ViNotion has been provided about the different legs of the intersection. Below, the discussion of this information will take place. First of all at traffic light 28, afterwards at the other legs of the intersection.

5.2.1 Traffic light 28 and ViNotion

As can be seen in the boxplot in Figure 8, the waiting time at traffic light 28 has been reduced by approximately 3 seconds. This does not seem like a huge difference, but given that so many people use the traffic light, the total travel delay will be significantly reduced. Also, it has to be stated that de data that has been used is only for the first cyclists that come up to the intersection. Note that ViNotion only works when a group of at least five cyclists enter the intersection. Therefore, it is clear that the waiting time will be even less when the data for every cyclist would have been provided. Unfortunately, this is not the case. Therefore, Figure 10 (see Data Analysis) is a better graph to show the effect of ViNotion. This Figure shows the average waiting time for the first person entering the intersection versus the number of times ViNotion has given priority in five minutes. Note that the graph goes up when the priority goes from zero times to one time. This is because there is a significant increase (53%) in average traffic flow in these cases. Sometimes, there is very little traffic in five minutes. ViNotion does not give priority for one cyclist, but the cyclist will get green very quickly because of the not so busy intersection.

Also, there is an increase between six and seven times. This is because there are almost no datapoints available that have six- or seven-times priority given in five minutes. There are only seven datapoints where priority is given six times in five minutes, and one datapoint where priority is given seven times. Further research with more datapoints should be done in order to have a clear vision on the effect when the amount of priority given goes over five times per minute. It should also be noted that the priority event might take place at another datapoint than the waiting time for the cyclists. This is because the five-minute intervals are taken based on the local time in the Netherlands. The conversion from one datapoint to another might be in the middle of a priority event happening. In this case, the priority will be allocated to a different datapoint than the waiting time for the first person entering the intersection, as this might take place after the five-minute interval has ended. Although this happens sometimes, enough datapoints are provided to limit the effect of this on the overall image. But this effect might also be a reason why there is an increase of the waiting time between six- and seven-times priority.

Furthermore, Figure 11 shows the average traffic flow versus the amount of times that priority is given by ViNotion. Once again, due to a lack of datapoints, the decrease after five times priority does not seem plausible. The same reasons as stated above can be given to state why this is indeed the case. Also, Figure 11 proves that ViNotion gives more priority when bigger groups of cyclists are entering the intersection. This is an effective way of giving priority, because the total waiting time for every cyclist will increase more when there are more people waiting at the traffic light.

5.2.2 Other legs of intersection

The boxplots of the other legs of the intersection are given in Appendix E. There seems to be no effect on the waiting time for the first cyclist on traffic light 22, but an increase can be seen at traffic light 24 and 26.

As traffic light 22 lies parallel to traffic light 28, the VLOG-data shows that, whenever cyclists enter both traffic light 22 and 28, can pass the intersection at the same time. Therefore, it can be concluded that ViNotion has a positive impact on the waiting time for first cyclists at traffic light 22. It is hard to get this out of the boxplot, tough. This has to do with the increase of the traffic flow at the intersection. There is a 6,8% increase of cars, and a 28,5% increase of cyclists. The Poortlandplein intersection is way more busy, and thus it seems highly likely that the waiting times would have gone up without the implementation of ViNotion.

This is also what happened to traffic light 24 and 26. The waiting times have gone up. Part of it has to do with the increase in traffic flow, but it seems plausible that ViNotion also plays a role in the increase. Further research needs to be provided in order to conclude clear things about this. For now, it is interesting to note that the total waiting time for every cyclist depends on the number of cyclists at the intersection as well. Below, Table 7 has been provided. This table gives the sum of the cyclists passing the given traffic lights from the dataset of 2024 (only relevant working days between 8:00 and 9:00, see 3.2 Data Collection).

Traffic light number	Traffic flow (2024) (number of cyclists)	Percentage (%)
22	1718	15.7
24	1524	13.9
26	1110	10.1
28	6588	60.2
total	10940	

Table 7: traffic flow per intersection in April 2024 (relevant working days)

60.2% of the cyclists are going through traffic light 28. Together with traffic light 22, 75.9% of the cyclists benefit from the implementation of ViNotion. It is hard to overcome the travel delay for the other 24.1% of the cyclists, also because of the increase of the traffic flow. Based on Table YYY and a few assumptions, it can be stated that ViNotion overall, has a positive impact on the travel delay for cyclists at the Poortlandplein intersection in Delft.

5.3 T-test

The performed Student's t-test gives a 99% chance that the dataset of 2024 is significantly different then the dataset of 2023. The rejection of the null-hypothesis is in line with the graphs that have been shown in Data Analysis. There is a clear effect of ViNotion on the waiting time for the first person entering the traffic light. Therefore, the two datasets are different.

Although this seems clear, it must be stated that there is a very small chance that this time difference is there purely on accident, based on the p-value of the t-test. But given that the intersection became busier, this does not seem plausible.

6. Conclusion and Recommendations

The aim of this report is to see what the effect of ViNotion is to the Poortlandplein intersection. The research question was about the effect on the travel delay. This effect can be researched when looking at the average waiting time for every cyclist. This information is only there for the first cyclists coming up to the intersection when there is a red light. The assumption has been made that, when there is a larger group of cyclists coming up to the traffic light, the average waiting time for every cyclist will be reduced even more, since there is also a higher chance that priority is given.

