FREEWAY WORK ZONE CAPACITY

EMPIRICAL RESEARCH ON WORK ZONE CAPACITY IN THE NETHERLANDS

MASTER THESIS – THIJS HOMAN

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Title: Freeway Work Zone Capacity
Empirical Research on Work Zone Capacity in the Netherlands

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Voorwoord

Voor u ligt het resultaat van mijn afstudeeronderzoek naar de wegcapaciteit van snelwegen bij wegwerkzaamheden. Met dit onderzoek is geprobeerd om meer inzicht te krijgen in de capaciteiten bij wegwerkzaamheden en welke factoren zorgen voor verschillen. Dit onderzoek is de afsluiting van mijn studie Civiele Techniek en Management aan de Universiteit Twente en mag dan ook gezien worden als de kroon op het werk. Het onderzoek is uitgevoerd in de periode van juli tot en met december 2011 bij ARCADIS te Arnhem in het team Stedelijke en Regionale Bereikbaarheid.

Mijn afstudeerperiode heb ik niet alleen gebruikt voor het doen van onderzoek, maar ook heb ik deze gebruikt om mee te kijken in de professionele wereld van verkeer en vervoer. Ik vond het zeer interessant om naast het doen van onderzoek ook onderdeel te zijn van een professioneel team van adviseurs, projectmanagers en specialisten. Hierdoor heb ik in deze periode meer geleerd dan alleen inhoudelijk onderzoek doen en dit tot een goed einde brengen.

Ik wil mijn afstudeercommissie bedanken voor de bijdrage die zij geleverd hebben bij de totstandkoming van dit afstudeerrapport. Eric van Berkum wil ik graag bedanken voor zijn algehele supervisie en Tom Thomas voor de inhoudelijke begeleiding tijdens het onderzoek en de data-analyses. Ook wil ik graag Jeroen Stegeman bedanken voor alle praktische adviezen en Martijn Loot voor de ondersteuning bij het theoretische gedeelte van het onderzoek en de hulp bij de data inwinning. Ook wil ik de medewerkers van Rijkswaterstaat bedanken voor de hulp bij het verkrijgen van informatie van de verschillende wegwerkzaamheden.

Tot slot wil ik ook alle andere collega's van de teams Stedelijke en Regionale Bereikbaarheid en Tactiek in Verkeer bedanken voor de leuke tijd die ik bij ARCADIS heb gehad. Met name de open werksfeer en de leuke borrels hebben gezorgd voor een aangenaam half jaar.

Thijs Homan
Nieuw Schoonebeek, 5 januari 2012

Summary

People in the Netherlands are constantly on the move and this will grow in the following years. Between 2005 and 2020, the transport of people will increase by 20% and the increase of the transport of goods will be even higher, between 40% and 80% according to the Nota Mobiliteit (Ministerie van Verkeer & Waterstaat, 2006). To cope with this growth in mobility, the infrastructure in the Netherlands is being improved constantly.

The necessary adjustments on the existing road network have an impact on the traffic flow and cause hindrance for road users, because the capacity of that road section is reduced during the road works. Freeway work zones have a significant impact on the congestion and traffic queue delays on freeways,thus knowledge about freeway work zone capacity is essential for traffic planners.

There is a lack of empirical research on the effect of freeway work zones on the capacity of a freewayin the Netherlands. This research paper tries to fill this gap by researching the capacity of freeway work zones and the conditions that affect this capacity in real situations in the Netherlands. The goal of this research is as follows:

> The main goal of this research is to develop more knowledge about the capacity at freeway work zones in the Netherlands by gaining insight in the capacity of different freeway work zone lay-outs and how differences in capacity between work zones can be explained.

This main research goal can be split in different research objectives:

1A Empirical estimation of the capacity of different freeway work zones lay-outs.
1B Estimation of the difference in capacity for different freeway work zone lay-outs compared to the standard situation.
2 Explaining differences in capacity by analyzing situation-specific variables.
3 Analysis of the effect of external variables on freeway work zone capacity.

The work zone lay-outs that are the most frequently present in the Netherlands in recent years and thus are analyzed in this research are:

- closure of the hard shoulder;
- lane narrowing on a two lane freeway;
- lane narrowing on a three lane freeway;
- 3 – 1 lane shift system;
- 4 – 0 lane shift system;
- 4 – 2 lane shift system.

For every work zone lay-out two or three locations are analyzed, which are located across the Netherlands.

The capacity of every work zone is estimated using the Empirical Distribution Method, which is the standard method for estimating capacity at bottlenecks since this method estimates the capacity flow. The estimated capacities are shown in the table beneath. The results show that work zone capacity differs a lot.The decrease in capacity caused by work zones differs from 11% to 43% compared to the standard capacity of a freeway. The biggest decrease can be found by work zones with the 3 – 1 and the 4 – 2 lane shift system, which are, in respective order,-31.7% and -35.1%, and -35.2% and -43.2%. The relative decrease in capacity of the 3- 1 and the 4 – 2 lane shift system is significantly bigger than the other work zones and the only thing that both work zones differentiate from the others is that the lanes of these two work zone lay-outs are split. Thus, from this can be concluded that the capacity of work zones with split lanes is lower than the capacity of work zones where the lanes are not split.

Location	Work zone lay-out	Capacity	Relative difference with CIA work zone	Relative difference with CIA standard
A9 Uitgeest – Alkmaar	Lane narrow.2 lane	3744	+17,0%	-10,9%
A12 Zoetermeer – Zevenhuizen	4 – 0 shifted	3660	+7,7%	-12,9%
A58 Batadorp – Oirschot	Clos. hard shoulder	3636	+1,0%	-13,4%
A2 Lage Weide – Utrecht Centrum	Lane narrow.3 lane	5292	+17,6%	-16,0%
A2 Zaltbommel – Kerkdriel	4 – 0 shifted	3516	+3,4%	-16,3%
A12 Zevenhuizen – Zoetermeer	4 – 0 non-shifted	3366	-1,0%	-19,9%
A28 Hattemerbroek – Zwolle Zuid	4 – 2 non-shifted	4896	+8,8%	-22,3%
A15 Klaverpolder – ‘s Gravendeel	4 – 2 non-shifted	4704	+4,5%	-25,3%
A50 Heteren – Renkum	3 – 1 non-shifted	3105	-8,7%	-26,1%
A2 Roosteren – Echt	Clos. hard shoulder	3048	-15,3%	-27,4%
A7 Zaandijk – Zaandam	Clos. hard shoulder	3030	-15,8%	-27,9%
A12 Zevenhuizen – Gouwe	Lane narrow.2 lane	3018	-5,7%	-28,1%
A12 Zoetermeer Centrum – Nootdorp	Lane narrow.3 lane	4518	+0,4%	-28,3%
A2 Kerkdriel – Empel	3 – 1 shifted	2868	-4,4%	-31,7%
A50 Renkum – Heteren	3 – 1 shifted	2724	-9,2%	-35,1%
A28 Zwolle Zuid – Hattemerbroek	4 – 2 shifted	4080	-5,1%	-35,2%
A16 ‘s Gravendeel – Klaverpolder	4 – 2 shifted	3576	-16,8%	-43,2%

Capacity does not only differ between different work zone lay-outs but also between researched work zone locations with the same lay-out. When comparing the guidelines for capacity of work zones from the “Capaciteit Infrastructuur Autosnelwegen” (CIA) handbook (Ministerie van Infrastructuur en Milieu, 2011)and the estimated capacities for the work zones part of this research, this dispersion is very clear shown. Only four of the seventeen estimated capacities are not significantly different from the guideline from the CIA handbook. The others are significant different from the CIA handbook guideline and these differences range between -17% and +18%.Thus can be concluded that there is great variation possible in work zone capacity.

From a sensitivity analysis on estimated capacities can be concluded that the dispersion of the estimated capacities is caused by the work zones themself. The dispersion is not attributable to the used method for capacity estimation when looking at the expected influence of traffic related aspects of a work zone. The sensitivity analysis found thator work zones with a high number of capacity measurements the Empirical DistributionMethod is a better method than the Product Limit Method and for work zones with a low number of capacity measurements both methods are equal, when respecting the traffic related aspects of the work zones.

The differences found in the capacity estimation are input for the analysis of the situation-specific variables that have influence on freeway work zone capacity. For this analysis seven situation-specific variables are distinguished from previous literature. With these situation specific variables a multiple linear regression analysis is carried out for work zones in general and per work zone system.

This analysis resulted in four situation specific variables that have significant influence on work zone capacity. These four variables are: the percentage of heavy vehicles, the presence of a nearby ramp upstream, the presence of a nearby ramp downstream and the length of a work zone. The percentage of heavy vehicles has a negative influence on work zone capacity when increasing. Also the presence of nearby ramps upstream and downstream have a negative effect on capacity and an increasing work zone length has a positive effect on work zone capacity.

Another finding of the analysis of the differences between estimated capacities is that there are no peculiarities when looking at the differences in capacity for one work zone system only. From this analysis the conclusion can be drawn that in most cases the measurements belonging to a specific work zone system are not significantly different from the model for work zones in general. For two work zone types the percentage of heavy vehicles and the presence of a nearby ramp downstream had a significant influence on the differences in capacity. The degree of influence of these variables changed per system, but the coefficient of determination and the number of measurements was quite low forboth work zone types, thus drawing a conclusion on the degree of influence per system is not feasible. The absence of the other variables can most of the times be addressed to insignificance caused by the low number of cases per work zone system.Hence the conclusion is drawn that for none of the work zone systems there are other variables with significant influence on capacity than the four that have significant influence on work in general.

A goodness of fit analysis showed that the four variables with significant influence are all important for explaining differences in estimated capacities and together these variables explain the most of the variance. Other combinations of these variables explained at least 4% less of the variance. The coefficient of determination of these four variables together is 0.375, which means that these four variables explain 37.5% of the variance in the difference betweenthe CIA guidelines and the estimated capacities. There can be concluded that these four variables explain a considerable part of the variance in capacity, but the majority of the variance is explained by other influences than the distinguished situation-specific variables of this research. Because of the uncertainty caused by the low coefficient of determination, determining the degree of effect of the variables is not plausible in this research.

For two external variables, which were fixed in the first parts of the research, the effect on work zone capacity is also estimated. These two variables are rain and duration of work zones.

The finding of the researchon the effect of rain is that rain causes a drop in capacity between 4% and 9% in the work zones studied in this research. The literature review shows that the effect of rain on capacity in normal situations is between -5% and -10%. The conclusion of this research is that the effect of rain on the capacity of work zones is the same as the effect of rain on capacity in normal situations, there is no reason to assume otherwise.

The findings of the research on the effects of duration of a work zone on the capacity of that work zone are not clear. After more than one month almost all cases show no significant difference in capacity and after more than two months half of the cases show an increase in capacity and the other half of the cases show no significant difference. Thus a clear conclusion on the effect of duration of a work zone on the capacity of that work zone is not found in this research.

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CHAPTER 1 Introduction

In this chapter the introduction to the subject of this master thesis research is described. First the background of this research is shown. Secondly the research objective is defined and thirdly the research questions resulting from this research objective are described. As last the report outline is given.

1.1 BACKGROUND

People in the Netherlands are constantly on the move and this will grow in the following years. Between 2005 and 2020, the transport of people will increase by 20% and the increase of the transport of goods will be even higher, between 40% and 80% according to the Nota Mobiliteit (Ministerie van Verkeer & Waterstaat, 2006). The ensuing growth in mobility causes a higher use of the Dutch infrastructure. To cope with this growth in mobility, the infrastructure in the Netherlands is being improved constantly.

The necessary adjustments on the existing road network have an impact on the traffic flow and cause hindrance for road users, because the capacity of that road section is reduced during the road works. Freeway work zones have a significant impact on the congestion and traffic queue delays which result in increased driver frustration, increased number of traffic accidents, increased road user delay costs and increased fuel consumption and vehicle emissions,this is especially the case at freeways. Thus knowledge about freeway work zone capacity is essential for traffic planners.

The Dutch equivalent of the Highway Capacity Manual (HCM)(Ackerman, 2000), the handbook “Capaciteit Infrastructuur Autosnelwegen” (CIA) (Ministerie van Infrastructuur en Milieu, 2011), deals slightly with freeway work zone capacity by giving guidelines for different types of work zone. These guidelines are based on model simulations and a small number of (international) case studies. Overall there is a lack in knowledge about freeway work zone capacity and the conditions that affect this capacity in real situations in the Netherlands.

The research described in this paper is conducted to gain more insight in the capacity of freeway work zone in the Netherlands. The objective of the research and the research questions are elaborated in the following paragraphs.

1.2 RESEARCH OBJECTIVE

There is a lack of empirical research on the effect of freeway work zones on the capacity of a freewayin the Netherlands. The research in this paper tries to fill this gap by researching the capacity of freeway work zones and the conditions that affect this capacity in real situations in the Netherlands. The research objective is as follows:

> The main goal of this research is to develop more knowledge about the capacity at freeway work zones in the Netherlands by gaining insight in the capacity of different freeway work zone lay-outs and how differences in capacity between work zones can be explained.

This main research goal can be split in different research objectives:

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3 Analysis of the effect of external variables on freeway work zone capacity

These aspects will contribute to better understanding of traffic flows and capacity at freeway work zones and with that knowledge better measures can be taken for future freeway work zones.

1.3 RESEARCH QUESTIONS

The research objectives from the previous paragraph result in the following research questions:

- What is the capacity of freeway work zones in the Netherlands?
  - What is the capacity of freeway work zones?
  - What is the decrease compared to the standard situation?
- How can differences in capacity between work zones be explained?
- What is the effect of external variables on freeway work zone capacity?

1.4 REPORT OUTLINE

This report is structured as follows. In this first chapter the background and research objective and research questions are described. In the second chapter the theoretical framework of the research is shown. This framework describes the theories behind freeway work zone capacity. Also a literature review on the subject of freeway work zone capacity is shown in this chapter. In chapter three the methodology of the research is described. In that chapter can be found how the research is structured and conducted. In the fourth chapter the results from the capacity estimation are described and in chapter five the results from the analysis of the differences between the capacity estimations are shown. In chapter six the analysis of the effect of external variables can be found. The final chapter, chapter seven, presents the conclusions and recommendations following from this research.

CHAPTER 2 Theoretical Framework

In this chapter, the theoretical framework of this research is written down. Firstly capacity and traffic flows at bottlenecks are described. Secondly, freeway work zones in the Netherlands are defined. The last part of this chapter is the literature review in which other researchon freeway work zone capacity in the Netherlands and in the rest of the world is described.

2.1 CAPACITY

The capacity of a road is defined in the HCM as "the maximum hourly rate at which vehicles reasonably can be expected to transverse a point or uniform section of a lane or roadway during a given time under prevailing roadway, traffic and control conditions" (Ackerman, 2000). Despite this clear definition, it is not possible to give a quantitative definition of roadway capacity. The definition for capacity from the HCM includes the term "reasonable expectation" which indicates that there is variability in the numerical value of the maximum number of vehicles.

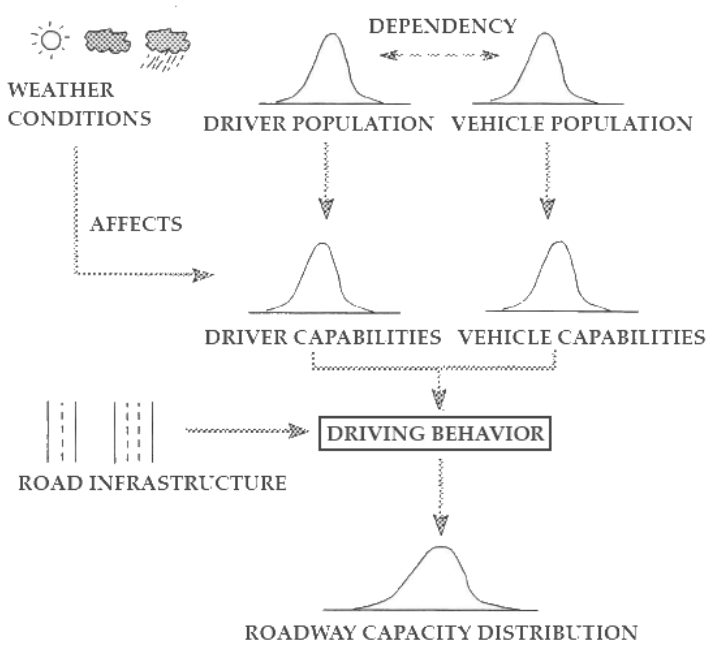
In other words capacity is a stochastic variable which is subject to the behavior of drivers passing the road section.The driving behavior is dependent on three factors; the capabilities of the driver, the capabilities of vehicle and the road infrastructure. All of these factors can be influenced in numerous ways.

The driver capabilities are subject to the driver population which characterizes the personal qualities of the driver, for example the quality of one's eyes or the familiarity with driving on freeways.These driver capabilities are affected by weather conditions. The vehicle capabilities are subject to the vehicle population which characterizes the quality of the vehicles, for example the braking ability or the maximum speed. The vehicle population and the driver population are also dependent on each other. The road capacity is affecting the driving behavior mainly by the quality of the road and the road signs.

These three factors affect the gap acceptance and speed of drivers, which represents driving behavior. This driving behavior on its turn affects the road capacity. Thus is clear that the road capacity is not a single value but a distribution. The influences on the roadway capacity distribution are shown in figure 1.

Figure1

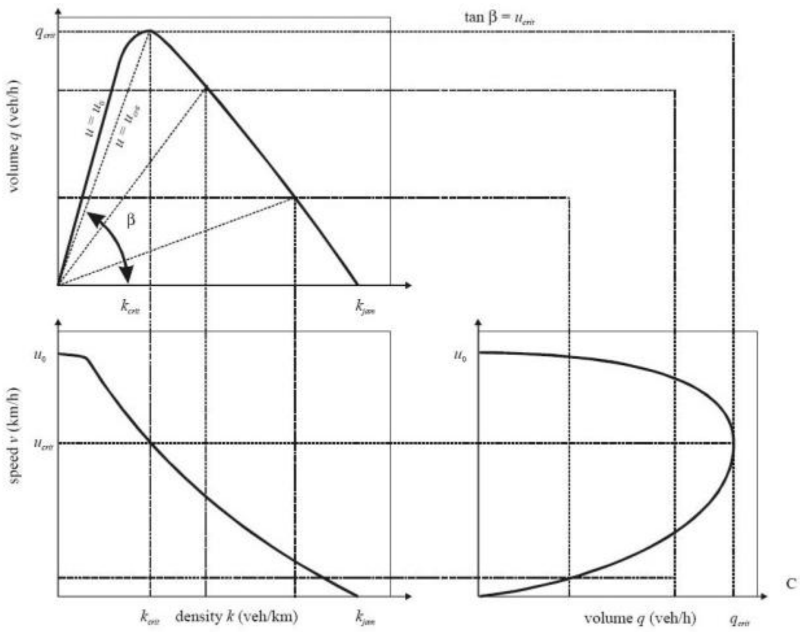
Factors affecting roadway capacity distribution



For better understanding of traffic flows, relationships have been established between the three main characteristics: volume (q), density (k) and speed (v).These three variables are related to each other through the fundamental relation: q = k * v. The fundamental relationship is illustrated by the fundamental diagram shown in Figure 2.

Figure2

Fundamental diagram traffic flow (May, 1990)



The fundamental diagram is featured by the following parameters which give information about traffic flows:

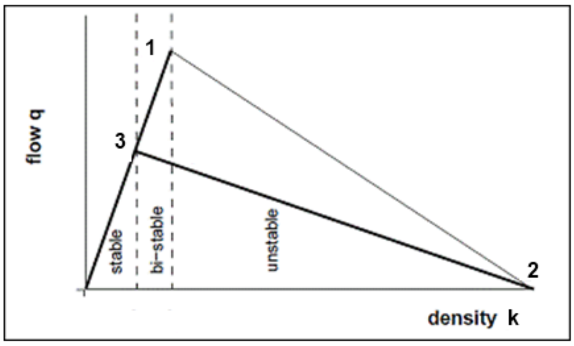
- q_c = [veh/s] critical intensity (road capacity)
- k_c = [veh/m] critical density (density at capacity)
- k_{max} = [veh/m] maximum density (density at full congestion)
- v_c = [m/s] critical speed (speed at capacity)

The critical intensity in this diagram represents the road capacity. The capacity of a road section is reached at bottlenecks. In the HCM a bottleneck is defined as a location where additional traffic enters the freeway and the total amount of traffic exceeds the capacity or where the capacity of the road section falls below the intensity. Work zones are clearly bottlenecks as in the latter description.

Road capacity is the maximum potential intensity of a road. It can be expressed in terms of vehicles per time unit. The capacity of a road section is reached at bottlenecks. In the HCM a bottleneck is defined as a location where additional traffic enters the freeway and the total amount of traffic exceeds the capacity or where the capacity of the road section falls below the intensity. Work zones are clearly bottlenecks as in the latter description.The flow leaving the bottleneck during congestion lies below the maximum flow rate that is achieved during the free flow regime. This effect is called the capacity drop. In figure 3 is shown what the capacity drop looks like. At moment 1, just before congestion occurred, the free flow capacity is reached. Then congestion occurs, shown in moment 2, and after that the capacity flow (or the queue discharge flow) will establish, shown in moment 3. The free flow capacity is higher than the capacity flow, as shown in the figure.

Figure3

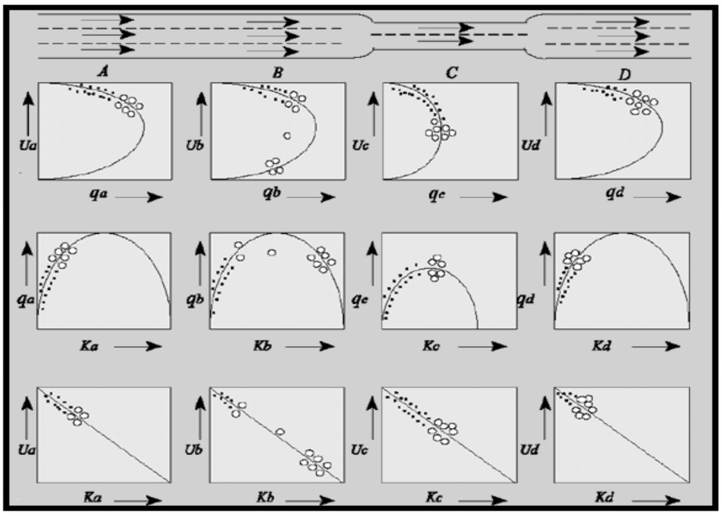
Capacity drop phenomenon(Lansdowne, 2006)



For bottlenecks such as work zones, the capacity flow is leading when estimating capacity. Bottlenecks are the locations where congestion occurs and therefore are leading for the capacity of a road segment because the throughput is the lowest at the bottleneck. In figure 4 the fundamental diagrams for 4 different locations are shown (A= influence free location, B= upstream of bottleneck, C= bottleneck, D=downstream of bottleneck). In the bottleneck the intensity will be at its maximum and the capacity will be reached. Upstream of the bottleneck congestion can occur if the capacity in the bottleneck is reached. Further downstream of the bottleneck there is no congestion and the measurements will be almost similar to the free flow.

