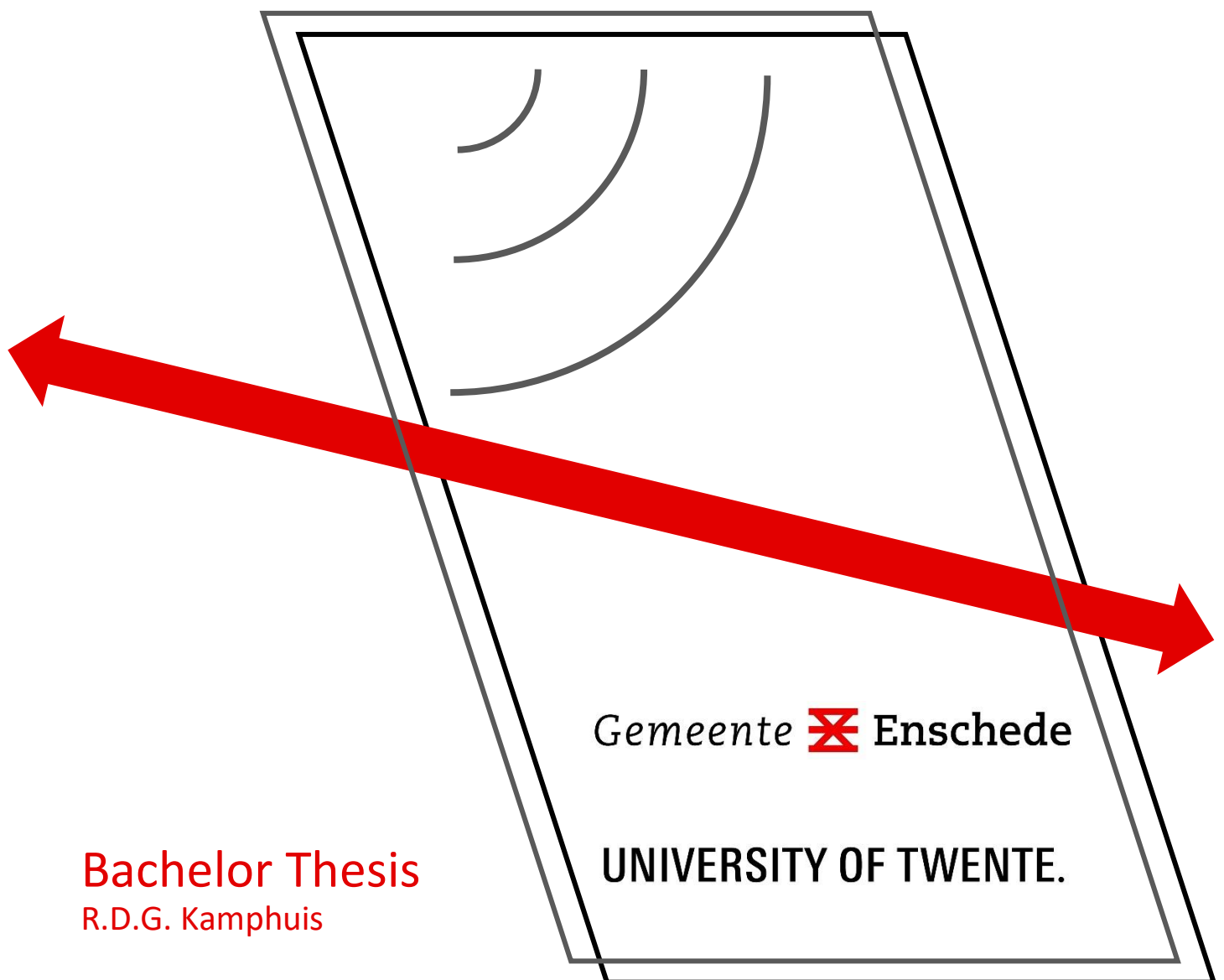


Quality comparison of Floating Car Data with Vehicle Inductive Profile technology for traffic management in Enschede



Bachelor Thesis
R.D.G. Kamphuis

Colophon

Title:	Quality comparison of Floating Car Data with Vehicle Inductive Profile technology for traffic management.
Educational institution:	University of Twente
External company:	Gemeente Enschede
Author:	R.D.G. Kamphuis
Occasion:	Bachelor Thesis
Supervisors:	C.J. van der Neut (Gemeente Enschede) dr. T. Thomas (University of Twente)
Place:	Enschede
Date:	12 November 2018 - 25 January 2019

Preface

You are reading my bachelor thesis called: Quality Comparison of Floating Car Data with Vehicle Inductive Profile technology for traffic management in Enschede. As a final assignment for the bachelor Civil Engineering at the University of Twente, I did an internship at the Municipality of Enschede. Within the department of Stadsingenieurs and Ontwerp I studied the difference of floating car data with vehicle inductive profile technology. The goal was to provide the municipality with enough information on the quality of floating car data, so they can consider phasing out the current measurement system.

I want to thank my supervisors. Tom Thomas for his constructive feedback on my results. Kees van der Neut with helping me in using the measurement systems and accessing all needed information. I also want to thank the colleagues of the department Stadsingenieurs and Ontwerp for the nice time at the Stadskantoor, the possibility to see how civil engineering is performed in practice and for the lunch walks and conversations.

Finally, I want to thank my friends and family for the trust and support during this period.

Ramon Kamphuis

January 2019, Enschede

Summary

The municipality of Enschede wants to know if Floating Car Data (FCD) could be used to measure travel times and these could be used in their traffic management applications.

Since 2011 the municipality of Enschede uses travel times of different routes for different goals. First, the travel times are used as a performance indicator for the accessibility and mobility of the city. In the performance of the network report, the municipality compares the accessibility of the city for the current year with all previous years till 2011. As performance indicator, travel times are used and compared with the reference year 2011 which is set at 100%. Second, the travel times are used for activating and deactivating scenarios in traffic control systems. This mainly encompasses extending green times for the directions from and to the city. Last, travel times are used on dynamic routing information panels (drip) on the side of the A35/N35 to inform drivers.

At the moment travel times are determined using Vehicle Inductive Profile technology (VIP), which is expensive. The first VIP system was placed in Enschede in 2011. It makes use of the induction loops that are placed at traffic light installations. When a car drives over a loop it causes a unique disturbance in the inductance, an inductive profile, which will change the frequency of the oscillator of which the loop is part. This can be used for reidentifying vehicles at consecutive loops.

Since a few years new techniques are available in measuring traffic, that have a broader coverage area and little to no costs. Floating Car Data (FCD) is one of those techniques and makes use of the GPS signals of devices that are present in cars. FCD is derived from individual probe vehicle measurement samples, that each have their own timestamp, anonymised identifier, speed estimate, vehicle heading and set of coordinates. The provider of floating car data is Be-Mobile, which uses mainly the application Flitsmeister to follow cars on their route and to give actual information about traffic. The data is available via the contract of the province of Overijssel and can be used via the online tool FLOWcheck for free by the municipality of Enschede.

From interviews with the user of VIP and two policy makers followed that the use of VIP by the municipality of Enschede is limited. An easy analysis tool on travel times is wanted. Given the management requirements and ambitions a switch to FCD can therefore be interesting for the municipality. The reliability is important; therefore, it should be examined what the quality of FCD is in Enschede.

In this research the quality of FCD is compared with VIP. This was done by examining the bias, time shift and penetration. First FCD and VIP were compared for a basis route. Thereafter, the influence of route characteristics is examined. Last, FCD and VIP are compared for the application of the state of the city index.

In the comparison mainly, data of 2017 is used. A Matlab script was made and used for loading, processing and plotting the data. The route or section, the year or years and the set of days can be specified in the script. This information is used to call the correct csv files. When more than one day is specified a mean of the given days is plotted. In this script, FCD is aggregated to 5 minutes for easy comparison with VIP travel times. The Root Mean Square Error (RMSE) and cross correlation were calculated and used in determining the time shift. The number of matched vehicles was given in the VIP files. The penetration of FCD was estimated only for a few routes using the VehicleCount from the segment analysis tool.

In basis the quality of VIP and FCD correspond very well for the route Zuiderval from the Wethouder Beverstraat to the Singel. For weekdays as well as Saturdays, the travel time profiles do match. On day level, however, FCD does have a lot of outliers. The penetration of FCD is very low compared to VIP. The penetration is sufficient during morning rush hour for the Zuiderval and did increase over the past years. When this trend continues FCD will become more valuable in the future. The penetration should improve to make good live analyses possible. On day level floating car data fluctuates too much for being reliable input for drips.

For each characteristic a (set of) route(s) is selected that includes the characteristic. The selection was based on literature and deductive reasoning. The following characteristics are examined: Speed, type of traffic, intensity on German Holidays and turn at a junction. The quality of FCD differs between routes. For some this difference can be assigned to a characteristic. The two characteristics speed and German Holidays have a clear effect on the quality of FCD compared with VIP. The other two have less distinctive to no effect.

Speed | The cut-off of too high speeds exceeding the maximum speed leads higher FCD travel times with respect to VIP. In the travel times of the 'Hengelosestraat richting stad' a clear bias or difference can be spotted between VIP and FCD. The difference is however minimal. VIP and FCD both detect the rush hour delays well.

Type of traffic | From the analysis on the characteristic type of traffic it follows that the results do better compare for weekdays than for Saturdays. Therefore, more value should be given to the data for weekdays over the data of the Saturdays. During the time intervals commuting traffic is more present FCD has less bias with respect to VIP. However, more research is needed to fully determine the effect of the characteristic.

German Holidays | During peak moments on German Holidays, differences between FCD and VIP were also found. FCD detects much more delay than VIP. For the application of activating scenario's this is positive. These peaks can be detected by the system and the scenarios can be activated. FCD produces travel times more in line with the expectation of high travel times during the rush hours caused by Germans going to shop in Enschede.

Turn at a junction | No distinctive difference could be distinguished for routes that turn at a junction. The routes Westerval and Singels noord-west XP38 n XP08 therefore do not need a special treatment with respect to routes without a turn at a junction.

The state of the city index determined with FCD does compare really well with the index determined with VIP. Within the context the municipality uses the state of the city index, FCD can be used for determining the state of the city index instead of VIP. Correcting factors for the three routes of the index were calculated by averaging the correcting factor of a route for 2016 and 2017. Applying the factors on FCD resulted in an index that differs little from the VIP index.

Recommended is to start using FCD for the historical analysis for the state of the city index. On year level the FCD has sufficient quality by virtue of the context in which the municipality uses the index.

Table of contents

Preface	iii
Summary	iv
1. Introduction	1
1.1 Problem statement.....	1
1.2 Research questions.....	1
1.3 Research methodology	2
1.4 Outline	2
2. Theoretical Framework	3
2.1 Vehicle Inductive Profile technology (VIP).....	3
2.2 Floating Car Data (FCD).....	5
2.2.1 Current research on and application of FCD.....	5
2.2.2 FCD provider Be-Mobile	6
2.2.3 Quality of FCD	6
3. Usages of traffic measurements systems by the Gemeente Enschede	9
3.1 Intention and structure of the interviews.....	9
3.2 Interview answers	9
4. Data editing and processing operations.....	13
4.1 VIP data and FCD	13
4.2 First example of data and applied operations	16
4.3 Data penetration	19
4.5 Basic comparison.....	21
5. Comparison results	25
5.1 Comparison for different characteristics	25
5.1.1 Speed.....	26
5.1.2 Type of traffic.....	28
5.1.3 Intensity on German holidays.....	30
5.1.4 Turn at a junction	33
5.2 Comparison for state of the city.....	35
5.2.1 State of the City.....	36
5.2.2 Absolute difference comparison.....	37
6. Discussion	40
7. Conclusion	42
8. Recommendation.....	44
References.....	46
Appendices	48

A. Data preparation procedures	48
B. VIP routes.....	49
C. Matlab comparison script	50

List of abbreviations and concepts

Here you find a list of used abbreviations and concepts in this report. Some of these are Dutch and used in the naming of routes.

Abbreviations and concepts:	Meaning:
ANPR	Automatic NumberPlate Recognition
Drip	Dynamic route information panel
Naar (or sometimes only n)	To
NDW	Nationale Databank Wegverkeersgegevens
Richting stad	In direction of the city
RMSE	Root Mean Square Error
Stad uit	In the direction away from the city
Singel(s)	Ring way(s) around the city centre
Van (or sometimes only v)	From
XP91	Intersection number 91

List of equations

Equation 1: Root Mean Square Error	7
Equation 2: Cross-correlation	8

List of figures

Figure 1: VIP and FCD route structure for the Zuiderval richting stad.....	14
Figure 2: 1-minute FCD compared with VIP for a single random weekday in 2017	17
Figure 3: 5-minute aggregated FCD compared with VIP for a single random weekday in 2017	17
Figure 4: aggregated FCD compared with VIP for 359 days of 2017	18
Figure 5: Abnormal high peak in FCD.....	18
Figure 6: Aggregated filtered FCD.....	18
Figure 7: FCD Penetration compared with VIP Matches for Zuiderval richting stad for a single random weekday in 2017.....	20
Figure 8: FCD penetration compared with VIP matches for Gronausestraat richting stad for all weekdays of 2017.	20
Figure 9: FCD penetration Zuiderval between 7h and 10h on weekdays	20
Figure 10: FCD penetration Zuiderval between 7h and 10h on Saturdays	20
Figure 11: Increasing year mean penetration on the Zuiderval richting stad between 7h and 10h	20
Figure 12: Mean travel times Zuiderval from the Wethouder beverstraat to the Singel	21
Figure 13: VIP and FCD route structure for Zuiderval from Wethouder beverstraat to Singel.....	21
Figure 14: Spread in FCD travel times for Zuiderv v weth beverstr n Singel	23
Figure 15: Spread in VIP travel times for Zuiderv v weth Beverstr n Singel	23
Figure 16: Increased FCD and Decreased VIP during a Dip in number of matches VIP	23
Figure 17: FCD Outlier with 'sufficient' penetration	23
Figure 18: Example of VIP travel times with no matches.....	23
Figure 19: Travel times for a year without days with no matches or too high peaks.....	23
Figure 20: Zuiderval from Wethouder beverstraat to Singel for all weekdays of 2017.....	24
Figure 21: Zuiderval from Wethouder Beverstraat to singel for all Saturdays of 2017	24
Figure 22: Hengelosestraat richting stad for all weekdays	27
Figure 23: Hengelosestraat richting stad for all Saturdays	27
Figure 24: First section of Hengelosestraat richting stad.....	27
Figure 25: Second section of Hengelosestraat richting stad	27
Figure 26: Gronausestraat richting stad for all weekdays of 2017	29
Figure 27: Gronausestraat richting stad for all Saturdays of 2017	29
Figure 28: Singels noord-west XP38 n XP08 for all weekdays of 2017	29
Figure 29: Singels noord-west XP38 n XP08 for all Saturdays of 2017	29
Figure 30: Gronausestraat richting stad on Allerheiligen 2017.....	31
Figure 31: Gronausestraat stad uit on Allerheiligen 2017	31
Figure 32: Zuiderval richting stad on Labour day	31
Figure 33: Route 6 (Gronausestraat) on Allerheiligen 2018.....	31
Figure 34: Zuiderval richting stad on German Unity day	32
Figure 35: Zuiderval stad uit on German Unity Day.....	32
Figure 36: Gronausestraat richting stad on German Unity Day	32
Figure 37: Gronausestraat stad uit on German Unity Day.....	32
Figure 38: Oldenzaalsestraat richting stad on German Unity Day.....	32
Figure 39: Oldenzaalsestraat stad uit on German Unity Day	32
Figure 40: Westerval richting stad for filtered weekdays	34
Figure 41: Westerval richting stad for filtered Saturdays	34
Figure 42: Singels noord-west XP38 n XP08 for filtered weekdays	34
Figure 43: Singels noord-west XP38 n XP08	34
Figure 44: State of the city index calculation	35

Figure 45: State of the city index from 2011 to 2018 for VIP and from 2016 to 2018 for FCD	36
Figure 46: Absolute state of the city indicator	37
Figure 47: State of the city index with VIP and FCD set at 100% for 2016.....	37
Figure 48: Comparison of the absolute year mean travel times for route 1, 3 and 6	38
Figure 49: Mean travel times per month for 2016 to 2018	38
Figure 50: State of the city index for corrected FCD.....	39
Figure 51: VIP routes in Enschede. In the small squares at the intersections the intersection numbers are given.....	49

List of tables

Table 1: Traffic management scenario times	4
Table 2: Missing data measurements for server 104	18
Table 3: Used Time intervals for State of the city index	35
Table 4: Added travel time values for state of the city index	35
Table 5: Correcting factors for FCD per route	39

1. Introduction

In this chapter the research is introduced. The problem statement, research questions, research methodology and the outline of this report is presented.

1.1 Problem statement

The municipality of Enschede is a municipality with 158.261 persons which makes it the 13th municipality on number of residents (CBS, 2018). Those citizens did travel over 978 km of road, which need to be managed (CBS, 2017). Since 2011 the municipality of Enschede uses travel times of different routes and parts of routes for different goals. First, the travel times are used as a performance indicator for the accessibility and mobility of the city. In the performance of the network report, the municipality compares the accessibility of the city for the current year with all previous years till 2011. As performance indicator, travel times are used and compared with the reference year 2011 which is set at 100%. Second, the travel times are used for activating and deactivating scenarios in traffic control systems. This mainly encompasses extending green times for the directions from and to the city. Last, travel times are used on dynamic routing information panels (drip) on the side of the A35/N35 to inform drivers.

At the moment travel times are determined using Vehicle Inductive Profile technology (VIP), which is expensive. Since a few years new techniques are available in measuring traffic, that have a broader coverage area and little to no costs. Floating Car Data (FCD) is one of those techniques and makes use of the GPS signals of devices that are present in cars. The municipality is interested in the opportunities of using FCD for their traffic management. The problem statement of the municipality of Enschede is: Can FCD be used to measure travel times for the performance of the road network and to activate and deactivate scenarios and can VIP be phased out?

1.2 Research questions

The aim of this research is to provide the municipality with enough information on the quality of floating car data, so that they can make a well-founded decision on phasing out VIP or not. The goal is to argue if FCD is sufficient enough and can be used instead of VIP by making a comparison between the two-measurement systems. Whether the quality FCD is sufficient enough is interpreted by virtue of the goals the municipality has. The main question is:

Is the quality of Floating Car Data sufficient enough to phase out the Vehicle Inductive Profile technology, to use Floating Car Data as source for travel times and to use Floating Car Data to indicate the state of the city of Enschede?

To answer the main question, the sub questions below are answered

1. How does the municipality use vehicle measurement systems now and in the future?
 - a. What is traffic management according to the municipality of Enschede and how is VIP used in this?
 - b. What are the ambitions of the municipality of Enschede on traffic management and measuring cars in the future and can FCD be used to achieve these ambitions?
2. What is the quality of FCD in comparison with VIP?
 - a. Are there time shifts between the data from FCD and VIP?
 - b. Is there a bias between the data from FCD and VIP?

- c. How do 5-minute travel times from FCD compare with 5-minute travel times from VIP and what is the root mean squared error?
 - d. How does the penetration of FCD and VIP compare?
- 3. Which characteristics cause differences in quality of travel time measured with VIP and FCD?
 - a. How do FCD and VIP compare on a route where the maximum speed is systematically exceeded?
 - b. How do FCD and VIP compare on a route for shopping traffic and commuting traffic?
 - c. How do FCD and VIP compare on a route coming from Germany on a German holiday?
 - d. How do FCD and VIP compare on a route with a turn at a junction?
- 4. What is the difference in performance of the road network of Enschede determined with FCD and with VIP for selected routes?
 - a. What is the difference in the state of the city index determined with VIP and with FCD for a group of selected routes?
 - b. Can a correcting factor be applied over FCD to overcome a possible trend break in the performance of the road network?

1.3 Research methodology

Answering the main question is done by answering the sub questions. The first question on the use of vehicle measurement systems by the municipality of Enschede is answered by doing interviews with two policy makers and with the user of VIP. The given answers serve to broaden the context in which the decision to phase out VIP and start using FCD is made.

The main part of the research was the data analysis. A big amount of VIP data and FCD was available for the analysis. To analyse as much data as possible, emphasis was put on building a Matlab script that enables loading data of multiple days and years of both measurement systems. All data is visually analysed by plotting the data of both systems in one figure. Next to that, the root mean squared error, standard deviation and cross correlation are calculated to describe the differences numerically.

First FCD and VIP are compared for a basis route. Thereafter, the influence of route characteristics is examined. Last, FCD and VIP are compared for the application of the state of the city index by calculating the index for both systems using a Matlab script. Differences are mostly visually detected. Outliers are considered as abnormal when deviations of 3σ are detected.

The methodology is described in more detail at the beginning of chapter 3, 4 and 5.

1.4 Outline

In the next chapter, more theoretical background is given about VIP and FCD. Thereafter, chapter 3 gives answers on how the municipality uses traffic management systems and what they want to measure in the future. In chapter 4 the data and applied procedures on the data are described. Chapter 5 is about the quality comparison results and the application of travel times in the state of the city. In Chapter 6 the results are discussed. A conclusion is given in chapter 7. Recommendations for follow-up research and recommendations for the Gemeente Enschede are given in the last chapter.

2. Theoretical Framework

In this chapter, more theoretical background is given on vehicle inductive profile technology (VIP) and floating car data (FCD). The basic working of VIP and the first experiences of VIP are described. For FCD, the working, current state of research, the provider and quality testing framework are presented.

2.1 Vehicle Inductive Profile technology (VIP)

The first VIP system was placed in Enschede in 2011 by the company PEEK traffic solutions, which is now part of the company Dynniq. VIP stands for Vehicle Inductive Profile technology. It makes use of the induction loops that are placed at traffic light installations. Those loops are in the first place used for detecting cars and to give the right of way to the detected vehicle. The loops also measure the intensity of cars. When a car drives over a loop it causes a unique disturbance in the inductance, an inductive profile, which will change the frequency of the oscillator of which the loop is part. This can be used for reidentifying vehicles at consecutive loops (Blokpoel & Vreeswijk, Vehicle Inductive Profile for Incident Detection, 2011).

The system consists of two main parts: a road side system and a hosting environment. These two parts are connected through a network (Leijsen & Hermkes, 2013). To analyse the data, software is needed from the external company Dynniq, which costs the municipality money. The VIP software compares the inductive profiles of vehicles from different consecutive loops and tries to match them. When two profiles match, the travel time can be calculated by using the time stamps of the measurements. The distance between two loops is known. So, if a car is detected on two loops on different times, the velocity of the car can also be determined. If a lot of cars are measured in a period, the density can be determined (Blokpoel & Vreeswijk, Vehicle Inductive Profile for Incident Detection, 2011).

For the reidentification of vehicle profiles, a comparison algorithm was made. This algorithm uses raw signature data from single induction loops as input. The input of two consecutive loops is compared. The profiles with the least difference inside the set border are matched. Profiles for which no match could be found inside the border value are classified as unknown. For good measurement of the profile, vehicles should not accelerate or decelerate above an induction loop (Blokpoel, Vehicle reidentification using inductive loops in urban areas, 2009). In further research a correction for the acceleration was applied, which showed that more matches could be obtained under challenging conditions (Blokpoel & Vreeswijk, Vehicle Inductive Profile for Incident Detection, 2011). In Enschede the induction loops of traffic lights furthest away from the intersection are used for the VIP measurements. These lay in general at 60 meters before the stop line at an intersection. These loops are used, since cars will decelerate and accelerate less on the 60-meter loop than on the loops closer to the intersection.

VIP was validated on a test location in Amersfoort and showed high matching rates as high as 100%. After applying a correction for false positives (adding the border value), caused by for example cars leaving the route before the last loop, the rate of matches is still high. Since for measuring travel times measuring every single car is not needed, 50% matched cars and 50% unknown is better than 90% matched and 10% wrongly matched (Blokpoel, Vehicle reidentification using inductive loops in urban areas, 2009).

Until the introduction of VIP, license plate cameras were used a lot for travel time evaluation, but these are expensive. The VIP system has as advantage that it is fully anonymous, works under every weather condition, is very reliable and is relatively cheap in comparison with other road side

equipment (NM Magazine, 2010) (Blokpoel, Vehicle reidentification using inductive loops in urban areas, 2009).

The VIP system is used by the municipality of Enschede for historic analysis of the performance of the road network of the city. A state of the city index is calculated to indicate the change in accessibility of the city for a whole year. Next to that, the VIP system provides actual travel times for the dynamic route information panel (drip) on the A35 and for the activation of scenarios (NM Magazine, 2010).

A scenario is a practical and regional approach in traffic management for solving traffic problems and is one of the possibilities to improve the flow through (CROW, 2017). Enschede only uses scenarios on German holidays on which a lot of Germans travel to Enschede to shop. These scenarios give extra green time to the routes from the border to the city and to the opposite direction. This means that side roads will get less priority and more red time. Enschede activates scenarios for 3 routes: Zuiderval, Oldenzaalsestraat and Gronausestraat. The scenarios will be activated only on a German holiday when the set travel times are exceeded during certain time intervals. An example of these travel times and intervals is given in Table 1 for the Gronausestraat.

VIP is only used by one person at the department Stadsingenieurs en Ontwerp. For Enschede, 40 routes can be analysed using VIP. Very limited literature is available on the application of VIP in other cities. Until now VIP is not used as comparison measurement system in a research on floating car data. The Nationale Databank voor Wegverkeersgegevens (NDW) argues that since the national availability of FCD it is interesting for traffic managers to investigate a possible switch from the current measurement system to FCD (Uenk, Vergelijkingsonderzoek Floating Car Data, 2018). Until now research on FCD was mainly focused on routes on big roads and highways and less on the inner city. In this research FCD is compared with VIP for the urban area of Enschede.

TABLE 1: TRAFFIC MANAGEMENT SCENARIO TIMES

	Activate	Deactivate
Gronausestraat → Oostweg		
Travel time (s)	> 390	≤ 300
Exceeded during (min)	5	10
Oostweg → Singel		
Travel time (s)	> 240	≤ 210
Exceeded during (min)	5	10
Singel → Oostweg		
Travel time (s)	> 260	≤ 260
Exceeded during (min)	5	10
Oostweg → Border		
Travel time (s)	> 360	≤ 300
Exceeded during (min)	5	15

2.2 Floating Car Data (FCD)

In the Netherlands, the Nationale Databank voor Wegverkeersgegevens (NDW) provides anonymised floating car data (FCD) since 1 March 2017 and makes it available for their partners. The NDW is the central organization concerning FCD. Floating car data comes from location data generated by probes, such as navigating systems, mobile telephones and fleet management systems that are present in cars. From the GPS data the mean speed and travel times can be derived (Felici, 2017) (Houbraken, Logghe, Audenaert, Colle, & Pickavet, 2018).