6.1 Answer to research question

The following conclusions can be stated regarding the research question:

- The traffic delay for the first cyclist entering traffic light 28 is approximately 3 seconds. Given that the traffic flow of cars has gone up with 6.8%, and the traffic flow of cyclists have gone up by 28.5%, it can be concluded that the effect of ViNotion is clearly visible. Three seconds may not seem big, but it is also noticeable that this statistic is only about the first cyclists entering the traffic light when it is red. ViNotion only gives priority to groups. When more cyclists are entering the intersection, the total waiting time will go up drastically. But with ViNotion, the priority means that the total waiting time will be reduced drastically
- For the other legs of the intersection, it is hard to give exact numbers on the effect of ViNotion on the total waiting time. Traffic light 22 seems to benefit from ViNotion, as the VLOG-data shows that this intersection, together with traffic light 28, have green times at the same time. The other traffic lights have higher waiting times, which is partially the effect of an increase in traffic flow, but potentially also a negative effect of ViNotion. Given that these two traffic lights only make up 24.1% of the total traffic flow at Poortlandplein, the overall effect of ViNotion is positive.
- The increase of 28.5% for cyclists at the Poortlandplein intersection is there because of many reasons, one of the reasons is the ViNotion system. Study shows that the negative view of cyclists towards signalized intersections is the waiting time (Salomons). As ViNotion reduces waiting time, cyclists will be happier and thus take their bikes out to work more. This leads to a more environmentally friendly transportations and the use of bikes require less space in traffic. Note that this is based on an assumption, there is no data that proves that this statement is indeed true.

There is a negative side to ViNotion as well. The system is implemented at only one side of the intersection, and therefore other cyclists (especially the cyclists at traffic light 24 and 26) are not benefitting from the detection system. The increase in traffic flow has led to higher waiting times for cyclists on these legs of the intersection. But given that only 24.1% of cyclists are going through these traffic lights between 8:00 and 9:00 on working days, the overall impact of ViNotion can be concluded to be positive.

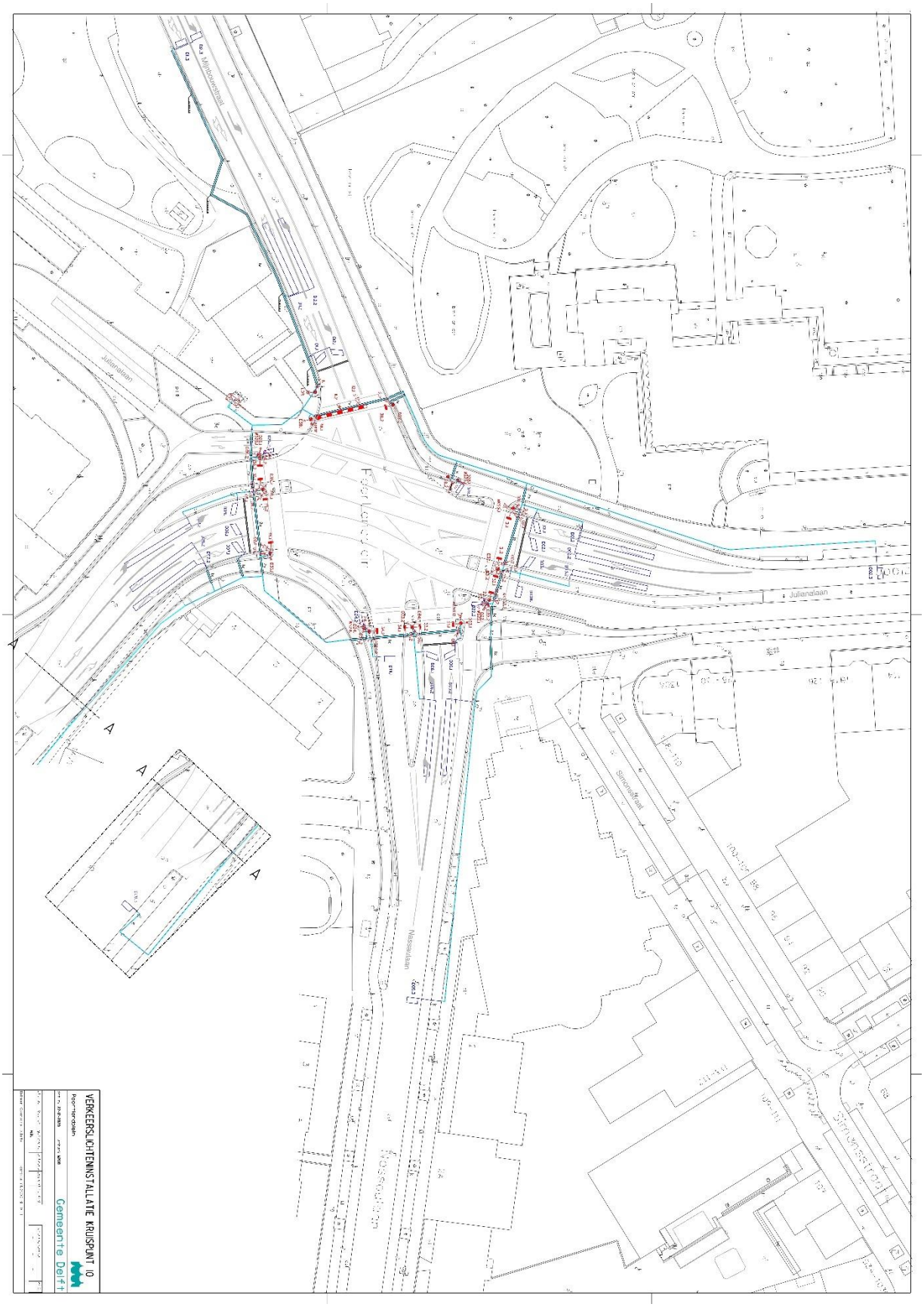
To summarize, ViNotion has, overall, a positive effect on the intersection at Poortlandplein. As over 60% of the cyclists between 8:00 and 9:00 pass traffic light 28, the reduction of the total waiting time for groups of cyclists entering the intersection at this leg is way bigger than the total waiting time for cyclists at traffic lights 24 and 26. The T-test has shown that there is a 99% chance that ViNotion does have an effect on the waiting time at traffic light 28. Also, the graphs show that, when ViNotion gives more priority per 5 minutes, the waiting time at traffic light 28 will be reduced from 41 seconds (at zero times priority) to 26 seconds (at five times priority). Lastly, the 28.5% increase in traffic flow by cyclists may be partially because of ViNotion.