Figure4

Fundamental diagrams at locations near a bottleneck (May, 1990)



2.2 FREEWAY WORK ZONES IN THE NETHERLANDS

The design of freeway work zones is based on the required space and time of the work activities on the specific location. In the Netherlands there are guidelines and regulations from the government that guide the design of the freeway work zone lay-out. These guidelines and regulations are there to ensure the safety of both road workers and passing road users and are written down in the CROW publication 96a called "Werk in Uitvoering: Maatregelen op Autosnelwegen" (CROW, 2005).

This publication classifies ten different types of road works on freeways; from work activities ten meters away from the road to activities on all lanes. The most common freeway work zone lay-outs are shown in figure 5, a bigger version is shown in appendix 1. This figure is extracted from the CIA handbook and show the simplified design and the capacity of the different freeway work zone lay-outs.

Figure5

Most common freeway work zones in the Netherlands with capacity guideline (Ministerie van Infrastructuur en Milieu, 2011)

Work zone lay-out	Description	Capacity
	Closure of hard shoulder without lane narrowing (90 km/h)	3600
	Lane narrowing two lanes (70 km/h)	3200
	Closure of left lane with usage of hard shoulder(90 km/h)	3400
	Closure of left lane with usage of hard shoulder and narrowed lanes (70 km/h)	3000
	closure of right lane (90 km/h)	1500
	closure of left lane (90 km/h)	1500
	Closure of all lanes with usage of hard shoulder (90 km/h)	1300

Work zone lay-out	Description	Capacity
	3 - 1 lane shift system (90 km/h)	3400 (A) 3000 (B)
	3 - 0 lane shift system (90 km/h)	3400 (A) 1500 (B)
	2 - 0 lane shift system (90 km/h)	1500
	4 - 0 lane shift system (90 km/h)	3400 (A) 3400 (B)
	4 - 2 lane shift system (90 km/h)	4500 (A) 4300 (B)

Work zone lay-out	Description	Capacity
	Closure of left lane (90 km/h)	3600
	Closure of middle and left lane with usage of hard shoulder(90 km/h)	3200
	Closure of middle and left lane without usage of hard shoulder (90)	1500
	Closure of middle and right lane (90 km/h)	1500

The work zone lay-outs that are the most frequently present in the Netherlands in recent years are:

- closure of the hard shoulder;
- lane narrowing on a two lane freeway;
- lane narrowing on a three lane freeway;
- 3 – 1 lane shift system;
- 4 – 0 lane shift system;
- 4 – 2 lane shift system.

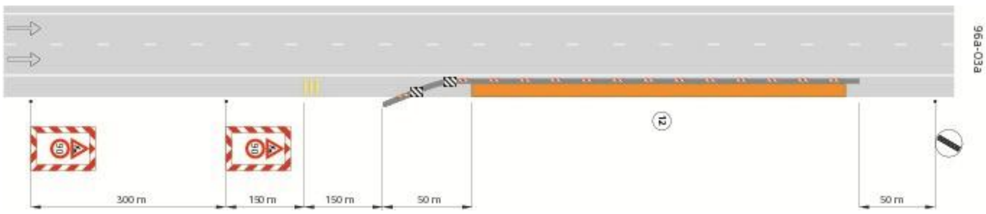
Because these lay-outs are most frequently present, these lay-outs are analyzed in this research. In the following paragraphs these lay-outs are described in more detail.

2.2.1 CLOSURE OF HARD SHOULDER

The lay-out of the work zone system for closure of the hard shoulder is given in figure 6. As shown, traffic on the road is not directly affected by the system. The lanes are not narrowed and none of the lanes is closed.

Figure6

Closure of hard shoulder(CROW, 2005)

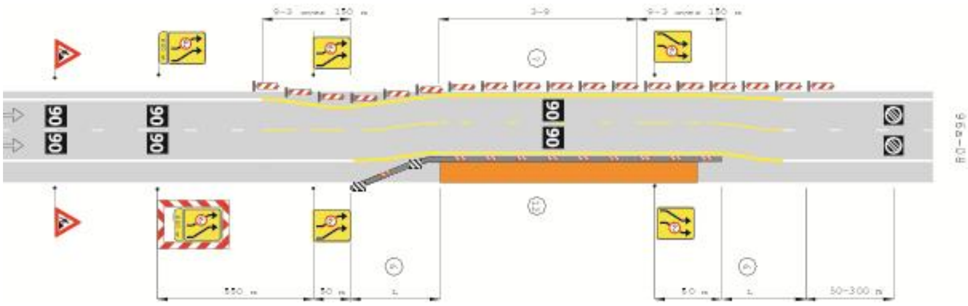


2.2.2 LANE NARROWING ON A TWO LANE FREEWAY

The lay-out of lane narrowing on a two lane freeway is shown in figure 7. In the Netherlands there is no single value for the adjusted lane widths, but there is a minimum of 2.75 meters for lane width of the left lane and 3.25 meters for the right lane at freeway workzones with a speed limit of 90 km/h. For a speed limit of 70 km/h, the minimum for the right lane is 2.75 meters and for the left lane 2.35 meters(CROW, 2005). Thus the lane width can differ between situations.

Figure7

Lane narrowing on a two lane freeway(CROW, 2005)

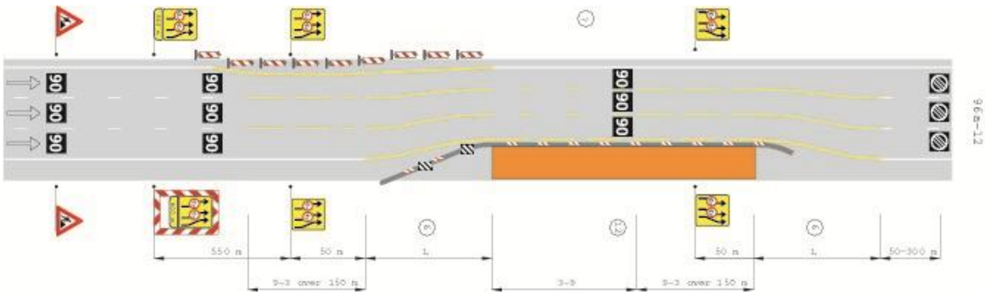


2.2.3 LANE NARROWING ON A THREE LANE FREEWAY

The lay-out of lane narrowing on a three lane freeway is shown in figure 8. Again there is no single value for the adjusted lane widths, but there is a minimum of 2.75 meters for lane width of the left and middle lane and 3.25 meters for the right lane at freeway workzones with a speed limit of 90 km/h. And for a speed limit of 70 km/h, the minimum for the right lane is 2.85 meters and for the left and middle lane 2.35 meters(CROW, 2005). Thus the lane width can differ between situations.

Figure8

Lane narrowing on a three lane freeway(CROW, 2005)

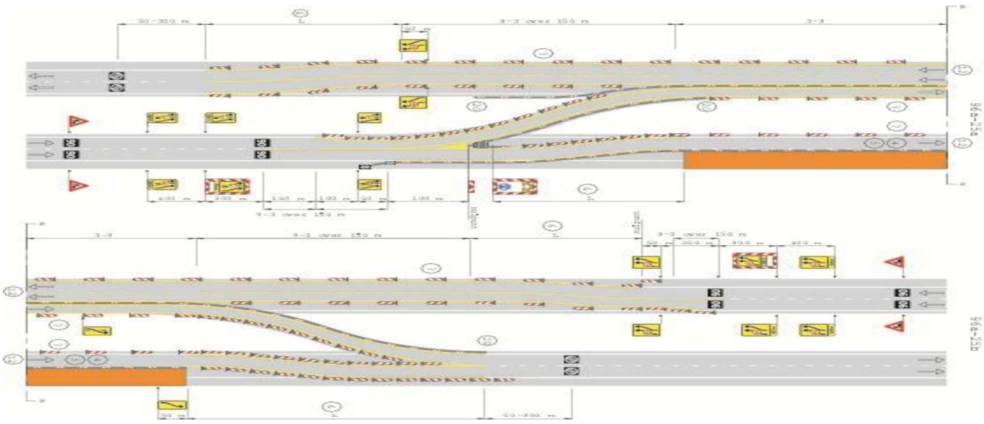


2.2.4 3 – 1 LANE SHIFT SYSTEM

The lay-out of the 3-1 system for freeway work zones is given in figure 9. Traffic is affected by this system in two directions. The biggest effect is expected on the side where the lanes are split and one of the lanes is shifted to the other side. The other side is also affected because the nearness of traffic in the other direction and a small shift and adjustments in lane width. Normally this system includes adjustments in lane width, which can differ between situations.

Figure9

3 – 1 lane shift system (CROW, 2005)

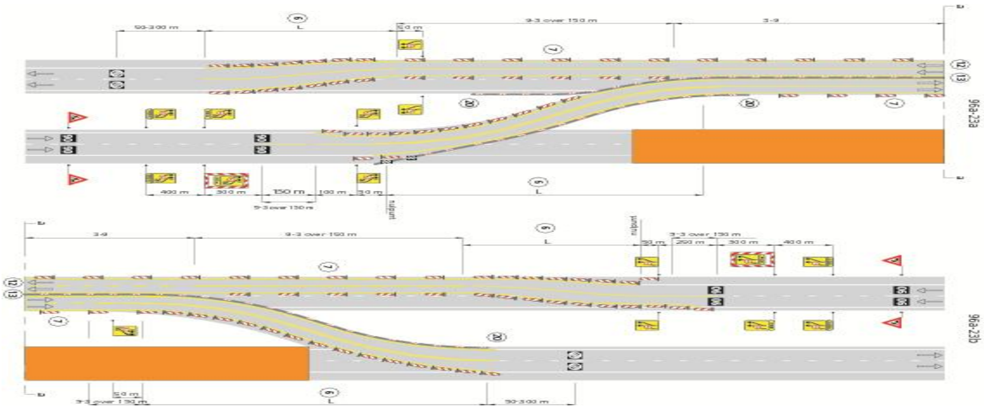


2.2.5 4 – 0 LANE SHIFT SYSTEM

The lay-out of the 4-0 system for freeway work zones is given infigure 10. Traffic in this situation is also affected in two directions. The biggest effect is expected on the side where the lanes are shifted to the other side. The other side is, just as with the 3-1 system, also affected because the nearness of traffic in the other direction and a small shift and adjustments in lane width. Normally this system includes adjustments in lane width, which can differ between situations.

Figure10

4 – 0 lane shift system system(CROW, 2005)

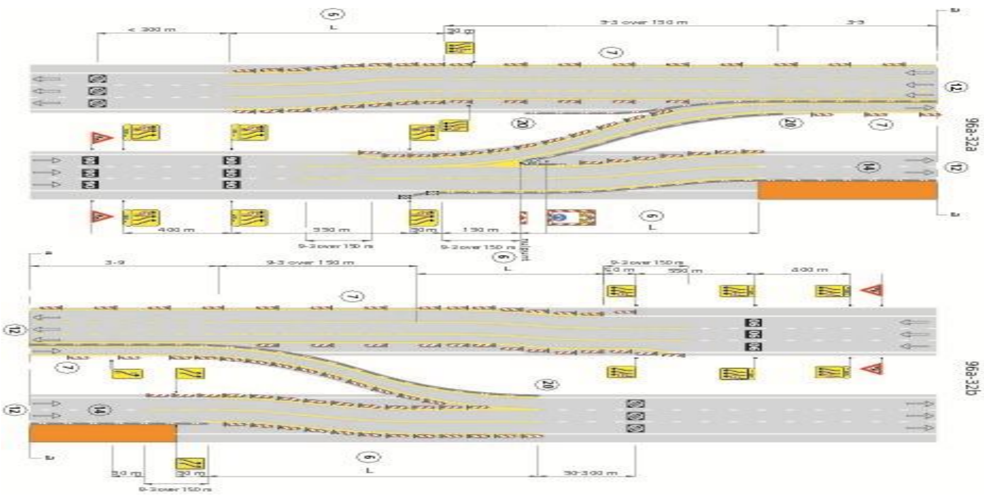


2.2.6 4 – 2 LANE SHIFT SYSTEM

The lay-out of the 4-2 system for freeway work zones is given in figure 11. Traffic is affected by this system in two directions. The biggest effect is expected on the side where the lanes are split and one of the lanes is shifted to the other side, just as with the 3-1 system. The other side is also affected because the nearness of traffic in the other direction and a small shift and adjustments in lane width. Normally this system includes adjustments in lane width, which can differ between situations. Therefore the lane width, along with external variables, will be part of the analysis of differences between situations.

Figure11

4 – 2 lane shift system(CROW, 2005)



2.3 LITERATURE REVIEW

From the HCM, the Dutch CIA handbook and research from Al-Kaisy & Fred (2002), Kim, Lovell, & Pracha (2001), Adeli & Jiang (2003) and Karim & Adeli (2003) 31 different variables are distinguished that can have influence on capacity at freeway work zones. These variables are listed in table 1.

Table1
Freeway work zone variables

Freeway work zone variables		
Traffic composition	Darkness	Hard shoulder occupation
Incident impact	Merge discipline	Lane narrowing
Lateral distance	Light supply	Location of closed lanes
Separation measures	Number of lanes	Number of closed lanes
Pavement condition	Distance to ramps	Presence of signs
Presence of signal controllers	Road curve radius	Road gradient
Month factor	Visibility of work	Temporary speed limit
Weather conditions	Work zone duration	Work intensity
Work zone length	Work zone transition	Work zone layout
Work zone location	Day of week	Work phase
Work time		

Some of these variables are directly related to the work zone lay-out, some are not directly related to the work zone, but are part of the environment wherein the work zone is located and others are even complete external of the work zone. Of this huge number of variables, the most important variables are selected because some have very little influence and others are not present in the Netherlands due to legislations (such as light supply, because the obligatory presence of lighting at work zones). Two studies from Adeli & Jiang (2003) and Zheng et al. (2010) and the CROW publication 96a called “Werk in Uitvoering: Maatregelen op Autosnelwegen” (CROW, 2005) serve as the basis for this selection. This selection of the variables can be found in table 2.

Table2
Most important freeway work zone variables

Most important variables	
Day of week	Road grade
Distance to ramps	Temporary speed limit
Time of day	Percentage of heavy vehicles
Duration	Type of separation barrier
Length of work zone	Visibility of work
Lane narrowing	Weather conditions
Work zone location	

The effects of the most important variables will be reviewed in the next two paragraphs by examining previous research. A distinction is made between research on situations in the Netherlands and the rest of the world.

2.3.1 THE NETHERLANDS

For a normal Dutch freeway the rule of thumb for the capacity is 2100 veh/h per lane(Ministerie van Infrastructuur en Milieu, 2011). At a work zone this is generally much lower, due to different reasons. In the past there were numerous studies and tools conducted for quantification of the decrease in capacity at work zones.

Of course there is the CIA handbook with its guidelines for capacity. The capacity of the most common work zone lay-outs is shown in figure 4 and appendix 1. The CIA handbook gives only one value for capacity per lay-out and is mostly based on model studies and not on empirical research. It also describes other research for the effects of a number of variables. Relevant studies are also described in this literature review.

A micro simulation study that explains the effect of a lot of different variables is the research of Zheng et al. (2010). This research first looked for for the variables that will have the biggest influence on freeway work zone capacity and after that they tried to quantify this effect by using microsimulations. Effects of different variables were:

- visibility of work: sight proof shields results in 100 veh/h more
- duration: 250 veh/h more in later stages of work zone
- distance to ramps: ramp at 0.5 km results in 250 veh/h less than a ramp at 1.0 km
- length of work zone: length of 1.0 km results in 170 veh/h less than length of 2.0 km

Remarkably, this study did not obtain any feasible results for some possible important variables like lane narrowing, closed lanes and percentage of heavy vehicles.

Another micro simulation study from Nelis & Westland (1992) shows that capacity decreases with 10% when lane width decreases from 3.60 meter to 3.00 meter. This study also showed that when drivers get more familiar with the work zone due to long duration, the capacity can increase with 20% compared to capacity at start of work.

In another micro simulation study of Vermijs & Schuurman (1993) the impact of different percentages of trucks is researched. The outcome is that when the percentage trucks doubles from 20% to 40% the capacity declines with 8% and when the percentage trucks declines from 20% to 5%, the capacity increases with 10%. This study also researched the effect of length of the work zone, but those results were ambiguous.

A study of Hoogendoorn (2010) showed that average to heavy rain can cause an decrease in capacity of 5 – 10%. The same study also showed that fog can cause a decrease in capacity up to 10%.

Besides these guidelines and micro simulation studies for capacity reduction there is also some empirical research conducted to describe the capacity decrease at work zones in the Netherlands. Ter Kuile (2006) conducted an empirical research to measure driving behavior and traffic flows at freeway work zones where lanes have a smaller width than normal. One of the outcomes of this research is that the capacity reduces with about 8% when the lanes are smaller; this is mostly due to a decrease in capacity on the left lane (in case of two lanes). Effects of the variables road grade, driver population and work zone location could not be found in Dutch research.

2.3.2 REST OF THE WORLD

In the previous section, research related to the situation in the Netherlands was described. The following description describes research done in other countries to gain extra insight in the capacity reduction at freeway work zones.

The HCM (Ackerman, 2000) is a worldwide guideline and reference for traffic engineers and basis of several country specific capacity manuals like the Dutch CIA handbook (Ministerie van Infrastructuur en Milieu, 2011). In the HCM there are guidelines for capacity reduction at freeway work zones,thus it gives estimations and average numbers and not specific values for specific situations.

Karim & Adeli (2003) have conducted a research in the United States whereby a lot of different variables were researched. The following results are desribed in their research:

- lane narrowing: 0.5m smaller lanes results in 175 veh/h less
- road grade: 100 veh/h less when road grade is 5%
- length of the closure: a length of 1.5 km results in 50 veh/h less than a length of 7.5 km
- distance to ramps: a decrease of 25 veh/h when close to a ramp (closer than 500m upstream or 200m downstream)

They also describe the influence of the road gradient, but the results are ambiguous. The results of a simulation study in Belgium from Van Begin (2002) on the effect length of work zones were also unclear.

In a research of capacities of freeway work zones by Al-Kaisy & Hall (2003) in Canada a significant lower capacity at sections with smaller lanes was found. Instead of the normal 2160 veh/h per lane, the capacity was 1800 pcu/h per lane. Besides that, this study also showed a decrease of 7% to 16% in capacity in a situation with less commuter drivers, i.e. in weekends and off-peak hours. The study also showed that different speed limits and types of seperation barriers cause differences in decrease between 1% and 12.5%.

A research of Dixon et al. (1996) in North Carolina in the United States of America showed that the location of a work zone can have a big influence. In rural areas the decrease in capacity is up to 300 veh/h more than in urban areas. They explain this by the difference in driving behaviour because of familiarity with congestion.

Maze & Bortle (2005) describe in their research that the difference in capacity between shortterm and longterm work zones is between 7% and 16%. They explain this by the fact that drivers will become more familiar with the work zone. They also state that the effect of the road gradient is related to the percentage of trucks, because its influence is mainly on trucks. They state that the decrease caused by trucks can grow with 16% till 33% when the road gradient increases.

Other research is done by Hunt et al. (1991) in the United Kingdom. They conclude in their research that a truck percentage of 30% causes a capacity reduction of 23% compared with a situation without trucks and that a smaller lane width, from 3.60m to 3.20m, causes a capacity reduction of 12%. Research on the German situation from Weinspach (1988) shows the same conclusion that lanes with smaller widths have influence on the capacity. They state that lanes smaller than 3.50m have a capacity reduction up to 15%.

2.3.3 CONCLUSION

The results from the studies are sometimes ambiguous; effects from variables differ a lot between the studies. But to get more insight in the effects of the different variables, the effect on capacity is summed up in table 3. The results from the studies show that especially the percentage of heavy vehicles has a big impact on capacity and the influence from the road grade and the visibility of work is rather small. The effect of the variable length of work zone is not very clear, many studies show ambiguous results, some show a positive effect when work zones are longer.

Table3

Effects of most important variables according to literature

Effect of most important variables according to literature			
Day of week	7-16%	**Work zone location**	10%
Distance to ramp	7-10%	**Road grade**	7%
Time of day	7-16%	**Temporary speed limit**	1-13%
Duration	7-20%	**Percentage of heavy vehicles**	8-33%
Length of work zone	2-7%	**Type of separation barrier**	1-12%
Lane narrowing	8-17%	**Visibility of work**	3-7%
Weather conditions	5-10%		

In general the guidelines and handbooks used in the Netherlands as well as in other countries give a good estimation of capacity and good average numbers of capacity reduction at freeway work zones. But there is a lack in knowledge of variables that affect this capacity and thus how much the capacity can differ between situations. Different studies (mostly micro simulations) in the Netherlands and other countries show that there is a big dispersion in effects of one variable on capacity. This means that the effect of variables on capacity is not very clear. In general, in the Netherlands there is (too) little empirical research done that focuses on the differences in capacity caused by these situation-specific variables.