FCD is derived from individual probe vehicle measurement samples, that each have their own timestamp, anonymised identifier, speed estimate, vehicle heading and set of coordinates. One of the challenges with FCD is that the sample rate can vary significantly and therefore impact the reliability of the data. The individual probe measurements are matched to the road network that consists of unidirectional segments of 50 meters. For each segment the mean travel time of all probes per minute is determined (Houbraken, Logghe, Audenaert, Colle, & Pickavet, 2018).

FCD also enables to gain information on origin and destination and incidents. In the future it can be used for automatic switching traffic management measures on or off (Felici, 2017). Major advantages of FCD are that it covers the whole of the Netherlands and that is very low in costs. The most important disadvantage is that you only measure the cars in which a device is present that uses the FCD software. So, there can be limited coverage on a road segment.

2.2.1 Current research on and application of FCD

Research on FCD is done by researchers from Ghent University and Be-Mobile for a road segment on the A27 where it is looked at the potential of using it as input for live automated traffic management systems. FCD is compared with data from road side equipment. The research shows that FCD is a valuable alternative for loop data in dynamic traffic management (Houbraken, Logghe, Audenaert, Colle, & Pickavet, 2018).

From (Klunder, Taale, Kester, & Hoogendoorn, 2017) it follows that with low percentages of FCD penetration already a relatively high number of links is available where a reasonably accurate average speed can be calculated. With 10% FCD penetration the speed error based on individual location errors from GPS is below 6%. This means that FCD is found sufficiently reliable for measuring travel times. This research from TNO focussed on the application of FCD in individual in-car routing advice and used data from the region of Amsterdam.

The Province of Zuid-Holland has already switched from using license plate recognition road side equipment to using FCD. The network the province now monitors is bigger, and the costs are lower. Their experiences are positive. With the old system data was sometimes missing and they were dependent on the availability of the measurement systems. FCD is at least the same as data from license plate recognition and most of the time even better (Blanken, 2017).

Rijkswaterstaat is doing research on using floating car data instead of induction loops on highways. The problem now is still that FCD is available on roadway level, while induction loops give data for individual lanes. This makes FCD less applicable for roadways with multiple lanes, lane separation, parallel roads and complex traffic junctions. FCD is also less applicable in tunnels. Their research therefore only focusses on relatively simple highways. They conclude that induction loops in the future will still be needed for measuring intensities and vehicle categories, but they can reduce the number of loops possibly with 75% (Schreuder & Avontuur, 2017).

The metropole region Rotterdam The Hague and Groningen have already analysed the accessibility of the cities using FCD. The metropole region was one of the first in analysing the network with FCD. They found that the chosen route length, definition of the rush hour period, holidays, events, incidents and measurement periods influence the measured travel times and the reliability of those measurements. Groningen uses FCD for determining reference values for the performance of the network. Also, in Utrecht FCD is used in combination with induction loop data for determining the traffic flow (Adams & Veurink, 2018).

In the research of Marthe Uenk (Uenk, Vergelijkingsonderzoek Floating Car Data, 2018) commissioned by the provinces of Noord-Holland, Utrecht and Overijssel and the municipalities of Den Haag, Rotterdam and Amsterdam, comparisons are made between travel times calculated with FCD and calculated with current road side systems. A switch to FCD for the municipalities of The Hague and Rotterdam and the province of Overijssel would be a good idea based on the results. For the province of Noord Holland and Utrecht and the municipality of Amsterdam more research is needed. The current measurement systems of the last two is likely to be the cause of the higher deviation and not FCD.

2.2.2 FCD provider Be-Mobile

The provider of FCD is Be-Mobile. Be-Mobile uses mainly the application Flitsmeister to follow cars on their route and to give actual information about traffic. Car following systems of for example package deliverers and tachographs in trucks are also used as source. The data is available via the contract of the province of Overijssel and can be used via the online tool FLOWcheck for free by the municipality of Enschede. For the FCD viewer FLOWcheck the municipality pays a small amount of money. FCD is probably most used by commuters and less by local traffic. The available data also comes from an application that is probably less used in Germany, which can cause less data on the routes from and to Germany. Flitsmeister provides the same information for Germany as for the Netherlands (Flitsmeister, sd) (Be-Mobile, 2018).

The FCD from Be-Mobile measures every minute the average speed of the cars on a 50-meter segment. It has an accuracy to 5 meters, which means that vehicles parked at the side of the road are not seen as queuing traffic (Be-Mobile, 2018). The FCD from Be-Mobile does not save speeds that exceed the maximum speed. For these speeds the maximum speed is documented. So, on segments where people drive systematically too fast, the travel times are expected to be higher for FCD than for VIP (Uenk, Vergelijkingsonderzoek Floating Car Data, 2018). In the case of Enschede, it needs to be investigated on which routes there is being driven systematically too fast.

2.2.3 Quality of FCD

The NDW provides travel times calculated with FCD as open data. To test the quality of the data you cannot easily compare the measured speed with the actual speed. Next to that you only measure a selection of the cars. An important question concerning FCD is if the measurements are representative to determine travel times and give a good image of the situation on the road.

The quality and accuracy of a single FCD measurement are dependent on the environment, accuracy of the device and the software that is used. Therefore, FCD measurements have an average position error of 2 meters on an open square to 15 meters in wide streets where buildings are placed on both sides of the roads (Klunder, Taale, Kester, & Hoogendoorn, 2017).

When FCD is compared with a roadside measurement technology, it can be that start and ending points of segments do not match. FCD needs to be compared for a couple of days to determine if the travel times are correct under different circumstances. From earlier research followed that for a good

comparison between FCD and a roadside system the chosen routes should not include a turn at a junction, since the route maker of NDW automatically interpolates for missing travel times (Uenk, Vergelijkingsonderzoek Floating Car Data, 2018). In this research FCD was compared with ANPR (Automatic NumberPlate Recognition) and a Bluetooth road side system. This is not tested with VIP, so it is unknown if the same applies for VIP.

The NDW has developed a test framework to determine the quality of FCD travel times. This framework consists of 4 steps (Uenk, Hoe de kwaliteit van FCD te bepalen?, 2017):

1. *Timeliness test*, in which FCD travel times are compared with travel times of the road side measurement systems and the time shift is determined;
2. *Signalling test*, in which is looked at the appearance of delays in travel times in FCD and the other measurement system;
3. *Accuracy test*, in which travel times of FCD and road side travel times are compared on 5-minute level. The root mean square error for travel times is determined;
4. *Availability test*, in which for all segments it is checked for how many minutes travel times are determined.

The timeliness test is important to do, since from previous research followed that time shifts from -10 to +15 minutes between FCD and the comparison road side system could appear (Uenk, Vergelijkingsonderzoek Floating Car Data, 2018). The signalling test is relevant on highways where traffic jams appear a lot. For the inner city of Enschede delays are mostly caused by queueing traffic at an intersection. In the accuracy test the FCD is aggregated, which allows better comparison. The measurement systems behaviour can more easily be compared. It is also important to know how many minutes of data are available. In this research this is done by examining the number of VIP matches and the number of counted vehicles for FCD.

In the accuracy test the root mean square error is calculated as follows (Hyndman & Koehler, 2006):

EQUATION 1: ROOT MEAN SQUARE ERROR

$$RMSE = \sqrt{\frac{\sum_{t=1}^T (Y_t - F_t)^2}{T}}$$

Where:

Y_t is the measurement of road side equipment;

F_t is the measurement of FCD;

T is the period or the number of times the variable is observed.

The NDW also calculates the mean absolute percentage error for speed in the accuracy test. This is not used in this research. This research focuses only on the travel times. There is only limited time available and the municipality is more interested in travel times.

If FCD is compared with a roadside system differences in the measurement don't have to come from FCD, but could also be caused by false measurement of the roadside system. Differences are not necessarily wrong. Both measurement systems can cause deviations from the real speed (Uenk, Vergelijkingsonderzoek Floating Car Data, 2018).

The RMSE can, next to determining the accuracy, also be used for determining the time shift. When a graph of FCD travel times is shifted over a graph of VIP travel times the optimum RMSE can be

determined. Next to this, cross-correlation can be used for determining the time shift. The next formula is used (Shen, Li, & Si, 2015):

EQUATION 2: CROSS-CORRELATION

$$Cross\ correlation = \frac{\sum_{i=1}^{n-k} (VIPtt_{i+k} \times FCDtt_i)}{\sqrt{\sum_{i=1}^{n-k} VIPtt_{i+k}^2 \times \sum_{i=1}^{n-k} FCDtt_i^2}}$$

Where:

VIPtt is for every *k* another selected part of the mean VIP travel time per 5 minutes over the chosen period;

FCDtt is a fixed selected part of the mean FCD travel time per 5 minutes over the chosen period;

i is the index that steps through all 5 minutes of the selected part.

n is equal to 288, the number of 5 minute entries of VIP and (aggregated) FCD in a day;

k is the index that shifts the graph of FCD over VIP.

Normally the cross correlation is calculated with respect to the mean. In this case the formula is adapted, and weight is only given to the positive peaks above the mean. This is done, because the low travel times are mostly during the night and are based on a few cars. The rush hours peaks on the other hand are for both measurement systems based on a lot of cars and can therefore be better compared. When shifting FCD over VIP and two peaks meet, the upperpart of the formula becomes big. So, based on where the peaks are located, the time shift is determined. For every *k* the cross-correlation is calculated. The *k* for which the cross-correlation has a maximum tells how much the graph needs to be shifted for the best match. In this research the RMSE and cross-correlation are calculated in Matlab to determine if there exists a time shift between FCD and VIP.

From the problem context follows that it is good to consider a possible switch from the current measurement system to floating car data. It is interesting to compare the quality of FCD with VIP for Enschede, since VIP was not used as a comparison measurement system before. To describe the quality of FCD an adapted form of the quality framework of the NDW is used. For comparing the quality with VIP, the time shift is determined, FCD is aggregated to 5 minutes and the RMSE and cross-correlation are calculated. Last, the availability and penetration of FCD is examined. The quality of FCD is evaluated with respect to the specific applications of VIP of the municipality.

3. Usages of traffic measurements systems by the Gemeente Enschede

VIP is used by the municipality of Enschede to determine travel times for two applications. These applications are: determining an accessibility index for the state of the city, live activating and deactivating traffic scenario's in traffic installations and displaying travel times on drips. FCD is the intended successor as travel time source for these applications. To give good advice to the municipality in deciding to phase out VIP and to start using FCD, the context in which this decision is made, is clarified and described in this chapter. This is done by doing interviews. In the first paragraph the intention and structure of the interviews are discussed and in the second paragraph the results are given.

3.1 Intention and structure of the interviews

To get an image of how traffic measurement systems are used in the municipality Enschede and where the municipality wants to use them for, it is important to know what traffic management is in the perspective of the municipality. It is meaningful to find out what problems need to be tackled and what the ambitions are for the future. If the municipality chooses to phase out VIP that decision is not only based on the quality of FCD in comparison with VIP. To get a better understanding of the motive the municipality has, interviews are done with Kees van der Neut, Rob van den Hof and Rob van Engelshoven (Neut, 2018) (Hof & Engelshoven, 2018). Kees van der Neut is the only user of VIP at the municipality of Enschede. Rob van den Hof and Rob van Engelshoven are both policy makers at the municipality.

The interview was a semi-structured interview with a prepared set of questions on which open answers can be given. This format allowed more elaboration on answers than a structured interview. First, questions on their experiences on traffic management were asked. Second, opinions are asked on whether the current system provides good information about the performance of the network. Last, questions were asked about what the interviewees want to do in measuring cars in the future and how FCD could help with this. The results of the interviews are meant to complement the problem context and to give insight on the decision dependencies of Enschede.

3.2 Interview answers

In this paragraph the outcomes of the interviews can be found. The answers of both interviews are combined and given as one answer on the question for better coherence, since there wasn't much difference in the answers on the questions. It is indicated when personal statements were made.

Could you tell something about your experiences in traffic management and what you do at the municipality of Enschede? | Enschede has within the department Stadsingenieurs en Ontwerp a couple of traffic experts which are concerned with (re)designing roads and junctions, handling complaints, giving advice on mobility problems and managing traffic. Traffic management in the municipality is mainly done by Kees van der Neut. He is responsible for policy making on traffic management as well as the operating and executive tasks. He is in control of all systems that are used in traffic management, which includes for example all traffic light installations. There does not exist a shared vision on traffic management in the municipality of Enschede. All is determined by Van der Neut in consultation with the general policy makers of the municipality.

Rob van Engelshoven is seconded at the municipality. He owns an own company that gives policy advices for multiple road managers. He has done the evaluation of the SMART app of Enschede in which users can get rewards for their travel behaviour and has worked at Rijkswaterstaat. For Enschede he mostly deals with bicycle problems. Rob van den Hof is policy advisor on accessibility and mobility at the municipality. He is involved in regional accessibility from and to Enschede and in public transport.

What is traffic management about? What needs to be managed and why? | According to Van den Hof and Van Engelshoven traffic management is about taking measures to increase the capacity within the limited available space. You try to make better use of the existing road network by for example adjusting traffic lights. All measures in traffic management are taken with safety in mind. Measures will be taken if for example incidents happen regularly on an intersection. In the decision process of taking measures priority is given to more important roads, like highways and national roads that lead to the city and hotspots indicated on priority maps.

Next to taking measures, traffic management encompasses doing reliable predictions about travel times and delays. It does not mean that delays need to be solved, but that active choices need to be made about where which delays are accepted and in which places traffic is more accepted to ultimately improve the quality of live.

How cities are planned has also an effect on the extent in which traffic management is needed. When different land use functions are placed together there is low mobility, which means little need for traffic management. When origin and destination are placed further away from each other there will be more mobility and more traffic needs to be managed. The way a city is designed determines the degree of needed traffic management.

When did the municipality start managing traffic and what did the municipality use before VIP? |

The first installation of traffic lights around 1960 can be seen as a (new) starting point in traffic management in Enschede. Actively measuring traffic started around 2000. Measuring traffic was first done by students driving around Enschede during rush hour with a stopwatch. This gave a first insight in the accessibility and flow through of the city. Automatic car measurements started around 2006/2007 with using the inductive loops of traffic lights for the measurement of the intensity. Around the same time priority maps were made for where traffic measures need to be taken. In 2011 this was extended by the implementation of VIP which gave also insight in the travel times of individual cars aggregated to 5-minute level.

Why did you choose start using VIP? | VIP is a product of the company Dynniq (former Peek Traffic). The developers contacted the municipality for testing their system. The first testing was done at the Gronausestraat. After the testing period VIP has been rolled out across entire Enschede. In the municipality of Enschede VIP is used by one person: Kees van der Neut. Rob van den Hof uses the analysed and merged data for determining the accessibility of the city. In the first years after implementation, the system was having a lot of trouble. The size of the measurement loop had more effect than expected beforehand. It was expected that the algorithm would automatically compensate for this. Also, the speed at which a car traverses the loop had more effect. So, they switched from using

the loops closest to the intersection to the loops the furthest away from the intersection, since on those loops, cars do accelerate and decelerate less. Cars with a constant speed can be better detected.

According to policy maker Van den Hof, when introducing VIP, the measurements system was seen as a possibility to automate traffic management. VIP does automatically measure the vehicles that drive over an inductive loop. However, the software does not automatically detect interesting delays. All data needs to be analysed by hand. The system collects a lot of data, which takes a lot of time to fully analyse. This makes VIP very labour-intensive, which isn't practical for policy goals. Now, the data is only historically analysed for a whole year for 4 routes and there is not looked in detail at the data of individual days. The data is however used for automatically switching on and off scenario's on German holidays, indicated Van der Neut. When the live VIP data exceeds a certain value, a scenario will be switched on in which through traffic to and from the city will get more green time and side roads get less.

VIP works now really well, why isn't it used in other places? | VIP is not used nationwide, since other road managers have put more emphasis on the use of Bluetooth systems. The costs of VIP are probably the biggest reason it is not that widely applied. In every new traffic installation, Enschede must install VIP and make costs. Next to that VIP only works on the automates of Dynniq, which is not the only supplier of traffic light automates.

How satisfied are you about VIP and how much value do you assign to VIP? | All three interviewees are fairly satisfied about VIP. VIP gives interesting results that can be used in searching for trends. Where VIP works, it works well, and it gives reproducible answers. VIP is a good start for insights in the trend of the accessibility of the city. However, more information is wanted.

VIP mostly confirms what you already know instead of highlighting new problems. Van der Neut commented that the biggest problem of VIP is that it is very maintenance sensitive. If during road works a problem with a loop appears the systems doesn't collect data for that loop anymore. That problem is not automatically detected. Only afterwards you will see the problem in the measured data. VIP is now insufficiently maintained and checked.

From the policy point of view, VIP is too limited and not clear how reliable the results are. The results presented in the performance of the city do not account for economic and environmental changes. When the economy becomes worse and less people travel by car, the mean travel times will decrease. This does, however, not mean that you can concluded that the taken measures have a positive effect and that they cause the reduced travel times. The indexes should be placed more in context.

What are the current challenges in traffic management? | The basic challenge in traffic management is to make better use of your network. There are opportunities in informing cars as best as possible about their travel times and guiding them through the city via the best routes. It is expected that the route choice of drivers will be actively influenced in the future. Both policy makers want more reliable information about travel times. You don't want too little data and too much data, since both make it hard to detect a good trend. Too much data gives too much details which makes analysing the data harder. Too little data gives too little information about the actual situation. From the available data good results should be made, that are easily interpreted. It is important to choose which information is needed and in which form it should be presented. What still will be challenging in the future is how

representable the data is for what is happening on the streets. It is important to know how well the measurement systems perform.

What is your ambition on traffic management (measuring systems) and what do you want to measure in the future? | The ambition is to have an easy and fast application that automatically takes measures if deviations appear. That application should easily give a complete analysis with a push on the button. In the future Enschede will take measures and directly have results on those measures. Drivers will get a route based on the travel time. Now the municipality only looks at historical data and is not actively influencing route choices. The ultimate solution would be a live overview of the whole network in which a link can be selected, and in which intensity and travel times of the cars are directly shown. Policy makers don't look in detail at the data, but look only at the final results for trends and developments.

Do you think that FCD will help in reaching your ambitions and tackling the current challenges? | Expected is that FCD will contribute in getting more and better information. In the future FCD will probably be supplemented with other data from cars, like breaking information and information about the environment cars drive in, Van den Hof and Van Engelshoven expect. A prerequisite for making good use of FCD is that the data suppliers are open about their performed operations on the data and the changes they will make in the operations. An example is the cut-off in FCD of real speeds above the maximum speed to the maximum speed. It should be transparent how data is and will be edited to make good use of the data and to give good conclusions. Also, the penetration of FCD should be clear to determine how representable the data is. Question will be how (financially) available the data will be in the future. Especially if one company provides all data, that company can ask higher prizes.

Concluding from this interview, it can be said that the use of VIP by the municipality of Enschede is limited. An easy analysis tool on travel times is wanted. Given the management requirements and ambitions a switch to FCD can therefore be interesting for the municipality. The reliability is important; therefore, it should be examined what the quality of FCD is in Enschede.

4. Data editing and processing operations

This chapter is a first introduction to the VIP data and FCD. The data and the applied operations are described. A first comparison was done to address the different operations that are needed to make a good quality comparison possible. An example is given to show how the travel time patterns of FCD and VIP look like. Next, the penetration of the Zuiderval and Gronausestraat is examined and described. Thereafter, a basic comparison on a small section is done to eliminate the possible influences of characteristics and to show what the nature of the data is.

4.1 VIP data and FCD

In this research a lot of data was compared. All floating car data for the years 2016, 2017 and 2018 were available. The data is online accessed and downloaded. The data is given per minute. For VIP all data of 2017 was available from the start. The data of 2016 and 2018 was later available. In the comparison mainly the data of 2017 was used, since this was the most recent year of which data of all days of the year were available from the start. The VIP data comes in CSV files per month, per server, per route, per day. In the CSV file per 5 minutes travel are given. Next to the route files, segment files are given corresponding to the segments the route is made out of. A VIP segment is defined by the induction loops and the intersections it runs in between. The following files were available:

- Route file: In the route csv file the date, time, minimum travel time, maximum travel time, average travel time and the number of matches are given.
- Segment files: In the csv files per segment the date, time, minimum travel time, maximum travel time, average travel time and the number of matches are given for the selected segment.
- ReferenceProfile: On the lowest folder level reference profiles were available. These files give the reference values for the minimum, maximum and average travel time per segment. When data is missing the reference values are automatically used by the system to fill in the gaps. In the segment and route files.

Using the VIP tool, a graph can be generated that presents travel times for multiple selected routes for the selected days. Next to that the route data is presented in a table and in a graph. This tool isn't used in this research. Instead a Matlab script is used for loading and plotting the data, since in Matlab operations can more easily be applied. The route files were used for the travel times of the whole route and segment files are used to look at smaller parts of the route. For VIP the number of matched vehicles is used to explain abnormalities in the data.

Figure 1 displays the structure of a VIP route (OpenStreetmap, 2019). For the route 'Zuiderval richting stad', the route consists of 5 segments, which are also indicated in the figure. For the first segment from 52E to 65A the profiles of vehicles detected at the black and green points are matches to the profiles of the first blue point. The blue point is the end of the first segment and the start of the second segment. The route files give thus the summed travel times over the 5 segments.

FCD differs from VIP in the route structure. The FCD can be accessed online in the FLOWcheck viewer of Be-Mobile. In the route analysis tool, first a route needs to be added. This is done by selecting the green start point and yellow end point, displayed in Figure 1, in the FLOWcheck viewer. Along the red

displayed route, the travel time is known for each 50-meter segment. The total travel time of the routes is calculated by summing the travel times of all 50-meter segments between start and end.

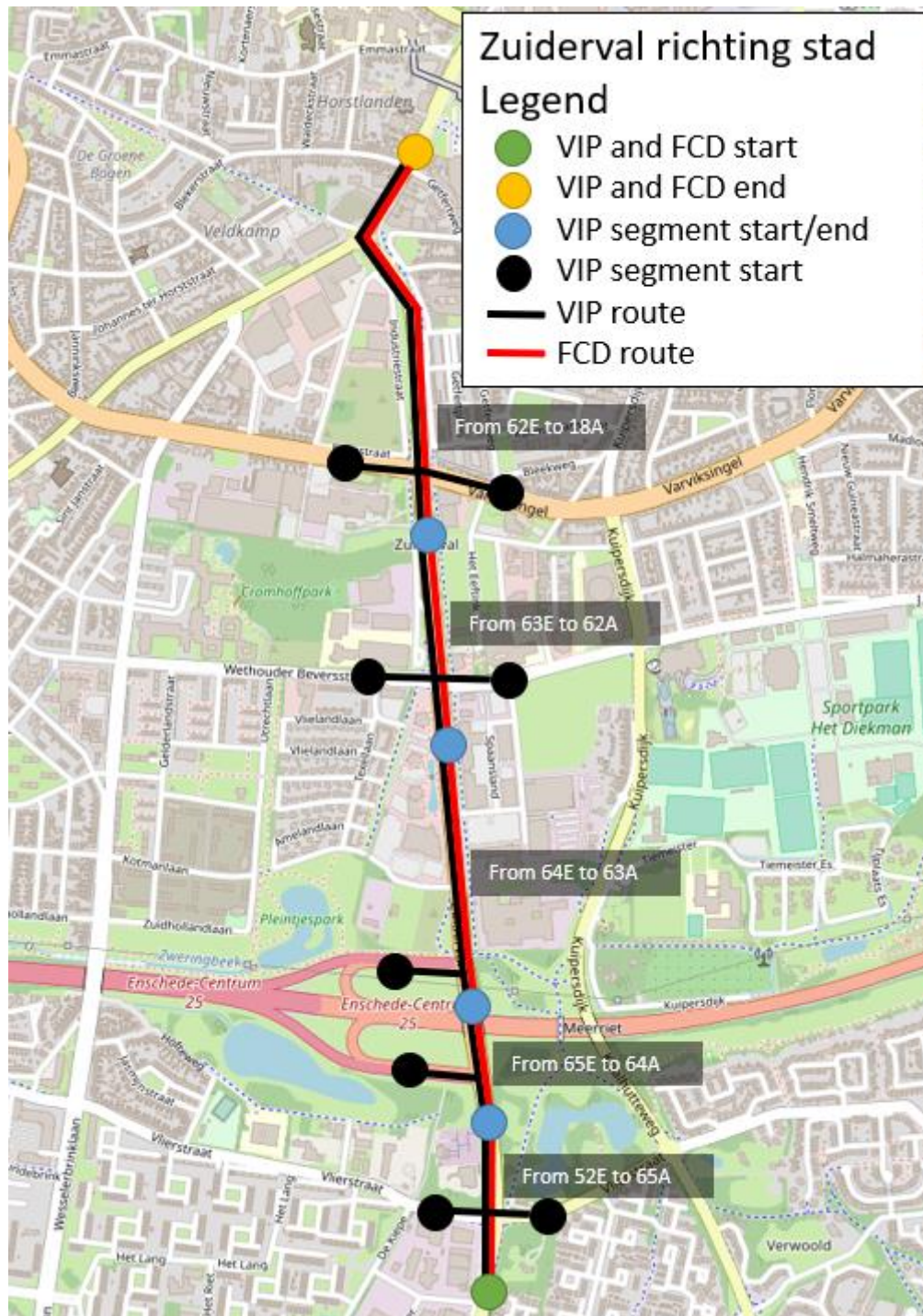


FIGURE 1: VIP AND FCD ROUTE STRUCTURE FOR THE ZUIDERVAL RICHTING STAD

When a job is created for a date range and a timeslot, the total travel time for the whole route is determined. After the job is completed, the data can be downloaded. The total length of the route is given in the online viewer. The FCD comes in five forms:

- Aggregatedcompleted: In a csv file per day the Segment ID, Time Stamp, Speed, TravelTime in milliseconds and Local Time Stamp are given.
- AggregatedTXPercentilesOverDateRange: Pictures of percentile 15, 50, 85 and 90.
- TravelTimeAverageOverDateRange: If the route is analysed for multiple days, this csv file gives the average travel time per minute for all days combined.
- TravelTimes: This csv file gives the Timestamp, travel time in microseconds, and the local time stamp for the total route. There is a separate file for every day.
- TravelTimeDailyAverages: This csv file gives the average travel time in milliseconds per day for the whole route.