6.2 Recommendations

During the report, many things have already been mentioned when it comes to further research of the Poortlandplein intersection. Given that the project only lasted for eight weeks, there was not enough time to go into really deep detail. Some statements were based on assumptions, not on pure facts (see 6.1 Conclusions, where the 28.5% increase assumption is made). Also, there are only 204 datapoints taken in 2023, and 204 at 2024. These datapoints are only between 8:00 and 9:00. There is also a rush hour in the evening, it would be recommendable to take a look at the intersection then, to see if ViNotion is for example also needed at other traffic lights.

Furthermore, the variables that have been selected are limiting the viewing on this subject. The waiting time for the first cyclists coming up to the intersection does not give a good view of the total waiting time of every cyclist. Especially when realizing that ViNotion only comes into play when more cyclists are going through the detection area. Lastly, the number of cyclists that need to be in the detection area in order for ViNotion to give priority is important for the system to work (even more) efficiently. Given that the number of cyclists could not be changed over the course of the report, it is hard to say anything about this. But when talking about making the system more effective and limiting the travel delay for cyclists, it is recommendable to do further research into this amount.

Appendix A: drawing of Poortlandplein intersection



Appendix B: overview of all possible variables in YAVV

General:

Detection mistakes
Detector pulse
Green times
Traffic flow

Safety:

End-yellow drivers
Red drivers
Velocity profile
Early starters

Traffic engineering:

Occupancy percentage
Capacity
Cycle times
Cycling jam detection
Samestart check
Average waiting time cyclists
Green without head loop
Green utilization
Follow-up green check (end)
Follow-up green check (start)
Overcome
Estimation of waiting row length
Chance of stopping
Waiting for nothing
Waiting time for first-waiting
Waiting time estimator check

Public Transport (not relevant):

-

Events:

Controller status
Detector notifications
Detector notification errors
Detector notification filtered
Entrance events
Signal group green time
Signal group red time
Exit events

Appendix C: data of relevant working days between 8:00 and 9:00, April 2023

22: traffic flow (cyclists)	24: traffic flow (cyclists)	26: traffic flow (cyclists)	28: traffic flow (cyclists)	22: average waiting time (s)	24: average waiting time (s)	26: average waiting time (s)	28: average waiting time (s)
4	9	3	12	26	9	30	30
4	5	5	11	45	20	43	22
12	8	5	15	25	2	37	21
11	12	3	10	43	16	44	39
9	2	2	16	27	20	74	71
7	5	5	31	47	18	25	34
9	4	7	19	16	43	21	28
13	8	5	22	27	9	32	66
6	2	4	39	46	12	64	69
11	4	2	34	22	22	39	37
13	8	1	31	37	13	44	64
9	6	2	21	22	5	53	39
7	4	2	11	22	14	0	24
8	9	3	9	42	14	56	54
6	11	3	18	19	12	7	36
8	11	3	18	17	23	22	31
8	7	2	21	17	10	50	49
5	4	2	27	34	15	24	36
7	5	6	32	24	3	62	30
12	8	5	36	24	13	47	39
9	18	4	29	26	16	41	61
21	6	3	33	28	22	27	51
10	10	8	32	32	20	52	53
7	5	2	33	38	5	27	34
4	4	7	8	44	17	22	14
13	10	2	10	27	18	16	52
8	12	0	8	23	12	33	24
10	10	7	15	26	10	59	38
4	6	3	23	51	19	25	41
9	9	5	23	30	8	27	22
3	6	6	25	38	8	54	25
3	6	9	26	25	7	39	61
10	5	10	23	50	7	47	57
14	9	1	25	35	0	30	49
9	5	3	20	15	16	43	76
8	7	4	36	31	12	35	35
6	7	4	13	17	4	2	12
10	5	4	24	29	18	32	26
6	6	2	11	46	9	31	21
7	5	2	12	34	9	9	30