CHAPTER

3 Research Methodology

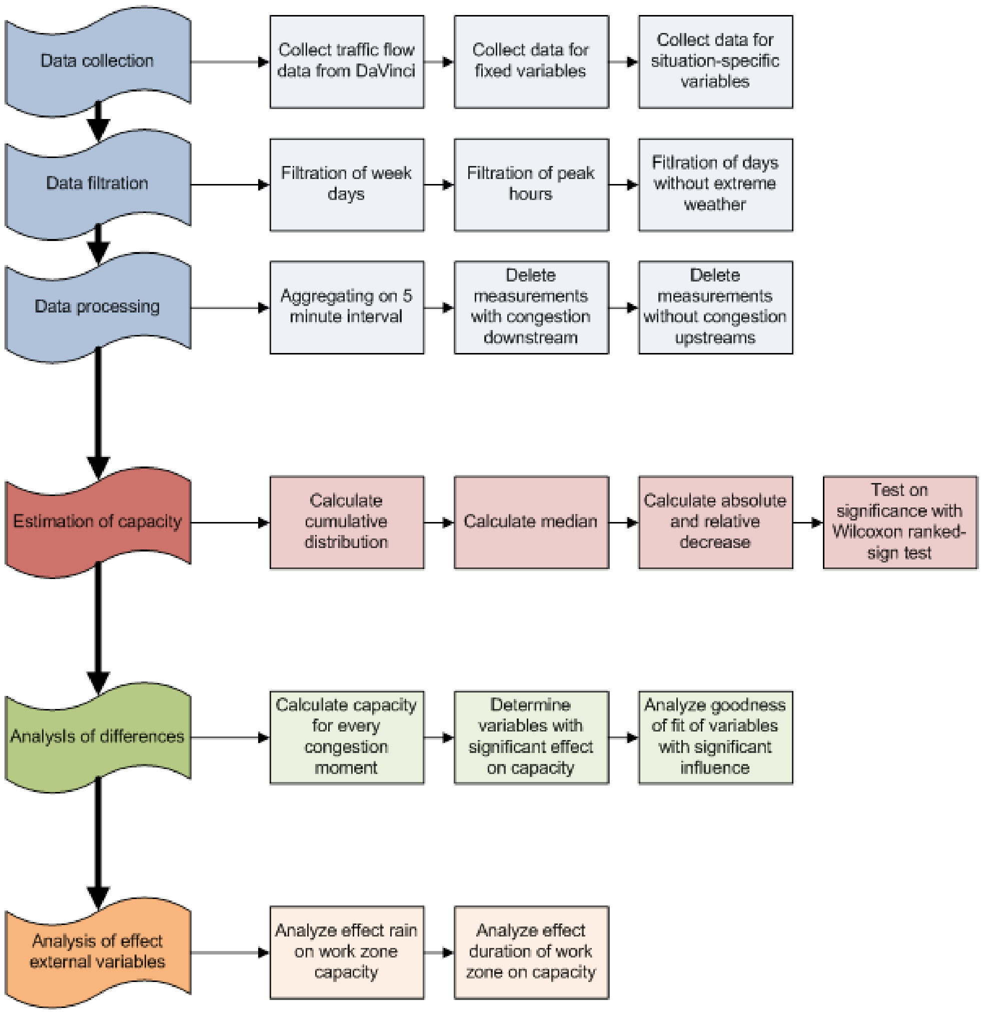
In this chapter the research methodology is shown. Here is thoroughly described how the research is carried out. First an overview of the research structure is presented. After that the fixation of some variables is described. Next, the capacity estimation is described and after that the analysis of the differences and the analysis of effects of external variables areshown. Following that, the data collection is described and as last the data processing is presented.

3.1 RESEARCH STRUCTURE

In figure 12 the structure of this research is shown.

Figure12

Research structure



This research consists of three main parts. These are the estimation of capacities for the different work zone lay-outs, the analysis of the differences between the work zones and the analysis of the effects of external variables. To analyze these three main themes, data is collected and processed first. This is described inthe following paragraphs.

3.2 FIXED VARIABLES

Some variables that are influencing the capacity at freeway work zones are not static in the lay-out of the work zone or the environment in which the work zone is situated. Therefore these external variables will be fixed. By fixing these variables, the environment of the work zone can be controlled to secure good comparison between different work zones. The variables are described in this paragraph including the value, period or situation that is most suitable for the variable in this research.

Day of week

In traffic, there is a lot of difference between work days and weekend days. At weekend days the purpose of a trip is more often recreational instead of commuting and business and therefore traffic is far less homogenous. Also the drivers at weekdays (especially commuters) are more familiar with the road and will react in another way on the work zone. Thirdly, there is a lot more traffic at work days and for this research high traffic volumes are needed since measurements in and around the congestion state are required. For those reasons this research will focus on workdays only.

Duration

In the literature review in paragraph 2.3 there can be seen that the duration of a work zone can have effect on the capacity, the capacity can increase when a work zone is longer present. Therefore the estimation of the capacity of all work zones is done in the first month in which the work zone is present. This is done because not all work zones have durations longer than a couple of weeks and the effect of long duration is excluded in the first parts of the research. The effect of duration on capacity is researched in the last part of the research.

Seperation barrier

In the Netherlands there are two types of seperation barriers for work zones; concrete barriers for long term work zones (>2 weeks) and traffic cones for short term work zones (< 2 weeks) (CROW, 2005). The type of separation barrier can be excluded based on the fact that the focus of this research is on long-term work zones and thusonly work zones with concrete barriers are part of the research.

Speed limit

In the Netherlands the temporary speed limit is not independent. This variable has two values, 70 km/h and 90 km/h. The speed limit is depending on the lane width, because the temporary speed limit has to be 70 km/h at a roadway with a right lane smaller than 3.25 meters and a left lane smaller than 2.75 meters. Because the lane width is part of this research, the speed limit as an independent variable is excluded.

Time of day

Because this research needs measurements in and around the congestion-state, which occurs mostly during peak hours, only peak hours are part of this research. In the peak hours a lot of commuting trips are made and in off-peak hours other trip purposes, like recreation and business trips, are predominant. This difference has effect on the homogeniousity of the traffic and thus also on the capacity. Due to the limitation of measurements in peak hours only, the driving population is almost exactly the same in all measurements and therefore the driving population variable will not be part of this research.

Visibility of work

The visibility of work is fixed by analyzing only work zones were no sight proof shields are installed. In these work zones the work activities can be seen by passing drivers.

Weather conditions

Weather can cause a huge change in driver behaviour. Therefore, extreme weather conditions, which are snow, fog, glazed frost and average to heavy rain (> 2 mm per hour)are filtered out completely in the first parts of the research to secure non-affected driving behaviour. The limit for precipation is chosen because it is the same that is used in all versions of the CIA handbook. This data will be obtained from the Dutch Royal Meteorologic Institute (KNMI), which has measurements on hourly basis for 36 weather stations in the Netherlands, see figure 13 and appendix 2. The effect of rain on capacity is researched in the last part of the research.

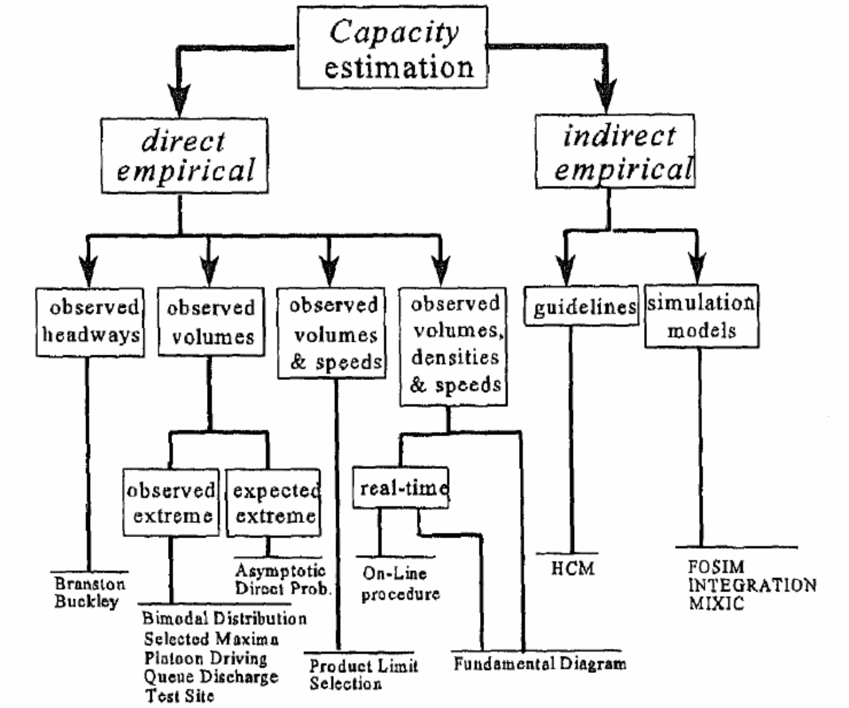
Figure13

Weather stations in the Netherlands (KNMI, 2011)

3.3 CAPACITY ESTIMATION

In previous years numerous methods have been designed to estimate the capacity on freeways. Roughly these methods can be divided into two groups; direct empirical and indirect empirical methods, see figure 14. This research is a direct empirical research, so the focus is on this group.

Figure14
Capacity estimation methods (Minderhoud et al., 1996)



Minderhoud, Botma & Bovy (1996) conducted a study in which they reviewed all the different methods for capacity estimation on freeways. This research concluded that the best three methods are (in order of appearance):

1. Product Limit Method (PLM);
2. Empirical Distribution Method (EDM);
3. Fundamental Diagram Method (FDM).

Whereby they noted that the PLM and the FDM are normally used for estimating the free flow capacity and the EDM is used for estimating the capacity flow.The capacity flow is the actual maximum throughput of a road segment, which arises at the bottleneck of the road segment(Ministerie van Infrastructuur en Milieu, 2011). Because this research focuses on work zones, which are generally always the bottleneck of a road segment, the capacity during the capacity flow will be estimated and not during the free flow (see also paragraph 2.1). This will be done using the Empirical Distribution Method.

When there is a high number of free flow measurements the capacity estimated with the PLM tend to be different from the capacity estimated with the EDM. Because all capacities in this research are estimated in the same way, the differences with each other will not differ when using the PLM instead of the EDM when there are a lot of measurements.

Also the CIA guidelines for work zones are estimated using the EDM, thus for good comparison the capacity flow should be measured in this research paper, otherwise a comparison between apples and oranges occurs. That is also why the EDM is preferred above the PLM.

The theory of the EDM is based on an explicit division of the flow observations that have been made over the observation period. The idea is that a capacity value can be derived from the distribution of capacity measurements. The EDM determines the capacity by a cumulative probability distribution of the flow measurements in the congestion state of the traffic. The median of the cumulative capacity probability distribution will be used as the value for the capacity. The differences are tested on significance with the median test in SPSS. More on theEDM and the PLM in appendix 3 and 4.

3.4 ANALYSIS OF DIFFERENCES

To analyze the differences between the capacities of different work zones, variables specific for the situation are used, which are derived from the variables mentioned in the literature review in chapter 2. These variables are listed and explained beneath. After that the method of the analysis is described.

3.4.1 SITUATION SPECIFIC VARIABLES

Percentage of heavy vehicles

The percentage of heavy vehicles is defined by the percentage of vehicles from the two classes medium-heavy and heavy vehicles. These classes are defined by Rijkswaterstaat by the length of the vehicle. Vehicles shorter than 5.2 meters are light vehicles (passenger cars), vehicles from 5.2 meters to 11.2 meters are the middle class (vans and cars with trailers) and heavy vehicles are defined as longer than 11.2 meters (trucks).

Nearby ramp upstream

The nearness of a ramp upstream is defined by the distance to the ramp. According to the Dutch guidelines for freeway design (Nieuwe Ontwerprichtlijn Autosnelwegen)(Rijkswaterstaat, 2007) the turbulence distance from a ramp is up to 500 meters from the end of the ramp. Therefore in this research a ramp upstream is nearby if it is closer than 500 meters from the work zone.

Nearby ramp downstream

For a ramp downstream the same criterion as for a ramp upstream is applied. This means that also a ramp downstream is nearby if it is closer than 500 meters from the work zone.

Lane width

The lane width is the width of a lane in meters. This variable is split up in left lane, right lane and, if present, middle lane.

Congestion familiarity

Congestion familiarity is defined by the presence of structural congestion on the researched road section in the normal situation, and thus if drivers are familiar with congestion on that road section. According to the CIA structural congestion occurs when the intensity/capacity (I/C) ratio is higher than 0.9. In this situation the flow of traffic is poor and there is structural daily congestion. In this research congestion familiarity is defined by an I/C ratio of 0.9 for the busiest hour of the morning or evening peak hours.

Road grade

The road grade is the maximum grade that drivers encounter on the researched road section.

Length of work zone

The length of the work zone is the length from the beginning of the work zone till the end of the work zone in meters.

3.4.2 SET-UP OFANALYSIS

For every moment during the measurement period in which congestion occurred, the actual capacity is estimated together with the situation specific variables belonging to that moment. In this way the real capacity of that moment is estimated and more capacity estimates are made per work zone. In this way the value of some situation-specific variables is more reliable and thus the analysis is more reliable. The congestion calculations are the base for this analysis. The goal of the analysis of the differences is to see which variables have a significant impact (significance level of 95%) on the differences between estimated capacities, and thus can explain differences between capacities of work zones.

First step in this analysis is to check on multicollinearity between the variables. Multicollinearity is a statistical phenomenon in which two or more predictor variables in a multiple regression model are highly correlated. Multicollinearity does not reduce the predictive power or reliability of the model as a whole, within the sample data themselves; it only affects calculations regarding individual predictors. When variables have a correlation coefficiënt higher than 0.8 one of the two will be excluded from the analysis.

With the relative difference in capacity compared to the CIA guideline, all systems can be compared to each other. In this way, the effect of the different situation specific variables can be estimated for work zones in general. With all situation-specific variables a multiple regression analysis is executed using SPSS to see which of the variables have significant influence on the relative difference between the CIA guideline for capacity and the estimated capacities from the work zones. With this regression analysis a prediction model for work zones in general can be made.

Adeli & Jiang (2003) state in their research that a neuro fuzzy logic model is slightly better for estimating capacity based on the input of variables than a empirical model based on linear regression. Also variables could have another type of influence on capacity, e.g. exponential. But because in this research not the degree of influence is estimated, but only presence of significant influence of a variable, the results of a multiple linear regression analysis will be the same as another method.

Nextper work zone lay-out the model the measurements are checked on differences with the model for work zones in general with the Kolmogorov-Smirnov test (see appendix 4). If the difference is significant, amultiple regression analysis for that work zone lay-out only is used to estimate the influence of predicting variables. This analysis is conducted to see if there are differences in explanatory variables between work zone lay-outs. If from this analysis other variables with significant influence arise, these variables are analyzed on its own by using the prediction model for work zones in general. At last, a goodness of fit analysis is executed to see how much the variables from the prediction model for work zones in general explain the differences in capacity.

3.5 EFFECTS OF EXTERNAL VARIABLES

Some variables that have effect on work zone capacity are fixed in this research to control the environment of the work zones and secure good comparison between them.

Nevertheless, some of these variables can have an effect on capacity of work zones. Due to data-restrictions only the effect of rain on capacity and the effect of a longer duration of a work zone on capacity can be analyzed. The estimation of the capacity in these situations is done with the Empirical Distribution Method in the same way as described in paragraph 3.3 and appendix 3. The differences are tested on significance with the median test in SPSS.

3.6 DATA COLLECTION METHOD

3.6.1 DATA FOR CAPACITY ESTIMATION

For analyzing the capacity, traffic data is needed. More specific: intensity and speed measurements are needed. For this research traffic data is obtained from induction loop data. This data is obtained by detection of vehicles that pass the induction loop; passing vehicles cause a change in the magnetic field of the loop and because of that loops can measure passing times. The speed and length of the vehicles can be obtained by two subsequent loops. With these induction loops the Dutch highway operator Rijkswaterstaat collects the average speed and intensity at the location of the loop with one minute intervals.

The datasets needed for this research are obtained from Rijkswaterstaat with the DaVinci tool. This software tool is be used to visualize data in speed contour plots, e.g. figure 15. These contour plots are used to visualize the traffic flow to find congestion, bottlenecks and errors in the data from the detection loops. By using the contour plots for selecting datasets, the quality of the used data sets will be higher. Hence the usage of the DaVinci tool makes outcomes of this research more reliable.

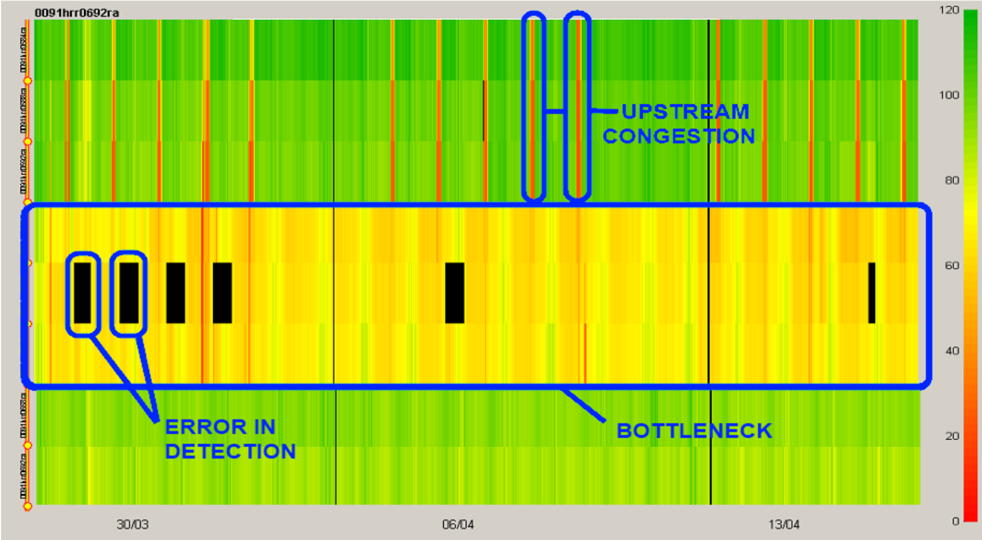
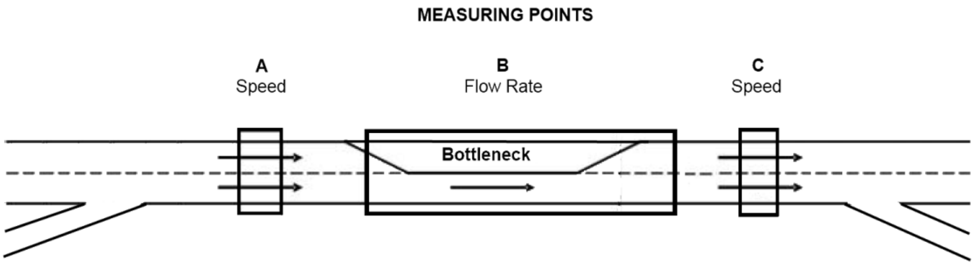


Figure15
DaVinci speed contour plot

Traffic volume data should be collected at well-chosen measuring points at a work zone, shown in figure 16. The data should be collected at or right after the bottleneck (location *B*) to obtain flow rate data that is representative for the variable that will be analyzed. Speed observations upstream of the bottleneck, location *A*, are required to distinguish congestion and non-congestion measurements of the traffic flow in location *B*, to determine if traffic is in capacity flow or free flow. Finally speed observations downstream the bottleneck, location *C*, are required to determine the possible occurrence of congestion. If congestion is measured at that point *C*, a bottleneck further downstream the freeway is likely to affect the observed intensities at location *B*, and the bottle-neck observations are then no longer representative for a capacity analysis, and therefore these observations cannot be included.

Figure16
Measurement locations at bottleneck



A lot of different threshold values are used for determining the congestion state of traffic. Brilon & Zurlinden (2003) state that a treshold for the average speed in a five minute interval between 50 km/h to 70 km/h is sufficient for determining congestion. For this research certainty is needed about the congestion state of the traffic and therefore a threshold value of 50 km/h is set for congestion. With a threshold value of 50 km/h the measured traffic state is most certain to be congested and at 70 km/h it it is not always certain if traffic is in congestion or free flow state, especially at freewaywork zones, where the maximum speed is 90 or 70 km/h. The CIA handbook has also a treshold of 50km/h and thus this research will match the CIA handbook.

3.6.2 DATA FOR ANALYSIS OF DIFFERENCES

For analysis of the differences between work zones situation-specific variables are used. These are described in paragraph 3.4.1. Data for these situation-specific variables is collected with different methods, these methods are described here.

The percentage of heavy vehicles is derived from the MTR+ system (Rijkswaterstaat, 2011). This system is based on induction loop data and calculates the average flow on freeways in the Netherlands per hour, per day of week, per month and per vehicle class. Thus the percentage of heavy vehicles per hour for a specific road section can be derived from this system. The value derived from this system is the average percentage of vehicles per class (heavy, middle or light) in a specific hour of a specific day of the week (Monday to Sunday) of a month (i. e. January 2012). For every work zone the percentage of heavy vehicles in the peak hours is obtained and used in the analysis.

The MTR+ system is also used for determining the intensity at a road section. The intensity is used to calculate the I/C ratio, which is the basis for the determination of the familiarity of congestion on that road section. The I/C ratio is calculated by dividing the intensity from the busiest hour in the morning and evening peak hour per day by the standard capacity of the road. The intensity is obtained from MTR+ by using data from the same month a year earlier.

The lane width will be obtained from drawings of the cross sectional profile from the different work zones. These drawings are obtained from the responsible regional departments of Rijkswaterstaat. The same drawings together with Google Maps and a Geotool from Rijkswaterstaat are used to determine the length of the work zone and the distance to ramps.

The last situation-specific variable, the road grade, is determined with the height database from the so called "Actueel Hoogtebestand Nederland" from Rijkswaterstaat(Rijkswaterstaat, 2011). This database contains the height of every squared meter in the Netherlands and with this information the road grade can be calculated in a length profile of the road section. The maximum road grade of the road section is used in this analysis.

3.6.3 DATA COLLECTION LOCATIONS

For this research there are some practical criteria for the data collection locations. These criteria are set to ensure that the locations fit the needs for this research. The criteria are:

- Freeway location with static long-term work zone;
- Work zone lay-out should fit one of the distinguished work zone lay-outs described in paragraph 2.2;
- Availability of traffic data on the location that suites the collection restrains (fixed variables);
- Occurrence of congestion in peak hours due to the work zone as bottleneck.

For this research, long-term static work zones on freeways in the Netherlands in the period between 2007 and 2011 are considered. This time interval is chosen to cover the road work projects of the "Spoedaanpak Wegen" project. This project consists of 30 freeway work zones, whereof most are suitable for this research, but also other work zones that meet the criteria are suitable for this research.

The basic specifications of these candidate locations are obtained from the "Werken Planningen Kaart" from the "Verkeerscentrale Nederland". This list contains over 1100 work zone locations and was brought back to 13 locations that meet all criteria mentioned before. Most work zones are excluded because they are short term or only present in weekends and nights (about 900) and the absence of proper data (about 150). For each work zone lay-out the most suitable locations for this research are chosen. This is constrained by a maximum of three locations per lay-out to keep this research controllable.