All five forms are in the end based on the same measurements. Only the TravelTimes files were used. These give the travel time for each separate day per minute for the whole route and give wanted flexibility for the analysis. The Aggregatedcompleted data is a purer form of FCD, but too detailed, to be used in the analysis. Also, the location of the 50-meter segment of which the Segment ID is given, cannot be traced back. The other three are too aggregated for the analysis and are therefore not used.

The number of probe vehicles per minute on which the travel times are determined are not standard provided in these files. The penetration of the FCD was downloaded using the segment analysis tool, which takes a lot of time. In this tool a link was selected of which the penetration was wanted. In the downloaded file, the selected link was listed first. From this link the VehicleCount is taken as the penetration for the route the segment is part of.

The VehicleCount gives the total number of Vehicles that have passed the segment within the specified time interval. As time interval three hours were taken, from which a mean is calculated per half hour. The given penetration is thus an estimation. It is a mean value of three hours on only 50 metres of the whole route. In reality the penetration will differ for the different parts of the route, since cars will enter the route after the starting point and leaving the route before the end.

In appendix A. Data preparation procedures, the procedures that must be taken to use the FCD in the analysis are described. To view the data and to detect peculiarities, a Matlab script was made for the quality comparison. This Matlab script can be found in appendix C. Matlab comparison script. Separate Matlab scripts are made for loading and plotting the FCD penetration and for determining the state of the city index based on three routes. In the 'Comparison Matlab script', a route or section, the year(s) and the set of days can be specified. This information is used to call the correct files. When more than one day is specified, a mean of the given days is plotted. In this script, FCD is aggregated to 5 minutes for easy comparison with VIP travel times.

In the script a filter was made for detecting and filtering to high peaks. The filter can reduce peaks to values that fit better in the whole profile and it can delete whole days out of the mean when too high peaks are detected. After the data is loaded and possibly filtered, the RMSE is calculated. A time shift is determined using the RMSE and finding the minimum RMSE and using the cross correlation in which the alignment of high peaks determine the time shift. In the last part of the script the data is plotted

in figures. Also, the spread is calculated and plotted. Depending on the selected days, different figures are made.

The 'FCD penetration Matlab script' loads the penetration for a given set of days. The penetration data is downloaded for time intervals of 3 hours. This script is mostly used after peculiarities arise in the FCD. Then the penetration of FCD for the time interval is downloaded and loaded in the script. The 'State of the city Matlab script' loads the data of the 3 drip routes on which the state of the city index is based at the same time for all Tuesdays, Thursdays and Saturdays. In the script data for the time intervals that are used in the index are selected. Next the month means and the index are calculated and plotted.

An example of the data and the operations applied in the comparison Matlab script is given in the next paragraph.

4.2 First example of data and applied operations

For the first example the route 'Zuiderval richting stad' is used, since it is expected that the penetration of FCD will be best for this route. This route is used by (commuting) traffic coming from the A35 traveling to the city centre. The route can be found in Figure 1 on page 14. FCD is provided per minute and VIP data is provided per 5 minutes.

An example of FCD per minute compared with VIP per 5 minutes for a single random day in 2017 can be found in Figure 2. VIP and FCD have both the same order of magnitude. FCD follows the VIP data well between 7h and 9h; the delay is well detected. Thereafter, it can be seen that after the morning rush hour, FCD starts to fluctuate a lot more than VIP. Between the rush hours a little bias is present. FCD is a little bit lower than VIP.

FCD is aggregated to 5 minutes to allow better comparison between the two data sources. For the same day the results with aggregated FCD can be found in Figure 3. For the aggregated FCD the RMSE was computed and can be found in the figure as well. The RMSE is in general high for individual days due to the fluctuating character of floating car data. When you compare the average travel times of a couple of days the RMSE is much lower (e.g. Figure 4).

An example of the average FCD and VIP travel times for a whole year can be found in Figure 4. FCD and VIP do compare really well during morning rush hour for the 'Zuiderval richting stad'. Thereafter, FCD follows the VIP travel times, but is always a bit lower. They have the same order of magnitude. The average is made from 359 days. VIP and FCD both deal with summer and winter time differently. FCD takes summer and winter time properly in to account by giving one day 23 hours (in 2017 on Sunday the 26th of march) and one day 25 hours (in 2017 on Sunday the 29th of October). VIP on the other hand ignores this completely and all days have 24 hours.

When VIP takes the start of summer or winter time in to account isn't fully clear. By looking at the days around those dates, differences of a complete hour cannot be detected. Therefore, it is assumed that except from the days the summer and winter time start, the timestamps corresponding to the VIP travel times are correct.

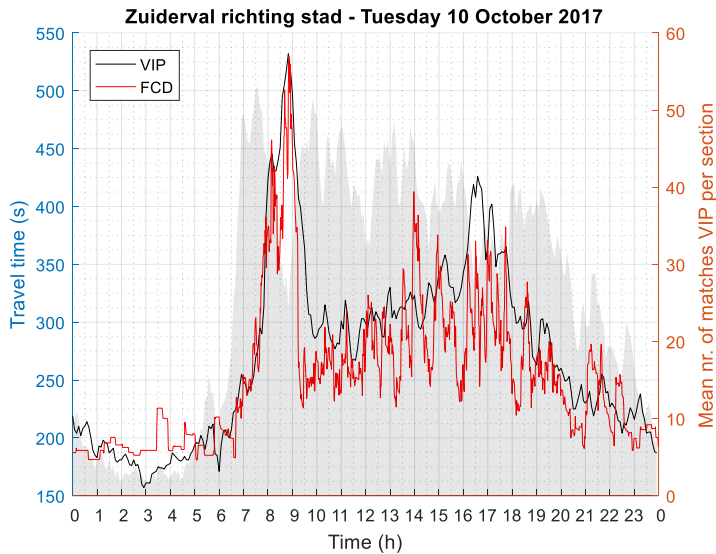


FIGURE 2: 1-MINUTE FCD COMPARED WITH VIP FOR A SINGLE RANDOM WEEKDAY IN 2017

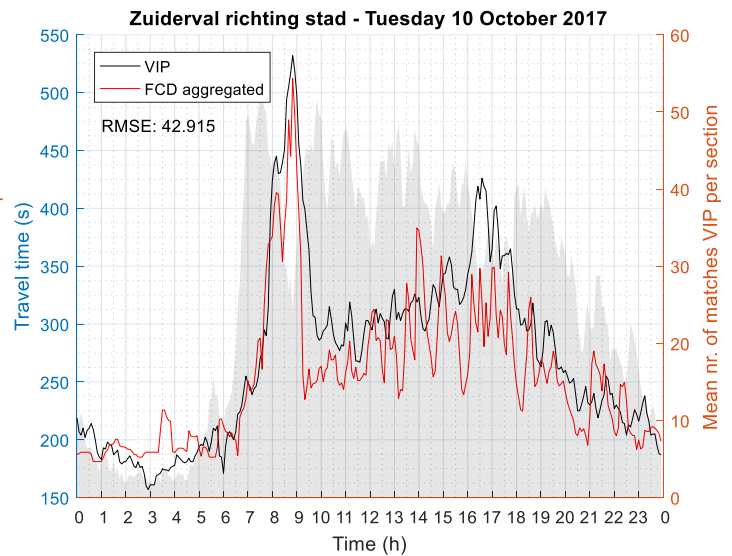


FIGURE 3: 5-MINUTE AGGREGATED FCD COMPARED WITH VIP FOR A SINGLE RANDOM WEEKDAY IN 2017

Next to those two days, there are four days where VIP data is missing for data saved on server 104, which are listed in Table 2. On server 104 the routes with high intensity traffic are saved, like the Gronausstraat, Hengelsestraat, all singels, Westerval, Zuiderval and all routes used for drip panels, travel time information panels, on the side of de road.

For the route 'Zuiderval richting stad' all missing data was added by interpolation if 1 measurement was missing or by copying data from a week later for the day 50 measurements were missing. This is time consuming when you do it for all routes and does not significantly change the yearly average. Therefore, when referencing to a yearly average, the 359 days without error are taken in to account, leaving 6 days out. For all figures in this report the 6 listed days in Table 2 are excluded.

The FCD that was downloaded does not have missing measurements. Instead, it has some strange outliers that are not detected in the VIP data. An example is shown in Figure 5. For a couple of minutes travel times higher than 3600 seconds or more than an hour are given, where normal maximum travel times for this route are around 600 seconds or 10 minutes. Looking at the penetration of the FCD between 16 and 19 hour only 29 cars traversing the route where collecting data. This is less than 6 cars per half hour and is seen as too low for reliable outcomes.

A filter was made to remove the outliers. This is done by comparing the travel time value with 3 times the value of the mean travel time of a whole day. The result of the aggregated filtered FCD can be found in Figure 6. The peak between 18 and 19 h is considerably reduced to a value that is closer to the VIP value. What causes these outliers or the differences in general is examined in the next paragraph by looking at the penetration and thereafter by looking at a basic route.

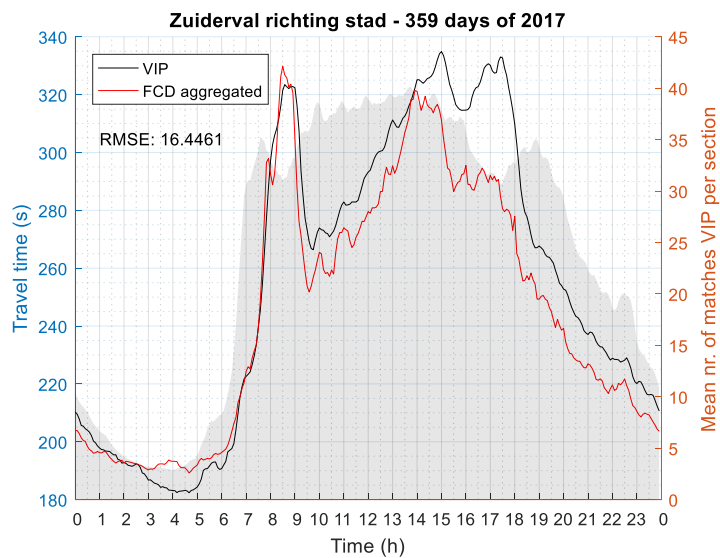


FIGURE 4: AGGREGATED FCD COMPARED WITH VIP FOR 359 DAYS OF 2017

TABLE 2: MISSING DATA MEASUREMENTS FOR SERVER 104

Date	Measurements missing
03-01-2017	1
21-03-2017	1
26-03-2017	12 too much (consecutive)
05-04-2017	50 (consecutive)
19-05-2017	2 (two different moments)
29-10-2017	12 too less (consecutive)

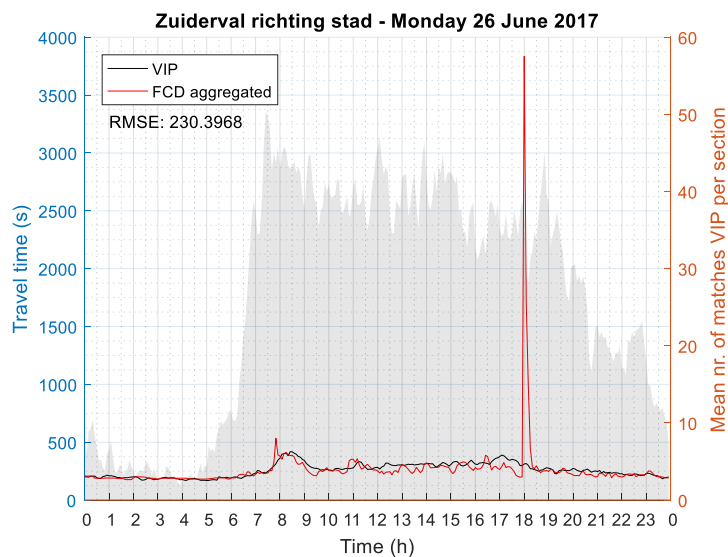


FIGURE 5: ABNORMAL HIGH PEAK IN FCD

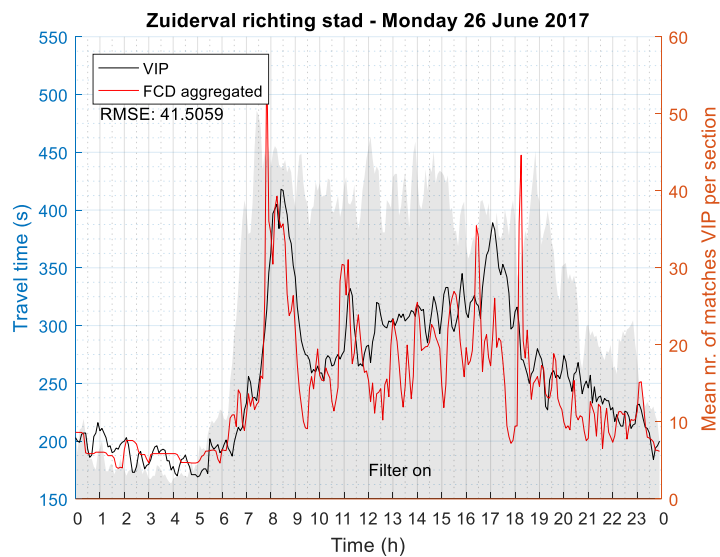


FIGURE 6: AGGREGATED FILTERED FCD

4.3 Data penetration

Only limited penetration could be examined, since the penetration of FCD takes time to be downloaded and analysed. A choice was made to only look in more detail at the penetration of Zuiderval and Gronausestraat. These streets are important radial routes of Enschede and interesting from a traffic management point of view.

For VIP the number of matched vehicles per 5 minutes is plotted in the background of the figures in the previous paragraph. The penetration of FCD does not come directly with the travel times and has to be determined separately. From the segment analysis tool files can be downloaded that only contain the total number of vehicles counted during the set time interval. The FLOWcheck tool only processes one job at a time. Since it takes a lot of time for the job to be completed, time intervals of three hours were taken. Three intervals of three hours in the morning, afternoon and evening are chosen to be examined: 7h to 10h, 12h to 15h and 16h to 19h.

The number of cars that travelled along the middle of the Zuiderval (between the Wethouder Beverstraat and the Singel) can be found in Figure 7 and along the middle of the Gronausestraat in Figure 8. The number of matches vehicles for VIP is quickly estimated by taking the mean number of matches per 5 minutes during the period of 3 hours multiplied by 36 (number of 5 minutes in three hours). The mean number of VIP matches plotted in the previous figures is the summed number of matches for all individual segments divided by the number of segments. The penetration differs for the different parts of the route as was seen by examining the individual VIP segments. Not all cars do travers the whole route, but enter or leave the route somewhere between the start and end point of the route.

For both the Zuiderval as the Gronausestraat the penetration of FCD is very low compared to VIP. The highest relative penetration is measured between 16h and 19h for the Gronausestraat: About 4.8%. For the 'Gronausestraat richting stad' the displayed penetration can be lower than in reality, since the road has a parallel road next to the selected segment. Inaccuracies in the GPS location can cause the travel time to be registered for the wrong 50-meter segment.

As a rule of thumb Be-Mobile says that with 6 cars measured in half an hour the penetration is sufficient enough for correct FCD. For the day in Figure 7 more than 6 cars per half hour were measured during the three intervals. For the Gronausestraat during all three intervals 4 or less cars per half hour were measured.

The penetration of the Zuiderval is examined for all the weekdays and Saturdays. The penetration is estimated for all workdays between 7h and 10h and plotted in Figure 9. This figure displays that only for 34 days the penetration is too low. It also shows that the penetration is increasing over the year. In the weekdays, holidays are also included on which less traffic traverses the route. On Saturdays there is no rush hour between 7h and 10h. As reference the penetration for Saturdays for the same interval is given in Figure 10. The penetration of FCD on this route is estimated as sufficient during the morning rush hour on weekdays based on the rule of thumb. Last the mean penetration of all weekdays between 7h and 10h was determined for 2016, 2017 and 2018. Figure 11 displays that the penetration increases over the years.

In conclusion, the penetration of FCD is very low compared to VIP. The penetration is sufficient during morning rush hour for the Zuiderval and did increase over the past years. When this trend continues FCD will become more valuable.

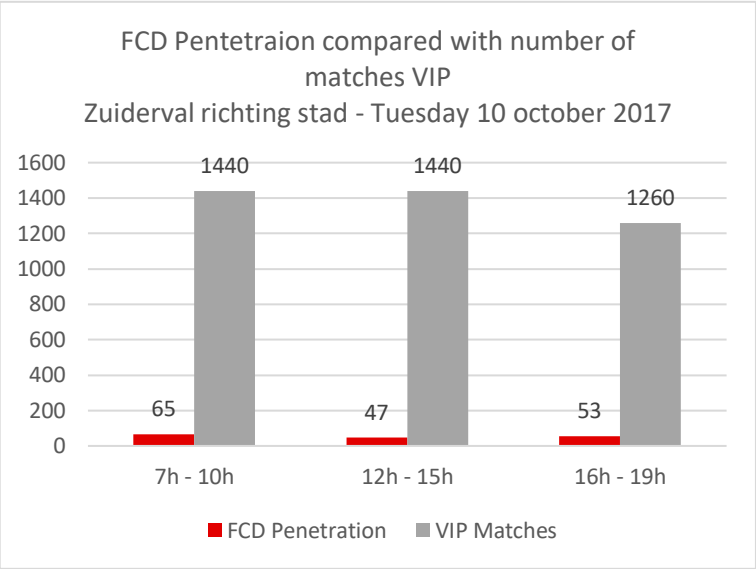


FIGURE 7: FCD PENETRAION COMPARED WITH VIP MATCHES FOR ZUIDERVAL RICHTING STAD FOR A SINGLE RANDOM WEEKDAY IN 2017

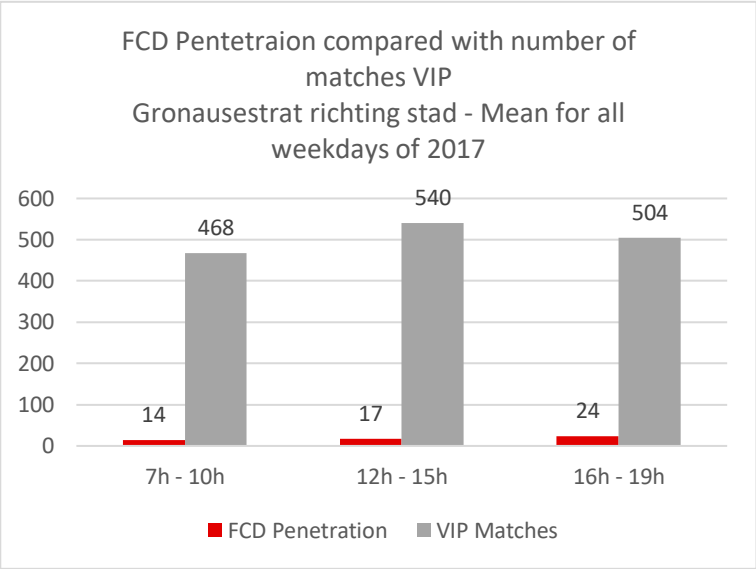


FIGURE 8: FCD PENETRAION COMPARED WITH VIP MATCHES FOR GRONAUSESTRAAT RICHTING STAD FOR ALL WEEKDAYS OF 2017.

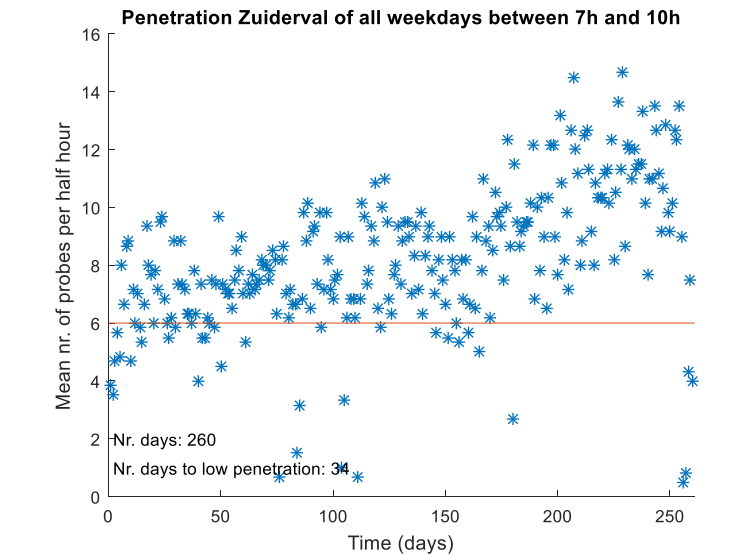


FIGURE 9: FCD PENETRAION ZUIDERVAL BETWEEN 7H AND 10H ON WEEKDAYS

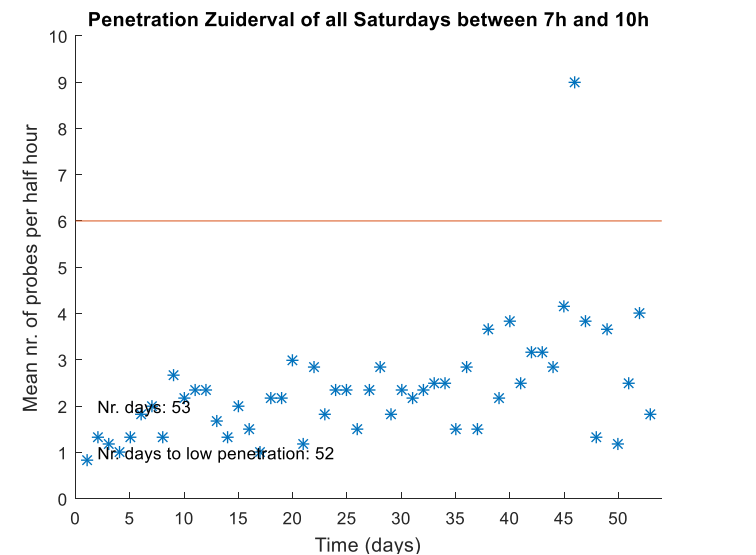


FIGURE 10: FCD PENETRAION ZUIDERVAL BETWEEN 7H AND 10H ON SATURDAYS

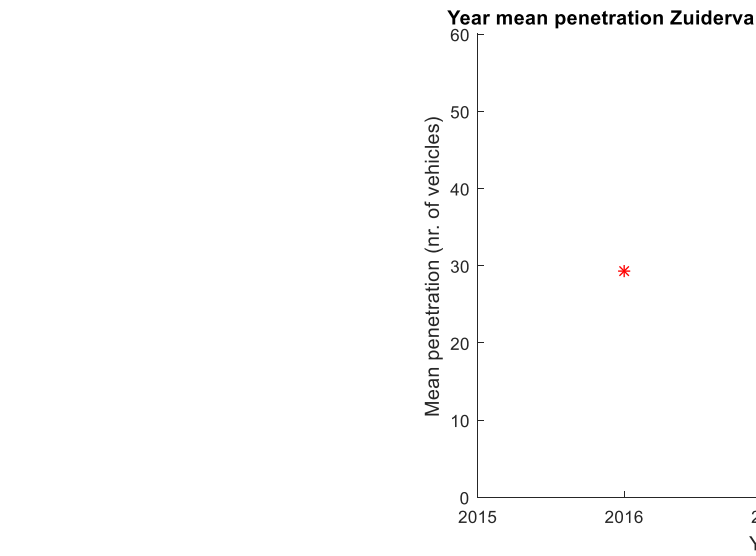


FIGURE 11: INCREASING YEAR MEAN PENETRATION ON THE ZUIDERVAL RICHTING STAD BETWEEN 7H AND 10H

4.5 Basic comparison

In this paragraph the results of a basic comparison between VIP and FCD and the applied data operations are presented. This comparison is done to eliminate all characteristics that could possibly influence the quality of FCD compared with VIP.

For this comparison the segment Zuiderval from the Wethouder Beverstraat to the Singel is used (VIP route name: 'Zuiderv v weth Beverstr n Singel'). This route segment is a segment of decent length, longer than 300 meters and shorter than a kilometre, and contains only one stop line or traffic light. It is one of the short segments of the route 'Zuiderval richting stad' examined in the previous paragraph. The mean VIP and FCD travel times can be found in Figure 12. The peak of the 26th of June shown in Figure 5 is also visually present on this segment. In the year mean below, this whole day is excluded.

Possible deviations in travel times caused by waiting at traffic lights is reduced by taking only one stop line in the segment. Less isn't possible since a comparison with VIP is wanted and a VIP route starts always 60 meter in front of a traffic light, traverses it and ends 60 meters in front of the next traffic light, with some exceptions. Taking a small segment also reduces a possible effect of cars entering the route after the start point and cars leaving the route before the end. Now only cars can enter the route from 3 sides at the intersection at the start point.

VIP combines the travel times from all 3 directions and calculates a mean. This differs from FCD as discussed in the first paragraph of this chapter. The FCD is a mean of all 50-meter segments between start and end point excluding all side roads. The structure of FCD and VIP for the Zuiderval from the Wethouder Beverstraat to the Singel can be found in Figure 13 (OpenStreetmap, 2019). The VIP measurements loops are located at the black start points and the end point. The FCD is composed by data from all 50-meter segments between the red start and yellow end point. Floating car data was also downloaded for the two side roads. An attempt is done to combine the three sets of data based on the intensity of cars from the different directions and construct one mean including all three directions. This, however, didn't give significantly interesting improvements.