11	7	3	17	29	18	53	15
2	10	7	30	61	10	26	42
11	1	2	31	15	33	56	42
8	10	6	33	27	13	16	51
8	5	5	34	52	22	30	62
10	4	3	36	34	10	77	44
11	10	4	33	19	17	53	39
7	1	3	27	18	18	47	34
6	6	3	13	25	32	52	34
11	6	1	13	31	24	4	42
7	10	3	23	20	11	40	38
8	10	2	22	44	18	40	20
8	13	6	24	42	12	20	58
10	6	4	33	34	20	20	39
6	1	5	34	30	0	35	33
4	6	7	26	37	0	39	43
9	9	9	44	17	5	65	42
14	9	1	33	26	5	20	42
10	5	1	31	23	15	37	61
8	9	3	23	54	6	77	86
5	3	1	9	17	49	22	23
8	6	4	13	26	8	42	33
8	11	2	13	20	13	40	36
9	11	3	15	31	31	24	32
9	5	1	19	35	30	54	53
8	5	3	33	16	20	27	49
5	2	6	31	32	33	31	41
8	8	7	23	27	8	26	64
15	6	4	35	27	34	24	44
10	6	3	34	32	21	8	48
12	6	4	23	60	39	18	45
7	2	2	21	27	33	47	61
6	5	1	12	25	11	12	13
7	7	5	17	24	15	34	31
8	7	1	15	29	8	19	39
10	11	2	15	19	15	64	36
8	5	1	20	40	10	39	58
8	6	5	24	26	19	21	49
6	11	5	41	22	12	53	46
3	3	6	35	19	19	61	50
7	6	1	35	36	11	71	63
12	10	2	15	44	9	24	61
13	6	5	49	31	29	77	38
3	7	5	32	29	18	48	64
6	7	1	10	32	6	5	45
8	6	5	19	24	8	28	19
8	10	1	12	26	20	81	33
8	9	3	10	26	16	16	20

7	7	5	17	36	17	39	66
3	9	8	38	27	6	15	29
10	9	7	39	21	12	66	48
13	6	6	25	25	11	44	43
9	7	2	43	25	0	55	51
13	6	2	23	23	10	30	56
12	8	7	22	44	16	24	77
7	7	4	31	31	9	9	33
5	11	2	19	24	9	19	26
8	14	1	17	47	19	15	36
11	11	2	23	30	11	56	31
11	11	4	18	30	19	58	34
4	7	8	23	46	11	38	60
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7	6	5	28	11	6	33	35
9	7	4	42	19	20	59	32
11	6	3	43	23	11	44	78
15	7	7	50	14	42	46	34
9	10	2	37	21	16	38	66
8	9	4	28	38	11	35	34
6	9	3	10	27	9	25	44
9	8	2	12	13	17	62	44
5	7	2	12	43	15	54	47
11	12	5	23	13	49	18	26
6	9	7	14	30	44	44	38
6	8	3	26	32	17	61	60
9	5	1	29	13	12	76	39
5	8	9	34	38	21	34	65
10	7	6	48	44	13	36	37
11	10	9	44	29	21	38	34
9	4	4	34	22	18	46	43
6	6	2	29	22	15	91	32
7	4	2	15	23	5	70	30
6	10	3	12	21	6	27	28
7	8	0	23	55	22	0	39
6	11	4	19	47	6	51	27
6	9	7	23	29	20	46	59
7	9	6	30	21	20	50	29
5	8	9	33	24	18	38	46
6	2	5	43	36	0	23	46
13	5	8	46	24	21	37	34
9	9	3	39	22	20	0	43
9	5	5	38	31	22	33	71
8	5	3	23	27	19	34	33
6	3	2	10	35	7	44	28
8	11	2	13	39	14	54	25
10	8	2	17	20	19	15	44
12	12	4	11	28	22	42	39

5	7	5	22	34	20	74	60
11	4	4	29	13	10	8	54
5	2	4	27	29	0	35	44
6	12	6	24	41	7	35	35
10	6	3	19	25	15	90	49
10	9	7	41	19	11	48	45
13	6	9	29	26	20	15	72
2	4	2	24	32	19	25	37
5	2	0	11	19	18	0	22
6	7	2	10	20	40	44	18
7	12	3	10	25	19	35	32
9	8	2	20	8	13	14	18
11	5	5	16	31	18	24	33
7	7	7	17	24	13	18	40
5	8	8	21	23	10	38	48
9	11	5	18	23	25	49	70
7	3	4	35	30	16	16	53
7	8	1	43	10	17	0	28
11	13	4	26	21	12	29	52
5	5	3	24	15	8	23	39
1	1	0	10	46	11	0	21
2	1	2	9	35	0	38	31
7	3	5	9	29	8	28	31
4	1	0	11	22	39	50	21
10	3	0	19	22	5	0	48
7	3	2	27	16	14	0	30
4	4	0	29	36	9	0	25
4	13	2	49	27	10	58	62
4	2	2	37	16	21	44	52
6	11	4	45	14	7	25	26
7	6	3	35	34	18	61	64
10	5	2	18	19	31	50	36
8	7	1	13	25	7	26	28
6	3	1	15	19	30	0	15
3	5	5	15	8	5	3	31
5	6	0	14	40	8	68	25
7	3	3	18	23	25	43	36
7	3	3	24	12	13	38	43
3	5	3	31	15	10	46	25
4	7	10	44	30	27	40	60
10	7	11	61	17	12	59	47
5	7	2	29	17	18	51	45
4	12	2	39	47	27	84	37
5	2	2	27	16	25	82	50
2	1	1	11	18	0	12	20
2	6	1	7	20	8	55	31
3	3	2	11	25	8	40	28
5	8	3	15	13	3	40	23