The chosen locations are categorized by their work zone lay-out and are listed below (see also figure 17):

- Closure of hard shoulder
  - A58 Batadorp – Oirschot
  - A2 Roosteren - Echt
  - A9 Zaandijk – Zaandam
- Lane narrowing on a two lane freeway
  - A12 Zevenhuizen - Gouwe
  - A9 Uitgeest – Alkmaar
- Lane narrowing on a threelane freeway
  - A2 Lage Weide – Utrecht Centrum
  - A12 Zoetermeer Centrum – Nootdorp
- 3 – 1 lane shift system
  - A2 Kerkdriel – Empel
  - A50 Renkum – Heteren
- 4 – 0 lane shift system
  - A2 Zaltbommel – Kerkdriel
  - A12 Zoetermeer – Zevenhuizen
- 4 – 2 lane shift system
  - A16 Klaverpolder – 's Gravendeel
  - A28 Zwolle Zuid – Hattemerbroek

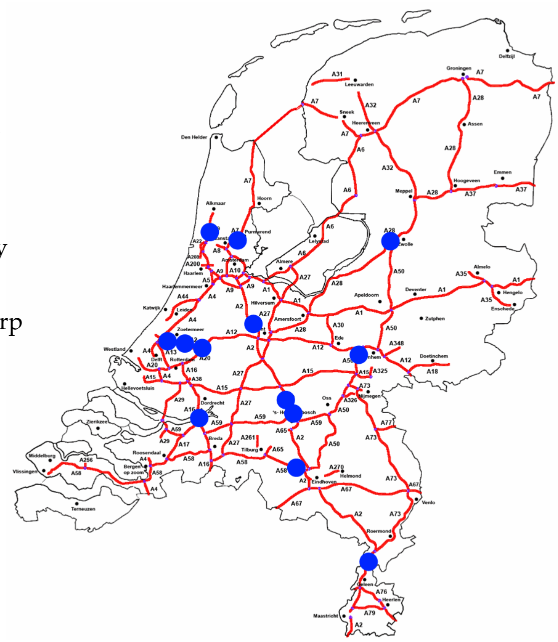


Figure17

Location of researched freeway work zones

3.7 DATA PROCESSING METHOD

The collected data is used to estimate the capacity with the Empirical Distribution Method. This method is based on the idea that every congestion flow observation contributes to the determination of the capacity. Therefore, in order to use this method, flow measurements of congestion state traffic are needed. Next to the flow measurements in or just downstream of the bottleneck, speed measurements from observation points upstream and downstream are needed for this method to divide the measurements in congestion flow and free flow measurements. The processing of this data entails a number of different phases which are described here.

First, the right data should be obtained, this means that the data will be filtered regarding to the fixed variables as described in paragraph 3.2. The first step is to exclude weekend days from the dataset. After that, data outside the peak hours is filtered out; in this research the peak hours are set from 6:00 AM till 10:00 AM and 3:00 PM till 7:00 PM. The last step in the data filtration is excluding data with extreme weather conditions which are snow, fog, glazed frost and average to heavy rain (>2 mm per hour). After the filtration valid datasets for capacity analysis research are acquired.

The second phase of processing the data starts with aggregating the datasets on five minute intervals. Brilon and Zurlinden (2003), who after experiments with different time intervals, came to the conclusion that a time interval of five minutes is the best for capacity analysis. They state that a time interval of five minutes is best for capacity estimation based on the consideration of number of measurements and the quality of the measurements. All data from the three measuring points will be averaged on a five minute interval for this analysis. After that, downstream congestion measurements (speed <50 km/h) are excluded from the dataset, because in that case the measured intensity does not represent the analyzed bottleneck (the work zone), but another bottleneck further downstream. Also upstream non-congestion measurements (speed > 50 km/h) are excluded from the dataset, because non-congestion measurements are not usable for capacity estimation with the Empirical Distribution Method.

The remaining dataset will be analyzed using SPSS. This program calculates a cumulative probability distribution function of the capacity and, with this the capacity at the specific work zone can be estimated. For determining the capacity, the median (F_c (q) = 0.5) of the cumulative probability distribution function is used.

After the estimation of the capacity, the relative and absolute difference between the standard capacity of the road obtained from the CIA handbook, and the calculated capacity of the work zone is tested on significance. The Wilcoxon signed-rank test in SPSS with a confidence level of 5% is used to test whether the median of the dataset differs from the standard value. The one-sample Wilcoxon signed-rank test is a nonparametric alternative method of one-sample t-test, which is used to test whether the median (and not the mean) of the measurement is equal to a specified value, whereby it is not required to assume that the underlying population is normally distributed. An elaboration of this method can be found inappendix 4.

The following step is the analysis of the differences between work zones. For this analysis, for every congestion moment in the peak hours the actual capacity is calculated together with the situation specific variables beloning to that moment. To compare all work zones with eachother, the relative difference of the measured capacities with the guideline from the CIA for that work zone lay-out is calculated. In this way, the effect of the different situation specific variables can be estimated for work zones in general. With all situation-specific variables a multiple regression analysis is executed using SPSS to test the variables on significant influence on work zones in general. The same is done for the different work zone lay-outs, whereby the difference is tested on significance with the Kolmogorov-Smirnov test with a confidence level of 95%. Also a goodness of fit analysis is conducted using multiple linear regression in SPSS.

For the third part, the analysis of the effect of external variables, again the capacity is estimated with the Empirical Distribution Method. The differences in capacity are tested on significance with the Wilcoxon signed-rank test in SPSS with a confidence level of 5%.

CHAPTER 4 Capacity EstimationResults

In this chapter the results of the capacity estimation are described. Per layout the work zones are shortly described and the results are summed up. Detailed information of all work zones is shown in appendix 5 and the statistics of the analysis can be found in appendix 6.

Firstly the results for the closure of the hard shoulder are described. The second layout is the lane narrowing on a two lane freeway and thirdly the lane narrowing on a three lane freeway is presented. After that, the results for the 3 – 1 lane shift system and the 4 – 0 lane shift system are described. The non-shifted directions of the 3 – 1 system and 4 – 0 system are put together because the effect on the capacity of these direction is more or less the same. As last the results of the capacity estimation of both directions of the 4 – 2 system are shown.

4.1 CLOSURE OF HARD SHOULDER

The closure of the hard shoulder is analyzed on two lane freeways only. The normal capacity is of a two lane freeway is 4200 veh/h. According to the CIA, the guideline for capacity of a two lane freeway where the hard shoulder is closed is 3600 veh/h. For work zones with a closed hard shoulder the capacities of three different cases are estimated, this is the only work zone lay-out from which more than two cases are analyzed.

4.1.1 A58 BATADORP – OIRSCHOT

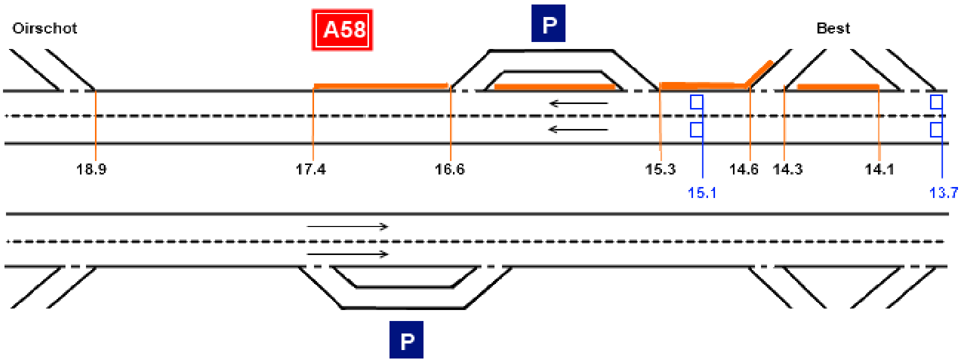
This work zone is located in the southern part of the Netherlands, in the province Noord-Brabant near Eindhoven on the A58, a freeway with two lanes in each direction. On this trajectory the closure of the hard shoulder took place from October 25th till November 19th, 2010 and was researched from October 25th till November 5th, 2010. Only the direction from Batadorp to Oirschot was affected by the road works. A schematic overview of the work zone is shown in figure 18, details of the work zone are shown in table 4.

Table4

Work zone details A58 Batadorp - Oirschot

Case A58 Batadorp - Oirschot	
Percentage of heavy vehicles	9 – 14%
Left lane width	3.50 m
Right lane width	3.50 m
Distance to ramp upstream	400 m
Distance to ramp downstream	1500 m
Length of work zone	3300 m
Familiarity with congestion in normal peak hour	No
Road gradient	0%

Figure18
Schematic trajectory A58 Batadorp - Oirschot



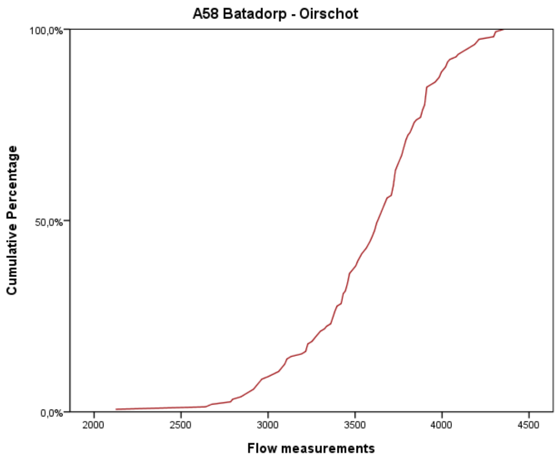
For the estimation of the capacity for this work zone, 152 measurements that satisfy the collecting restrains were collected. These measurements are plotted in figure 19 and the statistics of this distribution are shown in table 5.

Table5
SPSS statistics A58 Batadorp - Oirschot

Statistics A58 Batadorp – Oirschot	
No. measurements	152
Mean	3586.11
Median	3636
Standard deviation	381.246

Wilcoxon signed rank test Test: median = 3600	0.801 Retain
Wilcoxon signed rank test Test: median = 4200	0.000 Reject

Figure19
Cumulative capacity distribution A58 Batadorp - Oirschot



The estimated capacity of this work zone is 3636 veh/h. This is a significant difference of-564 veh/h (-13.4%) compared to the standard capacity of a two lane freeway. The difference between the capacity of this particular work zone and the guideline of the CIA handbook is +36 veh/h (+1.0%). This difference is not significant, which means that the capacity of this work zone is not significant different from the guideline for capacity of the CIA handbook for a freeway work zone with a closed hard shoulder.

4.1.2 A2 ROOSTEREN - ECHT

This case is located on the A2 between Roosteren and Echt in the Province Limburg. The freeway has two lanes in each direction at this location. The closure of the hard shoulder took place from March 18th till June 2nd, 2010 and was researched from March 22nd till April 2nd, 2010. The affected direction in this work zone was the northbound direction from Roosteren to Echt. A schematic overview of the work zone is shown in figure 20, details of the work zone are shown in table 6.

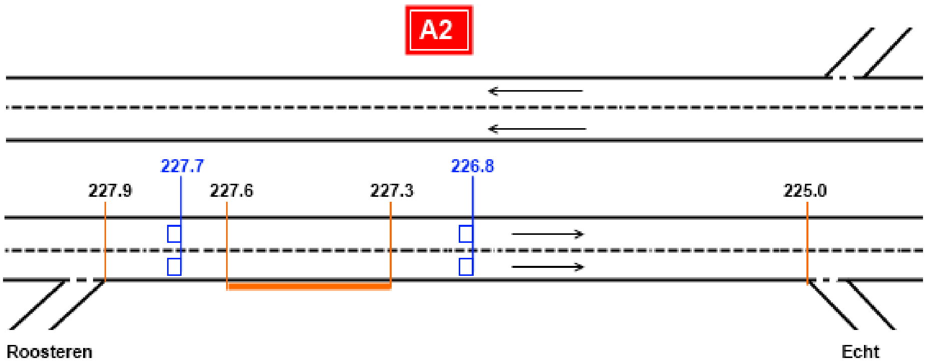
Table6

Work zone details A2 Roosteren - Echt

Case A2 Roosteren - Echt	
Percentage of heavy vehicles	22 – 25%
Left lane width	3.50 m
Right lane width	3.50 m
Distance to ramp upstream	300 m
Distance to ramp downstream	2700 m
Length of work zone	300 m
Familiarity with congestion in normal peak hour	No
Road gradient	0.3%

Figure20

Schematic trajectory A2 Roosteren - Echt



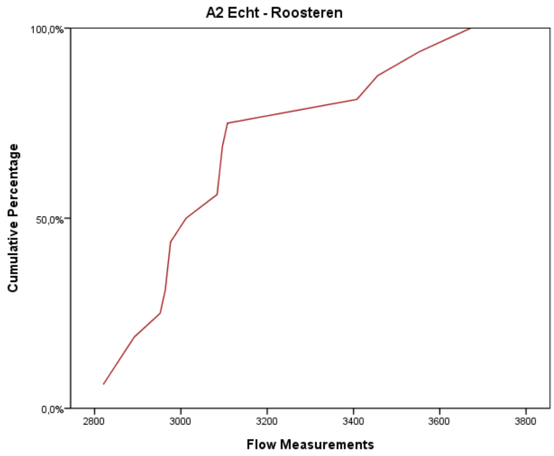
In the researched period, sixteen flow measurements were collected that satisfy the collection restrains. These flow measurements are plotted in figure 21 according to the empirical distribution method and the corresponding statistics of this distribution are shown in table 7.

Table7

SPSS Statistics A2 Roosteren - Echt

Figure21

Cumulative capacity distribution case A2 Roosteren - Echt



Statistics A2 Roosteren - Echt	
No. measurements	16
Mean	3122.25
Median	3048
Standard deviation	256.819

Wilcoxon signed rank test Test: median = 3600	0.001 Reject
Wilcoxon signed rank test Test: median = 4200	0.000 Reject

The estimated capacity of this work zone is 3048 veh/h. This is a significant difference of -1152 veh/h (-27.4%) compared to the standard capacity of a two lane freeway. The difference between the guideline from the CIA and the capacity of this specific work zone is significant and is -552 veh/h (-15.3%). This means that the capacity of this work zone and the guideline capacity value of the CIA handbook are not similar.

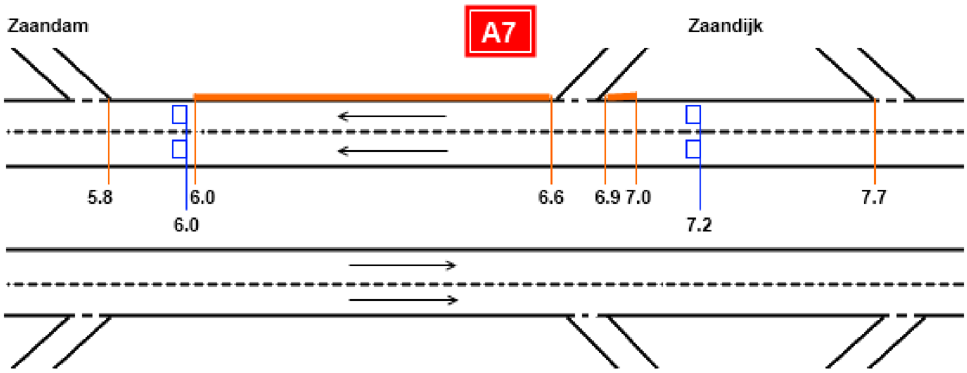
4.1.3 A7 ZAANDIJK – ZAANDAM

This work zone is located between Zaandijk and Zaandam on the freeway A7 near Amsterdam in the province Noord-Holland. The closure of the hard shoulder was present from September 13th, 2010 until February 18th, 2011 and the period it was researched was from September 13th until September 29th, 2010. Only the southbound direction from Zaandijk to Zaandam was affected in this work zone. A schematic overview of the work zone is shown in figure 22, details of the work zone are shown in table 8.

Table8
Work zone details A7 Zaandijk - Zaandam

Case A7 Zaandijk - Zaandam	
Percentage of heavy vehicles	5 – 11%
Left lane width	3.50 m
Right lane width	3.50 m
Distance to ramp upstream	700 m
Distance to ramp downstream	200 m
Length of work zone	1000 m
Familiarity with congestion in normal peak hour	No
Road gradient	0%

Figure22
Schematic trajectory A7 Zaandijk – Zaandam



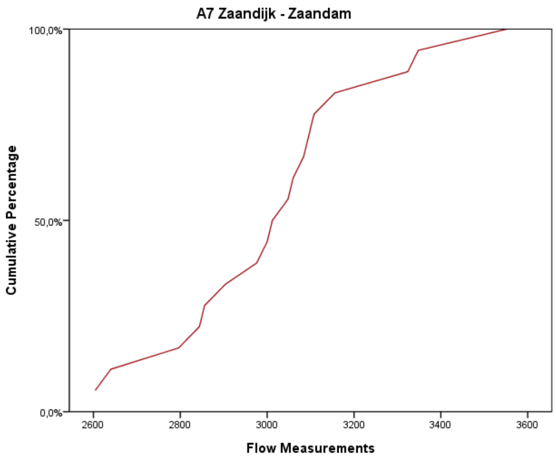
For the estimation of the capacity for this work zone, eighteen measurements that satisfy the collecting restrains where collected. These measurements are plotted in figure 23 according to the empirical distribution method. The statistics belonging to this distribution are shown in table 9.

Table9

SPSS statistics A7 Zaandijk - Zaandam

Figure23

Cumulative capacity distribution A7 Zaandijk - Zaandam



Statistics A7 Zaandijk - Zaandam	
No. measurements	18
Mean	3023.33
Median	3030
Standard deviation	238.210

Wilcoxon signed rank test	0.000
Test: median = 3600	Reject
Wilcoxon signed rank test	0.000
Test: median = 4200	Reject

The estimated capacity of this work zone is 3030 veh/h, which is a significant difference of -1170 veh/h (-27.9%) compared to the standard capacity of a two lane freeway. The difference between the guideline from the CIA and the capacity of this specific work zone is -570 veh/h (-15.8%) and this difference is significant. This means that the capacity of this work zone is lower from the guideline capacity from the CIA handbook.

4.2 LANE NARROWING ON A TWO LANE FREEWAY

The capacity for lane narrowing on a two lane freeway is estimated in two cases, which are described in this paragraph. The CIA guideline for lane narrowing on a two lane freeway is 3200 veh/h. The normal capacity of a freeway with two lanes is 4200 veh/h.

4.2.1 A12 ZEVENHUIZEN – GOUWE

This work zone is located on the A12 between Zevenhuizen and Gouwe in the province Zuid-Holland. The lane narrowing took place from August 11th till November 28th, 2008. The research focuses on the period between September 1st and September 30th, 2008, this because of lower traffic intensities due to holidays. The lane narrowing was only affecting the eastbound direction from Zevenhuizen to Gouwe. A schematic overview of the work zone is shown in figure 24,details of the work zone are shown in table 10.

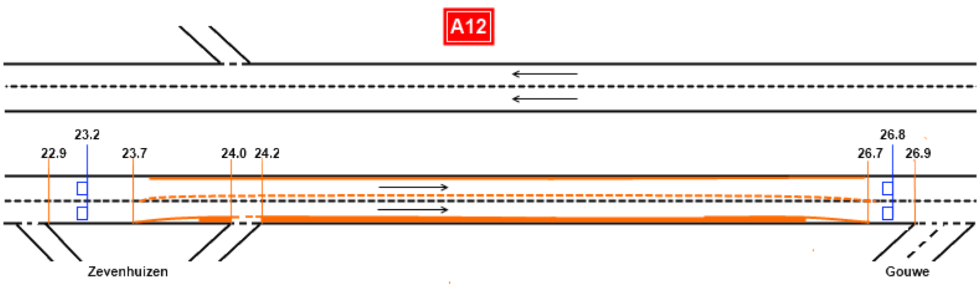
Table10

Work zone details A12 Zevenhuizen - Gouwe

Case A12 Zevenhuizen – Gouwe	
Percentage of heavy vehicles	6 – 10%
Left lane width	2.75 m
Right lane width	3.25 m
Distance to ramp upstream	800 m
Distance to ramp downstream	200 m
Length of work zone	3000 m
Familiarity with congestion in normal peak hour	No
Road gradient	0.7%

Figure24

Schematic trajectory A12 Zevenhuizen - Gouwe



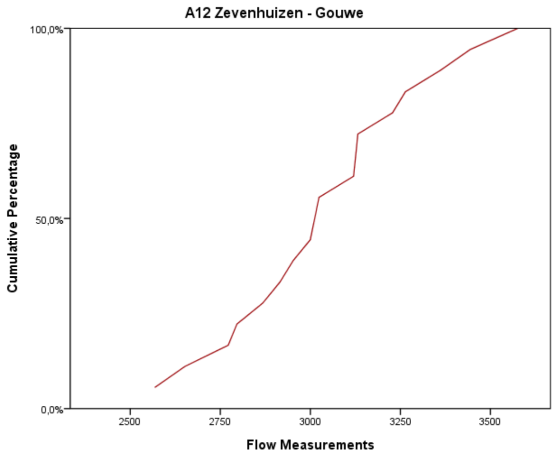
For the estimation of the capacity for this work zone, eighteen measurements that satisfy the collecting restrains where collected. These are plotted in figure 25 according to the empirical distribution method. The corresponding statistics are shown in table 11.

Table11

SPSS statistics A12 Zevenhuizen - Gouwe

Figure25

Cumulative capacity distribution A12 Zevenhuizen - Gouwe



Statistics A12 Zevenhuizen - Gouwe	
No. measurements	18
Mean	3045.33
Median	3018
Standard deviation	268.030

Wilcoxon signed rank test	0.022
Test: median = 3200	Reject
Wilcoxon signed rank test	0.000
Test: median = 4200	Reject

The estimated capacity of this work zone is 3018 veh/h. This is a significant difference of -1152 veh/h (-27.4%) compared to the standard capacity. The difference between the guideline from the CIA and the capacity of this specific work zone is -182 veh/h (-5.7%) and this difference is significant. This means that the capacity of this work zone is lower the guideline capacity from the CIA handbook.

4.2.2 A9 UITGEEST – ALKMAAR

This particular work zone is located on the A9, a freeway in the Province Noord-Holland between Uitgeest and Alkmaar. The lane narrowing took place from November 1st, 2010 till February 25th, 2011 and was researched was from November 1st and November 12th, 2010. The lane narrowing was only affecting the northbound direction from Uitgeest to Alkmaar at that time. A schematic overview of the work zone is shown in figure 26, details of the work zone are shown in table 12.

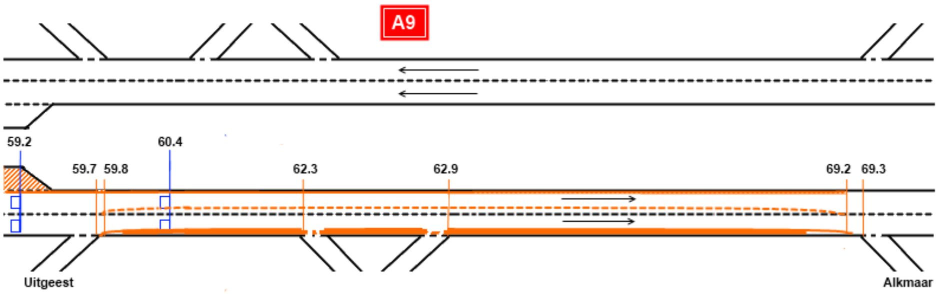
Table12

Work zone details A9 Uitgeest - Alkmaar

Case A9 Uitgeest - Alkmaar	
Percentage of heavy vehicles	6 – 9%
Left lane width	2.50 m
Right lane width	2.85 m
Distance to ramp upstream	100 m
Distance to ramp downstream	100 m
Length of work zone	9400 m
Familiarity with congestion in normal peak hour	Evening
Road gradient	1.5%

Figure26

Schematic trajectory A9 Uitgeest - Alkmaar



There were 206 measurements collected for this work zone that satisfies the collecting restrains during the research period. The measurements are plotted in figure 27 and the statistics belonging to this distribution are shown in table 13.