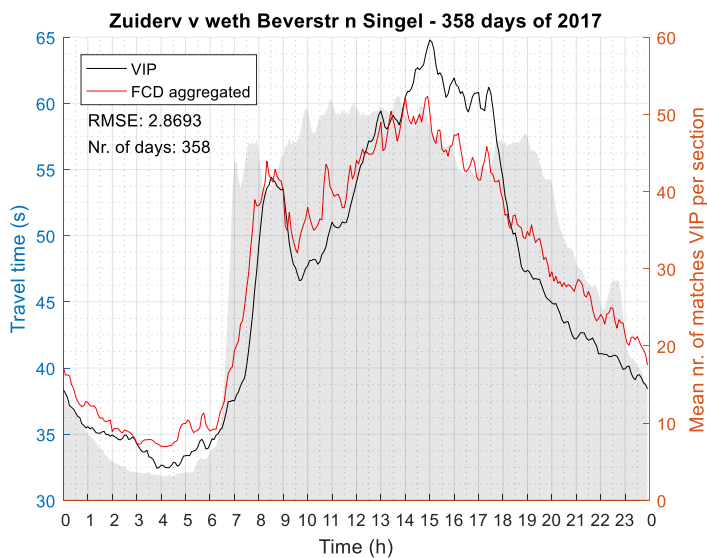


FIGURE 12: MEAN TRAVEL TIMES ZUIDERVAL FROM THE WETHOUDER BEVERSTRAAT TO THE SINGEL

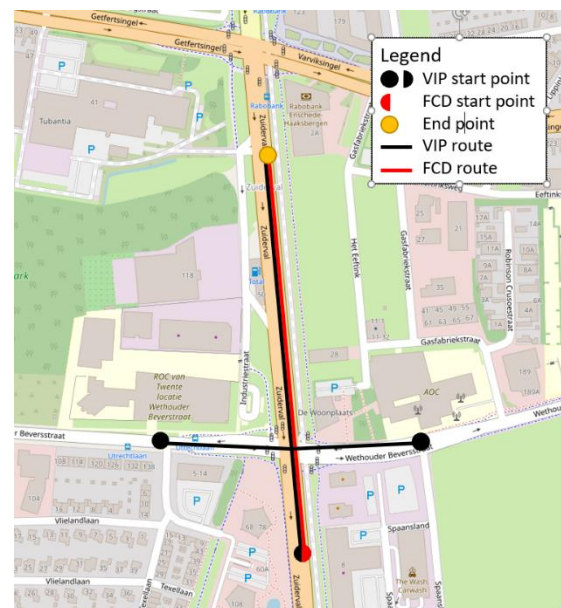


FIGURE 13: VIP AND FCD ROUTE STRUCTURE FOR ZUIDERVAL FROM WETHOUDER BEVERSTRAAT TO SINGEL

To examine how the travel times on a time stamp vary over the days, the spread in travel times is determined for VIP and FCD. In Figure 14 and Figure 15 the mean travel time and the standard deviation for each 5 minutes are plotted. Note that these are spreads for a whole year. Weekdays, holidays and weekends have different travel time profiles. This explains for example the big deviation during rush hour, since these do not take place in the weekends. It can be seen that the travel times of VIP are much closer to each other than the travel times of FCD. FCD contains more outliers than VIP.

Another way, in which VIP differs from FCD, is how it handles heavy traffic. When traffic comes to a hold, less cars will pass an induction loop, which means that less cars are matched per 5 minutes. The VIP software searches within a timeframe for a match at another loop. This means that when that time has passed a vehicle passing the loop will not be matched with the previous loop, resulting in less matches. The cars that do pass will thus give a lower mean travel time than actually is the case. An example of a dip in matches can be found in Figure 16. The FCD between 8h and 9h is based on 5 probes, which isn't much.

The penetration doesn't always say something. For the FCD travel times in Figure 17 there is an outlier between 8h and 9h. Here the penetration between 8h and 9h is 15 cars. This is above 6 per half hour and is argued as sufficient by the data provider Be-Mobile. Looking at individual days, there are a lot of days with an extreme peak in the FCD travel times. The more fluctuating character of FCD in comparison with VIP doesn't have to be wrong. It might be that FCD is more realistic and that VIP smooths the travel times more. However, peaks of 3σ are considered to be not correct.

In the VIP data, measurements are sometimes based on no matches. This is for the route Zuiderval from the Wethouder Beverstraat to the Singel in 65 days for at least one measurement (of the 288 measurements) the case. Sometimes, there aren't VIP matches at all having various causes. For example, road works could have taken place and no traffic has traversed the route or an error has occurred in the server through which no data is saved. For 9 days on this route there is no match at all. The days with no matches are: 18-02-2017 to 20-02-2017 and 6-06-2017 to 12-06-2017. The direct days before and after these periods have about half of the day no matches. In Figure 18 an example is given for how the data looks like for one of those days with no matches. The strange thing is that FCD has 58 matches between 8h and 9h for this route.

All these days with peculiarities can be excluded. The mean travel times for 203 days without days with no matches and without days with too high peaks can be found in Figure 19. For all days without outliers and sufficient number of matches, the FCD profile corresponds well to the VIP profile. During early morning, between 9h and 12h and in the evening, FCD gives higher travel times than VIP, for the other times VIP travel times are higher. The bias or difference in travel time is however very low, only 3 to 5 seconds.

The travel times are also examined for weekdays only and can be found in Figure 20. The travel times of all Saturdays are displayed in Figure 21. Different patterns can be distinguished. For weekdays, as well as the Saturdays, both measurement systems give almost equal travel times. FCD does fluctuate a little more. From the cross correlation and the minimum of the RMSE it follows that the FCD should be shifted 3 timesteps to the right, or 15 minutes. For Saturdays this is 25 minutes.

Concluding, in basis VIP and FCD correspond very well for the route Zuiderval from the Wethouder Beverstraat to the Singel. For weekdays as well as Saturdays, the travel time profiles do match. On day level, however, FCD does have a lot of outliers.

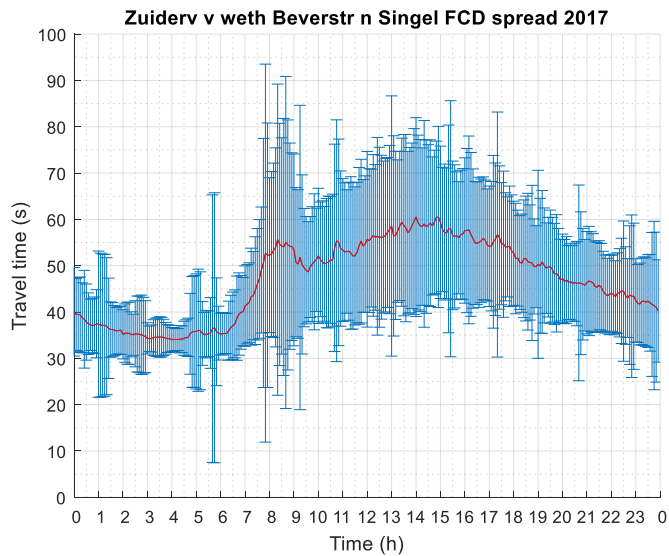


FIGURE 14: SPREAD IN FCD TRAVEL TIMES FOR ZUIDERV V WETH BEVERSTR N SINGEL

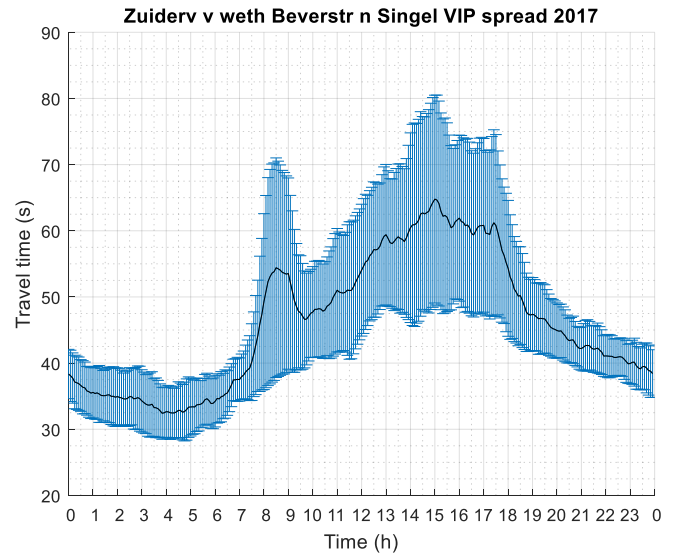


FIGURE 15: SPREAD IN VIP TRAVEL TIMES FOR ZUIDERV V WETH BEVERSTR N SINGEL

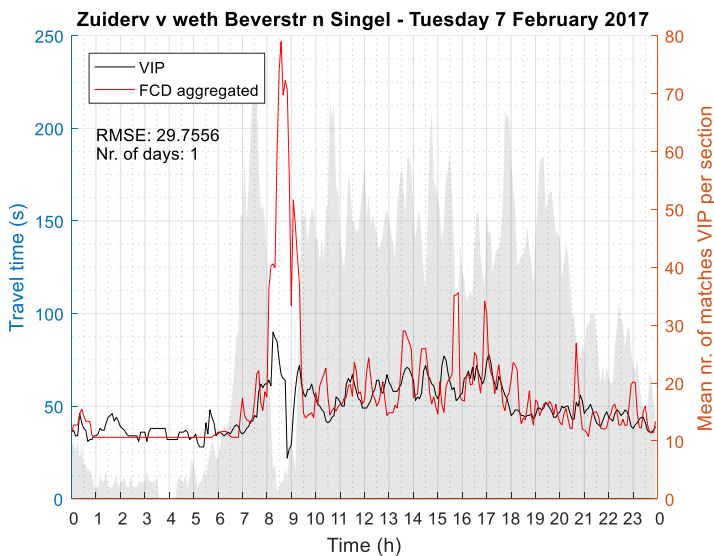


FIGURE 16: INCREASED FCD AND DECREASED VIP DURING A DIP IN NUMBER OF MATCHES VIP

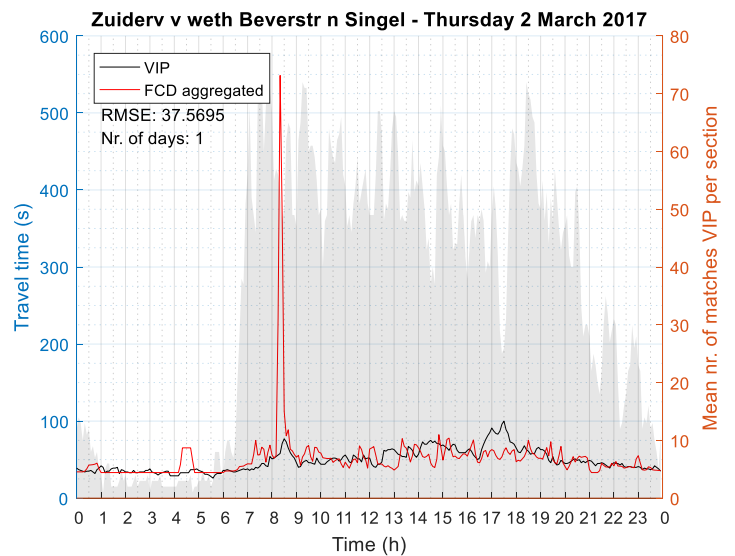


FIGURE 17: FCD OUTLIER WITH 'SUFFICIENT' PENETRATION

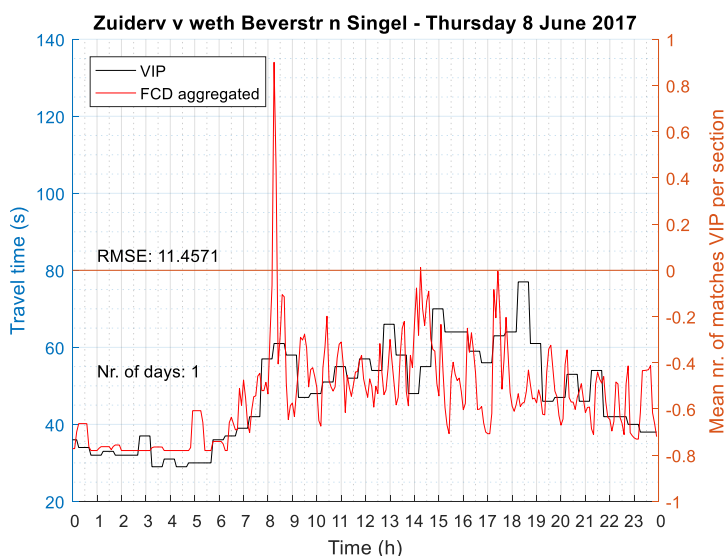


FIGURE 18: EXAMPLE OF VIP TRAVEL TIMES WITH NO MATCHES

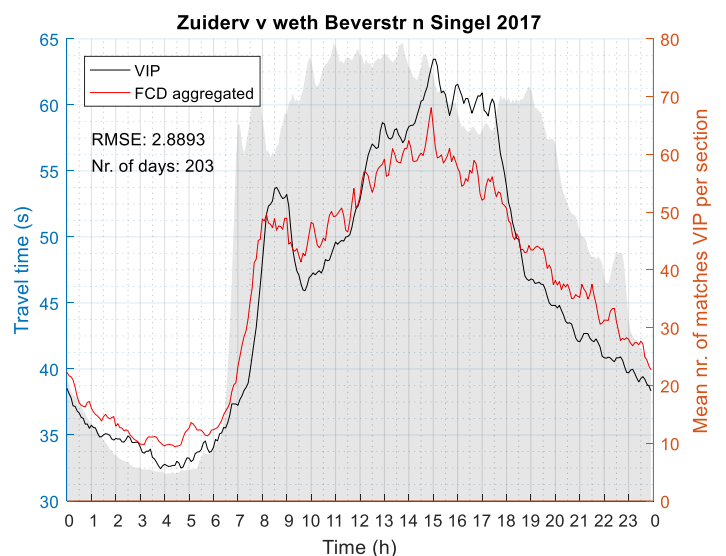


FIGURE 19: TRAVEL TIMES FOR A YEAR WITHOUT DAYS WITH NO MATCHES OR TOO HIGH PEAKS

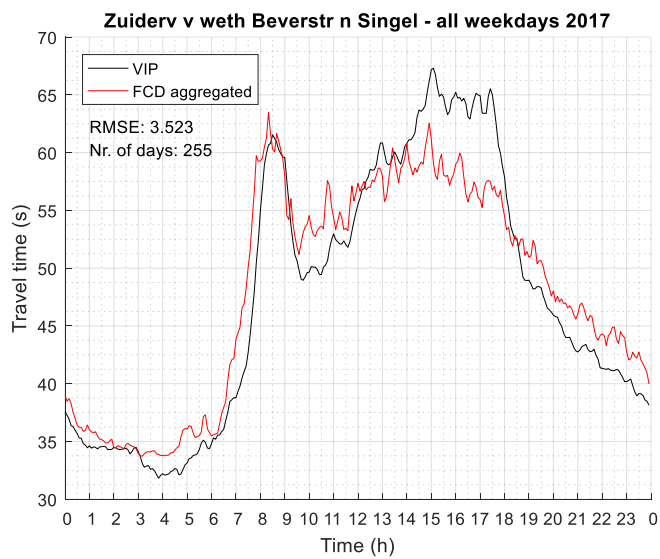


FIGURE 20: ZUIDERVAL FROM WETHOUDER BEVERSTRAAT TO SINGEL FOR ALL WEEKDAYS OF 2017

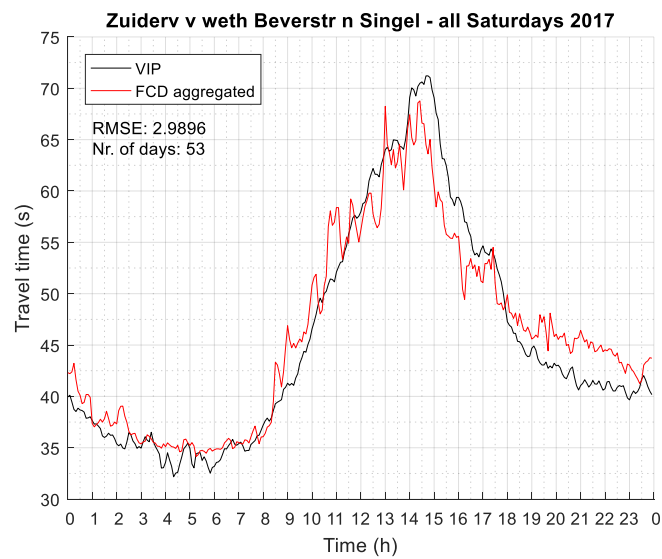


FIGURE 21: ZUIDERVAL FROM WETHOUDER BEVERSTRAAT TO SINGEL FOR ALL SATURDAYS OF 2017

5. Comparison results

How the quality of FCD compares with VIP doesn't necessarily have to be the same for each route. Therefore, the effect of 4 different characteristics is examined. In the first paragraph the comparison for different characteristics is described.

In the second paragraph the results of the comparison for the state of the city index are presented. For the state of the city only data of selected time intervals of 3 routes is used. The comparison is done for the index values as well as absolute travel times.

5.1 Comparison for different characteristics

Differences between FCD and VIP can be systematically present for all routes or present for some routes only. 4 characteristics are selected based on literature and deductive reasoning. There is little to no information in literature about which characteristics will cause a difference in quality of FCD (in comparison with VIP). From (Uenk, Vergelijkingsonderzoek Floating Car Data, 2018) followed that a turn at a junction and fast drivers will cause differences when you compare FCD with ANPR and Bluetooth road side systems. For routes with a turn at a junction the route maker tool used by the NDW causes differences when the penetration is too low. As discussed in the theoretical background the cut-off of high speeds does also cause differences. It will be investigated if this is also the case in a comparison with VIP.

The two other characteristics are based on deductive reasoning. Shopping traffic will less likely use an application like Flitsmeister than commuting traffic of which drivers want the fastest route. On German national holidays when Germans shops are closed more traffic will use the routes from the east, but will this also be detected by FCD that is probably less used by Germans.

For each characteristic a (set of) route(s) is selected that includes the characteristic. In appendix B. VIP routes an overview of all VIP routes in Enschede can be found. Enschede has a lot of routes, that are used in different ways and by different kinds of traffic. This allows selecting specific routes for a certain characteristic. The selection is based on knowledge of the municipality and on my own experiences in the city of Enschede. The selected routes are all routes of which VIP data is available. The same route is constructed in the online viewer FLOWcheck from Be-Mobile. The FCD is thereafter downloaded. The data is analysed as described in the previous chapter.

The following characteristics are examined:

- Speed
- Type of traffic
- German Holidays
- Turn at a junction

In the next subparagraphs for each characteristic, the choice of route, peculiarities and effect of the characteristic on the difference between FCD and VIP are described.

5.1.1 Speed

Hengelosestraat richting stad |

The first characteristic that is examined is speed, rather too high speeds. The floating car data that is provided by Be-Mobile is edited for high speeds that exceed the maximum speed on the road segment. If the measured speed exceeds the maximum speed the registered speed is set equal to the maximum speed. According to Andy Berkouwer, the account manager of Be-Mobile for the Netherlands, one of the reasons this is done is preventing that dynamic route information panels (drip) give a travel time for which you have to drive too fast to reach the destination in the given time.

The cut-off of high speeds was expected to be seen in routes where is driven systematically to hard. The route 'Hengelosestraat richting stad' is known as route where cars often drive too fast, especially on the segments from the city boundary until the end of the University and is therefore chosen to be examined.

When a car drives faster it has a lower travel time than a slow driving car. This means that the VIP travel time for a car that drives too fast will be lower than the FCD travel time, due to the cut-off. In the figures this appears in FCD detecting delays only when it causes cars driving slower than the maximum speed, which is on the whole route 50 kilometres per hour. Next to that VIP, peaks will be lower than FCD peaks, since fast drivers will lower the mean VIP travel times more than mean FCD travel times.

The travel times measured with VIP and FCD for the whole route for all weekdays of 2017 can be found in Figure 22 and for all Saturdays of 2017 in Figure 23. For the weekdays between 7h and 19h VIP and FCD do follow each other really well. They both detect the same delays during rush hour at almost the same time. From the cross correlation it follows that the FCD graph should be shifted 5 minutes to the right for better alignment of the peaks. The minimum RMSE can be obtained by shifting the graph 2 timesteps, or 10 minutes to the right. During late evening and early morning, FCD has low penetration and fluctuates around a constant value. For Saturdays VIP and FCD do follow each other between 10h and 16h. Do note the difference in scale on the y-axis between Figure 22 and Figure 23. On Saturdays there are much less delays detected in the travel times.

Since expected was that the cut-off in speed, and thus in travel times, would appear more on the first two segments, all segments of the route are examined separately for all weekdays. The results of the first two segments are plotted in Figure 24 and Figure 25. The total travel time of the route is for VIP the sum of the individual segment travel times. For the first segment of the Hengelosestraat from intersection 98 to intersection 97, Figure 24 shows that FCD and VIP both detect the same delays between 7h and 19h, but that FCD travel times are consequently about 7 seconds higher than VIP travel times. This is more than 10% of the VIP travel times. For the second and longest segment from XP97 to XP19 in Figure 25, this is 10 to 15 seconds, or 5% to 8% of the mean VIP travel times.

The third segment is more city inwards and situated between the Roesinkbleekweg and the Singel. For this segment the difference between the VIP and FCD travel times is less, which is also reflected in the low RMSE of 6.6. For the fourth segment, between the Singel and De Ruyterlaan, less distinctive delays belonging to the rush hours and less significant difference between VIP and FCD were detected.

The difference between FCD and VIP is bigger during night when probably more cars drive too fast. When delays are detected during rush hours one should expect that FCD and VIP should be almost the same. This is however not the case for the first two sections. This is explained by the character of the road. Delays on the first two segments are caused by longer waiting times at the junctions. The route has two lanes on whole first segment and on the first part of the second segment. In between the traffic can still keep their speed. So, there are probably still fast drivers during rush hour causing the

difference between VIP and FCD. For the first segments from own experience delays are only taking place in the direct proximity of the traffic lights.

It can be concluded that the cut-off of too high speeds exceeding the maximum speed leads to higher FCD travel times with respect to VIP. In the travel times of the whole route in Figure 22 difference can be spotted between VIP and FCD. The difference is however minimal. VIP and FCD both detect the rush hour delays well.

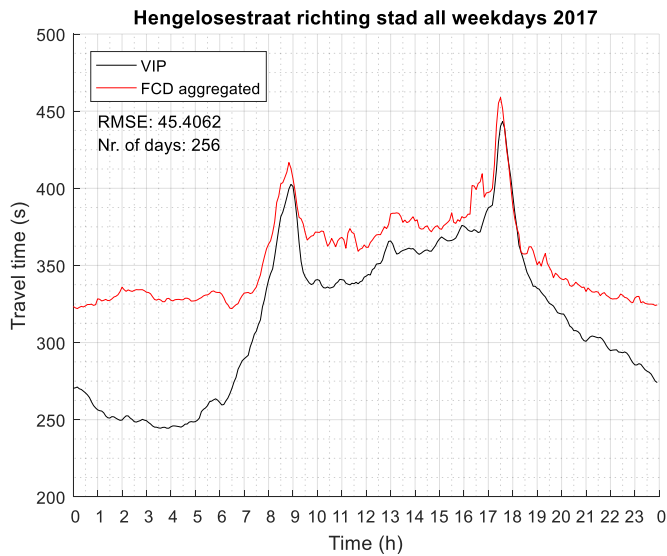


FIGURE 22: HENGELOESTRAAT RICHTING STAD FOR ALL WEEKDAYS

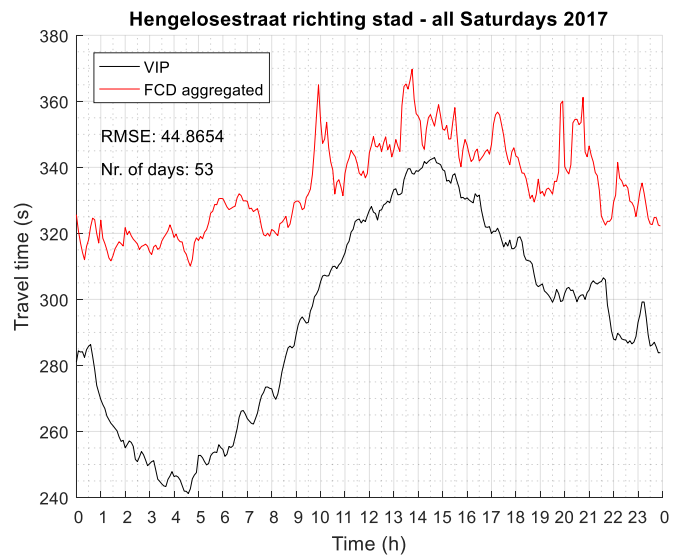


FIGURE 23: HENGELOESTRAAT RICHTING STAD FOR ALL SATURDAYS

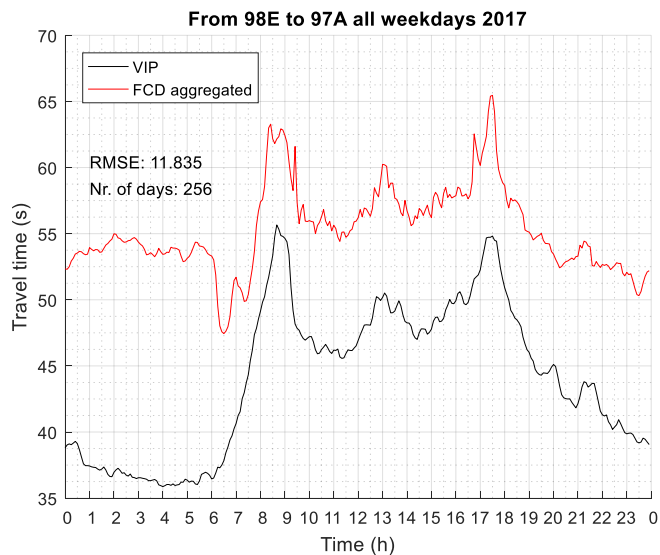


FIGURE 24: FIRST SECTION OF HENGELOESTRAAT RICHTING STAD

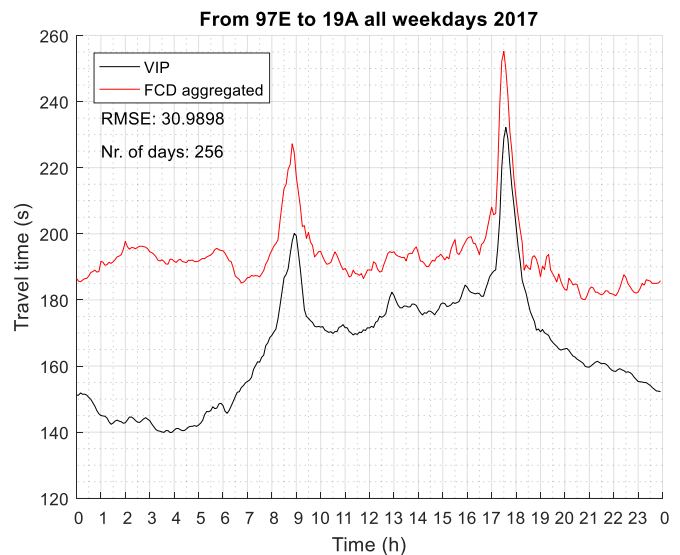


FIGURE 25: SECOND SECTION OF HENGELOESTRAAT RICHTING STAD

5.1.2 Type of traffic

The second characteristic that was examined is type of traffic. A distinction is made between two types of traffic, namely commuting traffic and shopping traffic. The available data does not give origin and destinations. Therefore, it is not exactly known to which type the measured cars belong. Assumed is that during weekday rush hours commuting traffic predominates and during Saturdays shopping or non-commuting traffic predominates.