8	6	1	16	24	7	40	17
6	3	2	26	13	14	0	40
9	5	4	26	14	6	24	48
3	6	2	37	34	6	31	37
9	6	21	33	23	6	14	34
7	7	4	19	12	12	0	39
4	4	2	30	3	12	34	51
9	6	4	19	25	0	36	29
2	0	0	4	26	0	0	22
1	8	1	7	9	0	9	16
2	2	1	9	26	3	8	9
7	1	3	10	30	7	7	17
5	1	1	6	23	13	4	25
5	3	1	14	9	12	10	24
2	4	1	13	27	5	14	25
5	3	2	27	16	4	9	39
6	2	0	23	19	1	0	24
7	3	0	23	20	0	0	23
4	5	5	21	16	6	12	31
1	5	4	13	26	4	25	29

Appendix D: data of relevant working days between 8:00 and 9:00, April 2024

22: traffic flow (cyclists)	24: traffic flow (cyclists)	26: traffic flow (cyclists)	28: traffic flow (cyclists)	22: average waiting time (s)	24: average waiting time (s)	26: average waiting time (s)	28: average waiting time (s)	ViNotion_PRI (at 28)
7	6	1	14	16	14	24	32	0
11	7	6	12	26	6	61	58	0
11	10	6	32	17	27	34	23	2
9	10	3	25	24	23	58	34	1
10	8	5	27	35	20	42	32	1
10	8	5	30	20	14	34	37	1
7	9	14	30	12	2	51	36	3
8	8	9	40	14	14	74	46	3
13	10	5	65	18	27	78	23	5
10	13	5	42	44	18	31	31	3
9	5	4	69	18	25	66	41	3
8	8	5	52	44	11	47	22	5
7	9	2	15	14	10	23	44	0
4	4	3	10	16	14	42	25	0
13	12	1	18	29	23	70	62	0
9	14	2	10	28	18	50	54	0
8	6	8	25	40	27	39	37	2
5	5	5	30	44	4	52	53	1
8	1	7	37	32	0	55	20	3
10	6	7	52	14	11	41	23	5
9	4	7	42	18	0	21	29	5
8	9	4	32	36	27	72	45	1
10	3	5	42	26	0	33	36	5
9	4	4	29	30	2	25	21	3
5	4	3	13	24	25	53	43	1
6	6	2	12	14	19	49	55	1
9	8	6	18	20	11	34	21	0
8	8	4	9	26	18	52	60	0
7	5	2	25	20	25	51	43	0
6	4	10	20	37	5	49	54	2
7	5	8	32	29	19	42	34	3
9	3	8	45	30	32	35	25	7
7	10	6	56	23	16	54	26	5
8	2	5	25	43	49	33	34	1
6	3	2	41	40	9	82	35	4
9	6	5	37	15	14	65	57	2
1	4	4	12	26	4	0	36	0
11	10	5	8	11	16	54	60	0
11	11	3	20	22	16	18	31	1
5	11	6	18	24	14	58	37	1
11	7	7	28	27	11	52	43	2

7	3	7	23	30	8	33	41	0
9	7	6	26	18	8	53	39	1
8	6	6	28	34	6	57	52	2
11	5	3	40	16	30	49	16	5
11	4	5	30	33	16	79	48	1
7	8	4	40	24	8	6	35	2
8	5	3	34	19	4	33	33	2
7	4	5	19	9	18	38	33	0
10	7	3	19	41	14	81	47	0
9	13	6	17	45	15	72	65	1
5	12	6	24	32	14	34	28	2
10	14	4	23	39	19	60	27	2
7	9	12	32	34	9	26	47	3
13	3	8	40	25	32	57	49	2
7	13	5	31	28	14	62	47	2
14	4	6	47	21	17	57	31	5
10	8	4	58	7	35	0	21	3
13	4	7	46	22	20	12	41	5
12	5	9	49	30	6	43	22	5
3	8	5	17	20	14	33	33	1
6	11	3	18	36	4	24	55	0
10	10	5	30	20	24	28	26	3
7	12	3	23	20	32	49	22	1
10	7	5	29	35	14	22	41	2
6	4	5	21	21	9	90	55	1
10	6	9	66	23	19	41	49	3
8	7	6	49	40	21	114	36	3
8	10	7	51	35	15	14	20	5
10	6	3	53	36	20	61	26	6
9	6	8	57	22	16	21	16	5
11	8	3	45	16	20	57	19	5
5	6	4	11	33	24	26	35	0
7	5	2	22	39	9	15	47	0
14	13	7	22	23	40	49	35	1
7	14	5	18	20	29	36	45	1
9	15	3	33	41	29	17	20	2
8	9	10	29	31	7	37	39	4
11	7	6	30	18	10	66	44	2
13	11	7	36	13	9	31	26	6
10	12	3	57	23	4	45	19	5
8	6	12	42	29	18	35	56	2
13	8	4	39	21	21	23	42	3
8	8	5	31	21	29	70	34	4
7	9	5	16	9	7	22	38	0
10	9	7	13	24	12	31	26	1
10	12	6	17	24	11	20	58	0
6	13	7	15	17	11	26	49	0
10	11	4	26	23	21	57	66	1