Table13

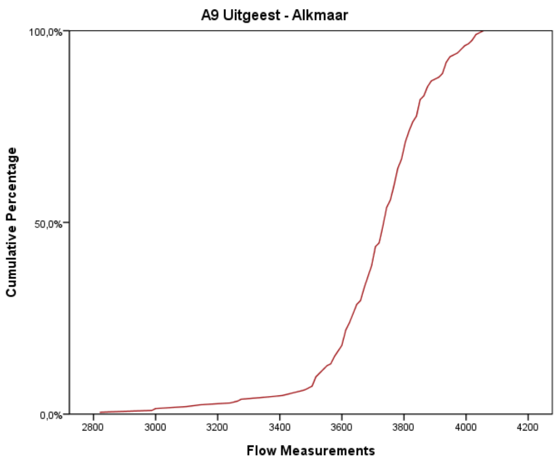
SPSS statistics A9 Uitgeest – Alkmaar

StatisticsA9 Uitgeest - Alkmaar	
No. measurements	206
Mean	3721.22
Median	3744
Standard deviation	185.648

Wilcoxon signed rank test Test: median = 3200	0.000 Reject
Wilcoxon signed rank test Test: median = 4200	0.000 Reject

Figure27

Cumulative capacity distribution A9 Uitgeest - Alkmaar



The capacity of this work zone is 3744 veh/h. Compared to the standard capacity of a two lane freeway this is a significant difference of -456 veh/h (-10.9%). The difference between the guideline from the CIA and the capacity of this specific work zone is +544 veh/h (+17.0%) and this difference is significant. This means that the capacity of this work zone and the guideline capacity from the CIA handbook are different.

4.3 LANE NARROWING ON A THREE LANE FREEWAY

For the work zone lay-out lane narrowing on a three lane freeway the capacity is also estimated for two cases. This is described in this paragraph. The CIA guideline for lane narrowing on a three lane freeway is 4500 veh/h. The normal capacity of a freeway with three lanes is 6300 veh/h.

4.3.1 A2 LAGE WEIDE – UTRECHT CENTRUM

This work zone is located on the A2 in the Province Utrecht, in the middle of the Netherlands. The lane narrowing took place from January 1st, 2009 till November 30th, 2010 and was researched between January 5th and 19th, 2009. The lane narrowing was only affecting the southbound direction from Lage Weide to Utrecht Centrum. A schematic overview of the work zone is shown in figure 28, details of the work zone are shown in table 14.

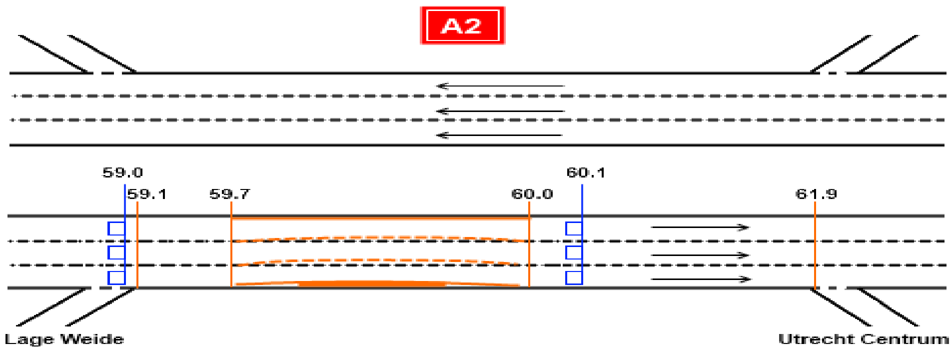
Table14

Work zone details A2 Lage Weide – Utrecht Centrum

Case A2 Lage Weide – Utrecht Centrum	
Percentage of heavy vehicles	11 – 17%
Left lane width	3.05 m
Middle lane width	3.15 m
Right lane width	3.25 m
Distance to ramp upstream	600 m
Distance to ramp downstream	900 m
Length of work zone	300 m
Familiarity with congestion in normal peak hour	No
Road gradient	0%

Figure28

Schematic trajectory A2 Lage Weide – Utrecht Centrum



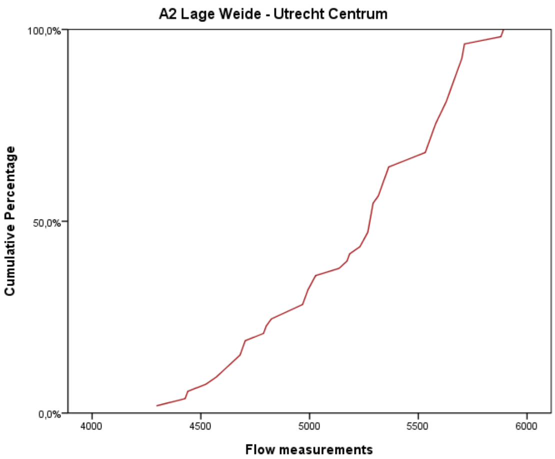
For the estimation of the capacity for this work zone, 53 measurements that satisfy the collecting restrains where collected. These are plotted in figure 29 according to the empirical distribution method. The corresponding statistics are shown in table 15.

Table15

SPSS statistics A2 Lage Weide - Utrecht Centrum

Figure29

Cumulative capacity distribution A2 Lage Weide - Utrecht Centrum



StatisticsA2 Lage Weide – Utrecht Centrum	
No. measurements	53
Mean	5217.06
Median	5292
Standard deviation	420.625

Wilcoxon signed rank test	0.000
Test: median = 4500	Reject
Wilcoxon signed rank test	0.000
Test: median = 6300	Reject

The capacity of this work zone is 5292 veh/h. Compared to the standard capacity of a three lane freeway this is a significant difference of -1008 veh/h (-16.0%). The difference between the guideline from the CIA and the capacity of this specific work zone is +792 veh/h (+17.6%) and this difference is significant. This means that the capacity of this work zone is higher than the guideline capacity from the CIA handbook.

4.3.2 A12 ZOETERMEER CENTRUM - NOOTDORP

This particular work zone is located on the A12, a freeway in the Province Zuid-Holland in the western part of the Netherlands. The lane narrowing took place from January 7th, 2011 till February 25th, 2011 and was researched was from January 10th till 21st, 2011. The lane narrowing was only affecting the westbound direction from Zoetermeer Centrum to Nootdorp. A schematic overview of the work zone is shown in figure 30, details of the work zone are shown in table 16.

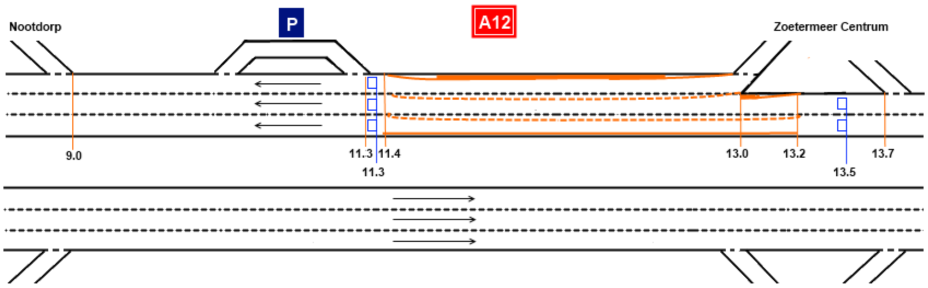
Table16

Work zone details A12 Zoetermeer Centrum - Nootdorp

Case A12 Zoetermeer Centrum – Nootdorp	
Percentage of heavy vehicles	5 – 7%
Left lane width	2.95 m
Middle lane width	3.05 m
Right lane width	3.50 m
Distance to ramp upstream	500 m
Distance to ramp downstream	100 m
Length of work zone	1800 m
Familiarity with congestion in normal peak hour	No
Road gradient	0%

Figure30

Schematic trajectory A12 Zoetermeer Centrum – Nootdorp



There were 35 measurements collected for this work zone that satisfies the collecting restrains during the research period. The measurements are plotted in figure 31. The statistics belonging to this distribution are shown in table 17.

Table17

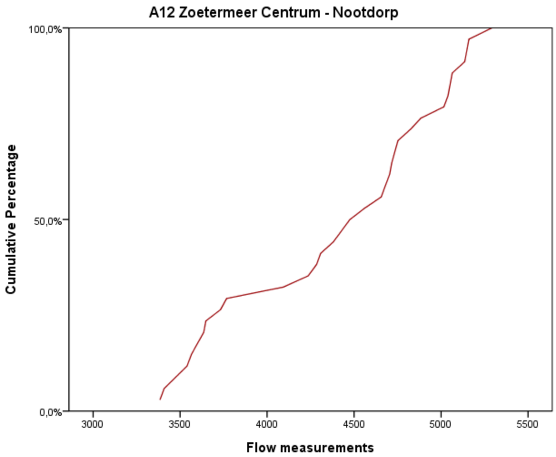
SPSS statistics A12 Zoetermeer Centrum - Nootdorp

StatisticsA12 Zoetermeer Centrum - Nootdorp	
No. measurements	34
Mean	4397.29
Median	4518
Standard deviation	605.395

Wilcoxon signed rank test Test: median = 4500	0.402
	Retain
Wilcoxon signed rank test Test: median = 6300	0.000
	Reject

Figure31

Cumulative capacity distribution A12 Zoetermeer Centrum - Nootdorp



The estimated capacity of this work zone is 4518 veh/h. This is a significant difference of -1782 veh/h (-28.3%) compared to the standard capacity. The difference between the capacity of this work zone and the guideline is +18 veh/h (+0.4%). This difference is insignificant and means that the capacity of this work zone and the guideline from the CIA handbook do not differ from each other.

4.4 3 – 1 LANE SHIFT SYSTEM

In this paragraph the capacity estimation for shifted direction of the 3 – 1 lane shift system is described. Also for this work zone lay-out, the capacity is estimated for two cases. The CIA guideline for the shifted direction of the 3 – 1 lane shift system is 3000 veh/h. The normal capacity of a freeway with two lanes is 4200 veh/h.

4.4.1 A50 RENKUM - HETEREN

This work zone is located on the A50 in the province Gelderland close to Arnhem on the bridge over the river Neder-Rijn. The researched work zone was present from September 6th till September 17th, 2010 and also researched during this period. During the road works one of the lanes in the southbound direction from Renkum to Heteren was shifted. A schematic overview of the work zone is shown in figure 32, details of the work zone are shown in table 18.

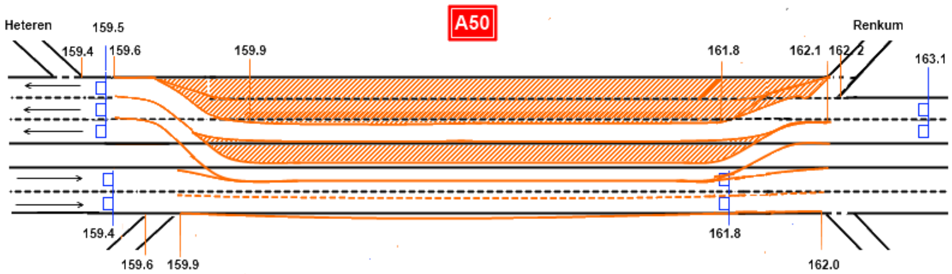
Table18

Work zone details A50 Renkum - Heteren

Case A50 Renkum – Heteren	
Percentage of heavy vehicles	12 –22%
Left lane width	2.85 m
Right lane width	3.30 m
Distance to ramp upstream	0 m
Distance to ramp downstream	200 m
Length of work zone	2700 m
Familiarity with congestion in normal peak hour	Evening
Road gradient	0.7%

Figure32

Schematic trajectory A50 Renkum - Heteren



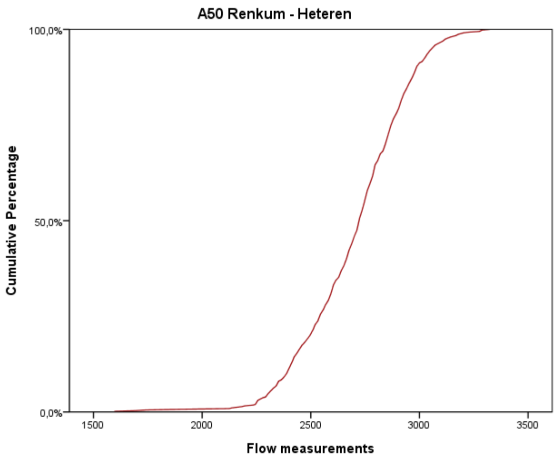
For the capacity estimation of the shifted direction, 560 measurements that satisfy the collecting restrains where collected. These flow measurements are plotted in figure 33 andthe statistics are shown in table 19.

Table19

SPSS statistics A50 Renkum - Heteren

Figure33

Cumulative capacity distribution A50 Renkum - Heteren



Statistics A50 Renkum - Heteren	
No. measurements	560
Mean	2706.71
Median	2724
Standard deviation	241.478

Wilcoxon signed rank test Test: median = 3000	0.000 Reject
Wilcoxon signed rank test Test: median = 4200	0.000 Reject

The estimated capacity of this work zone is 2724 veh/h. This is a significant difference of -1476 veh/h (-35.1%) compared to the standard capacity of a two lane freeway. The difference between the capacity of this work zone and the guideline from the CIA is -276 veh/h (-9.2%) and this difference is significant. This means that the capacity of this work zone is lower than the guideline capacity from the CIA handbook.

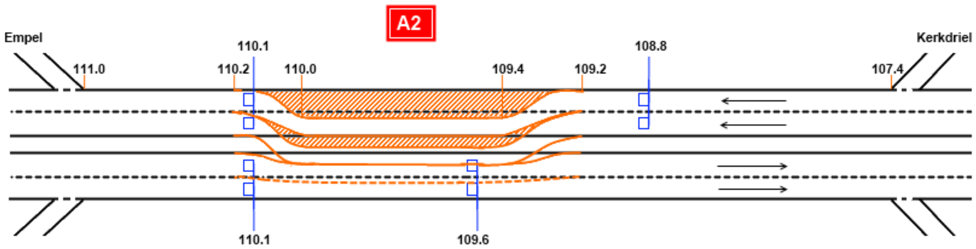
4.4.2 A2 KERKDRIEL - EMPEL

This work zone is located on the A2 on the bridge over the river Maas which is the border of the provinces Noord-Brabant and Zuid-Holland. The researched work zone was present from August 10th till August 15th, 2010, and therefore the researched period is shorter than at other researched work zones, but it was no problem regarding the number of measurements. In this researched period the one of the lanes in the direction from Kerkdriel to Empel was shifted. A schematic overview of the work zone is shown in figure 34, details of the work zone are shown in table 20.

Table20
Work zone details A2 Kerkdriel - Empel

Case A2 Kerkdriel - Empel	
Percentage of heavy vehicles	9 – 16%
Left lane width	2.75 m
Right lane width	3.25 m
Distance to ramp upstream	1800 m
Distance to ramp downstream	800 m
Length of work zone	1000 m
Familiarity with congestion in normal peak hour	No
Road gradient	0.8%

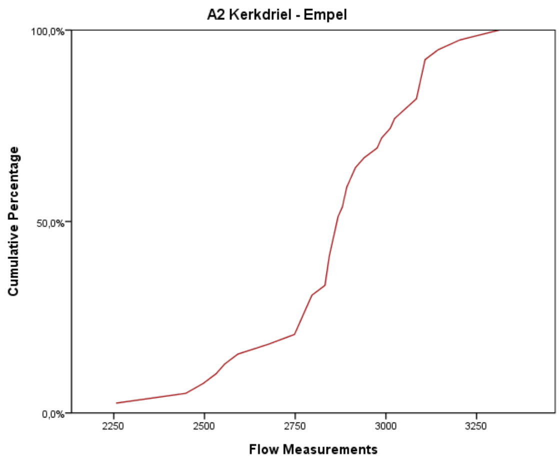
Figure34
Schematic trajectory A2 Kerkdriel - Empel



In this case, 39 measurements were collected that satisfy the collecting restrains. These flow measurements are plotted in figure 35 according to the empirical distribution method.The statistics belonging to this plotted distribution are shown in table 21.

Table21
SPSS statistics A2 Kerkdriel - Empel

Figure35
Cumulative capacity distribution A2 Kerkdriel - Empel



Statistics A2 Kerkdriel - Empel	
No. measurements	39
Mean	2869.23
Median	2868
Standard deviation	220.132

Wilcoxon signed rank test Test: median = 3000	0.001 Reject
Wilcoxon signed rank test Test: median = 4200	0.000 Reject

The estimated capacity of this work zone is 2868 veh/h. Compared to the standard capacity this is a significant difference of -1332 veh/h (-31.7%). The difference of this specific work zone and the guideline from the CIA is -132 veh/h (-4.4%) and this difference is significant. This means that the capacity of this work zone and the guideline capacity from the CIA handbook are not the same.

4.5 4 – 0 LANE SHIFT SYSTEM

The capacity estimation for shifted direction the 4 – 0 lane shift system is described in this paragraph. Again the capacity is estimated for two cases with this lay-out. The CIA guideline for the shifted direction of the 4 – 0 lane shift system is 3400 veh/h. The normal capacity of a freeway with two lanes is 4200 veh/h.

4.5.1 A2 ZALTBOMMEL - KERKDRIEL

This work zone is located in the Province Gelderland on the A2 between Zaltbommel and Kerkdriel. The work zone was present from January 16th till May 27th, 2009. The period researched was January 19th till February 2nd, 2009. In this period the two lanes in the northbound direction from Kerkdriel to Zaltbommel were shifted. A schematic overview of the work zone is shown in figure 36, details of the work zone are shown in table 22.

Table22
Work zone details A2 Zaltbommel - Kerkdriel

Case A2 Zaltbommel – Kerkdriel	
Percentage of heavy vehicles	9 – 14%
Left lane width	3.25 m
Right lane width	3.25 m
Distance to ramp upstream	2000 m
Distance to ramp downstream	900 m
Length of work zone	700 m
Familiarity with congestion in normal peak hour	No
Road gradient	1.7%

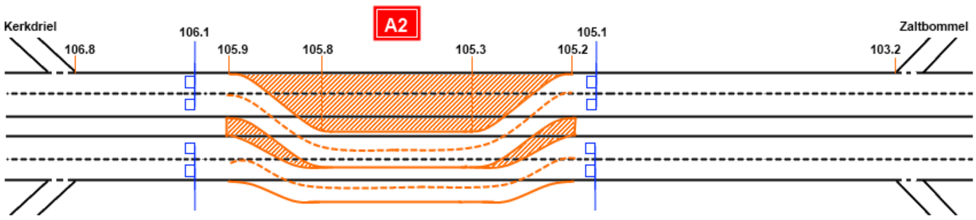


Figure36
Schematic trajectory A2 Zaltbommel - Kerkdriel

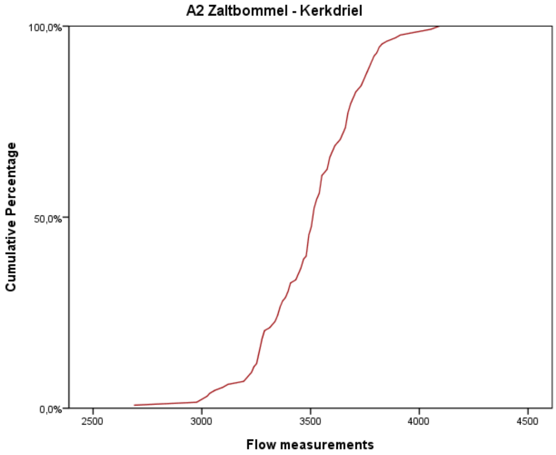
For the capacity estimation of the shifted direction, 128 measurements that satisfy the collecting restrains where collected. These flow measurements are plotted in figure 37.The statistics belonging to this distribution are shown table 23.

Table23

SPSS statistics A2 Zaltbommel - Kerkdriel

Figure37

Cumulative capacity distribution A2 Zaltbommel - Kerkdriel



Statistics A2 Zaltbommel - Kerkdriel	
No. measurements	128
Mean	3507.00
Median	3516
Standard deviation	229.909

Wilcoxon signed rank test	0.000
Test: median = 3400	Reject
Wilcoxon signed rank test	0.000
Test: median = 4200	Reject

This work zones capacity is 3516 veh/h. Compared to the standard capacity of a two lane freeway this is a significant difference of -684 veh/h (-16.3%). The capacity of this specific work zone and the guideline from the CIA is +116 veh/h (+3.4%). This difference is significant and that means that the capacity of this work zone and the guideline capacity from the CIA handbook are not the same.

4.5.2 A12 ZOETERMEER - ZEVENHUIZEN

This work zone is located in the Province Zuid-Holland on the A12 between Zoetermeer and Zevenhuizen. The 4 – 0 system was present from April 15th until June 15th, 2009 and it was researched from April 20th until May 5th, 2009. In the time the system was present, the eastbound direction from Zoetermeer to Zevenhuizen was shifted. A schematic overview of the work zone is shown in figure 38, details of the work zone are shown in table 24.

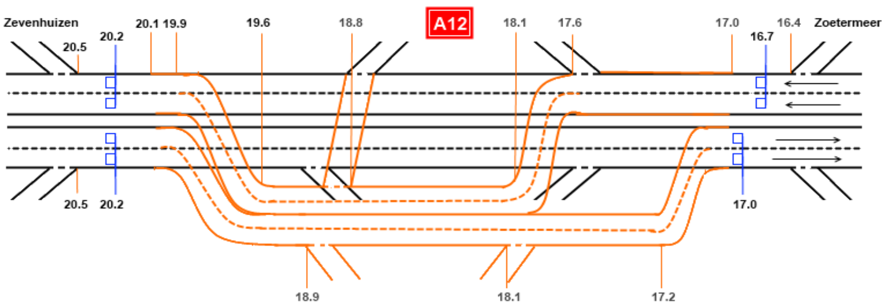
Table24

Work zone details A12 Zoetermeer - Zevenhuizen

Case A12 Zoetermeer – Zevenhuizen	
Percentage of heavy vehicles	5 – 10%
Left lane width	3.00 m
Right lane width	3.25 m
Distance to ramp upstream	400 m
Distance to ramp downstream	600 m
Length of work zone	2900 m
Familiarity with congestion in normal peak hour	Evening
Road gradient	1.7%

Figure38

Schematic trajectory A12 Zoetermeer - Zevenhuizen



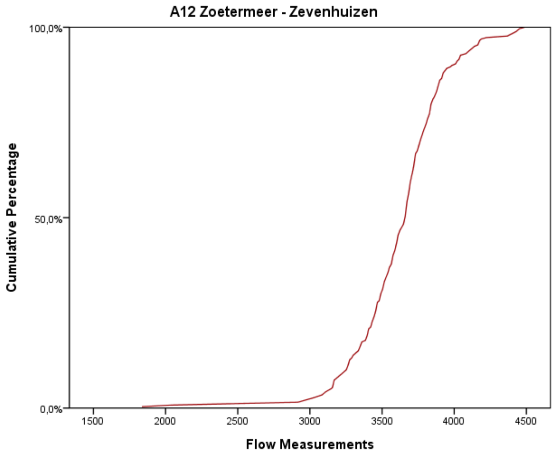
In this case, 259 measurements were collected that satisfy the collecting restrains. These flow measurements are plotted in figure 27 and the statistics are shown in table 14.