Two routes are analysed for this characteristic: 'Gronausestraat richting stad' and 'Singels Noord-west XP38 n XP08'. The 'Gronausestraat richting stad' was chosen, since it connects the east side of Enschede with the centre and has therefore commuting traffic during rush hours on weekdays, shopping traffic on weekdays to the surrounding stores and also shopping traffic during weekend.

Expected was that VIP and FCD would differ more for shopping traffic than for commuting traffic, since shopping traffic, is less bound by being in time on the destination, travels shorter distances and therefore is less likely using an application like Flitsmeister.

The travel times for the Gronausestraat on weekdays and on Saturdays can be found in Figure 26 and Figure 27. For the Gronausestraat a peak can be detected between 14h and 15h. The cause could be the shops at the MIRO center on the Gronausestraat attracting a lot of people. According to Van der neut, Enschede is a city where some companies work in shifts through which commuting traffic can appear outside the rush hours. FCD has always a bias for the Gronausestraat; FCD is a bit higher than VIP data. From the cross correlation it follows that on weekdays FCD for the Gronausestraat has a time shift of 15 minutes. On the Saturdays the travel times of FCD and VIP are comparable for the Gronausestraat. However, the mean penetration for all Saturdays is only 17 cars in three hours between 12h and 15h.

The route 'Singels noord-west XP38 n XP08' is a bit different. Here the weekdays are very comparable and the bias is little. But for the Saturdays there is a big bias. The cross correlation does not give a time shift on weekdays. It does give a time shift of 15 minutes on Saturdays for the Singels.

From the analysis follows that the travel times of FCD and VIP do better compare for weekdays than for Saturdays. Less fluctuations are detected for weekdays in comparison with Saturdays. Therefore, more value should be given to the data for weekdays over the data of the Saturdays. During the time intervals commuting traffic is more present FCD has less bias with respect to VIP.

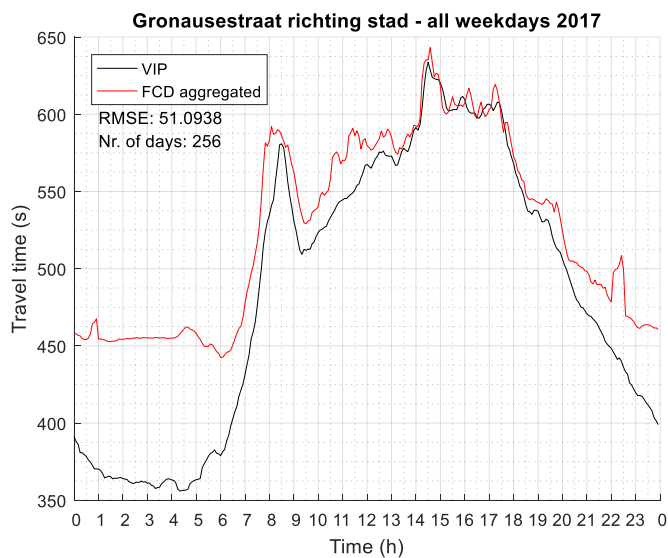


FIGURE 26: GRONAUSESTRAAT RICHTING STAD FOR ALL WEEKDAYS OF 2017

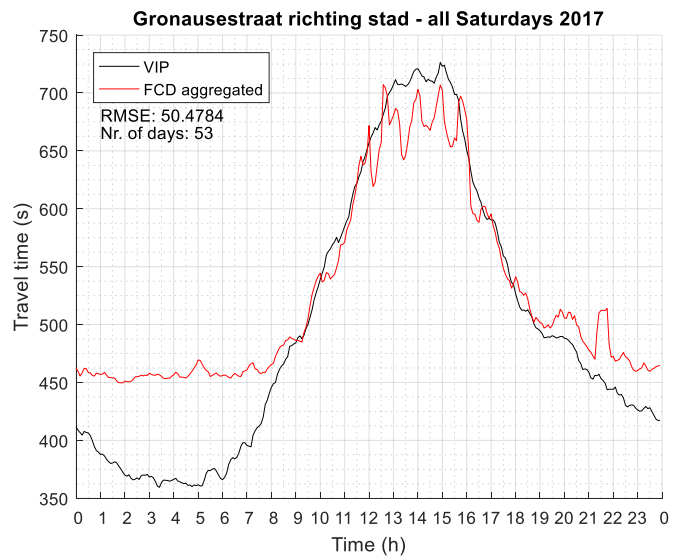


FIGURE 27: GRONAUSESTRAAT RICHTING STAD FOR ALL SATURDAYS OF 2017

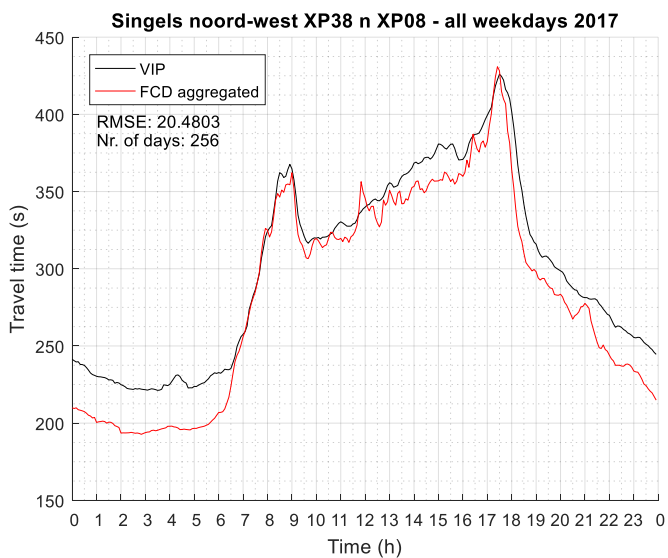


FIGURE 28: SINGELS NOORD-WEST XP38 N XP08 FOR ALL WEEKDAYS OF 2017

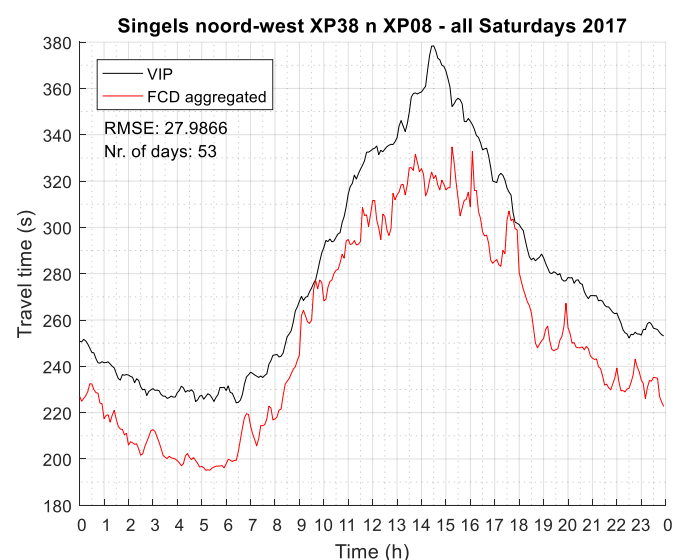


FIGURE 29: SINGELS NOORD-WEST XP38 N XP08 FOR ALL SATURDAYS OF 2017

5.1.3 Intensity on German holidays

The third characteristic that is examined is the intensity on German Holidays. Germany has holidays the Netherlands do not have (Ferien Wiki, sd). On those days most Germans do not have to work and German shops are closed. In Enschede the shops are open, resulting in Germans massively traveling to Enschede.

German holidays are important to examine for Enschede, since these belong to the busiest days of the year. The German national holidays Labour Day, Allerheiligen and German Unity Day are examined. These three days were on a weekday in 2017, which means that, next to the traffic from Germany, commuting traffic during the rush hours is also present. For the activation of scenarios, as described in the theoretical background, the live travel times of VIP are used. The travel times of FCD for the German Holidays can also provide insight on how sufficient FCD is for the application of the municipality. The three routes (both directions) for which the municipality uses scenarios are analysed. All figures are plotted with number of matches, since these show that the number of matches drop when high peaks appear for FCD. This indicates the different character of FCD in comparison with VIP.

Allerheiligen (or All Saints' Day) takes place on the first of November. In 2017 this was on a Wednesday. Figure 30 and Figure 31 display that for the Gronausestraat FCD follows VIP, but fluctuates a lot. The penetration between 12h and 15h is only 17 cars in three hours for the direction towards the city. The low number of detected cars can be caused by the parallel road next to the chosen segment. The data can be assigned to the wrong segment if the GPS wasn't exact enough. The FCD of route 6, the main part of the 'Gronausestraat richting stad', was already downloaded for 2018 and therefore quickly analysed. Discovered was that the VIP data for this route was lower than expected as displayed in Figure 33. Also, the number of matches was low. Sample-wise examining the days revealed that 2 of the 3 sections this route is made of have 0 matches since the 17th of march until the end of the year. This means that VIP is broken and needs maintenance. The possible cause is the installation of new traffic lights.

FCD and VIP are also plotted for Labour day for the Zuiderval richting the stad (Figure 32). A clear extra rush hour on the middle of the afternoon can be distinguished. Between 7h and 10h the number of cars counted for FCD is 10 and between 12h and 15h 32. The peak during morning rush hour is therefore based on too little data. What is learned from this is that a big peak in VIP doesn't necessarily to be correct, even on days where big peaks are expected.

On the German Unity Day the biggest delays can be spotted in the FCD and VIP data. For this day the data is plotted for both directions of the Zuiderval, Gronausestraat and Oldenzaalsestraat and can be found in Figure 34 to Figure 39. What these six routes have in common is that when big delays are detected in the FCD, the number of VIP matches drop. The peak for the 'Zuiderval richting stad' between 12h and 15h is based on 33 vehicles for FCD. The penetration of this route between 12h and 15h is on the surrounding days almost equal or sometimes even a bit higher. That despite the high intensity the penetration is still relatively low, might be caused by Germans making up the biggest group of road users which possibly are not using the app Flitsmeister. Due to the sudden drop in VIP matches it is expected that the given travel times are too low for VIP and that the FCD travel times approach the real situation.

The delays on the German Unity Day are not only detected for the Oldenzaalsestraat, Gronausestraat and Zuiderval, but also on other major routes, as the Singels and the Hengelosestraat. The big amount of traffic causes delays in the whole city.

Concluding, during peak moments on German Holidays, FCD detects much more delay than VIP. For the application of activating scenario's this is positive. These peaks can be detected by the system and the scenarios can be activated. However, due to the fluctuations, it should be determined what time should pass when a set value is exceeded, so that fluctuations are not causing the system to activate and deactivate in a short time. FCD produces travel times more in line with the expectation of high travel times during the rush hours caused by Germans going to shop in Enschede. In the future, when the penetration of FCD is increased, the difference on German holidays should be examined again.

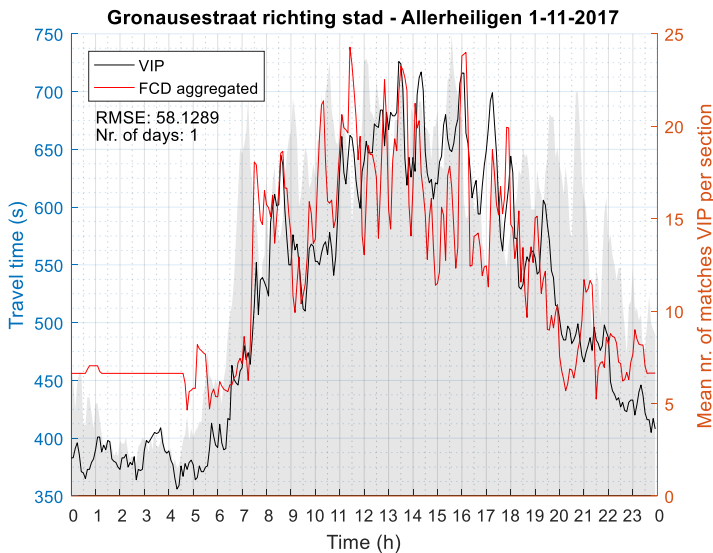


FIGURE 30: GRONAUSESTRAAT RICHTING STAD ON ALLERHEILIGEN 2017

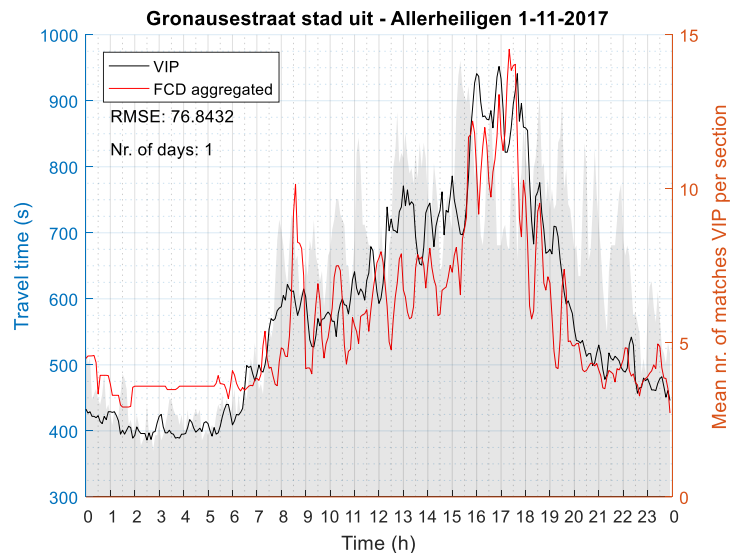


FIGURE 31: GRONAUSESTRAAT STAD UIT ON ALLERHEILIGEN 2017

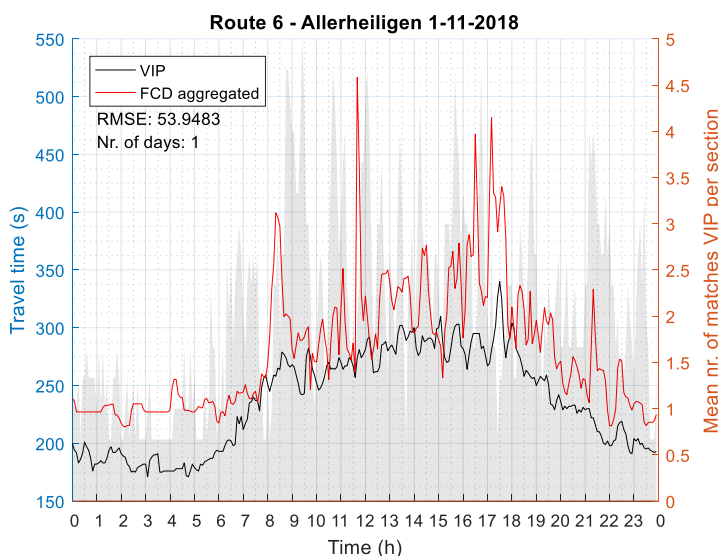


FIGURE 33: ROUTE 6 (GRONAUSESTRAAT) ON ALLERHEILIGEN 2018

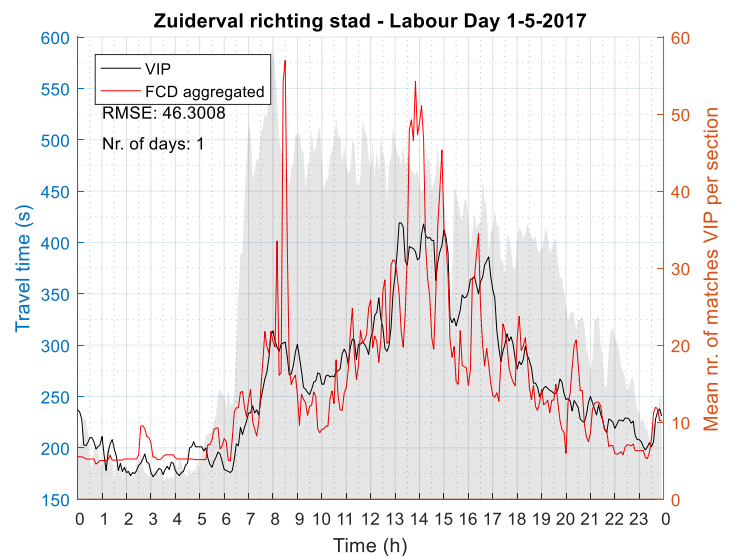


FIGURE 32: ZUIDERVAL RICHTING STAD ON LABOUR DAY

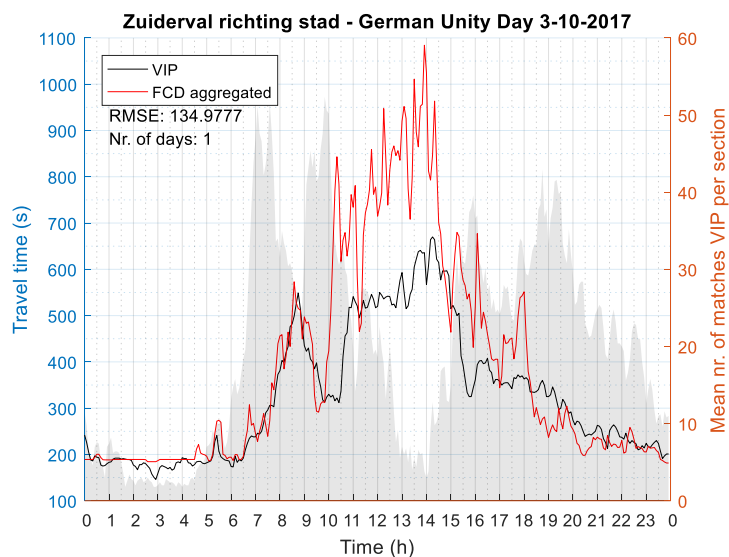


FIGURE 34: ZUIDERVAL RICHTING STAD ON GERMAN UNITY DAY

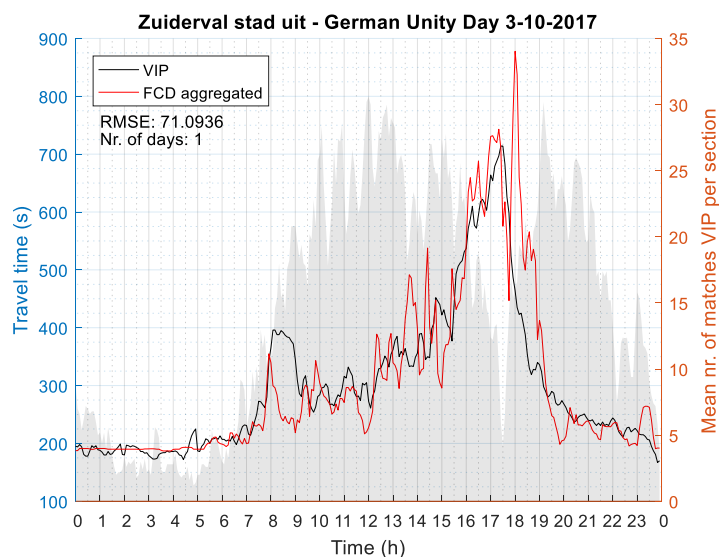


FIGURE 35: ZUIDERVAL STAD UIT ON GERMAN UNITY DAY

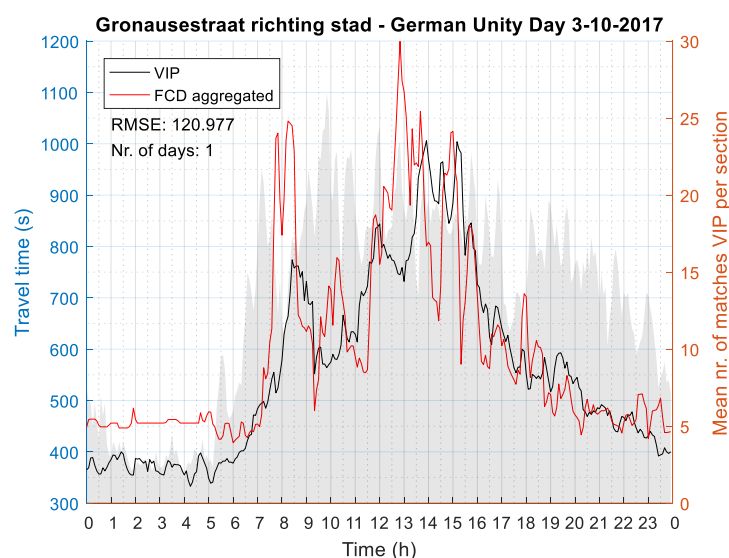


FIGURE 36: GRONAUSESTRAAT RICHTING STAD ON GERMAN UNITY DAY

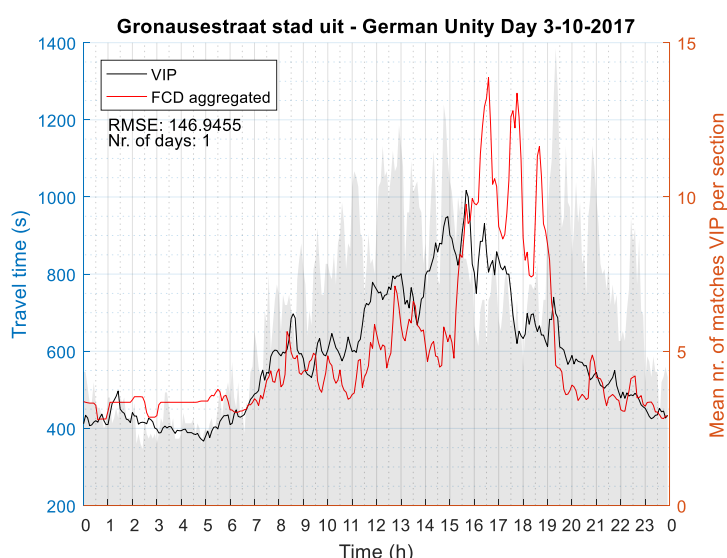


FIGURE 37: GRONAUSESTRAAT STAD UIT ON GERMAN UNITY DAY

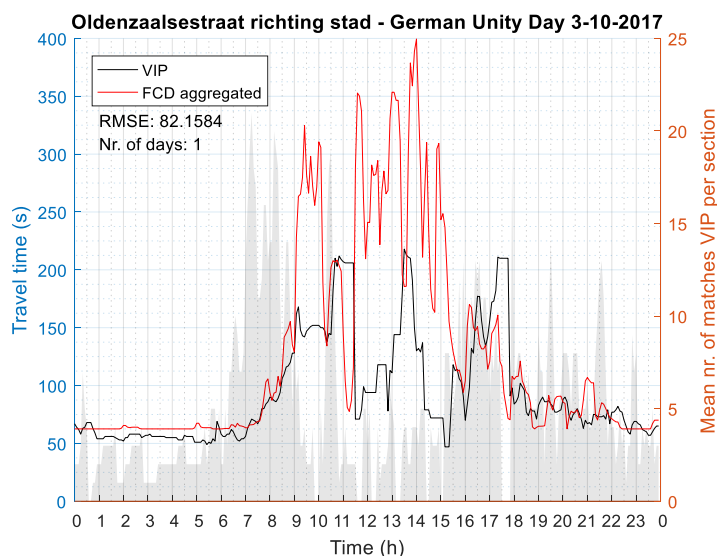


FIGURE 38: OLDENZAALSESTRAAT RICHTING STAD ON GERMAN UNITY DAY

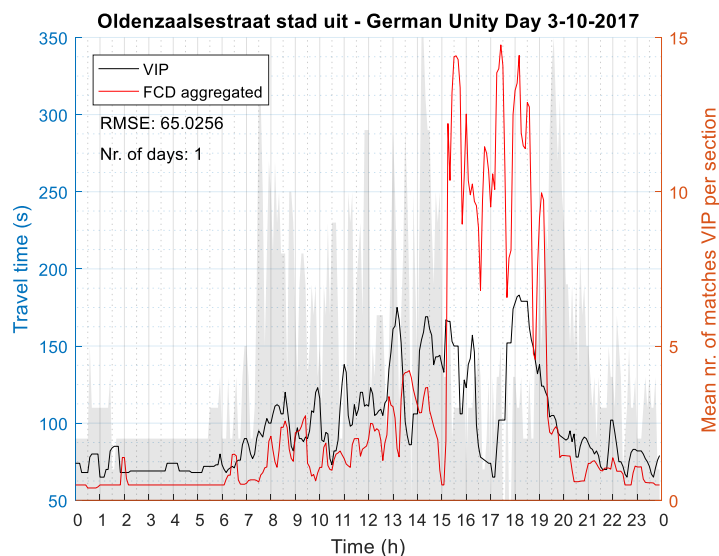


FIGURE 39: OLDENZAALSESTRAAT STAD UIT ON GERMAN UNITY DAY

5.1.4 Turn at a junction

From literature it followed that a turn at a junction could cause differences in the travel times measured with floating car data with respect to the other measurement system. (Uenk, Vergelijkingsonderzoek Floating Car Data, 2018). This characteristic is tested for the route 'Westerval richting stad' which turns to the left at intersection XP38 and for 'Singels noord-west XP38 n XP08', which turns at XP12.

There are only two VIP routes that have a turn at a junction. All other routes run straight across the intersection between start and end point. The Westerval is one of the main routes in Enschede. VIP travel times for this route are also used for drips on the side of the A35. Therefore it is important to rule out a possible effect of a turn at a junction and to determine how well FCD is for this route. The route on the north west part of the Singel is analysed as reference.

When VIP data for a route with a turn at a junction is compared with VIP data for a route without a turn at a junction, no difference is expected. VIP always compares the profiles from all directions on the intersection to the profile of the end direction. For FCD other data around the intersection is used for the incoming direction when a turn is made. Random fluctuations in FCD, comparable to the results of the comparison research of Uenk, were expected.

For the Westerval a lot of days with outliers were found. It could be that the outliers are a product of the turn at the junction. This is however not easy to prove, since outliers are also present for the other routes and can possibly have another cause. To get a better image of the profile of the travel times for the route, the days with outliers are in its entirety filtered out. For the weekdays, the mean of the remaining 199 days of 2017 is plotted in Figure 40. The same was done for the Saturdays. The mean of the 41 remaining Saturdays is plotted in Figure 41. For the 'Singels noord-west XP38 n XP08' the same was done resulting in Figure 42 and Figure 43.