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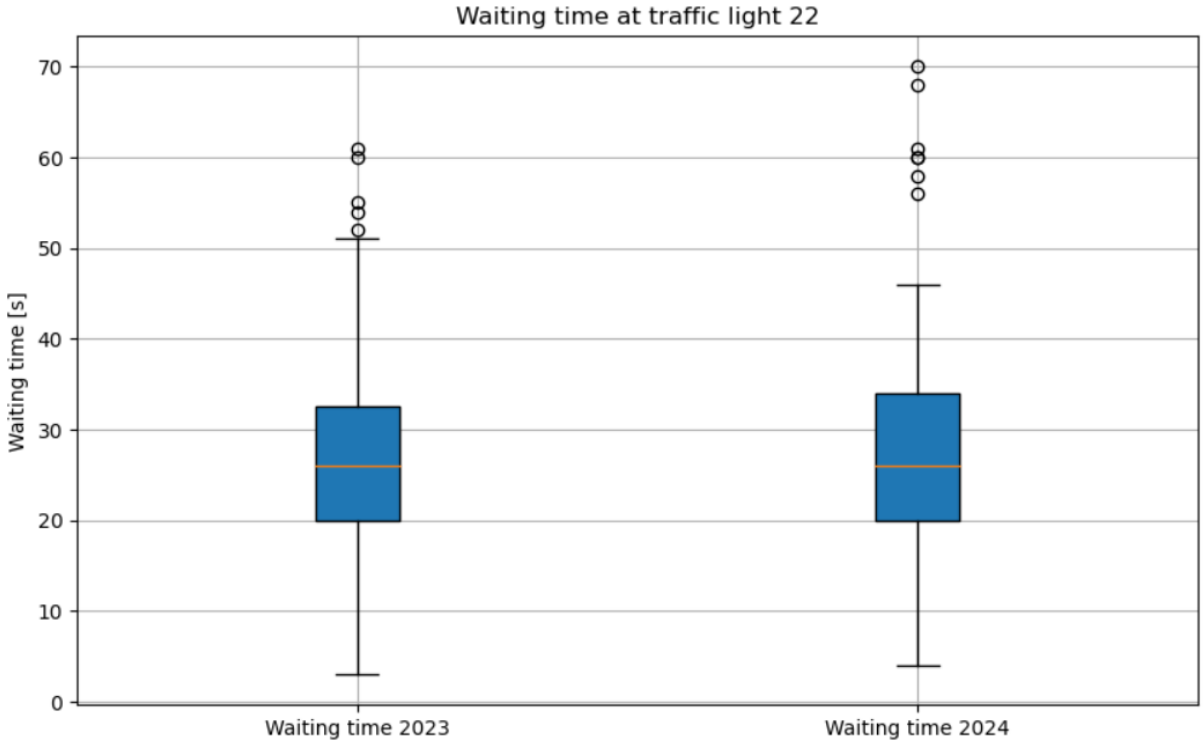
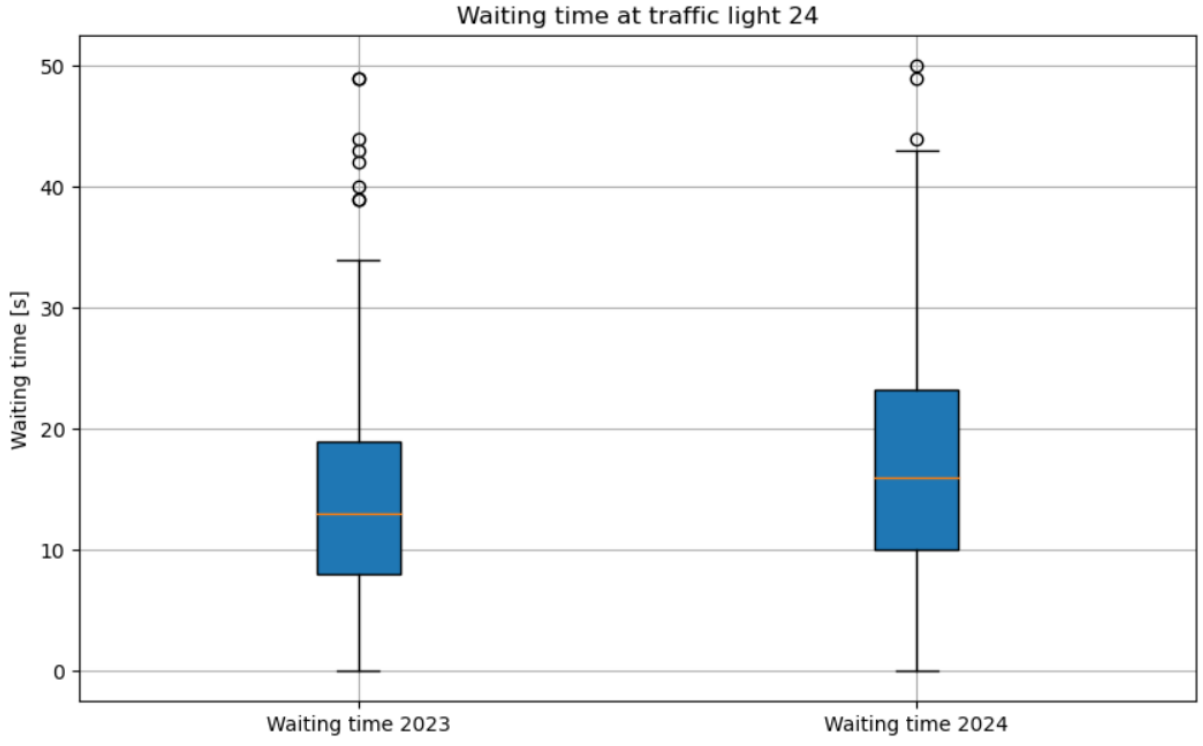
10	3	2	30	39	29	60	24	1
9	5	13	39	30	18	123	50	3
13	11	4	55	19	15	76	16	6
6	4	1	47	29	4	90	25	4
7	10	4	34	43	10	24	41	3
9	5	4	48	19	10	45	40	6
6	6	4	14	18	6	20	32	0
8	11	10	7	34	25	43	58	0
14	17	7	14	23	23	28	40	0
11	12	4	19	35	12	35	37	0
5	5	5	22	26	12	24	41	2
10	3	10	26	17	3	31	35	1
4	6	9	22	22	13	37	27	2
7	5	10	53	25	16	36	33	4
10	5	7	60	16	7	22	35	4
9	11	5	49	15	9	31	30	6
7	5	1	37	58	9	40	33	4
6	6	8	33	24	40	89	39	3
7	5	1	14	28	0	30	22	0
10	13	0	21	19	25	78	36	1
12	13	7	13	45	28	66	48	0
9	17	7	16	36	29	38	32	1
5	6	5	21	36	18	79	51	1
10	6	10	35	30	40	37	28	4
8	3	6	46	30	37	81	21	4
9	6	4	44	29	35	47	52	2
18	8	10	72	37	18	42	25	4
9	9	6	62	45	15	60	29	5
7	7	5	53	27	15	53	26	3
9	11	6	41	19	19	64	29	5
6	3	3	7	29	12	59	22	1
8	8	4	14	60	27	34	37	0
7	8	2	10	24	16	39	43	0
6	9	5	30	41	22	53	25	2
6	9	4	26	29	8	73	52	1
8	3	3	29	28	1	42	31	2
6	3	6	50	22	22	55	31	3
11	4	7	49	20	32	90	37	4
4	9	11	59	61	35	68	28	5
9	6	4	62	19	34	52	30	6
6	6	1	32	36	26	44	26	2
8	5	5	45	70	11	0	60	2
8	8	4	19	23	28	25	29	1
8	8	3	13	29	25	63	45	0
10	10	4	20	20	22	30	30	0
6	5	10	15	26	18	35	41	1
8	8	5	24	18	9	22	57	2