Table25

SPSS statistics A12 Zoetermeer - Zevenhuizen

Figure39

Cumulative capacity distribution A12 Zoetermeer - Zevenhuizen



Statistics A12 Zoetermeer - Zevenhuizen	
No. measurements	259
Mean	3629.33
Median	3660
Standard deviation	332.058

Wilcoxon signed rank test Test: median = 3400	0.000 Reject
Wilcoxon signed rank test Test: median = 4200	0.000 Reject

The estimated capacity of this work zone is 3660 veh/h. This is a significant difference of -540 veh/h (-12.9%) compared to the standard capacity. The difference between the capacity of the work zone and the guideline of the CIA handbook is +260 veh/h (+7.6%) and this difference is significant. This means that the capacity of this work zone is higher than the guideline for capacity from the CIA handbook.

4.6 NON-SHIFTED DIRECTION 3 – 1 AND 4 – 0 LANE SHIFT SYSTEMS

In this paragraph the capacity estimation for the non-shifted direction of the 3 – 1 and 4 – 0 lane shift systems is described. Also for this work zone lay-out, the capacity is estimated for two cases. For the cases A2 Kerkdriel – Empel and A2 Zaltbommel – Kerkdriel there were no congestion measurements and thus the capacity could not be estimated with the empirical distribution method. The CIA guideline for the non-shifted direction of the 3 – 1 and 4 – 0 lane shift systems is 3400 veh/h. The normal capacity of a freeway with two lanes is 4200 veh/h.

4.6.1 A50 HETEREN – RENKUM

This 3 – 1 lane shift system was located on the A50 in the province Gelderland close to Arnhem on the bridge over the river Neder-Rijn. The researched work zone was present from September 6th till September 17th, 2010. During the road works the non-shifted direction was northbound from Heteren to Renkum. The lanes were affected because they were narrowed. A schematic overview of the work zone is shown in figure 40, details of the work zone are shown in table 26.

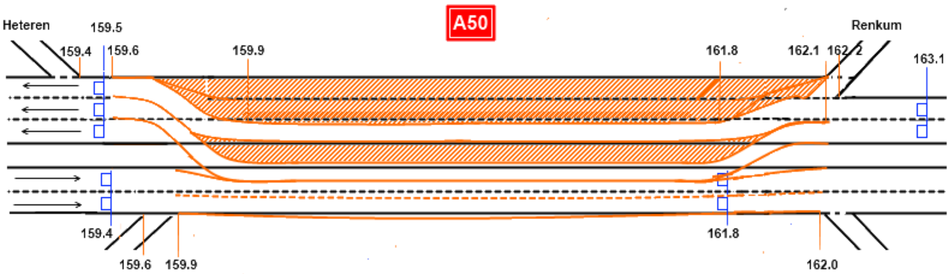
Table26

Work zone details A50 Heteren - Renkum

Case A50 Heteren – Renkum	
Percentage of heavy vehicles	10 – 18%
Left lane width	3.50 m
Right lane width	3.50 m
Distance to ramp upstream	300 m
Distance to ramp downstream	0 m
Length of work zone	2100 m
Familiarity with congestion in normal peak hour	No
Road gradient	0.5%

Figure40

Schematic trajectory A50 Heteren - Renkum



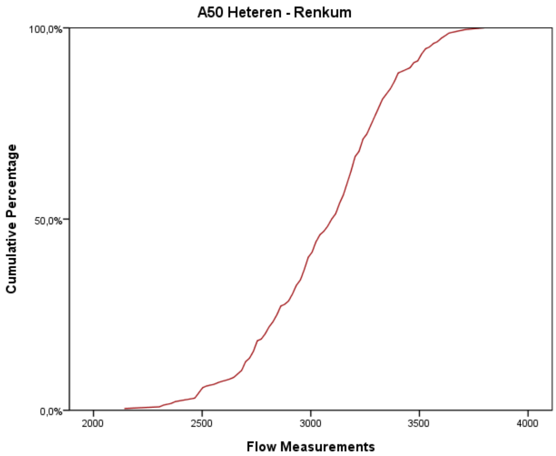
For the capacity estimation of the non-shifted direction, 220 measurements that satisfy the collecting restrains where collected. These flow measurements are plotted in figure 41 according to the empirical distribution method.The corresponding statistics are shown in table 27.

Table27

SPSS statistics A50 Heteren - Renkum

Figure41

Cumulative capacity distribution A50 Heteren - Renkum



Statistics A50 Heteren - Renkum	
No. measurements	220
Mean	3070.55
Median	3105
Standard deviation	309.247

Wilcoxon signed rank test Test: median = 3400	0.000 Reject
Wilcoxon signed rank test Test: median = 4200	0.000 Reject

The estimated capacity of this direction is 3105 veh/h. This is a significant difference of -1095 veh/h (-26.1%) compared to the standard capacity of a two lane freeway. The difference between the capacity of this work zone and the guideline is -295 veh/h (-8.6%) and this difference is significant. This means that the capacity of this direction is significantly lower than the capacity guideline from the CIA handbook.

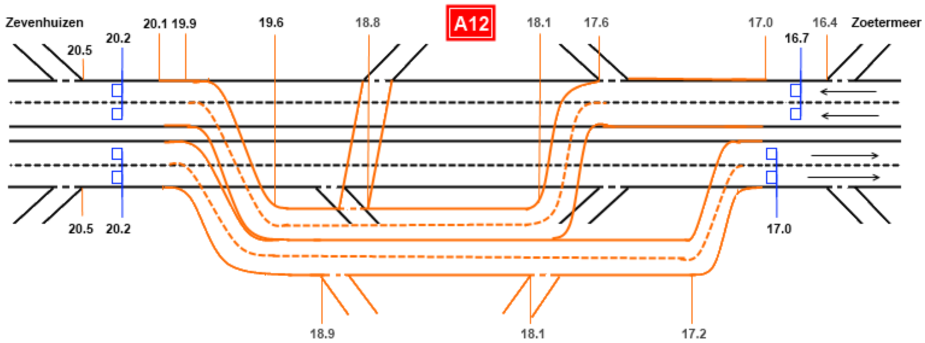
4.6.2 A12 ZEVENHUIZEN – ZOETERMEER

This work zone was located in the Province Zuid-Holland on the A12 between Zoetermeer and Zevenhuizen. The 4 – 0 lane shift system was present from April 15th until June 15th, 2009 and it was researched from April 20th until May 5th, 2009. In the time the system was present, the westbound direction from Zevenhuizen to Zoetermeer was the non-shifted direction. A schematic overview of the work zone is shown in figure 42, details of the work zone are shown in table 28.

Table28
Work zone details A12 Zoetermeer - Zevenhuizen

Case A12 Zevenhuizen – Zoetermeer	
Percentage of heavy vehicles	4 – 10%
Left lane width	3.00 m
Right lane width	3.50 m
Distance to ramp upstream	400 m
Distance to ramp downstream	600 m
Length of work zone	3100 m
Familiarity with congestion in normal peak hour	No
Road gradient	0.5%

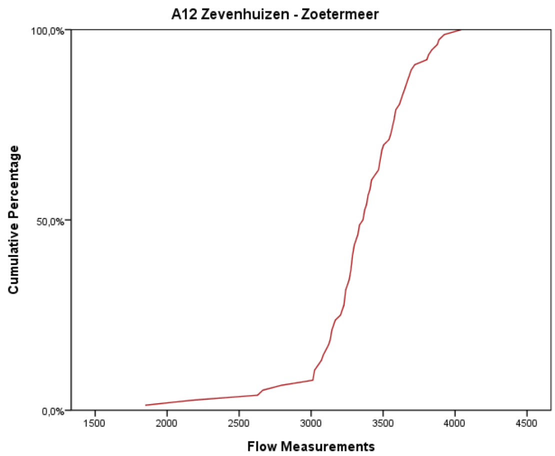
Figure42
Schematic trajectory A12 Zevenhuizen - Zoetermeer



For this direction, 76 measurements were collected that satisfy the collecting restrains. These flow measurements are plotted in figure 43. The statistics belonging to this distribution are shown in table 29.

Table29
SPSS statistics A12 Zevenhuizen - Zoetermeer

Figure43
Cumulative capacity distribution A12 Zevenhuizen - Zoetermeer



Statistics A12 Zevenhuizen - Zoetermeer	
No. measurements	76
Mean	3351.00
Median	3366
Standard deviation	353.184

Wilcoxon signed rank test Test: median = 3400	0.453 Retain
Wilcoxon signed rank test Test: median = 4200	0.000 Reject

The capacity of this direction of the work zone is 3366 veh/h. Compared to the standard capacity this is a significant difference of -834 veh/h (-19.9%). The difference between the calculated capacity and the guideline is -34 veh/h (-1.0%). This difference is not significant. This means that the guideline from the CIA handbook and the capacity of this work zone are not significantly different.

4.7 4 – 2 LANE SHIFT SYSTEM

In this paragraph the capacity estimation for shifted direction of the 4 - 2 lane shift system is described. Also for this work zone lay-out, the capacity is estimated for two cases. The CIA guideline for the shifted direction of the 4 – 2 lane shift system is 4300 veh/h. The normal capacity of a freeway with three lanes is 6300 veh/h.

4.7.1 A28 ZWOLLE ZUID – HATTEMERBROEK

This work zone is located on the A28 close to Zwolle on the bridge over the river IJssel which is the border of the provinces Gelderland and Overijssel. This work zone lay-out was present from April 4th till April 8th, 2011, thus the researched period is shorter than at other researched work zones, but it was no problem regarding the number of measurements. In the researched period lanes in the southbound direction from Zwolle Zuid to Hattemerbroek were shifted. A schematic overview of the work zone is shown in figure 44, details of the work zone are shown in table 30.

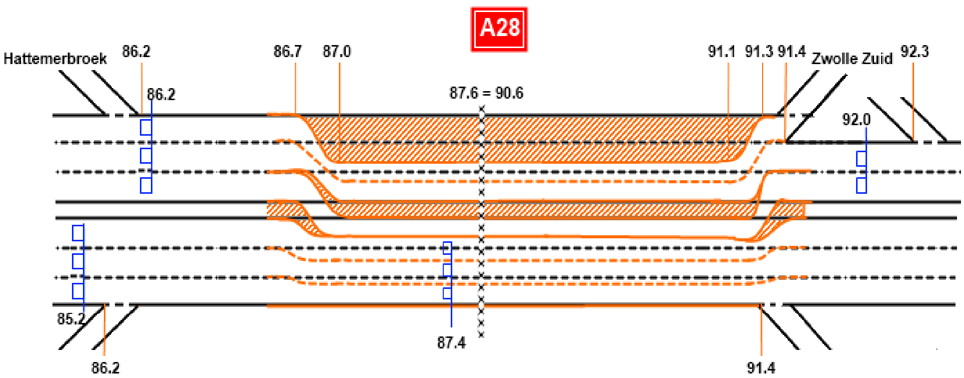
Table30

Work zone details A28 Zwolle Zuid - Hattemerbroek

Case A28 Zwolle Zuid – Hattemerbroek	
Percentage of heavy vehicles	9 – 14%
Left lane width	3.00 m
Middle lane width	3.00 m
Right lane width	3.50 m
Distance to ramp upstream	0 m
Distance to ramp downstream	500 m
Length of work zone	1700 m
Familiarity with congestion in normal peak hour	No
Road gradient	1.5%

Figure44

Schematic trajectory A28 Zwolle Zuid - Hattemerbroek



For the estimation of the capacity of the shifted direction of this work zone, 114 measurements that satisfy the collecting restrains where collected. The distribution is plotted in figure 45. The statistics belonging to this distribution are shown in table 31.

Table31

SPSS statistics A28 Zwolle Zuid - Hattemerbroek

Statistics A28 Zwolle Zuid - Hattemerbroek	
No. measurements	114
Mean	4015.16
Median	4080
Standard deviation	366.374

Wilcoxon signed rank test Test: median = 4300	0.000
	Reject
Wilcoxon signed rank test Test: median = 6300	0.000
	Reject

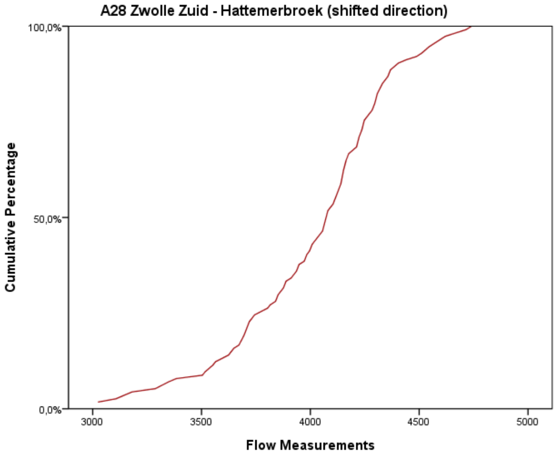


Figure45

Cumulative capacity distribution A28 Zwolle Zuid - Hattemerbroek

The capacity for the sifted direction of this work zone is 4080 veh/h. This is a significant difference of -2220 veh/h (-35.2%).The difference between the guideline and the capacity of this particular work zone is -220 veh/h(-5.1%).This difference is significant and that means that the capacity of this direction of this work zone differs from the guideline from the CIA handbook.

4.7.2 A16'S GRAVENDEEL – KLAVERPOLDER

This work zone is located on the A16 on the bridge over the river Hollandsch Diep which is the border of the provinces Noord-Brabant and Zuid-Holland. It was present from February 16th till August 15th, 2008 and researched from the February 18th till February 29th, 2008. In this period the lanes in the southbound direction from 's Gravendeel to Klaverpolder were shifted. A schematic overview of the work zone is shown in figure 46, details of the work zone are shown in table 32.

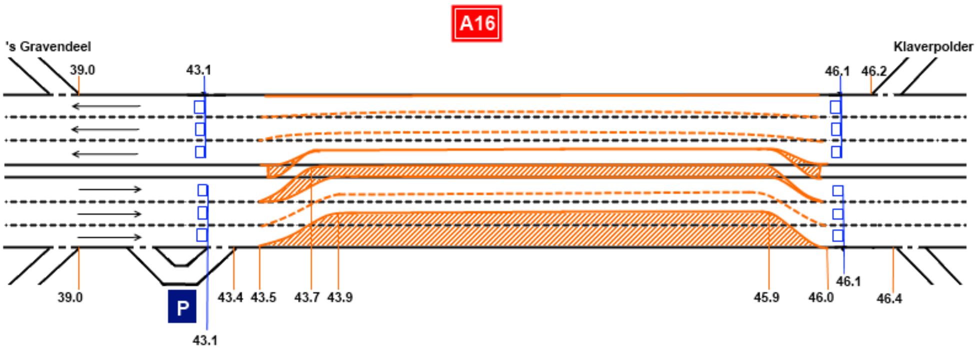
Table32

Work zone details A15 's Gravendeel - Klaverpolder

Case A16 's Gravendeel - Klaverpolder	
Percentage of heavy vehicles	10 – 22%
Left lane width	3.00 m
Middle lane width	3.00 m
Right lane width	3.25 m
Distance to ramp upstream	100 m
Distance to ramp downstream	400 m
Length of work zone	2500 m
Familiarity with congestion in normal peak hour	No
Road gradient	1.9%

Figure46

Schematic trajectory A16 ‘s Gravendeel - Klaverpolder



There are 54 measurements that satisfy the collecting restrains for capacity estimation of the shifted direction of this work zone. These measurements are plotted in figure 47 according to the empirical distribution method. The statistics belonging to this plotted distribution are shown in table 33.

Figure47

Cumulative capacity distribution A16 ‘s Gravendeel - Klaverpolder

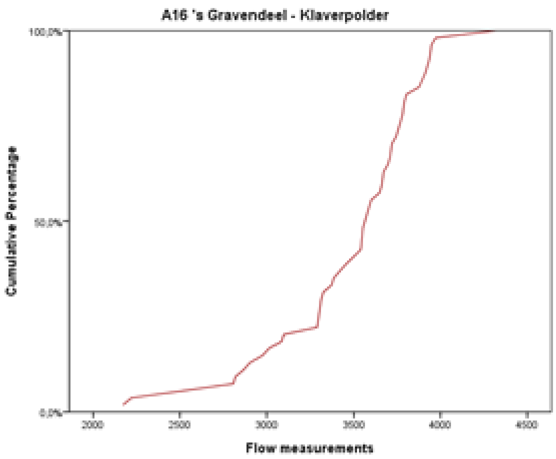


Table33

SPSS statistics A16 ‘s Gravendeel - Klaverpolder

Statistics A16 ‘s Gravendeel - Klaverpolder	
No. measurements	54
Mean	3476.44
Median	3576
Standard deviation	437.497

Wilcoxon signed rank test	0.000
Test: median = 4300	Reject
Wilcoxon signed rank test	0.000
Test: median = 6300	Reject

The capacity for this work zone is 3576 veh/h. Compared to the standard capacity this is a difference of -2724 veh/h (-43.2%).The difference between the guideline for the shifted direction of a 4 – 2 lane shift system and the capacity of this specific work zone is -724 veh/h (-16.8%). This difference is significant ant that means that the capacity of this work zone is lower than the guideline capacity value of the CIA handbook.

4.8 NON-SHIFTED DIRECTION 4 – 2 LANE SHIFT SYSTEM

In this paragraph the capacity estimation for the non-shifted direction of the 4 – 2 lane shift system is described. Also for this work zone lay-out, the capacity is estimated for two cases. The CIA guideline for the non-shifted direction of the 4 – 2 lane shift system is 4500 veh/h. The normal capacity of a freeway with two lanes is 6300 veh/h.

4.8.1 A28 HATTEMERBROEK – ZWOLLE ZUID

This work zone is located on the A28 close to Zwolle on the bridge over the river IJssel which is the border of the provinces Gelderland and Overijssel. This work zone lay-out was present from April 4th till April 8th, 2011, thus the researched period is shorter than at other researched work zones, but it was no problem regarding the number of measurements. During the road works the non-shifted direction was northbound from Zwolle Zuid to Hattemerbroek. The lanes were affected because they were narrowed. A schematic overview of the work zone is shown in figure 48, details of the work zone are shown in table 34.

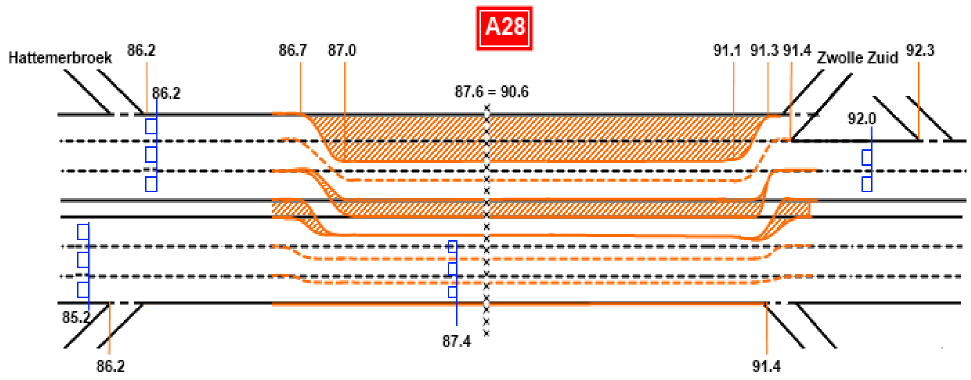
Table34

Work zone details A28 Hattemerbroek – Zwolle Zuid

Case A25 Hattemerbroek – Zwolle Zuid	
Percentage of heavy vehicles	10 – 11%
Left lane width	3.00 m
Middle lane width	3.25 m
Right lane width	3.50 m
Distance to ramp upstream	500 m
Distance to ramp downstream	0 m
Length of work zone	1700 m
Familiarity with congestion in normal peak hour	No
Road gradient	1.%

Figure48

Schematic trajectory A28 Hattemerbroek – Zwolle Zuid



For the non-shifted direction, 34 measurements were collected that satisfy the collecting restrains. These flow measurements are plotted in figure 49. The statistics belonging to this plotted distribution are shown in table 35.

Table35

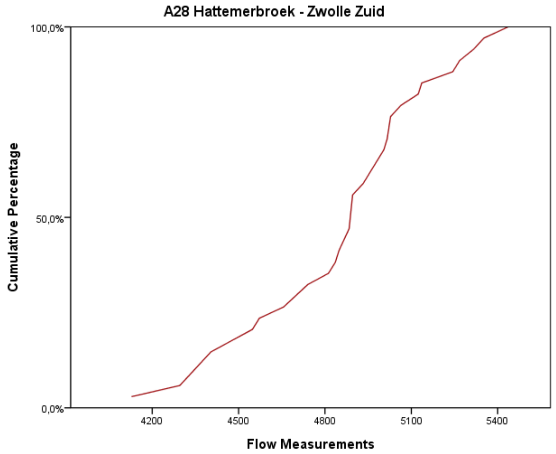
SPSS statistics A28 Hattemerbroek – Zwolle Zuid

Statistics A28Hattemerbroek – Zwolle Zuid	
No. measurements	34
Mean	4856.47
Median	4896
Standard deviation	321.377

Wilcoxon signed rank test Test: median = 4500	0.000 Reject
Wilcoxon signed rank test Test: median = 6300	0.000 Reject

Figure49

Cumulative capacity distribution A28 Hattemerbroek – Zwolle Zuid



The capacity of this direction of the work zone is 4896 veh/h. Compared to the standard capacity this is a difference of -1408 veh/h (-22.3%).The difference between the capacity of this specific work zone and the guideline of the CIA handbook is +396 veh/h (+8.8%). This difference is significant and that means that the capacity for non-shifted direction of this work zone is significantly higher than the guideline for capacity of the CIA handbook.

4.8.2 A16KLAVERPOLDER – 'S GRAVENDEEL

This work zone is located on the A16 on the bridge over the river Hollandsch Diep which is the border of the provinces Noord-Brabant and Zuid-Holland. It was present from February 16th till August 15th, 2008 and researched from the February 18th till February 29th, 2008. During the road works the non-shifted direction was northbound from Klaverpolder to 's Gravendeel. The lanes were affected because they were narrowed. A schematic overview of the work zone is shown in figure 50, details of the work zone are shown in table 36.