The VIP and FCD mean travel time for the weekdays compare well for the 'Westerval richting stad'. The rush hour peaks are about the same height. A bias appears between the rush hours; FCD is a little bit higher than VIP. From the cross correlation and the minimum RMSE it follows that there is no time shift. No big distinctive differences can be distinguished that can be assigned to the characteristic turn at a junction. The same can be said about the Singels route. For the weekdays on this route, no shift needs to be applied.

For the Saturday an extra peak between 4h and 7h is detected in the VIP data and not in the FCD. This is not explained as caused by the turn at a junction. Perhaps, nightlife traffic, Saturday market traffic or another type of traffic which does not use the application Flitsmeister is causing the difference. FCD does follow the VIP data, but fluctuates more for the Saturdays. For the Saturday, FCD is better aligned if it is shifted 30 minutes to the right. The Saturday has a much more fluctuating character. This probably due to low penetration. The mean travel times of the Saturdays for the Singels has a bias. FCD is always lower than the VIP data. Based on the cross correlation should be shifted 15 minutes to the right.

Concluding, no distinctive difference can be distinguished that can be assigned to the turn at a junction. The routes 'Westerval richting stad' and 'Singels noord-west XP38 n XP08' therefore do not need a special treatment with respect to routes without a turn at a junction. However, a lot of outliers were detected.

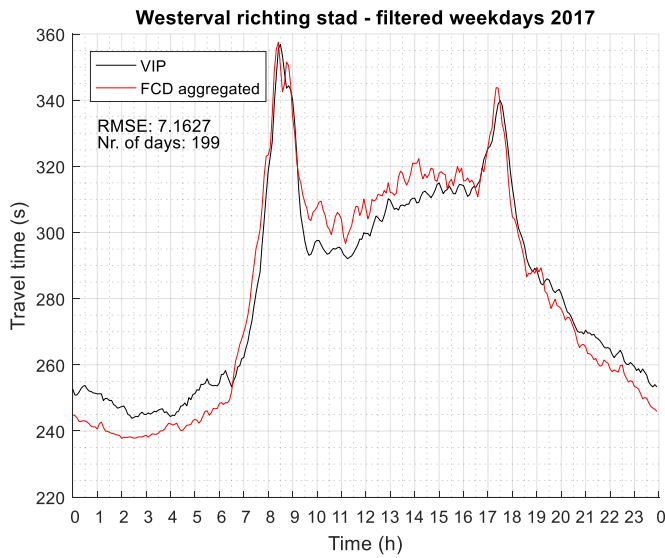


FIGURE 40: WESTERVAL RICHTING STAD FOR FILTERED WEEKDAYS

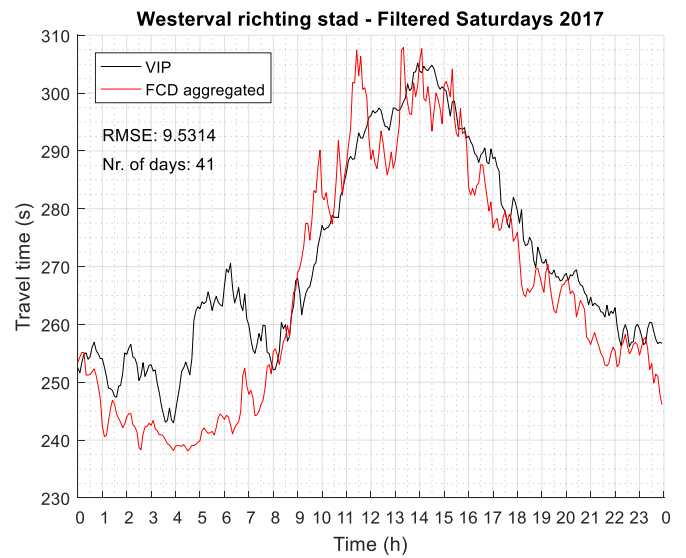


FIGURE 41: WESTERVAL RICHTING STAD FOR FILTERED SATURDAYS

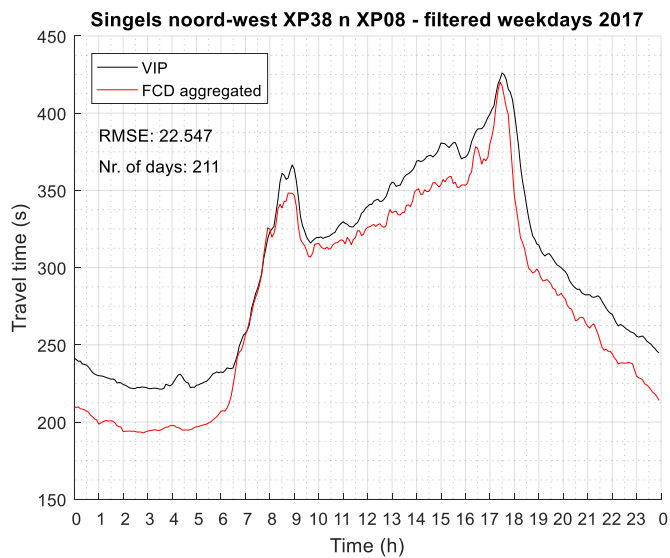


FIGURE 42: SINGELS NOORD-WEST XP38 N XP08 FOR FILTERED WEEKDAYS

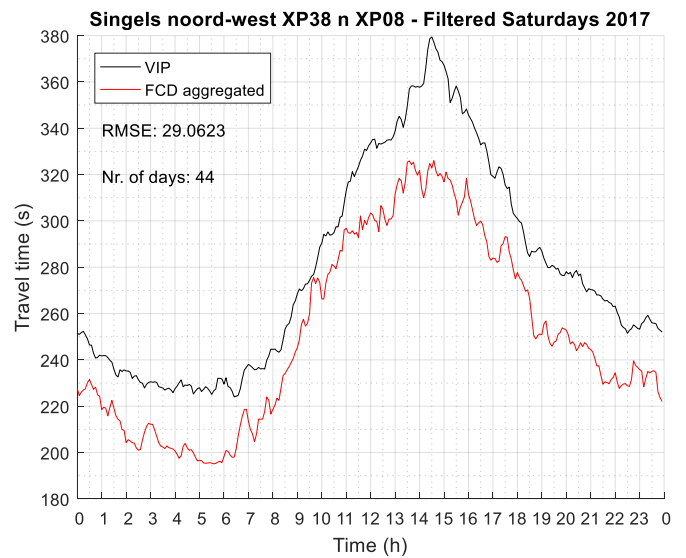


FIGURE 43: SINGELS NOORD-WEST XP38 N XP08

5.2 Comparison for state of the city

Every year for the state of the city an index is determined to describe the accessibility of the city of Enschede. This index is based on VIP travel times of three routes: Westerval, Zuiderval and Gronausestraat all in direction of the city. More exactly, the corresponding routes 1, 3 and 6, used for the travel times on the drips along the A35/N35, are used in determining the state of the city. From these routes, only the travel times on selected intervals of selected days, listed in Table 3 (Gemeente Enschede, 2017), are used in determining the index.

For this comparison a separate Matlab script was made to enable loading files of 3 routes at the same run. Based on the calculations in the Indicatoren Bereikbaarheid – rekensheet 2017 december geheel excel sheet (Gemeente Enschede, 2017), the index for VIP and FCD both are calculated, plotted and visually examined. The VIP data and FCD were available for 2016, 2017 and 2018. The index is thus calculated for three years. FCD was downloaded for whole years. From this, the Tuesdays, Thursdays and Saturdays were first selected and loaded in Matlab. Second, the columns in which the travel times corresponding to the time intervals are located are called.

The state of the city index of a year is a mean value of the indices of the three separate routes. The index of an individual route is the mean of the mean travel time per month divided by the reference value from 2011 times 100% to make it an index. The mean value of a month is calculated by taking the mean value of the three means of the three time intervals. The means of the time intervals are made out of 8 to 10 days for the Tuesdays and Thursdays and of 4 to 5 days for Saturdays depending on how many of those days are in a month. An overview of the calculation is displayed in Figure 44.

Since for the index the routes 1, 3 and 6 are used, the given travel times in the csv files differ from the sum of travel times of all segments of which the route consists. The travel times are used on the drips along the A35/N35. Therefore, the travel time from the drip to the starting point of the route is added to the total value. For a good comparison between VIP and FCD the value is also added to the FCD travel times. The added travel time values are displayed in Table 4. (Gemeente Enschede, 2016)

TABLE 3: USED TIME INTERVALS FOR STATE OF THE CITY INDEX

Days	Interval
Tuesdays and Thursdays	7:30 – 9:00
Tuesdays and Thursdays	10:00 – 12:00
Saturdays	12:00 – 14:00

TABLE 4: ADDED TRAVEL TIME VALUES FOR STATE OF THE CITY INDEX

Route	Added travel time
1 – Westerval	325
3 – Zuiderval	120
6 – Gronausestraat	240



FIGURE 44: STATE OF THE CITY INDEX CALCULATION

Now, VIP is used as source for the travel times. In the future FCD could be a possible source to determine the state of the city. In this paragraph, first the comparison of VIP with FCD for the index of the status of the city is presented. A comparison based on absolute travel time has also been done and is described in the second part. Thereafter a correcting factor for FCD was calculated to overcome the trend break between VIP and FCD. This factor is determined for each route separately and based on the absolute travel time values. This factor can be applied to overcome the trend break between VIP and FCD measured travel times.

5.2.1 State of the City

Since 2011, every year the state of the city is determined. The index for 2011 is set at 100%. The aim of the municipality was to decrease the travel times with respect to 2011 (Gemeente Enschede, 2017). In 2015 the aim was adjusted to the value of 2015. Using the VIP data and FCD of 2016 to 2018, the accessibility index is calculated. Figure 45 displays the calculated index for VIP and FCD. The VIP values for 2011 to 2015 are also plotted. (Gemeente Enschede, 2017)

For FCD the same reference value is taken as for VIP. FCD is consequently higher than VIP; FCD travel times are higher than VIP travel times. Since 2016 a slight increase of the indicator can be seen for VIP as well as for FCD. Over the period of three years, VIP and FCD are becoming a little bit closer. In Figure 46 the absolute mean travel times can be found. This figure displays that the difference between VIP and FCD changes from 30 seconds in 2016 to 22 seconds in 2018.

The reference value can also be set at 100% for both measurement systems in 2016. This results in Figure 47. It can clearly be seen that VIP increases more over the two years than FCD: 6% for VIP against 4% for FCD. The cause of the difference is examined by looking at month level at the mean travel times for each individual route.

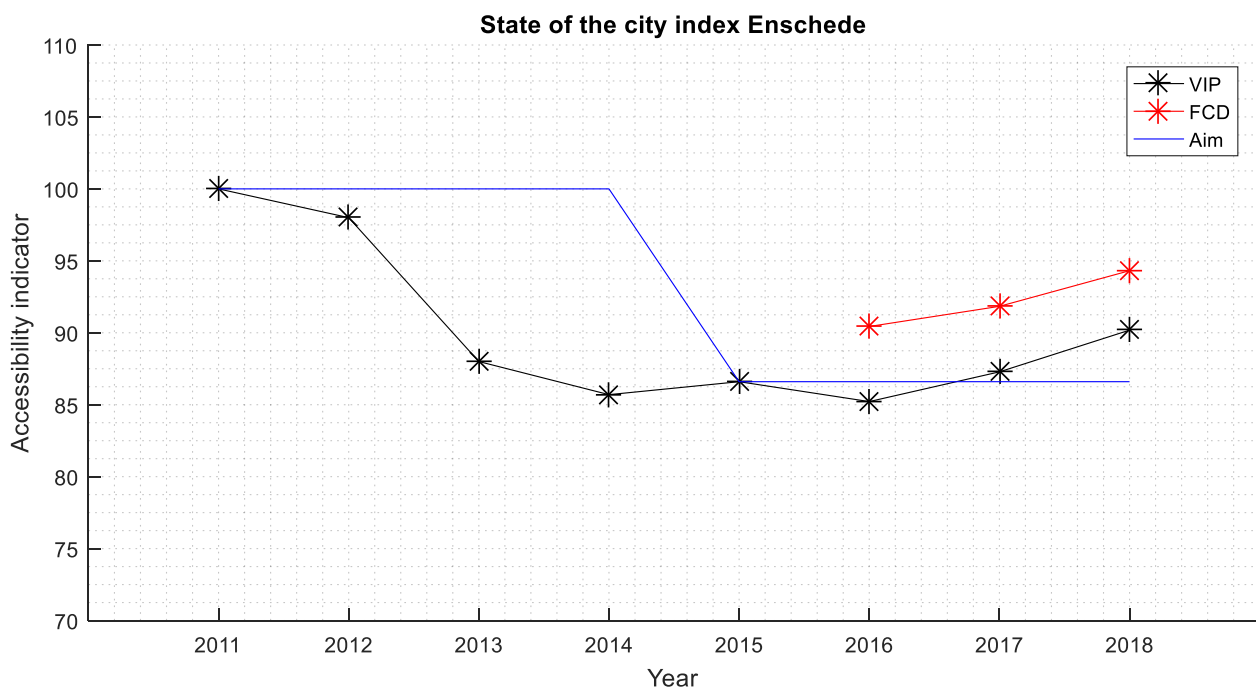


FIGURE 45: STATE OF THE CITY INDEX FROM 2011 TO 2018 FOR VIP AND FROM 2016 TO 2018 FOR FCD

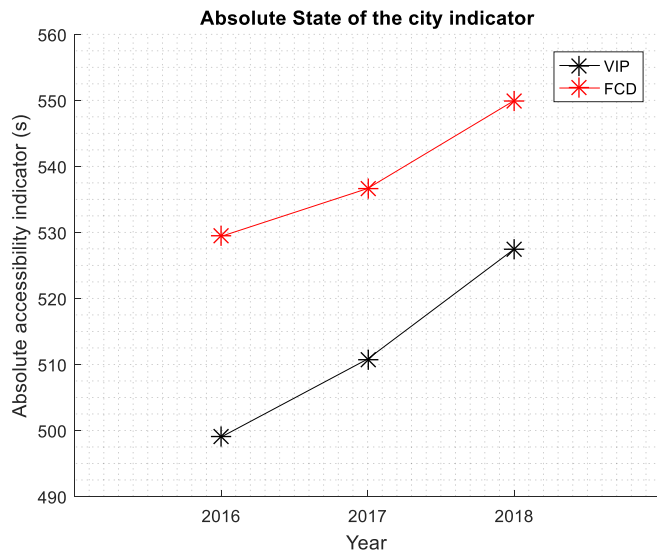


FIGURE 46: ABSOLUTE STATE OF THE CITY INDICATOR

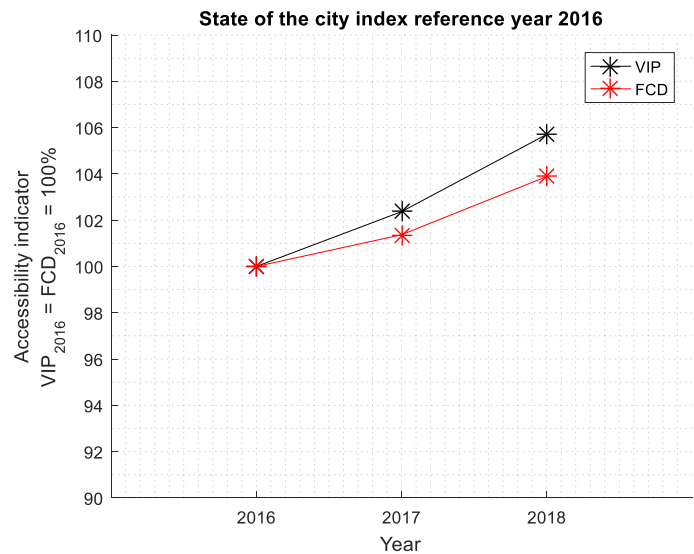


FIGURE 47: STATE OF THE CITY INDEX WITH VIP AND FCD SET AT 100% FOR 2016

5.2.2 Absolute difference comparison

The travel times are also examined per month for each individual route. The mean travel time per route for all months of 2016 to 2018 for both FCD and VIP can be found in Figure 49. Differences between the three routes can be seen. For route 1, the VIP and FCD travel times are close to each other. The difference fluctuates the least of the three routes. For route 2, the difference in travel time fluctuates little until august 2018. Thereafter big differences start to appear. For route 6 the difference is in 2016 consequently around 60 seconds. Thereafter this starts to change.

Looking at Figure 49 for route 3, the travel time of VIP decreases in the last months of 2018 were an increasement is expected as shown by the purple line for FCD. By looking at the segment files of the VIP route, it was discovered that two of the four sections of route 3 do not work since august 2018. Analysing the segment files of route 6 revealed that two of the six sections do not register travel times since 17 March 2018. This was not known by the municipality. This shows the vulnerability of VIP. Without clear notice, the system can stop working. For route 1 no peculiarities in the number of matches were spotted.

9 months the drips on the side of the A35/N35 displayed incorrect travel times for the route from the Oostweg via the Gronausestraat to the city centre. For the route via the Zuiderval this was around 5 months. The possible cause for both routes is the replacement of the traffic light installations around the time the measurement systems started having no matches (Secretariaat Stadsingenieurs en Ontwerp, 2018). The company that did the replacement insured the municipality unjustified that all systems were working again. The zero number of matches are only detected when the segment files are examined, since for the whole route, the number of matches is the sum of matches of all its segments. The two sections that are working disguise the non-working sections. This problem was therefore not automatically detected by the municipality.

Based on the differences per route shown in Figure 48, a correcting factor per route is advised. Since the VIP data of 2018 is not fully reliable due to the non-working sections, the factor is based only on the values of 2016 and 2017.

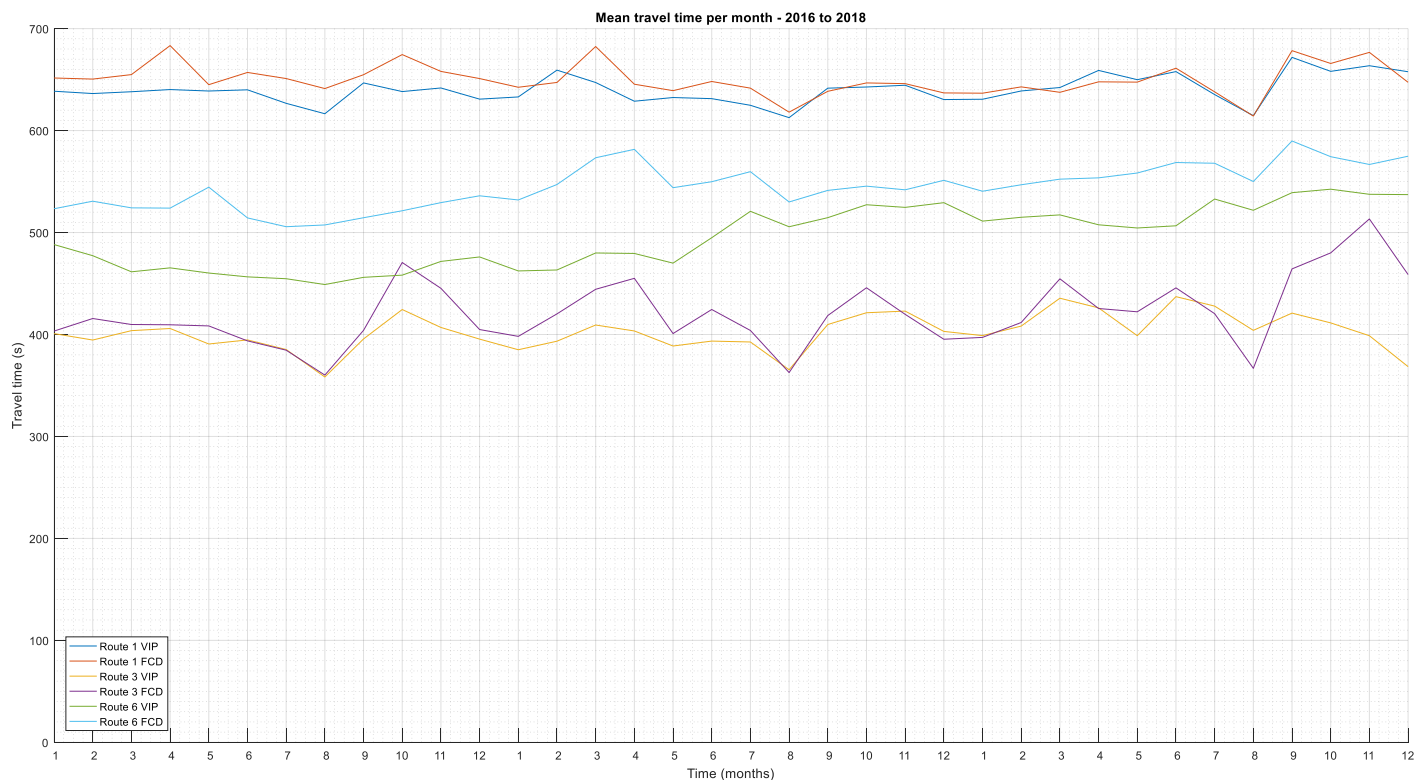


FIGURE 49: MEAN TRAVEL TIMES PER MONTH FOR 2016 TO 2018

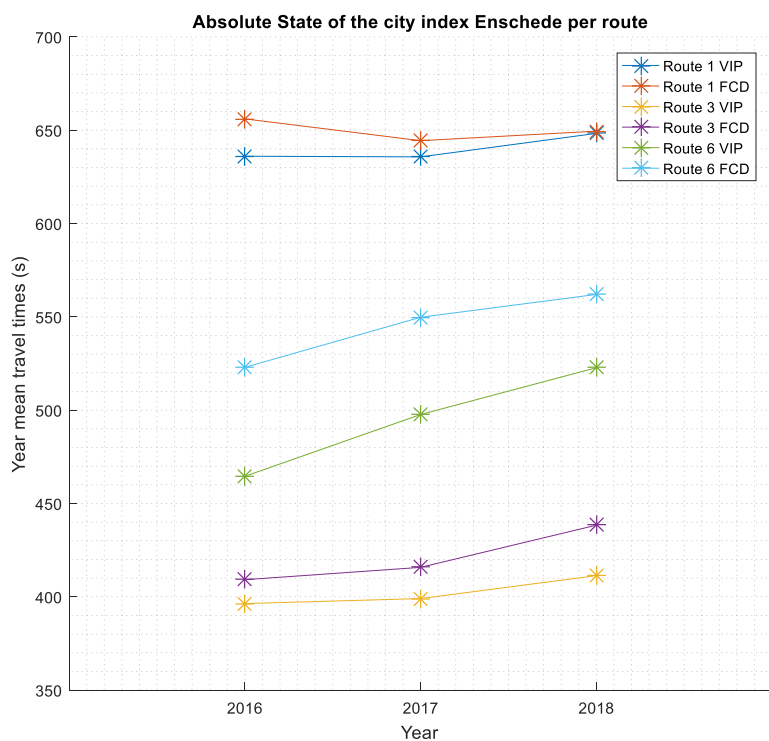


FIGURE 48: COMPARISON OF THE ABSOLUTE YEAR MEAN TRAVEL TIMES FOR ROUTE 1, 3 AND 6

The correcting factors for the three routes were calculated by averaging the correcting factor of a route for 2016 and 2017. In determining the correcting factor, assumed is that the difference between VIP and FCD does not change over the years. The correcting factors are listed in Table 5. The factors are also applied on FCD. The state of the city index with corrected FCD is displayed in Figure 50. Note that the VIP index of 2018 does not give a good representation of the accessibility of the city for 2018, due to the non-working segments. The corrected FCD differs little from VIP. The index for corrected FCD increases less than the VIP index, but shows almost the same trend.

Therefore, it is concluded that, within the context the municipality uses the state of the city index, FCD can be used for determining the state of the city index instead of VIP.

TABLE 5: CORRECTING FACTORS FOR FCD PER ROUTE

Route	Correcting factor
1 – Westerval	0.9780
3 – Zuiderval	0.9642
6 – Gronausestraat	0.8968

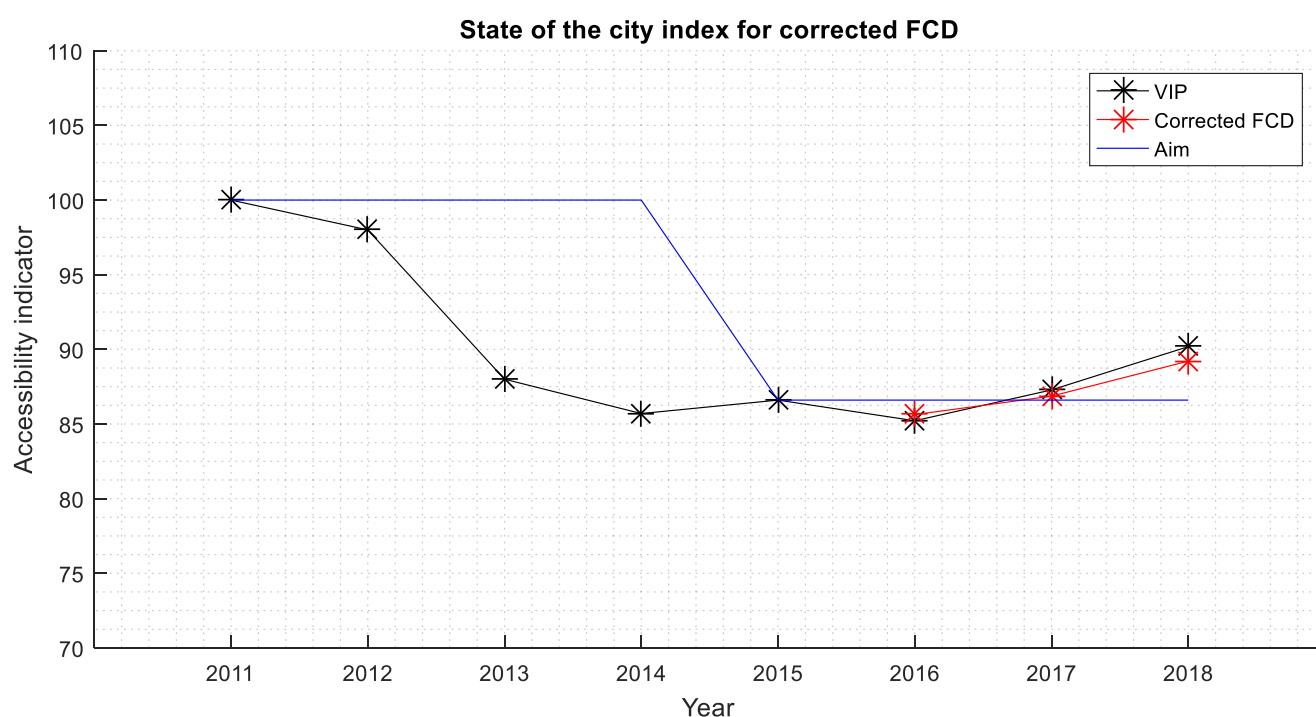


FIGURE 50: STATE OF THE CITY INDEX FOR CORRECTED FCD

6. Discussion

In this chapter the procedures, data and results are discussed.