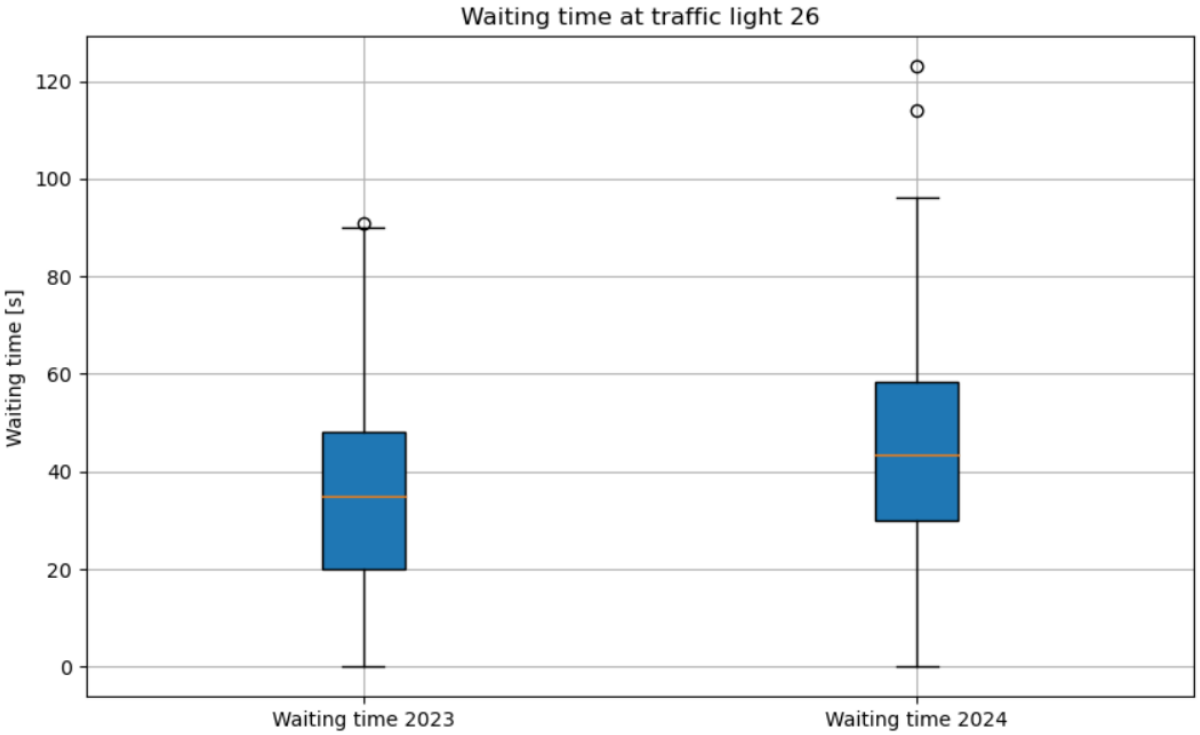
10	7	4	28	40	24	58	40	3
10	8	5	45	25	42	42	20	4
12	8	10	51	24	2	87	32	6
6	7	4	71	16	25	26	28	5
9	5	7	40	15	7	21	29	2
4	4	2	25	60	21	46	46	1
2	3	4	17	35	18	67	64	0
4	7	3	6	11	12	10	53	0
8	18	2	18	31	19	49	41	1
9	17	3	23	18	13	87	49	1
11	11	6	19	39	44	55	32	0
5	6	6	20	29	21	86	74	2
9	7	7	34	38	27	29	34	3
8	5	9	36	21	33	26	42	3
11	7	6	45	22	8	57	33	4
13	6	6	57	17	43	11	14	7
12	5	4	39	21	10	63	29	4
10	4	5	39	18	5	27	56	2
9	6	4	40	37	32	35	28	5
7	8	4	4	15	19	63	43	0
3	1	3	8	33	0	30	31	0
11	7	3	9	16	11	9	79	1
4	2	3	4	17	33	47	38	1
7	5	4	17	39	23	35	39	1
4	4	6	16	28	6	52	42	0
4	3	6	16	4	9	81	50	1
5	6	7	37	10	3	61	29	3
6	2	5	50	35	10	52	22	7
7	4	6	56	28	4	43	36	4
6	5	7	31	33	24	33	28	2
10	5	4	24	17	22	62	43	2
6	7	5	11	26	14	50	14	0
7	5	10	15	24	21	38	40	1
10	14	3	25	41	19	71	37	0
8	14	6	18	20	9	72	50	0
13	10	3	39	31	23	37	33	3
11	8	8	44	25	9	30	34	3
8	4	6	53	24	12	17	13	7
8	6	10	72	38	16	62	25	4
9	6	10	56	19	12	47	26	4
16	9	11	60	31	12	21	15	7
9	6	5	38	21	28	55	41	2
2	15	13	37	68	13	28	37	4
6	6	4	12	44	17	81	9	0
12	12	4	21	27	50	21	54	1
14	14	8	22	23	29	55	49	1
7	13	7	28	46	14	52	31	2
11	8	2	31	39	13	10	18	5