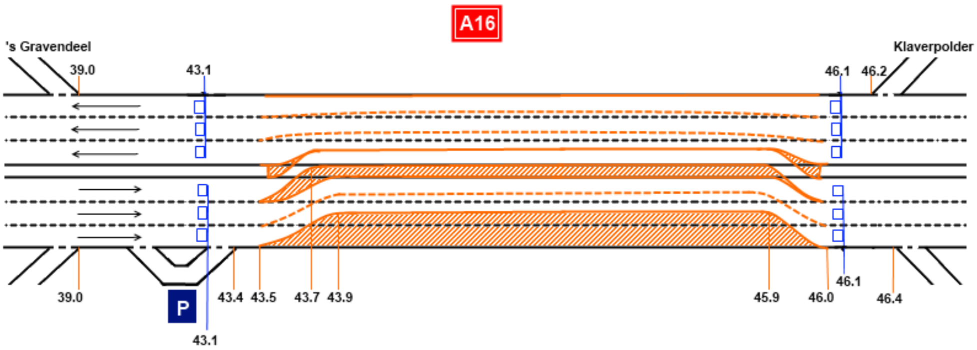
Table36

Work zone details A16 Klaverpolder – 's Gravendeel

Case A16 Klaverpolder – 's Gravendeel	
Percentage of heavy vehicles	12 – 14%
Left lane width	3.25 m
Middle lane width	3.25 m
Right lane width	3.50 m
Distance to ramp upstream	200 m
Distance to ramp downstream	4500 m
Length of work zone	2500 m
Familiarity with congestion in normal peak hour	No
Road gradient	1.5%

Figure50

Schematic trajectory A16 Klaverpolder – 's Gravendeel



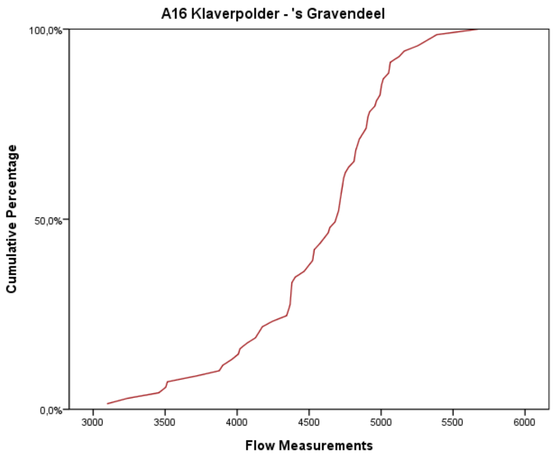
There are 69 measurements that satisfy the collecting restrains for capacity estimation of the non-shifted direction of this work zone. These measurements are plotted in figure 51. The statistics belonging to this plotted distribution are shown in table 37.

Table37

SPSS statistics A16 Klaverpolder – 's Gravendeel

Figure51

Cumulative capacity distribution A16 Klaverpolder – 's Gravendeel



Statistics A16 Klaverpolder – 's Gravendeel	
No. measurements	69
Mean	4563.65
Median	4704
Standard deviation	513.442

Wilcoxon signed rank test Test: median = 4500	0.085 Retain
Wilcoxon signed rank test Test: median = 6300	0.000 Reject

The capacity of this direction for this work zone is 4704 veh/h. This is a significant difference of -1596 veh/h (-25.3%) compared to the standard capacity of a three lane freeway. The difference between the calculated capacity of the non-shifted direction of this work zone and the guideline is +204 veh/h (+4.5%), this difference is not significant. This means that the capacity of this direction does not differ from the guideline of the CIA handbook.

4.9 SENSITIVITY ANALYSIS ON ESTIMATED CAPACITIES

The capacities that are estimated in the previous paragraphs are all estimated with the Empirical Distribution Method (EDM). This method estimates the capacity flow on a road section. As stated in chapter 2, the capacity flow is leading for estimating the capacity at bottlenecks where often congestion occurs. In this chapter the assumption is made that work zones are the bottleneck of a road section, and thus the capacity flow is leading for estimating the capacity.

The dispersion of the estimated capacities compared to the CIA guideline for work zones is very high. The high dispersion is mostly found at locations with a low number of capacity measurements and is not always is line with what can be expected regarding the traffic influencing aspects of the location. A low number of capacity measurements means that the bottleneck is not often active and the estimated capacity with the EDM is maybe not the real capacity of the work zone. Therefore, in this paragraph a sensitivity analysis that is conduct on the estimated capacities is described.

Minderhoud, Botma, & Bovy(1996)state that the Product Limit Method (PLM) is the best method for estimating the capacities is situations without bottlenecks that are often active. Therefore the PLM is also used for estimating the capacity of the work zones. The difference between the capacities estimated with the PLM and EDM are analyzed. The sensitivity analysis focuses on work zones with a low number of measurements, because it is possible that the EDM is not the best method for capacity estimating with a low number of capacity measurements. A low number of measurements for a work zone is defined as less than 100 capacity measurements.

In appendix 7 the estimated capacities of all work zones with both methods is shown. This is summarized in table 38 below together with the expected influence of the traffic related aspects of the work zone with reference to the CIA guideline.The thick line represents the separation between the work zones with a low (above) and a high (beneath) number of capacity measurements.

Table38

Estimated capacities EDM and PLM

Location	Capacity EDM	Capacity PLM	rel.diff. EDM w. CIA work zone	rel.diff. PLM w. CIA work zone	Expected influence (--,-,0,+,++)
A2 Roosteren – Echt	3048	3552	-15,3%	-1,3%	- -
A12 Zevenhuizen – Gouwe	3018	2892	-5,7%	-9,6%	0
A7 Zaandijk – Zaandam	3030	3132	-15,8%	-13,0%	0
A28 Hattemerbroek – Zwolle Zuid	4896	4740	8,8%	5,3%	0
A12 Zoetermeer Centrum – Nootdorp	4518	4788	0,4%	6,4%	0
A2 Kerkdriel – Empel	2868	2892	-4,4%	-3,6%	+
A2 Lage Weide – Utrecht Centrum	5292	5544	17,6%	23,2%	+
A16 ‘s Gravendeel – Klaverpolder	3576	3528	-16,8%	-18,0%	- -
A16 Klaverpolder – ‘s Gravendeel	4704	4590	4,5%	2,0%	+
A12 Zevenhuizen – Zoetermeer	3366	3480	-1,0%	2,4%	+
A28 Zwolle Zuid – Hattemerbroek	4080	3840	-5,1%	-10,7%	-
A2 Zaltbommel – Kerkdriel	3516	3516	3,4%	3,4%	+
A58 Batadorp – Oirschot	3636	3408	1,0%	-5,3%	+
A9 Uitgeest – Alkmaar	3744	3612	17,0%	12,9%	+ +
A50 Heteren – Renkum	3105	2952	-8,6%	-13,2%	-
A12 Zoetermeer – Zevenhuizen	3660	3540	7,6%	4,1%	+

For analyzing the sensitivity of the estimated capacities, it is interesting to look at is the difference between the estimated capacities of the EDM and the PLM compared to the CIA guidelines, these differences are big for both methods. To see which method gives a better estimation of the capacity, the relative difference with the CIA guideline for the specific work zone is analyzed with respect to the expected effect of the situation-specific variables of that work zone derived from the literature and thus with respect to the traffic influencing aspects of the work zone. The situation-specific variables can be found in appendix 8.

For work zones with a high number of capacity measurements the capacities estimated with EDM give better estimations when respecting the influence of the traffic related aspects of the work zone. The dispersion when comparing the estimated capacity to the CIA guideline values is about the same for both methods. Hence, this sensitivity analysis shows that for work zones with a high number of capacity measurements the EDM is the better method for estimating capacity.

For work zones with a low number of measurements both methods are equal when analyzing the difference between the estimated capacities and the CIA guideline value with respect to the influence of the traffic related aspects of the work zone. About half of the capacity estimations are better when using the EDM and logically the same applies for the PLM. The dispersion when comparing the estimated capacity to the CIA guideline values is also about the same for both methods. Thus, for work zones with a low number of capacity measurements the capacities estimated with the PLM are not better than the capacities estimated with the EDM.

From this sensitivity analysis on estimated capacities can be concluded that the dispersion of the estimated capacities is caused by the work zones themself. The dispersion of the estimated capacities found in the previous paragraphs is not attributable to the used method for capacity estimation when looking at the expected influence of traffic related aspects of a work zone. The sensitivity analysis showed that the EDM is a better method for estimating capacity for work zones than the PLM. For work zones with a high number of capacity measurements the EDM method is better and for work zones with a low number of capacity measurements both methods are equal when respecting the influence of the traffic related aspects of the work zone. Hence, the dispersion of the estimated capacities found in the previous paragraphs is not attributable to the used method for capacity estimation.

4.10 CONCLUSIONS

The estimation of capacity of the different work zones in this chapter showed some interesting results. The estimated capacities together with the decrease compared to the standard capacity of a two or three lane freeway and the difference with the CIA guideline for the corresponding type of work zone is shown in table 39.

Table39

Capacities of work zones

Location	Work zone lay-out	Capacity	Relative difference with CIA work zone	Relative difference with CIA standard
A9 Uitgeest – Alkmaar	Lane narrow.2 lane	3744	+17,0%	-10,9%
A12 Zoetermeer – Zevenhuizen	4 – 0 shifted	3660	+7,7%	-12,9%
A58 Batadorp – Oirschot	Clos. hard shoulder	3636	+1,0%	-13,4%
A2 Lage Weide – Utrecht Centrum	Lane narrow.3 lane	5292	+17,6%	-16,0%
A2 Zaltbommel – Kerkdriel	4 – 0 shifted	3516	+3,4%	-16,3%
A12 Zevenhuizen – Zoetermeer	4 – 0 non-shifted	3366	-1,0%	-19,9%
A28 Hattemerbroek – Zwolle Zuid	4 – 2 non-shifted	4896	+8,8%	-22,3%
A15 Klaverpolder – 's Gravendeel	4 – 2 non-shifted	4704	+4,5%	-25,3%
A50 Heteren – Renkum	3 – 1 non-shifted	3105	-8,7%	-26,1%
A2 Roosteren – Echt	Clos. hard shoulder	3048	-15,3%	-27,4%
A7 Zaandijk – Zaandam	Clos. hard shoulder	3030	-15,8%	-27,9%
A12 Zevenhuizen – Gouwe	Lane narrow.2 lane	3018	-5,7%	-28,1%
A12 Zoetermeer Centrum – Nootdorp	Lane narrow.3 lane	4518	+0,4%	-28,3%
A2 Kerkdriel – Empel	3 – 1 shifted	2868	-4,4%	-31,7%
A50 Renkum – Heteren	3 – 1 shifted	2724	-9,2%	-35,1%
A28 Zwolle Zuid – Hattemerbroek	4 – 2 shifted	4080	-5,1%	-35,2%
A16 's Gravendeel – Klaverpolder	4 – 2 shifted	3576	-16,8%	-43,2%

The work zone lay-out with the biggest decreases in capacity is the shifted direction of the 4 – 2 lane shift system. The decreases in capacity are 35.2% and 43.2% compared to the standard capacity of a three lane freeway. The shifted direction of the 3 – 1 lane shift system has the second biggest decrease in capacity. Compared to the standard capacity of a two lane freeway the cases of this work zone lay-out show decreases in capacity of 35.1% and 31.7%. The relative difference of these work zone lay-outs is much higher than the other work zones. The differences of the other work zones range between 10.9% and 28.3%.

The difference between the 3 – 1 and 4 – 2 systems on one hand and the other work zone lay-outs on the other hand is tested on significance. The T-Test gives a significance value of 0.1% (see appendix 6), which is below the confidence level of 5% and thus can be stated that the difference in decrease in capacity between these two lay-outs and all other lay-outs is significant. This means that the decrease in capacity of the 3 – 1 and 4 – 2 lane shift systems is bigger than for other systems. The only thing that both work zones differentiate from the others is that the lanes of these two work zone lay-outs are split. Thus the conclusion that can be drawn is that the capacity of work zones with split lanes is lower than the capacity of work zones where the lanes are not split.

The estimated capacities of the work zones show great dispersion. Because of this great dispersion, no other conclusion can be drawn on differences of decrease in capacity between work zone lay-outs. But, what can be concluded is that the estimated capacities differ a lot from the guidelines for capacity of the CIA handbook, which is shown by the great dispersion between the cases of the work zone lay-outs. Only four of the seventeen estimated capacities are not significantly different from the guideline from the CIA handbook. The others are significant different from the CIA handbook guideline and these differences range between -17% and +18%. There is great variation possible in work zone capacity, also between work zones with the same lay-out.

From a sensitivity analysis on estimated capacities can be concluded that the dispersion of the estimated capacities is caused by the work zones themself. The dispersion of the estimated capacities is not attributable to the used method for capacity estimation when looking at the expected influence of traffic related aspects of a work zone. The sensitivity analysis showed that the Empirical Distribution Method is a better method for estimating capacity for work zones than the Product Limit Method. For work zones with a high number of capacity measurements the Empirical DistributionMethod is a better method and for work zones with a low number of capacity measurements both methods are equal when respecting the influence of the traffic related aspects of a work zone. Hence, the dispersion of the estimated capacities found in the research is not attributable to the used method for capacity estimation, but to the work zones themselves.

CHAPTER 5 Analysis of Differences

In the previous chapter the capacities of the different work zones are estimated. It was concluded that there is a great dispersion between the measured capacities.These differences are used in this chapter for the analysis of the effect of the most important situation-specific variables which are obtained from the literature review in chapter 2. For every work zone of which the capacity is estimated, the situation specific variables are listed in appendix 8.

In this chapter the effects of the situation-specific variables are analyzed to get insight in which variables affect work zone capacity. First the situation-specific variables are checked on multicollinearity to see whether variables are highly correlated with each other and some variables should be excluded based on multicollinearity. Then the differences in capacity for work zones in general are analyzed to see which variables have significant influence on work zone capacity. This is done by using the relative difference of the work zone with the CIA guideline for that type of work zone. After that the influence of the situation-specific variables is analyzed for every work zone lay-out separately to see if there are differences per work zone type. As last a goodness of fit analysis of combinations of variables with significant influence is conducted to analyze how powerful the determination of the combinations is.

5.1 MULITCOLLINEARITY

First step in analyzing the influence of the situation-specific variables is to check on multicollinearity. Multicollinearity is a statistical phenomenon in which two or more predictor variables in a multiple regression model are highly correlated. Multicollinearity does not reduce the predictive power or reliability of the model as a whole, within the sample data themselves; it only affects calculations regarding individual predictors. Multicollinearity is difficult to determine, but high values (close to 1 and -1) in the correlation matrix indicate this.A correlation coefficiënt higher than 0.8 indicates multicollinearity (Siemerink, 2011).

In table 40 the correlation matrix for all situation-specific variables in this analysis is shown.

Table40

Correlation matrix

	%heavy vehicles	Width left lane	Width mid. l.	Width right l.	Cl. ramp upstream	Cl. ramp downstr.	Work z. length	Road grade	Congest. fam.
% heavy veh.	1	0.198	0.132	0.138	0.009	0.220	-0.308	-0.201	-0.262
Width left lane	-	1	0.920	0.748	-0.042	-0.192	-0.543	-0.353	-0.488
Width mid. La.	-	-	1	0.576	-0.027	-0.731	0.165	0.053	n/a
Width right la.	-	-	-	1	0.157	-0.161	-0.588	-0.428	-0.372
Ramp upstr.	-	-	-	-	1	0.346	0.445	0.096	0.314
Ramp downst.	-	-	-	-	-	1	0.277	-0.190	-0.010
Work z. length	-	-	-	-	-	-	1	0.219	0.539
Road grade	-	-	-	-	-	-	-	1	0.292
Congest. fam.	-	-	-	-	-	-	-	-	1

As shown in the table, there are only two variables that are highly correlated with each other; the width of the left lane and the width of the middle lane. Between these two variables there exists multicollinearity and therefore one of the two should be excluded from the analysis. In this case, it is logical to exclude the middle lane width from the analysis because that variable is not present in most of the work zones.

5.2 WORK ZONES IN GENERAL

For every moment during the measurement period in which congestion occurred, the actual capacity is estimated together with the situation specific variables belonging to that moment. In this way the real capacity of that moment is estimated and more capacity estimates are made per work zone. In this manner the value of some situation-specific variables is more reliable and thus the results of the analysis are more reliable. With the capacities estimated per congestion moment the relative difference in capacity compared to the CIA guideline can be estimated. Using this means that all systems can be compared to each other. In this way, the effect of the different situation-specific variables can be estimated for work zones in general.

With allsituation-specific variables a multiple regression analysis is executed using SPSS to see which of the variables have significant influence on the relative difference between the CIA guideline for capacity and the estimated capacities from the work zones.The results of this regression analysis are shown in appendix 9 and summarized in table 41. The B-value represents the regression coefficient for the specific variable. The Sig.-value is the chance that the variable is not significant for estimating the capacity. The R^2 is the correlation coefficient which tells how well the model explains the variance in capacity.

The variable middle lane width is excluded based on multicollinearity. Both other lane widths and the road gradient are excluded from the analysis because the calculated effect is not in line with what can be expected according to the literature. Congestion familiarity is excluded because the influence is not significant.

Table41
Multiple linear regression output for work zones in general

Multiple linear regression model R^2 = 0.375		
Variable	**B**	**Sig.**
(Constant)	10.695	0.000
Percentage of heavy vehicles	-0.777	0.000
Nearby ramp upstream (≤ 500 m)	-6.609	0.002
Nearby ramp downstream (≤ 500 m)	-8.183	0.000
Length of work zone	0.002	0.000

The variables, percentage of heavy vehicles, the presence of a nearby ramp upstream and downstream and the work zone length do all affect the relative difference in capacity. The effect of the work zone length is positive, which means that if the work zone is longer, the capacity is higher. The other variables affect the capacity negatively, that means that if there is a ramp nearby (upstream or downstream) the capacity is lower and if the percentage of heavy vehicles is higher the capacity is also lower. The coefficient of determination (R^2) of this general model is 0.375, which means that these variables together explain 37.5% of the variance in relative capacity for work zones in general.

The equation of the prediction model, which is composed from the results from the regression analysis, is as follows:

$$Y = 10.695 - 0.777 * X_{phv} - 6.609 * X_{nru} - 8.183 * X_{nrd} + 0.002 * X_{lwz}$$

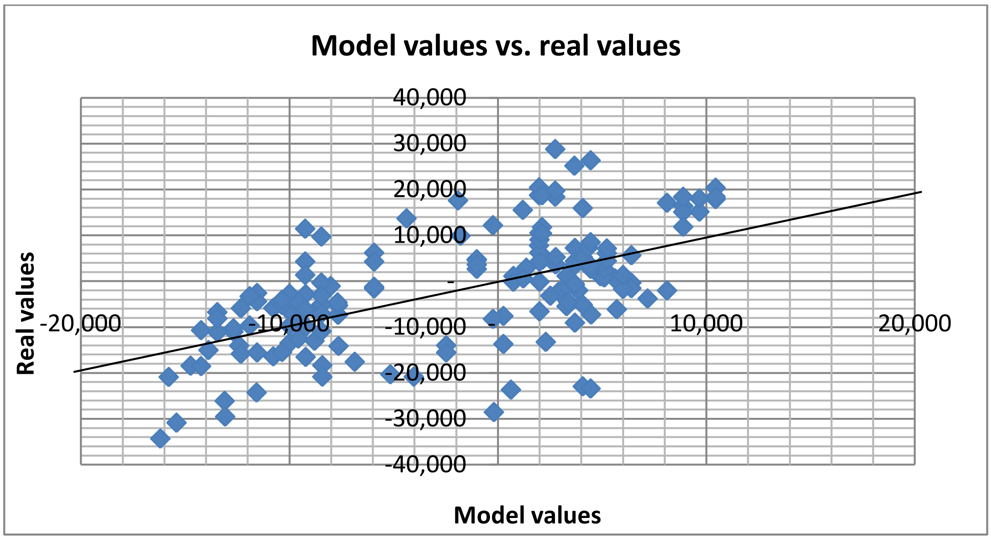
Whereby:

Y = Relative difference in capacity compared to CIA guideline (in %)
X_{phv} = Percentage of heavy vehicles
X_{nru} = Presence of nearby ramp upstream
X_{nrd} = Presence of nearby ramp downstream
X_{lwz} = Length of work zone in meters

In figure 52 a plot is shown with the model values for capacity compared to the real values for capacity. The model equation is plotted by the line. The scatter is fairly high, which is also shown by the models coefficient of determination of 0.375. Nevertheless, although these variables do not explain everything, the tendency of the effect of these variables is clearly shown in the figure.

Figure52

Model values versus real values for work zones in general



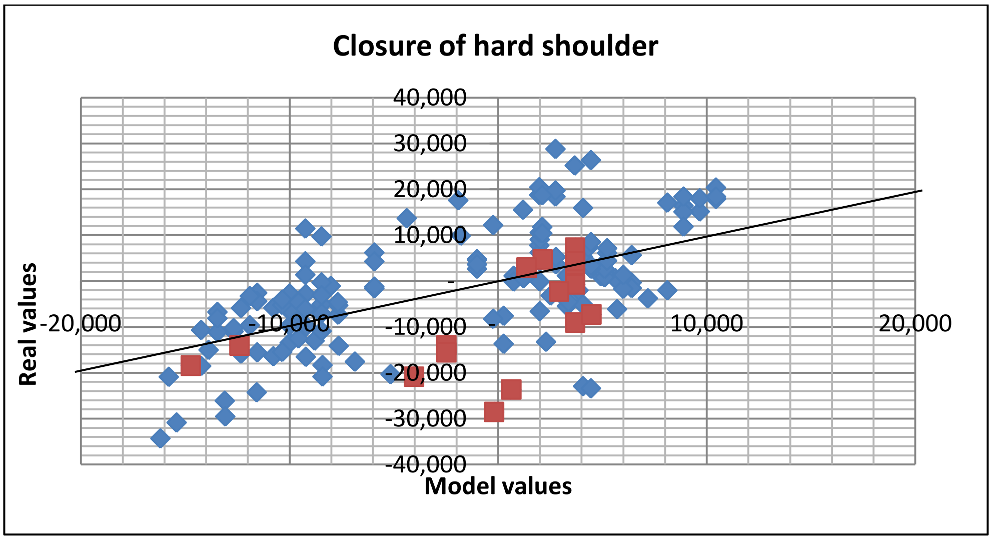
The analysis of the different systems one by one to explain the variance in this general model and the over- and/or underestimation of this model per system is described next. This is done by checking the distribution of the work zone type on difference with the general model. If this difference is significant, a linear regression analysis is executed to find differences with the model for work zones in general.