Used Data | It is important to note that in this comparison research FCD is compared to another measurement system of which the data can differ from the real-world situation. When comparing FCD to VIP, VIP is assumed to be the truth. This is inescapable. Since VIP data is well available FCD is easy to compare with VIP. The goal was to compare as much FCD as possible. For this VIP is particularly suitable. For the analysis mostly the data of 2017 was used. At the start of the research, 2017 was the most recent year of which all days were available. Due to time limitations, chosen was to mainly examine 2017 and to examine 2018 only for some selected routes.

Inaccuracies | There is a little inaccuracy caused by the difference of start and end point of the FCD route compared with the VIP route. There are no exact GPS coordinates known for the induction loops and also GPS coordinates cannot be used as input in FLOWcheck. The location of a loop was found using google satellite and the drawings of the junctions (of which some were not available). The found locations of the far away loop at about 60 meters before the stop line was selected by hand in the online viewer. For a lot of VIP routes three loops are used at the beginning of a segment. In FLOWcheck the start point of the route is placed on the loop with the highest intensity.

Limited use VIP | From the interviews followed that the usage of VIP by the municipality of Enschede is limited. VIP only contributes little in traffic management in Enschede. Historical analyses are only done for three routes: Westerval, Zuiderval and Gronausestraat. These routes are arguably the routes on which traffic management is most needed, since these routes endure high intensities. For these routes it followed from quick analysis that the penetration is a bit higher compared to the other routes. Still, the penetration needs more research. VIP data of the other routes is not actively used or analysed. So, in comparing FCD with VIP the results for these three routes are most important. From the interview with Van Engelshoven and Van den Hof, it followed that from the policy point of view FCD is more seen as a just replacement of VIP or a different source for the same data. The quality of FCD can thus be examined within this context.

FLOWcheck | The online viewer FLOWcheck needs to be used for accessing the FCD. This viewer provides easy access to the data and makes the data well visible in the viewer for short date ranges. However, a yearly analysis of FCD needs to be made outside the tool. The tool does not work well for a job with a big date range. Therefore, the municipality should look into how it wants to execute the yearly analysis with FCD. Besides, the tool does not allow to select which data is downloaded. This causes downloading data costs unnecessarily more space and time.

FCD Penetration | Long time during this research it was not known how to find the penetration of FCD. Ultimately, after consultation with the account manager of Be-Mobile a way was found to get the penetration of segments of the route. The penetration cannot be accessed on minute level, but only for time interval that is selected in FLOWcheck. Therefore, all given penetrations in this report are estimations. The penetration is only determined for one of the multiple 50-meter segments of FCD and may vary along the route.

For FCD it is difficult to find abnormalities based on the penetration, since the penetration does not directly come with the travel times. This means that when you see a big peak indicating a delay, you don't know if this is correct or not. If you want to be sure, you must make a job in the segment analysis tool for the day and period the peak is in. For VIP the number of matches comes directly with the travel times. This means that you directly can see per 5 minutes how many vehicles the data is based on. This adds value to VIP data over FCD.

The penetration of FCD is very important that it should directly come with the travel times. From a scientific point of view, I think that worse FCD travel time data with known penetration is more valuable than good FCD travel time data with unknown penetration.

When more time was available it would be possible to systematically download all penetration data and call this data when calculating mean travel times. Then the penetration can be plotted with the travel times in one graph. But this would still be very time consuming.

When the penetration is high enough, FCD is much more robust than VIP. VIP on the other hand gives more results for individual days that have less fluctuations. However, it is not clear until which intensity VIP registers the travel times correctly. In some cases, the number of matches is dropping directly after a high number of matches, through which the average VIP travel times also drops while the FCD travel times increase.

Time shift | From the basic comparison for the Zuiderval in chapter 4 it followed that FCD should be shifted 15 minutes. Even when most influences are filtered out and a route with sufficient penetration is examined a time shift appears.

Characteristics | It was difficult to determine to which extent a characteristic is causing deviations. For speed this is really clear, but for the type of traffic and turn at a junction this is less clear. To fully examine the characteristic type of traffic more information about origin and destination is needed. The effects of characteristics are only examined through examples. This allowed analysing more characteristics within the limited available time.

State of city index | The idea with phasing out VIP and start using FCD is that the applications VIP is used for do not change. However, when a switch is made from VIP to FCD the state of the city can also be determined in other ways. Now the state of the city is a mean of means of means with a reference value of 2011. From the interviews follows that the resulting index is just a tool that only in its context provides some answers. That FCD fluctuates a lot is not that bad when determining an index over a whole year. FCD of 2017 has some strange outliers, but VIP also has its abnormalities that are also included in the index.

The state of the city is based on all Tuesdays, all Thursdays and all Saturdays in 2017. This also includes Saturday 18-02-2017 and 6, 8 and 10 June 2017. So, data of 4 of the 156 days (2,56%) is based on no matches and is included in the state of the city. Expected is that this will have little effect since it are so few days and the data on these days is based on reference values representative for normal situations on these days. Still, it says something about how well the index of the performance of the city is. However, since you are dealing with an index, the same problem can appear in the index of the consecutive years which will middle out the effect.

For determining the index, the drip routes 1, 3 and 6 are used. These are almost equal to Westerval, Zuiderval and Gronaussestraat. An offset travel time is added to the travel times of this route. This is the travel time from the drip to the start of the route. This offset is fixed and is for route 1 almost halve the total travel time. This has as result that when the actual travel time on the different sections of the route changes over the years, the change in the index is limited, since the fixed value determines halve of the total value. A change in the situation is thus less see able.

7. Conclusion

The aim of this research was to provide the municipality with enough information on the quality of floating car data, so that they can consider phasing out VIP or not. The main research question was:

Is the quality of Floating Car Data sufficient enough to phase out the Vehicle Inductive Profile technology, to use Floating Car Data as source for travel times and to use Floating Car Data to indicate the state of the city of Enschede?

From the results follows that within the given context by the municipality of Enschede, the quality of FCD is sufficient enough for a couple of routes on specific times, but not on all. FCD is a good alternative for VIP data in determining the state of the city index of Enschede.

From the interviews followed that in the perspective of the municipality, traffic management is about taking measures to increase the capacity within the limited available space. For determining where measures are needed traffic measurements are done among others. The use of measurement systems by the municipality of Enschede is however limited. VIP data is only used in a few applications. VIP does work well, but problems with the measurement system are only detected afterwards and the system needs a lot of maintenance. An easy analysis tool on travel times is wanted. Given the management requirements and ambitions a switch to FCD is therefore relevant and interesting for the municipality.

In basis the quality of VIP and FCD correspond very well for the route Zuiderval from the Wethouder Beverstraat to the Singel. For weekdays as well as Saturdays, the travel time profiles do match. On day level, however, FCD does have a lot of outliers. The penetration of FCD is very low compared to VIP. The penetration is sufficient during morning rush hour for the Zuiderval and did increase over the past years. When this trend continues FCD will become more valuable in the future. The penetration should improve to make good live analyses possible. On day level floating car data fluctuates too much for being reliable input for drips. For individual days, VIP produces better data.

The quality of FCD differs between routes. For some this difference can be assigned to a characteristic. 4 characteristics were examined of which 2 have a clear effect and 2 a less distinctive to no effect.

Speed | The cut-off of too high speeds exceeding the maximum speed leads higher FCD travel times with respect to VIP. In the travel times of the 'Hengelosestraat richting stad' a clear bias or difference can be spotted between VIP and FCD. The difference is however minimal. VIP and FCD both detect the rush hour delays well. A time shift of 5 to 10 minutes was detected

German Holidays | During peak moments on German Holidays, differences between FCD and VIP were also found. FCD detects much more delay than VIP. For the application of activating scenario's this is positive. These peaks can be detected by the system and the scenarios can be activated. However, due to the fluctuations, it should be determined what time should pass when a set value is exceeded, so that fluctuations are not causing the system to activate and deactivate in a short time. FCD produces travel times more in line with the expectation of high travel times during the rush hours caused by Germans going to shop in Enschede.

Type of traffic | From the analysis on the characteristic type of traffic it follows that the results do better compare for weekdays than for Saturdays. Therefore, more value should be given to the data for weekdays over the data of the Saturdays. During the time intervals commuting traffic is more

present FCD has less bias with respect to VIP. The time shifts that were detected are about 15 minutes. More research is needed to fully determine the effect of the characteristic.

Turn at a junction | No distinctive difference could be distinguished for routes that turn at a junction. For both examined routes there was no time shift detected for weekdays. The routes 'Westerval richting stad' and 'Singels noord-west XP38 n XP08' therefore do not need a special treatment with respect to routes without a turn at a junction.

The state of the city index determined with FCD does compare really well with the index determined with VIP. There is only a small difference. Therefore, it is concluded that, within the context the municipality uses the state of the city index, FCD can be used for determining the state of the city index instead of VIP. Correcting factors for the three routes of the index were calculated by averaging the correcting factor of a route for 2016 and 2017. Applying the factors on FCD resulted in an index that differs little from the VIP index. The index determined with FCD increases less than the VIP index, but shows almost the same trend.

8. Recommendation

A switch from the vehicle inductive profile technology to floating car data is partially recommended. Recommended is to start using FCD for the historical analysis for the state of the city index. For other applications the municipality should look more into the penetration of FCD.

VIP is a valuable system, since it produces good data of travel times. The municipality should consider not phasing out VIP. From the data analysis point of view, it is valuable source of data. Especially for the information on the drips, VIP is valuable. The municipality could consider phasing out VIP for the routes that are not used. This would mean that only on the routes Westerval, Zuiderval, Gronausestraat and Oldenzaalsestraat VIP should be maintained.

Expected is that FCD will contribute in getting more and better information. In the future FCD will probably be supplemented with other data from cars, like breaking information and information about the environment cars drive in. A prerequisite for making good use of FCD is that the data suppliers are open about their performed operations on the data and the changes they will make in the operations

The tool through which FCD is accessed for historical analysis does not allow easy year analysis. Next to that it is not possible to select which types of data are downloaded for a route. An improvement of FLOWcheck would be enabling selecting the files that need to be downloaded for a completed job. Another improvement would be if the penetration is given for each minute in the travel time files. This would help a lot in determining the quality of the data.

FCD can be used for calculating the index. Before switching from VIP to FCD, it should be determined through which method the data will be analysed. Since the municipality does not use the program Matlab another method has to be used. One method would be using the FCD files `TravelTimeAverageOverDateRange` that give the average travel time per minute over the whole date range. The municipality has to create 9 jobs, namely for the 3 routes and for the two time intervals on the weekdays (Tuesday and Thursday) and the time interval on the Saturdays. From these 9 jobs, 9 files need to be looked into for mean values. The index can be determined in excel using these 9 files.

The municipality should also examine their index and consider adjusting it or start using a new index. In the current index travel times of routes are used to which a constant value for the travel time for the drip to the first measurement point for the route is added. This constant value causes less visible changes in the index. It is advised to calculate the index for travel times without this constant value.

In a follow-up research live FCD should be analysed for the application of activating and deactivating scenarios in the traffic control systems. This research focussed only on the historical analysis. This analysis of live data could shine light on how well FCD can be used for the travel time information on dynamic route information panels (drip). Next to that, it could be examined if scenarios only need to be activated on German Holidays or that they also should be active for other days. A test with FCD travel times on drips could be executed and analyse after a period.

In a follow-up research the penetration of FCD could be examined for different routes of Enschede. Now only a few routes are examined. On a route could be examined how the penetration differs for each segment of the route. In this research only one segment per route was analysed.

This research could be executed again over a couple of years to investigate the change in quality of FCD in Enschede. In follow-up research data of 2018 and later can also be fully analysed and compared with the data of 2017. Recommended is to look at the difference between VIP and FCD for 2019 and recalculate the correcting factors for the state of the city index if the difference between FCD and VIP has changed much. The VIP data of 2018 is for the Zuiderval for 4 months of 2018 based on zero

matches on two segments and for the Gronausestraat also for 7 months of 2018 based on zero matches on two segments. Comparing 2018 with the previous years is therefore for these routes less meaningful.

Now, only a couple of routes are analysed. In the future, more routes could be analysed. This research is a comparison between VIP and FCD. The chosen routes always correspond with a VIP route. In further research there could also be looked at routes other than the VIP routes. In follow-up research FCD could also be compared with other road side systems for Enschede, for example ANPR.

References

- Adams, K., & Veurink, A. (2018). Verkeersbeleid toetsen met floating car data. *NM Magazine*, 13(2), 13-15. Retrieved November 6, 2018, from http://www.nm-magazine.nl/pdf/NM_Magazine_2018-2.pdf
- Be-Mobile. (2018). *FLOWcheck*. Retrieved November 6, 2018, from Be-Mobile: https://www.be-mobile.com/wp-content/uploads/2017/09/Be-Mobile_FLOWcheck_brochure_EN.pdf
- Be-Mobile. (2019). Retrieved from FLOWcheck: <https://flowcheck.be-mobile.biz/>
- Blanken, T. (2017). "Onze verwachtingen zijn meer dan waargemaakt". *NM Magazine*, 12(1), 13. Retrieved November 6, 2018, from http://www.nm-magazine.nl/pdf/NM_Magazine_2017-1.pdf
- Blokpoel, R. (2009). Vehicle reidentification using inductive loops in urban areas. *ITS World congress*, (pp. 1-8). Stockholm. Retrieved November 6, 2018, from https://www.researchgate.net/publication/313038210_Vehicle_reidentification_using_inductive_loops_in_urban_areas
- Blokpoel, R., & Vreeswijk, J. (2011). Vehicle Inductive Profile for Incident Detection. *ITS World Congress*. Orlando. Retrieved November 6, 2018, from <https://pdfs.semanticscholar.org/d24f/4a8b21c7f37bb54f54bec1b081a86b20c10c.pdf>
- CBS. (2017, 7 6). *Lengte van wegen; wegkenmerken, regio*. Retrieved from StatLine: <https://opendata.cbs.nl/statline/#/CBS/nl/dataset/70806ned/table?ts=1541077612150>
- CBS. (2018, 10 23). *Huishoudnes; personen naar gelsacht, leeftijd en regio, 1 januari*. Retrieved from StatLine: <https://opendata.cbs.nl/statline/#/CBS/nl/dataset/71488ned/table?ts=1541077994616>
- CROW. (2017). *Handboek verkeersmanagement - Module Regelaanpak*. Ede: CROW. Retrieved November 9, 2018, from https://www.crow.nl/downloads/pdf/verkeer-en-vervoer/publicatie/290a_handboek-verkeersmanagement_module-regelaanpa.aspx
- Felici, E. (2017). De mogelijkheden van floating car data. *NM Magazine*, 12(1), 8-11. Retrieved 10 30, 2018, from http://www.nm-magazine.nl/pdf/NM_Magazine_2017-1.pdf
- Ferien Wiki. (n.d.). *Feiertage 2017 in Deutschland*. Retrieved from Ferien Wiki: <https://www.ferienwiki.de/feiertage/2017/de>
- Flitsmeister. (n.d.). *Flitsmeister FAQ en Privacystatement*. Retrieved from Flitsmeister: <https://support.flitsmeister.nl>
- Gemeente Enschede. (2016). *secties-2016-5.xlsx*.
- Gemeente Enschede. (2017). *Indicatoren Bereikbaarheid - Rekensheet 2017decembergeheel*.
- Hof, R., & Engelshoven, R. (2018, November 26). Interview on traffic measurement systems. (R. Kamphuis, Interviewer)
- Houbraken, M., Logghe, S., Audenaert, P., Colle, D., & Pickavet, M. (2018). Examining the potential of floating car data for dynamic traffic management. *Intelligent Transport Systems*, 12(5), 335-344. doi:10.1049/iet-its.2016.0230

- Hyndman, R., & Koehler, A. (2006). Another look at measures of forecast accuracy. *International Journal of Forecasting*, 22, 679-688. doi:10.1016/j.ijforecast.2006.03.001
- Klunder, G., Taale, H., Kester, L., & Hoogendoorn, S. (2017, December 5). Improvement of Network Performance by In-Vehicle Routing Using Floating Car Data. *Journal of Advanced Transportation*, 16. doi:<https://doi.org/10.1155/2017/8483750>
- Leijsen, S. v., & Hermkes, R. (2013, January 3). Gebruikershandleiding VIP. Amersfoort.
- Neut, K. (2018, November 26). Interview on traffic measurement systems. (R. Kamphuis, Interviewer)
- NM Magazine. (2010). Nieuw VIP-technologie bepaalt reistijden en verkeersstromen met inductielussen. *NM Magazine*, 5(3), 45. Retrieved November 6, 2018, from http://www.nm-magazine.nl/pdf/NM_Magazine_2010-3.pdf
- OpenStreetmap. (2019, 11 01). *OpenStreetMap*. Retrieved from <https://www.openstreetmap.org/#map=17/52.20759/6.88941>
- Schreuder, M., & Avontuur, G. (2017). Filestaartbeveiliging op basis van floating car data. *NM magazine*, 12(1), 18-19. Retrieved November 6, 2018, from http://www.nm-magazine.nl/pdf/NM_Magazine_2017-1.pdf
- Secretariaat Stadsingenieurs en Ontwerp. (2018). Wegafsluitingen week 11.xlsx.
- Secretariaat Stadsingenieurs en Ontwerp. (2018). Wegafsluitingen week 34.xlsx.
- Shen, C.-u., Li, C.-l., & Si, Y.-l. (2015, February). A detrended cross-correlation analysis of meteorological and API data in Nanjing, China. *Physica A*(419), 417-428. doi:<https://doi.org.ezproxy2.utwente.nl/10.1016/j.physa.2014.10.058>
- Uenk, M. (2017). Hoe de kwaliteit van FCD te bepalen? *NM Magazine*, 12(1), 12. Retrieved 10 31, 2018, from http://www.nm-magazine.nl/pdf/NM_Magazine_2017-1.pdf
- Uenk, M. (2018). *Vergelijkingsonderzoek Floating Car Data*. Utrecht: Nationale Databank Wegverkeersgegevens. Retrieved 10 31, 2018, from http://www.ndw.nu/downloaddocument/e26419853a3439b59c32d6b89438e35f/NDW_Onderzoekrapport_FCD_def1.pdf

Appendices

A. Data preparation procedures

Before travel time data can be analysed, some preparations need to be taken. VIP is directly ready to be analysed, since it comes in csv files per day per route. FCD, however, needs to be downloaded from the online viewer FLOWcheck first. Before it can be downloaded the route needs to be created and a job has to be started.

FLOWcheck is the online viewer in which the historical floating car data can be accessed. For each year the municipality has a separate account. This means that everything needs to be performed for each individual year.

A route in FLOWcheck can be constructed by dropping a start and end point with the mouse on the map. Dropping these points is done by orientation on the environment. For a good comparison between FCD and VIP, the start and end points of both need to be the same. However, it is difficult to select the exact location of these point by clicking on the map. This means that a small error in the route distance and therefore the travel times is introduced. The constructed routes are given exactly the same name as in VIP. This makes it possible to load the data simultaneously in Matlab for as much days as wanted. When the route is saved a job can be created.

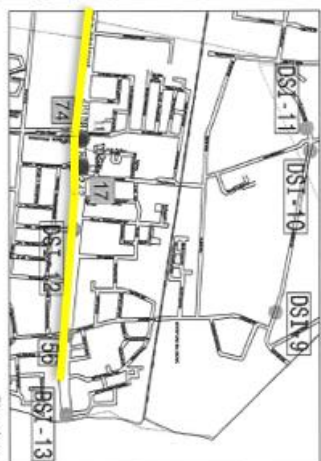
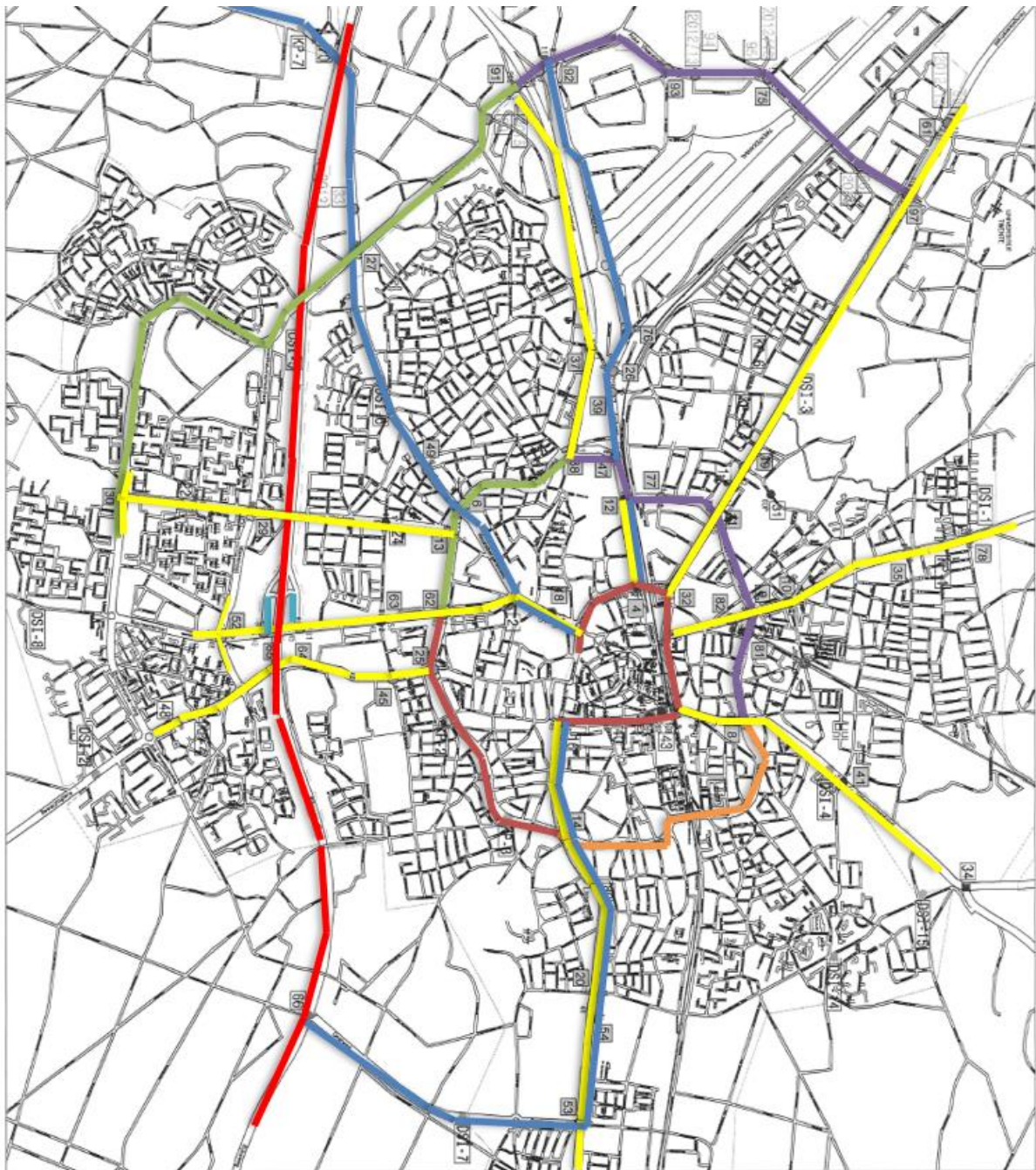
The name of the job and the selected period, start and end date, are used by FLOWcheck in the naming of the folders in which the downloaded data is placed. A single file has the year, month and day as name, for example 20170620 for the 20th of June 2017. In this research jobs were named the same as the routes they were completed for. In front of the name the year is placed for distinguishing the jobs of different years when the files are downloaded. The names of the folders and files are used in the Matlab code to call the correct files. A typo in the name will result in an error.

The selected date range was 1 January until 31 December and the selected timeslot was 00:00 until 23:59. All week days were selected. In step 2 the route is selected. Thereafter the job can be started. For easy use of the Matlab script, FCD needs thus always be downloaded for a whole year, or all for the same period, otherwise the file path needs to be changed by hand every time a new route will be analysed. When a job is analysed the data can be downloaded.

Some VIP routes have consequently typos in their name, so are for example all files of the Oldenzaalsestraat named with an extra space at the end: oldenzaalsestraat .csv. For this example, an exception in the code is added to call the correct files. The Hendrik ter Kuilestraat is consequently called hendrikterkullestraat.csv with two l's instead of il. For this example, the FCD folders have gotten the exact same name, with typo. Sometimes, double spaces appear in names. The script also deals with this. Double spaces are changed into a single space and thereafter all single spaces are changed into an underscore. When FCD is downloaded, in the downloaded folders all spaces are changed into underscores.