10	6	7	45	29	25	33	35	5
10	5	7	64	23	16	52	20	5
6	14	8	86	38	8	35	20	2
8	4	4	64	23	22	29	16	6
8	10	10	40	31	4	32	26	4
7	7	5	41	56	12	96	36	5
9	9	4	49	21	10	53	27	3
9	6	3	16	39	31	22	25	0
8	9	3	12	20	20	56	24	0
6	8	5	11	14	36	69	38	0
8	10	4	17	16	10	41	47	1
8	5	4	24	33	5	33	46	2
10	12	4	32	22	19	52	36	2
9	7	8	62	14	2	47	40	4
6	5	7	57	26	10	82	31	5
9	6	8	47	30	23	14	41	4
10	2	2	40	9	20	18	23	4
8	8	6	28	27	16	20	39	1
7	2	3	31	32	12	62	40	2

Appendix E: Waiting time 2023 v Waiting time 2024 at traffic light 22, 24 and 26






Waiting time at traffic light 26
Waiting time [s]
0
20
40
60
80
100
120
Waiting time 2023
Waiting time 2024

Appendix F: Python code for performing t-test

```python
#Eenzijdige t-test

# Merge de datasets on traffic flow
merged_data = pd.merge(data_2023, data_2024, on='28: traffic flow (cyclists)', suffixes=('_2023', '_2024'))


# performing t-test for waiting time
t_stat, p_value = ttest_rel(merged_data['28: average waiting time (s)_2023'], merged_data['28: average waiting time (s)_2024'], alternative='greater')

# Results
print(f"t-statistic: {t_stat}")
print(f"p-value: {p_value}")

# Hypothesis conclusion
if p_value < 0.05:
    print("The null-hypothesis can be rejected. The waiting time of 2024 is significantly smaller than in 2023.")
else:
    print("We can not reject the null-hypothesis: There is no significant difference in the waiting time in 2023 and 2024.")
```

```
t-statistic: 2.3259723963489045
p-value: 0.0102499210708703
The null-hypothesis can be rejected. The waiting time of 2024 is significantly smaller than in 2023.
```

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