B. VIP routes

VIP-Routes



VRI's Gemeente Enschede

- EC-2
- EC-1
- ADE80
- MAIN-EC-2
- MDSI, router / CPIS
- NLB
- Privé
- ▲ RWIS
- Kopertol (q7)
- Dynamische Snelheids indicator
- Huidige kopertol
- Gedachte kopertol

10 VRI met KVC

17 januari 2022

49 FIGURE 51: VIP ROUTES IN ENSCHEDE. IN THE SMALL SQUARES AT THE INTERSECTIONS THE INTERSECTION NUMBERS ARE GIVEN.

C. Matlab comparison script

```
% Comparison between VIP and FCD
% Bachelor Thesis | Ramon Kamphuis | s1487841 | 24-01-2019

close all
clear all
clc

%% 0 Explanation
%{
VIP travel times are given per 5 minutes in the files.
FCD travel times are given per 1 minute in the files.

For FCD is assumed that data of a full year is downloaded. This is used
in the name of the folder the data is placed in.

Available routes:
'Gronausestraat richting stad' (2017 and 2018) 6 sections
'Gronausestraat stad uit' 6 sections
'Hengelosestraat richting stad' 4 sections
'Oldenzaalsestraat richting stad' note: the VIP files have an extra space in the title at the
end. from '007' 1 section
'Oldenzaalsestraat stad uit' from '007' 1 section
'Singels noord-oost XP08 n XP14' note: there is an extra space in the title 1 section
'Singels noord-west XP38 n XP08' 6 sections
'Singels zuid-west XP62 naar XP38' 3 sections
'Westerval richting stad' 5 sections
'Zuiderval richting stad' (2016, 2017 and 2018) 5 sections
'Zuiderval stad uit' 5 sections
'Zuiderv v weth Beverstr n Singel' (This is section From 63E to 62A)

Available sections:
'From 98E to 97A' of route 'Hengelosestraat richting stad' from '104'
'From 97E to 19A' of route 'Hengelosestraat richting stad'
'From 19E to 11A' of route 'Hengelosestraat richting stad'
'From 11E to 32A' of route 'Hengelosestraat richting stad'
'From 78E to 10A' of route 'Deurningerstraat richting stad' from '007'
'From 18F to 06B' of route 'Haaksbergerstraat stad uit' from '007'
'From 39E to 47A' of route 'H. ter Kullestraat richting stad' of server
'007' Note: there is a typo in the street naam
'From 39F to 76B' of route 'H. ter Kullestraat stad uit' from '007'
'From 76E to 26A' of route 'H. ter Kullestraat richting stad' from '007'

%}

%% 1.1 Input
Route      = 'Zuiderval richting stad'; % Route name
Section    = 'From 39F to 76B'; % Section
Nrsections = 5; % Number of sections in the whole route
sss        = '104'; % VIP server number
year       = [2017]; % Year
PlotTime   = [00 00 24 00]; % [hh mm hh mm] From:Until -> Time for which the
data will be plotted.
Plotagg    = 1; % 1 to plot FCDagg 0 to plot FCD
AGGfactor  = 5; % Minutes for Which FCD is aggregated.
Plotmatch  = 1; % 1 to plot nr of matches VIP or 0.
Plotroute  = 1; % 1 to plot/analyse a total route, 0 to plot a
section of the route.
Filter     = 0; % 2 filter day with peak out, 1 for filter peaks
out, 0 for filter off
alldays    = 6; % This number determines for which days the script
is runned.

%% 1.2 Daysofmonth
%{
Here the days corresponding to the selected scenario are loaded. The
written function importdays contains an if statement with for each scenario
the days per month.

% 0 --> Fill in your own custom day selection below
% 1:7 --> Monday:Sunday
% 8 --> All 365 days
% 9 --> All 359 days of 2017 without VIP data missing and summer and winter time.
% 10 --> All 354 days without VIP errors for server 007
```

```

% 11 --> All Winter time days
% 12 --> All Summer time days
% 13 --> Selected good days for Zuiderval
% 14 --> State of the City 2016 (all Tuesdays, Thursdays and Saturdays)
% 15 --> State of the City 2017 (all Tuesdays, Thursdays and Saturdays)
% 16 --> State of the City 2018 (all Tuesdays, Thursdays and Saturdays)
% 17 --> Weekdays
%}
if alldays == 0 % Custom
    dom{1} = []; % Jan
    dom{2} = []; % Feb
    dom{3} = []; % Mar
    dom{4} = []; % etc.
    dom{5} = [];
    dom{6} = [];
    dom{7} = [];
    dom{8} = [];
    dom{9} = [];
    dom{10} = [10];
    dom{11} = [];
    dom{12} = [];
    Datetitle = '- custom'; % Is used in the title of the figures.
else
    [dom,Datetitle] = importdays(alldays);
end
Nrdays = 0; % Initialisation;
for i=1:12
    Nrdays = Nrdays + numel(dom{i}); % Number of days in comparison
end
Nryears = length(year); % Number of yeras in the comparison
if alldays == 0 || alldays == 9 || alldays == 10
    Datetitle = ['- ' num2str(Nrdays) ' days of'];
end

peak = zeros(Nrdays,4);
%% 2 Import VIP and FCD travel times and compute mean travel times
% Here, the VIP and FCD data are imported for the days given in the section
% input.

% Preparation
if Plotroute == 1
    RouteFCD = regexprep(Route, ' ','_'); % Interchanges double spaces with _
    RouteFCD = regexprep(RouteFCD, ' ','_'); % Interchanges spaces with _
else
    SectionFCD = regexprep(Section, ' ','_'); % Interchanges double spaces with _
    SectionFCD = regexprep(SectionFCD, ' ','_'); % Interchanges spaces with _
end

% Initialisation
filepathVIP = 'C:\Users\Ramon\Documents\VIP data\'; % The folder VIP data is placed in
filepathFCD = 'C:\Users\Ramon\Documents\FCD data\'; % The folder FCD data is placed in
VIPdata = zeros(289,Nrdays,Nryears); % Matrix VIP travel times per day
VIPmatches = zeros(289,Nrdays,Nryears); % Matrix VIP number of matches
FCDdata = zeros(1440,Nrdays,Nryears); % Matrix FCD travel times per day
VIPtt = zeros(289,1,Nryears); % Mean travel time value of all given days
VIPmatch = zeros(289,1,Nryears); % Total number of matches of all given
days
FCDtt = zeros(1440,1,Nryears); % Mean travel time value of all given days
if Filter == 1
    FCDttnofilter = zeros(1440,1,Nryears); % Mean value of all given days
    FCDdatanofilter = zeros(1440,Nrdays,Nryears); % Matrix FCD travel times per day
end
i = 1; % Used for increasing day index
k = 1; % Used for increasing day index on which the filter is applied.
nomatchcount = 0;
nomatch = [];

% Load data and compute summed values
for m = 1:12 % For all months
    if m < 10 % Below 10
        mm = ['0' num2str(m)]; % Add a zero for file address and make a string
    else
        mm = num2str(m); % Make a string of months 10, 11 and 12
    end
    ddd = dom{m}; % Use the days belonging to month m. (This definition
makes the for loop run quicker)

```



```

for d = ddd % For day d
    if d < 10 % Add a zero for file address and make a string
        dd = ['0' num2str(d)];
    else
        dd = num2str(d); % Make a string of all days above 9.
    end
    for y = 1:Nryears; % Loop over all given years
        yyyy = num2str(year(y)); % Make a string of the year.
        if Plotroute == 1 % Load data for a complete route
            if ~strcmp(Route, 'Oldenzaalsestraat richting stad') % Exception to add a space
                to the Oldenzaalsestraat
                    fileadresVIP = [filepathVIP yyyy '_' mm '_csvreport-' sss
'\VIP\CsvReports\' Route '\' yyyy '_' mm '_' dd '\' Route '.csv'];
            else
                    fileadresVIP = [filepathVIP yyyy '_' mm '_csvreport-' sss
'\VIP\CsvReports\' Route '\' yyyy '_' mm '_' dd '\' Route '.csv'];
            end
            fileadresFCD = [filepathFCD yyyy '_' RouteFCD '\' yyyy '_' RouteFCD '-'
RouteFCD '-' yyyy '0101-' yyyy '1231' '\TravelTimes\' yyyy mm dd '.csv'];
            else % Load data for a section of a route
                    fileadresVIP = [filepathVIP yyyy '_' mm '_csvreport-' sss '\VIP\CsvReports\'
Route '\' yyyy '_' mm '_' dd '\' Section '.csv'];
                    fileadresFCD = [filepathFCD yyyy '_' SectionFCD '\' yyyy '_' SectionFCD '-'
SectionFCD '-' yyyy '0101-' yyyy '1231' '\TravelTimes\' yyyy mm dd '.csv'];
            end
            VIPdata(:,i,y) = importVIPfile(fileadresVIP); % Import all VIP data
            for given days
                VIPmatches(:,i,y) = importVIPmatchesfile(fileadresVIP); % Import Nr of matches
            for given days
                FCDdata(:,i,y) = importFCDfile(fileadresFCD)/1000; % Import all FCD data
            for given days

                %----- FCD filter -----
                if Filter == 1 % When the filter is on for
                    filtering out high peaks
                        FCDdatanofilter(:,i,y) = FCDdata(:,i,y); % The unfiltered data is saved
                    in a new variable.
                    for j=1:1440 % for all minutes of a day
                        if FCDdata(j,i,y) > 3*mean(FCDdata(:,i,y)) % Compare value with live
                            mean. Changes after filter correction
                                if j ==1 % Exception for first value
                                    log(k,:) = [d m year j FCDdata(j,i,y) FCDdata(1440,i-1,y)
3*mean(FCDdata(:,i,y))]; % Safe which data is adjusted.
                                    FCDdata(j,i,y) = FCDdata(1440,i-1,y); % The new value is equal to
the value 1 minute earlier.
                                else % For all minutes >1
                                    log(k,:) = [d m year j FCDdata(j,i,y) FCDdata(j-1,i,y)
3*mean(FCDdata(:,i,y))];
                                    FCDdata(j,i,y) = FCDdata(j-1,i,y);
                                end
                                k = k+1; % Save the next change in the
                                next entry.
                            end
                        end
                    end
                    %{
                    When the filter is applied, the day, month, year, value, new
                    value and three times the mean value to which the changed value
                    was compared is saved. Thereafter the FCDdata point is changed
                    to the new value.

                    This Filter makes exceptional high peaks less high.
                    %}
                    % ----- End of FCD filter -----

                    VIPtt(:,i,y) = VIPtt(:,i,y) + VIPdata(:,i,y); % Summing all VIP
values per time stamp
                    VIPmatch(:,i,y) = VIPmatch(:,i,y) + VIPmatches(:,i,y); % Summing the matches
per time stamp
                    FCDtt(:,i,y) = FCDtt(:,i,y) + FCDdata(:,i,y); % Summing all FCD
values per time stamp
                    if Filter == 1;
                        FCDttnofilter(:,i,y) = FCDttnofilter(:,i,y) + FCDdatanofilter(:,i,y); % Summing
all FCD values per time stamp
                    end
                    if max(FCDdata(:,i,y)) > 3* mean(FCDdata(:,i,y)) % Detect outliers

```

```

        peak(i,1:4,y) = [d m year(y) i];
        if Filter == 2 % second filter for deleting whole days based on exceedance of
3 times mean value
            FCDtt(:, :, y) = FCDtt(:, :, y) - FCDdata(:, i, y); % do not include the day in
the mean
            VIPtt(:, :, y) = VIPtt(:, :, y) - VIPdata(:, i, y); % do not include the day in
the mean
            Nrdays = Nrdays - 1; % the number of days on which
the mean is based is decreased by one.
        end
    end
    nomatchcount = 0;
    if min(VIPmatches(:, i, y)) == 0 % Detect 0 VIP matches in
the data
        for j = 1:288
            if VIPmatches(j, i, y) == 0
                nomatchcount = nomatchcount + 1; % Number of measurements
without matches on a single day
            end
        end
        nomatch(i, 1:5, y) = [d m year(y) nomatchcount i]; % Save the day and the
number of measurements without matches.
    end

    end
    i = i+1; % Increasing the day index (day 1 of month 2 is saved in the 32nd entry etc.)
end

Toohighpeaks = peak(all(peak, 2), :); % delete rows with only zeros
Toofewmatches = nomatch(all(nomatch, 2), :); % delete rows with only zeros

% Mean Travel Times
VIPtt = VIPtt./Nrdays; % Deviding summed value by number of days
VIPmatch = VIPmatch./Nrdays./Nrsections; % Deviding summed value by number of days
FCDtt = FCDtt./Nrdays; % Deviding summed value by number of days
if Filter == 1
    FCDttnofilter = FCDttnofilter./Nrdays; % Deviding summed value by number of days
end
VIPtt(289, :, :) = []; % Deleting the value of 00:00 of the next day
VIPdata(289, :, :) = []; % Deleting the value of 00:00 of the next day
VIPmatch(289, :, :) = []; % Deleting the value of 00:00 of the next day

%% 3 Calculate Aggregated data
% Here, the FCD data will be aggregated for per number of minutes defined
% by the AGGfactor under input. This will be 5 minutes for most applications.
FCDaggregated = zeros(length(FCDtt)/AGGfactor, 1, Nryears); % Aggregated mean
FCDagg = zeros(length(FCDdata)/AGGfactor, Nrdays, Nryears); % Aggregated days
for y = 1:Nryears
    for i = 1:(length(FCDtt)/AGGfactor) % For every 5 minutes of FCD data
        j = 1+AGGfactor*(i-1); % First minute in the 5 minute interval
        k = AGGfactor+AGGfactor*(i-1); % Last minute in the 5 minute interval
        FCDaggregated(i, :, y) = mean(FCDtt(j:k, :, y)); % The mean of 5 minutes is placed in
entry i
        for d = 1:Nrdays
            FCDagg(i, d, y) = mean(FCDdata(j:k, d, y)); % Same is done for each individual day
        end
    end
end

%% 4 Define time corresponding to data values.
% Here the corresponding timestamp to the measured travel times are
% determined. VIP data is always given for a whole day and the FCD data is
% downloaded for a whole day.
VIPtime = 0:5:1435; % 5 minutes intervals from 00:00 til 23:55
FCDtime = 0:1:1439; % 1 minute intervals from 00:00 til 23:59
FCDaggregatedtime = 0:AGGfactor:1440-AGGfactor; % Time corresponding to aggregated values

%% 5.1 RMSE - Root Mean Square Error
%{
In this section the Root Mean Square Error is calculated. Herefore, the
traveltimes of VIP and FCD need to be aggregated to the same minute
level. This will be 5 minutes. k is used for index to save RMSE.
Differs from i when RMSE is calculated for a different start time
then 00:00. RMSE is calculated separately for each year.

```

```

%}
k = 0;
RMSE = zeros(1,Nryears);
if AGGfactor == 5
    MSE = zeros(1,Nryears);
    for y = 1:Nryears
        for i = (PlotTime(1)*60 + PlotTime(2))/5 +1:(PlotTime(3)*60 + PlotTime(4))/5 %
1:length(FCDaggregated)
            MSE(y) = MSE(y) + (VIPtt(i,:,y)-FCDaggregated(i,:,y))^2; % calculate the mean
square error
        k = k +1;
    end
    RMSE(y) = sqrt(MSE(y)/k); % The Root Mean Square Error is calculated.
end
end
display(RMSE)

%% 5.2 Determine Shift
%{
The middle half values of FCD are shifted over the VIP values and are
compared. Determined is for which shift the RMSE is lowest and the cross
covariance is the highest.

More value is assigned to the cross covariance, since in this value the
high peaks determine more how well the values correspond.
%}
if PlotTime(1) == 0 && PlotTime(3) == 24
if Nryears == 1 && Plotagg == 1 % If aggregated data of one year is compared
    FCDcross(:, :, :) = FCDaggregated(73:216, :, :); % Use the middle half values of FCD
    RMSEcross = zeros(1,145);
    Crosscov = zeros(1,145);
    for j=1:145 % to shift the FCD graph over the VIP graph
        MSE = zeros(1,Nryears);
        Crossco = zeros(144,1);
        for i = 1:144 % 144 values of FCD and VIP are compared.
            MSE = MSE + (VIPtt(i+j-1,:) - FCDcross(i,:))^2;
            Crossco(i,j) = (VIPtt(i+j-1,:) * FCDcross(i,:)) );
        end
        RMSEcross(:,j) = sqrt(MSE/i); % The Root Mean Square Error is calculated.
        Crosscov(j) = sum(Crossco(:,j)) / sqrt(sum(VIPtt(j:j+143,:).^2) *
sum(FCDcross(1:144,:).^2));

    end
    [RMSEcrossmin, Imin] = min(RMSEcross);
    [Crosscovmax, Imax] = max(Crosscov);
    Shift = (Imin - 73);
    Crossshift = (Imax - 73);
    display(RMSEcrossmin)
    display(Shift)
    display(Crossshift)
end
end

%% 5.3 Determine Shift 2
%{
This one is used when the set time differs from 00:00 till 24:00. FCD Data
of the set time interval is shifted over all VIP data.
It works the same as the previous part.
%}
if PlotTime(1) ~= 0 && PlotTime(3) ~= 24
    d = ( (PlotTime(3)*60+PlotTime(4))/5 ) - ( (PlotTime(1)*60+PlotTime(2))/5 );
if Nryears == 1 && Plotagg == 1 % If aggregated data of one year is compared
    FCDcross(:, :, :) = FCDaggregated( (PlotTime(1)*60+PlotTime(2))/5+1 :
(PlotTime(3)*60+PlotTime(4))/5 , :, : ); % Use the middle half values of FCD
    RMSEcross = zeros(1,288-d+1);
    Crosscov = zeros(1,288-d+1);
    for j=1:288-d+1 % to shift the FCD graph over the VIP graph
        MSE = zeros(1,Nryears);
        Crossco = zeros(d,1);
        for i = 1:d % 144 values of FCD and VIP are compared.
            MSE = MSE + (VIPtt(i+j-1,:) - FCDcross(i,:))^2;
            Crossco(i,j) = (VIPtt(i+j-1,:) * FCDcross(i,:)) );
        end
        RMSEcross(:,j) = sqrt(MSE/i); % The Root Mean Square Error is calculated.
        Crosscov(j) = sum(Crossco(:,j)) / sqrt(sum(VIPtt(j:j+d-1,:).^2) *
sum(FCDcross(1:d,:).^2));

```

```

end
[RMSEcrossmin, Imin] = min(RMSEcross);
[Crosscovmax, Imax] = max(Crosscov);
Shift = Imin - ( (PlotTime(1)*60+PlotTime(2))/5+1 );
Crossshift = Imax - ( (PlotTime(1)*60+PlotTime(2))/5+1 );
display(RMSEcrossmin)
display(Shift)
display(Crossshift)
% Positive Crossshift means that FCD needs to be shifted to the right
% and vice versa
end
end
%%
% -----
% Plot
% -----

%% 6.1 Plot figure of the travel times determined with VIP and with FCD.
for y = 1:Nryears
figure(y)
clf(y)
hold on
grid on
grid minor

if Plotmatch == 1
yyaxis left
end
plot(VIPtime, VIPtt(:, :, y), 'k')
if Plotagg == 1
plot(FCDaggregatedtime, FCDaggregated(:, :, y), 'r')
legend('VIP', 'FCD aggregated', 'Location', 'NorthWest')
else
plot(FCDtime, FCDtt(:, :, y), 'r')
legend('VIP', 'FCD', 'Location', 'NorthWest')
end
if Plotroute == 1
title([ Route ' ' Datetitle ' ' num2str(year(y))])
else
title([ Section ' ' Datetitle ' ' num2str(year(y))])
end
xlabel('Time (h)')
ylabel('Travel time (s)')

if Plotmatch == 1
yyaxis right
%plot(VIPtime, VIPmatches(1:288))
set(area(VIPtime, VIPmatch(:, :, y)), 'FaceColor', [0 0 0], 'FaceAlpha', 0.1, 'LineStyle', 'none');
ylabel('Mean nr. of matches VIP per section')
%ylim([0 250])
yyaxis left
end

% Plot the hours on the x-axis
xtickat = 0:60:1440; % Only for 24 hours
set(gca, 'XTick', xtickat, 'XTickLabel', cellstr(num2str(mod(round(xtickat./60), 24))))
xlim([ (PlotTime(1)*60 + PlotTime(2)) (PlotTime(3)*60 + PlotTime(4))])
%ylim([0 400])
if Filter == 1
text(720, min(FCDtt(:, :, 1)), 'Filter on')
end
if Plotagg == 1
text(60, max([max(FCDaggregated(:, :, 1)) max(VIPtt(:, :, 1))]) - 40, ['RMSE: ' num2str(RMSE)])
end
text(60, max([max(FCDaggregated(:, :, 1)) max(VIPtt(:, :, 1))]) - 60, ['Nr. of days: '
num2str(Nrdays)])
hold off
end
fig = Nryears;
%% 6.2 Plot all days
% For 1 to 7 selected days, the travel times of each separated day will be
% plotted consecutively in the same figure.
if Nrdays > 1 && Nrdays < 8 && Nryears < 2
figure(2)
clf(2)

```

```

hold on
grid on
grid minor
% Construct 1 array for all days of FCD and VIP data
for i = 1:Nrdays
    VIPdays((1+(i-1)*288):(288+(i-1)*288),1) = VIPdata(:,i);
    if Plotagg == 1
        FCDdays((1+(i-1)*288):(288+(i-1)*288),1) = FCDagg(:,i);
    else
        FCDdays((1+(i-1)*1440):(1440+(i-1)*1440),1) = FCDdata(:,i);
    end
end

VIPdaystime = 1:5:(Nrdays*1440);
if Plotagg == 1
    FCDdaystime = 1:5:(Nrdays*1440);
else
    FCDdaystime = 1:1:(Nrdays*1440);
end

% Plot all days next to eachother
plot(VIPdaystime,VIPdays,'k')
plot(FCDdaystime,FCDdays,'r')
legend('VIP','FCD','Location','NorthWest')
if Plotroute == 1
    title([ Route ' - Multiple days'])
else
    title([ Section ' - Multiple days'])
end
% Plot the hours on the x-axis
if Nrdays == 2
    xtickat = 0:120:1440*Nrdays; % Only for 24 hours
elseif Nrdays == 3
    xtickat = 0:60:1440*Nrdays; % Only for 24 hours
elseif Nrdays > 3 && Nrdays<7
    xtickat = 0:240:1440*Nrdays; % Only for 24 hours
elseif Nrdays == 7
    xtickat = 0:720:1440*Nrdays; % Only for 24 hours
end
set(gca,'XTick',xtickat,'XTickLabel',cellstr(num2str(mod(round(xtickat.'./60),24))))

xlim([0 1440*Nrdays])
xlabel('Time (h)')
ylabel('Travel time (s)')
hold off
fig = fig + 1;
end

%% 6.3 Spread of FCD
%{
The spread of values per (5) minute(s) is determined. The mean and standard
deviation are calculated and plotted in a graph.
%}
if Nrdays > 1
    for y = 1:Nryears
        if Plotagg == 1
            FCDspread = zeros(288,2,Nryears);
            FCDspreadtime = FCDaggregatedtime;
            for i = 1:288
                FCDspread(i,1,y) = mean(FCDagg(i,:,y)); % instead of mean med can also be used
                FCDspread(i,2,y) = std(FCDagg(i,:,y));
            end
        else
            FCDspreadtime = FCDtime;
            FCDspread = zeros(1440,2,Nryears);
            for i = 1:1440
                FCDspread(i,1,y) = mean(FCDdata(i,:,y)); % instead of mean med can also be
                FCDspread(i,2,y) = std(FCDdata(i,:,y));
            end
        end
        figure(fig+y)
        hold on
        grid on
        grid minor
    end
end

```

```

errorbar(FCDspreadtime,FCDspread(:,1,y),FCDspread(:,2,y))
if Plottag == 1
    plot(FCDspreadtime,FCDaggregated(:,y),'r')
else
    plot(FCDspreadtime,FCDtt(:,y),'m')
end
if Plotroute ==1
    title([ Route ' FCD spread ' num2str(year(y))])
else
    title([ Section ' FCD spread ' num2str(year(y))])
end
xlabel('Time (h)')
ylabel('Travel time (s)')
% Plot the hours on the x-axis
xtickat = 0:60:1440; % Only for 24 hours
set(gca,'XTick',xtickat,'XTickLabel',cellstr(num2str(mod(round(xtickat./60),24))))

xlim([(PlotTime(1)*60 + PlotTime(2)) (PlotTime(3)*60 + PlotTime(4))])
%ylim([20 90])
hold off
end
fig = fig + Nryears;
end
%% 6.4 Spread of VIP
if Nrdays > 1
    for y = 1:Nryears
        VIPspread = zeros(288,1,y);
        for i = 1:288
            VIPspread(i,1,y) = mean(VIPdata(i,:,y));
            VIPspread(i,2,y) = std(VIPdata(i,:,y));
        end
        figure(fig+y)
        hold on
        grid on
        grid minor
        errorbar(VIPtime,VIPspread(:,1,y),VIPspread(:,2,y))
        plot(VIPtime,VIPtt(:,y),'k')
        if Plotroute ==1
            title([ Route ' VIP spread ' num2str(year(y))])
        else
            title([ Section ' VIP spread ' num2str(year(y))])
        end
        xlabel('Time (h)')
        ylabel('Travel time (s)')
        % Plot the hours on the x-axis
        xtickat = 0:60:1440; % Only for 24 hours
        set(gca,'XTick',xtickat,'XTickLabel',cellstr(num2str(mod(round(xtickat./60),24))))
        xlim([(PlotTime(1)*60 + PlotTime(2)) (PlotTime(3)*60 + PlotTime(4))])
        hold off
    end
    fig = fig + Nryears;
end
%% 6.5 Plot VIP of multiple years in 1 graph.
% This can be used when data for a route is downloaded for more than one
% year. For each year a line will be plot in the figure.
if Nryears >1
    figure(fig+1)
    clf(fig+1)
    hold on
    grid on
    grid minor
    labels = {};
    for y = 1:Nryears
        plot(VIPtime,VIPtt(:,y))
        labels(y) = {'VIP ' num2str(year(y))};
    end
    legend(labels)
    if Plotroute == 1
        title(['VIP ' Route ' ' Datetitle '- Multiple years'])
    else
        title(['VIP ' Section ' ' Datetitle '- Multiple years'])
    end
    xlabel('Time (h)')
    ylabel('Travel time (s)')
    xtickat = 0:60:1440; % Only for 24 hours
    set(gca,'XTick',xtickat,'XTickLabel',cellstr(num2str(mod(round(xtickat./60),24))))
    xlim([(PlotTime(1)*60 + PlotTime(2)) (PlotTime(3)*60 + PlotTime(4))])

```

```

        hold off
        fig = fig + 1;
    end

%% 6.6 Plot FCD of multiple years in 1 graph.
% This can be used when data for a route is downloaded for more than one
% year. For each year a line will be plot in the figure.
if Nryears > 1
    figure(fig+1)
    clf(fig+1)
    hold on
    grid on
    grid minor
    labels = {};
    for y = 1:Nryears
        if Plotagg == 1
            plot(FCDaggregatedtime,FCDaggregated(:, :, y))
        else
            plot(FCDtime,FCDtt(:, :, y))
        end
        labels(y) = {'FCD ' num2str(year(y))};
    end
    legend(labels)
    if Plotroute == 1
        title(['FCD ' Route ' ' Datetitle '- Multiple years'])
    else
        title(['FCD ' Section ' ' Datetitle '- Multiple years'])
    end
    xlabel('Time (h)')
    ylabel('Travel time (s)')
    xtickat = 0:60:1440; % Only for 24 hours
    set(gca, 'XTick', xtickat, 'XTickLabel', cellstr(num2str(mod(round(xtickat./60),24))))
    xlim([(PlotTime(1)*60 + PlotTime(2)) (PlotTime(3)*60 + PlotTime(4))])
    hold off
    fig = fig + 1;
end

```