5.3 CLOSURE OF HARD SHOULDER

The red dots in figure 53 represent the relative difference between with the CIA guideline and the capacity of the cases where the hard shoulder is closed.As shown, most of the measurements for this system are located beneath the model line. A test showed that this difference is significant(see appendix 9), which means that the model for work zones in general slightly overestimates the effects of the variables heavy vehicles, nearness of ramps and the work zone length for the cases of this system.

Figure53

Model values versus real values for closure of hard shoulder



To explain the differences between the effects of the variables on general work zones and on this system, again a multiple linear regression analysis is executed for the cases of this system only. The results are shown in appendix 9 and are summarized in table 42. The lane width variables and congestion familiarity are equal for all measurements and therefore are not part of this analysis. Road gradient is excluded because the effect is not in line with what can be expected from the literature and the variables nearby ramp upstream and work zone length show no significant influence.

Table42

Multiple linear regression output for closure of hard shoulder

Multiple linear regression model R^2 = 0.510		
Variable	**B**	**Sig.**
(Constant)	8.702	0.117
Percentage of heavy vehicles	-1.103	0.030
Nearby ramp downstream (≤ 500 m)	-17.842	0.005

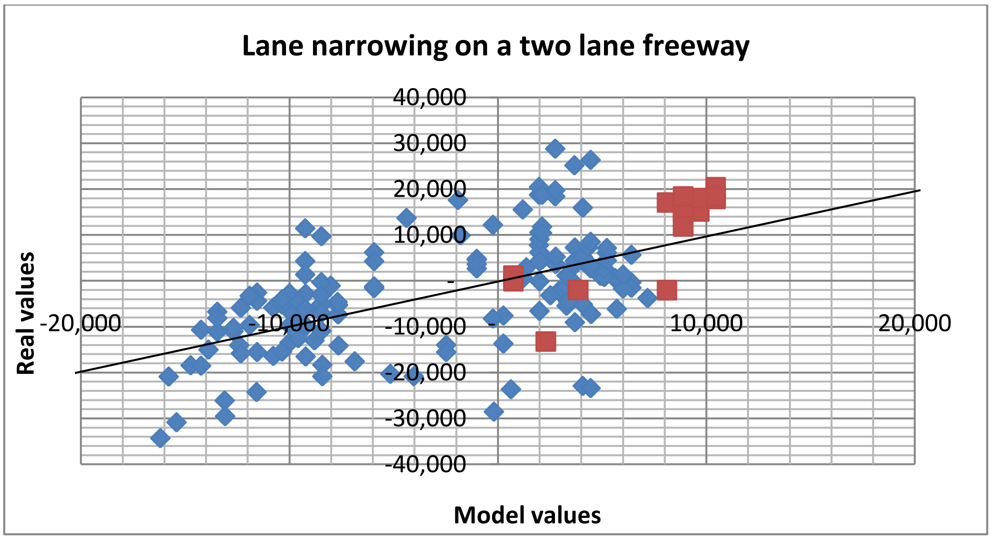
This prediction model shows that the variable percentage of heavy vehicles and the variable nearby ramp downstream are the only variables that have significant influence on the differences in capacity. Compared to the model for work zones in general the variable nearby ramp upstream and the variable work zone length have no significant influence, which is probably caused by the low number of measurements. The overestimation by the model for work zones in general can be attributed to the degree of effect of the variables, because both variables have a bigger influence on capacity. The coefficient of determination is 0.510, so about half of the variance is explained.

5.4 LANE NARROWING ON A TWO LANE FREEWAY

The red dots in figure 54 represent the relative difference between the CIA guideline and the capacity of the cases on a two lane freeway where the lanes are narrowed.As shown, most of the measurements for this system are located in a group above the model line and some measurements are located beneath the model line. A test on significanceshowed that the measurements of this type of work zone are not different from the model for work zones in general (see appendix 9).

Figure54

Model values versus real values for lane narrowing on a two lane freeway

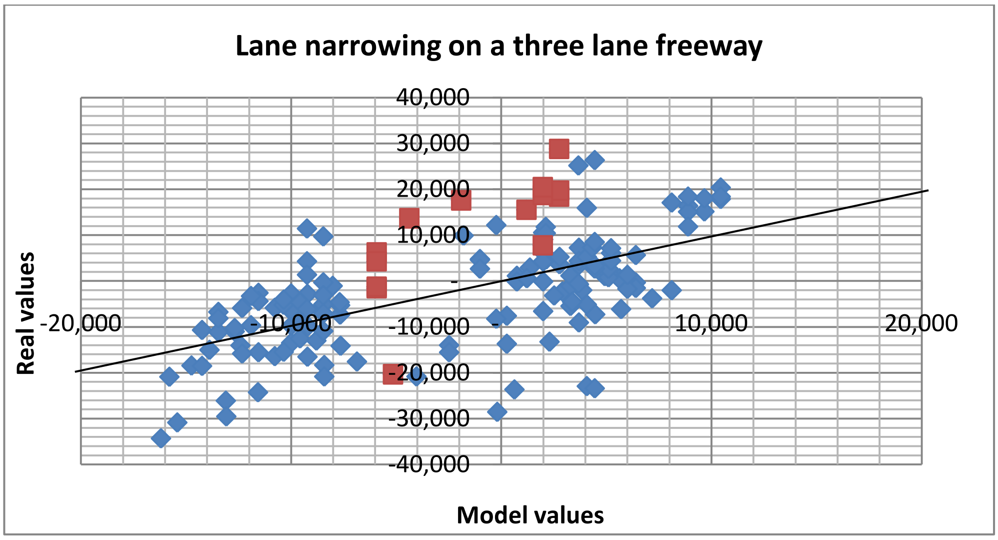


5.5 LANE NARROWING ON A THREE LANE FREEWAY

In figure 55 red dots are plotted that represent the relative difference between the CIA guideline and the capacity of the cases of a three lane freeway with narrowed lanes. Almost all measurements for this system are located above the model line. A test showed that this difference is significant(see appendix 9), which means that the model for work zones in general slightly underestimates the effects of the variables percentage of heavy vehicles, nearness of ramps and the work zone length for the cases of this system.

Figure55

Model values versus real values for lane narrowing on a three lane freeway



The results of the multiple linear regression analysis for this system only are shown in appendix 9 and are summarized in table 43. Road gradient and congestion familiarity showed no difference between the measurements and therefore are excluded. Other excluded variables based on significance are all lane widths, percentage of heavy vehicles, work zone length and nearby ramp upstream. The only variable with significant influence and thus the only variable in the model for this system is nearby ramp downstream.

Table43

Multiple linear regression output for lane narrowing on a three lane freeway

Multiple linear regression model R^2 = 0.559		
Variable	**B**	**Sig.**
(Constant)	18.381	0.000
Nearby ramp downstream (≤ 500 m)	-18.215	0.002

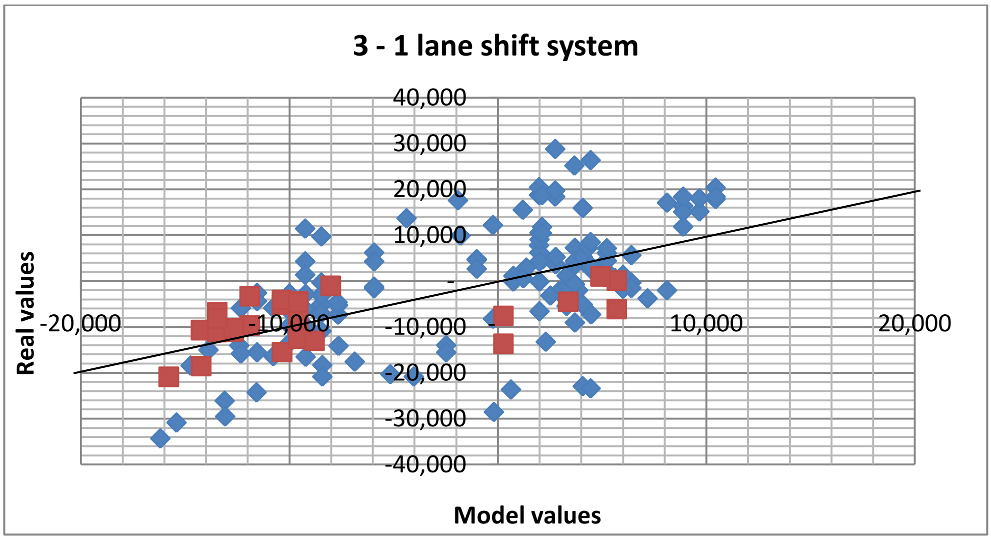
The only variable with significant influence in the model for this system is nearby ramp downstream. The coefficient of determination is 0.559, so the model explains about half of the variance in capacities. The difference with the model for work zones in general is the absence of the variables nearby ramp upstream, work zone length and the percentage of heavy vehicles because of insignificance and the degree of effect of the presence of nearby ramp downstream. The predictor is fairly constant (present or absent) and thus is the capacity also fairly constant, which makes the model not very plausible, this is probably caused by the low number of measurements.

5.6 3-1 LANE SHIFT SYSTEM

The red dots in figure 56 represent the relative difference between with the CIA guideline and the capacity of the cases of the 3-1 lane shift system. It looks like the measurements of this system are all in line with the model for general work zones. A test on significance showed that the measurements of this type of work zone are not different from the model for work zones in general (see appendix 9).

Figure56

Model values versus real values for 3 – 1 lane shift system

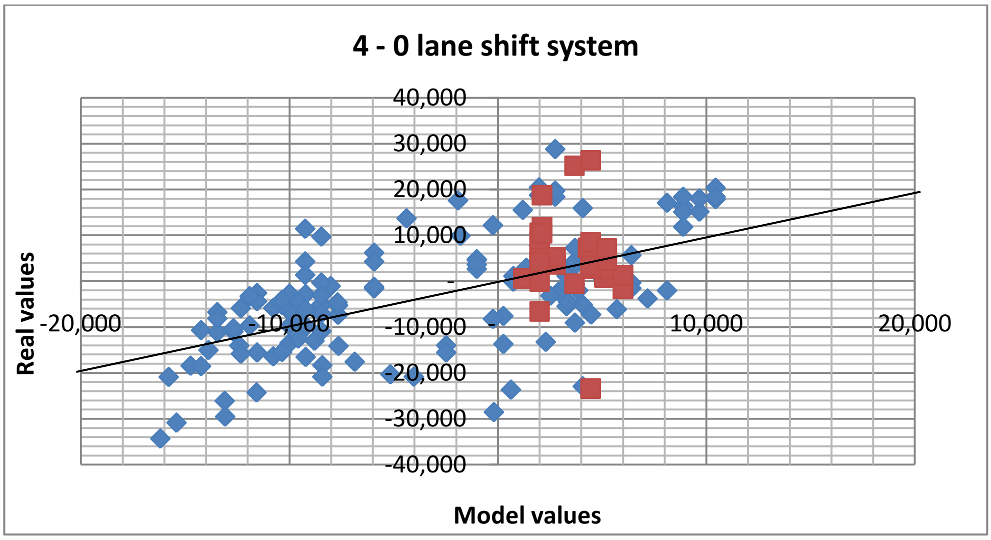


5.7 4 – 0 LANE SHIFT SYSTEM

In figure 57 the red dots represent the relative difference between with the CIA guideline and the capacity of the cases with a 4-0 lane shift system. Most of the measurements of this system are grouped around the line of the model for work zones in general. There is no sign of overestimation or underestimation by the model for work zones in general for the cases in this system. A test on significance showed that the measurements of this type of work zone are not different from the model for work zones in general (see appendix 9).

Figure57

Model values versus real values for 4 – 0 lane shift system

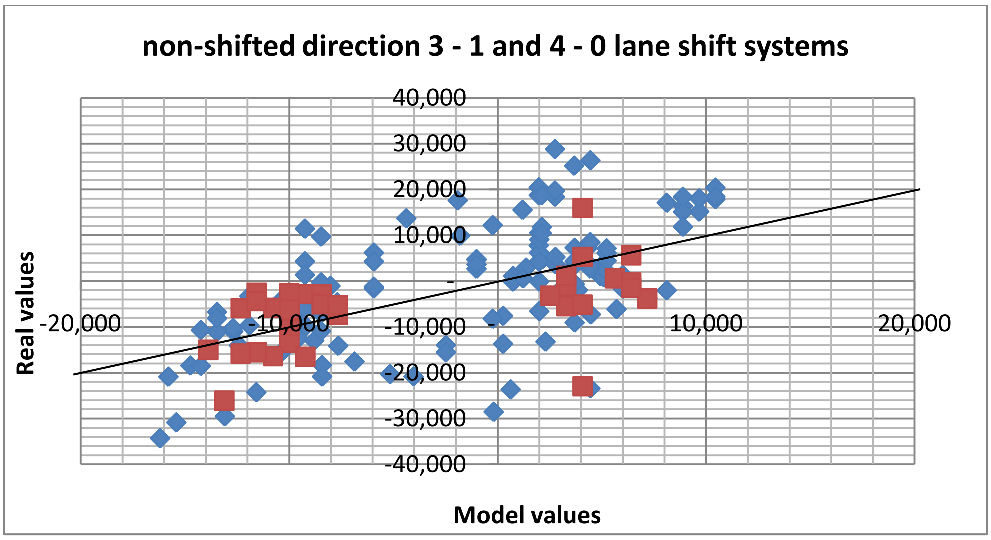


5.8 NON-SHIFTED DIRECTION OF 3 – 1 AND 4 – 0 LANE SHIFT SYSTEMS

The red dots in figure 58 represent the relative difference between the CIA guideline and the capacity of the cases of the non-shifted direction of the 3-1 and 4 - 0 lane shift systems. It looks like most measurements of this system are in line with the model for general work zones. A test on significance showed that the measurements of this type of work zone are not different from the model for work zones in general (see appendix 9).

Figure58

Model values versus real values for non-shifted 3 – 1 and 4 – 0 lane shift systems

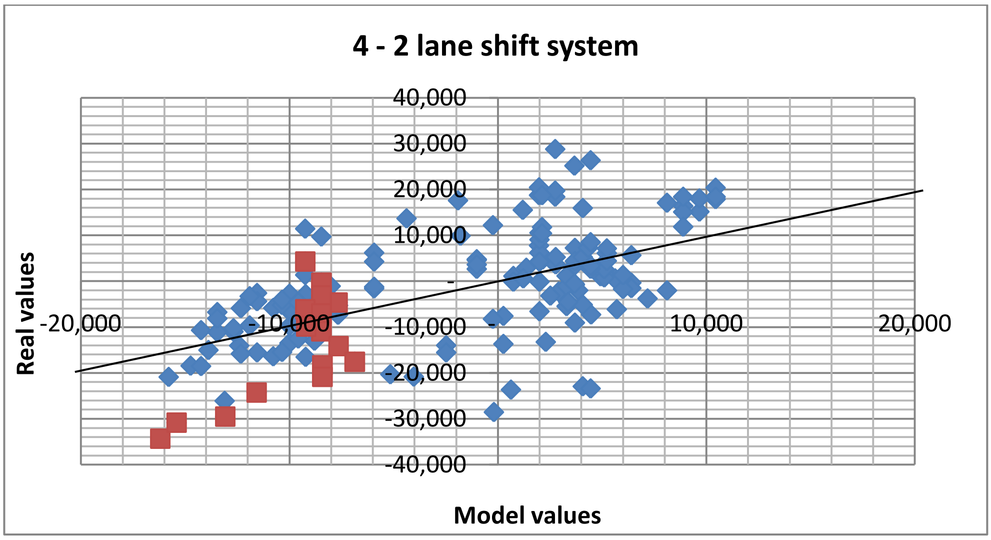


5.9 4 – 2 LANE SHIFT SYSTEM

The red dots in figure 59 represent the relative difference between the CIA guideline and the capacity of the cases of the 4 – 2 lane shift system. Most of the measurements for this system are located beneath the line of the model for work zones in general, which means that the model slightly overestimates the effects of the variables for the cases of this system. A test on significance showed that the measurements of this type of work zone are not different from the model for work zones in general (see appendix 9).

Figure59

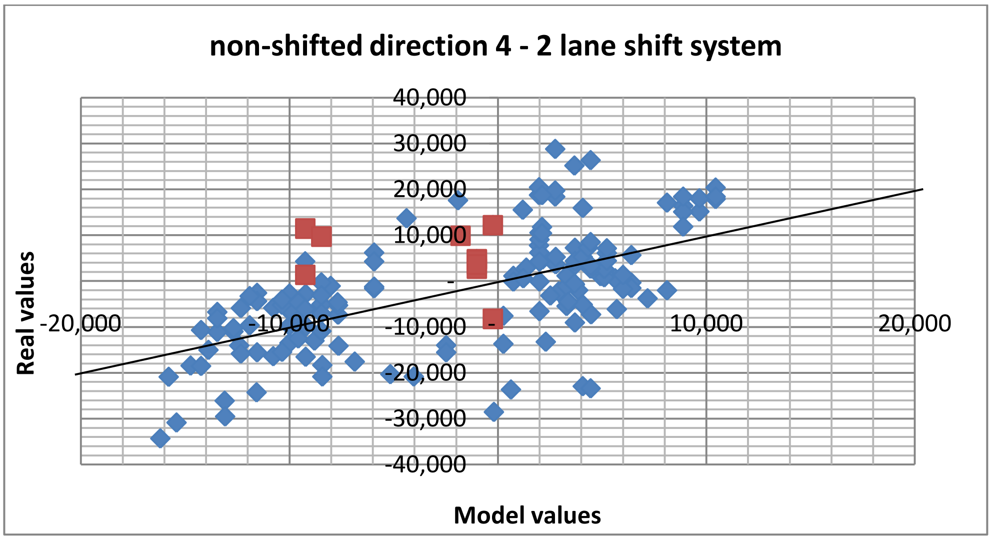
Model values versus real values for 4 – 2 lane shift system



5.10 NON-SHIFTED DIRECTION 4 – 2 LANE SHIFT SYSTEM

The red dots in figure 60 represent the relative difference between the CIA guideline and the capacity of the cases of the non-shifted direction of the 4 – 2 lane shift system. Almost all measurements for this system are located above the model line. A test showed that this difference is significant(see appendix 9), which means that the model for work zones in general slightly underestimates the measurements of this type of work zone.

Figure60
Model values versus real values for non-shifted direction 4 – 2 lane shift system



The results of the multiple linear regression of this system only are shown in appendix 9. The variables nearby ramp upstream and congestion familiarity are excluded from the analysis because they demonstrate no difference between the measurements and therefore cannot explain differences in capacity. All other variables are excluded based on insignificance, caused by the low number of measurements. This means that none of the variables can explain the differences in capacity in this system.

5.11 GOODNESS-OF-FIT OF COMBINATIONS OF VARIABLES

In the analysis per system not all variables with significant influence from the model for work zones in general were present. In fact, only the variables heavy vehicles and nearby ramp downstream have significant influence in the analysis per system. The presumption arose that maybe not all four variables are of equal importance for the prediction model for work zones in general. Therefore combinations of these four variables will be analyzed on goodness of fit. This is done to test if the explaining power of combinations of variables is very high or very little. The coefficient of determination (R^2) is used to show the goodness of fit of the different combinations of variables. If the coefficient of determination is higher, a bigger part of the variance is explained by the model and thus the fit of the model is better.

In table 44 all combinations of variables from the model for work zones in general are listed together with the coefficient of determination of that combination of variables. The results from the multiple regression analysis can be found in appendix 9.

Table44

Goodness of fit of combinations of variables with significant influence

Combinations of variables	R^2
Heavy vehicles – Nearby ramp upstream – Nearby ramp downstream – Work zone length	0.375
Heavy vehicles – Nearby ramp upstream – Nearby ramp downstream	0.281
Heavy vehicles – Nearby ramp downstream – Work zone length	0.336
Heavy vehicles – Nearby ramp upstream – Work zone length	0.288
Nearby ramp upstream – Nearby ramp downstream – Work zone length	0.323
Heavy vehicles – Nearby ramp upstream	0.230
Heavy vehicles – Nearby ramp downstream	0.274
Heavy vehicles – Work zone length	0.217
Nearby ramp upstream – Nearby ramp downstream	0.136
Nearby ramp upstream – Work zone length	0.177
Nearby ramp downstream – Work zone length	0.275

None of the combinations of variables has a better goodness of fit than the four variables together. The coefficients of determination of the combinations differ from 0.136 to 0.336, and the coefficient of determination for the four variables together is 0.375. The combination with the second best goodness of fit is with the variables heavy vehicles, nearby ramp downstream and work zone length, followed directly by the combination with the variables nearby ramp upstream, nearby ramp downstream and work zone length. But the explaining power for the variance of these combinations is still respectively 3.9% and 5.2% less than the explaining power of the total model.

The prediction model with four variables for work zones in general set up in the first paragraph of this chapter, has the best goodness of fit compared to prediction models with combinations of these variables. The difference between the coefficients of determination is at least 3.9%. The prediction model with all four variables together is thus the best prediction model for differences in capacity.

Because ofthe uncertainty caused by the low coefficient of determination, determining the degree of effect of the variables is not plausible in this research.

5.12 CONCLUSIONS

In the multiple linear regression analysis for work zones in general there is a clear and significant relation found between four situation-specific variables and the relative difference in capacity compared to guidelines from the CIA. These four variables are: the percentage of heavy vehicles, the presence of a nearby ramp upstream, the presence of a nearby ramp downstream and the length of a work zone. The other situation-specific variables, which were obtained from the literature review in chapter 2, do not have a significant or feasible influence on the relative differences in capacity.

Found in the analysis for work zones in general is the negative influence on capacity from an increasing percentage of heavy vehicles.Also the presence of nearby ramps upstream and downstream causes a negative effect on capacity. Nearby is in this case 500 meters or less. For the variable work zone length a positive influence is found in this analysis. This means that a long work zone has a higher capacity than a short work zone. The coefficient of determination of these four variables together is 0.375, which means that these four variables explain 37.5% of the variance in estimated capacities.

The second part of this analysis was estimating the variables that influenced the differences in capacity per work zone system. From this analysis the conclusion can be drawn that in most cases the measurements belonging to a specific work zone system are not significantly different from the model for work zones in general. For two work zone types the percentage of heavy vehicles and the presence of a nearby ramp downstream had a significant influence on the differences in capacity. The degree of influence of these variables changed per system, but the coefficient of determination and the number of measurements was also quite low in both work zone types, thus drawing a conclusion on the degree of influence per system is not feasible. The absence of the other variables can most of the times be addressed to insignificance caused by the low number of cases per work zone system.

The goodness of fit analysis showed that the four situation-specific variables with significant influence on work zone capacity are all important for explaining differences in estimated capacities and together these variables explain the most of the variance. The coefficient of determination of these four variables together is 0.375, which means that these four variables explain 37.5% of the variance in estimated capacities. Thus there can be concluded that these four variables explain a considerable part of the variance in capacity, but the majority of the variance is explained by other influences than the distinguished situation-specific variables of this research.

Other influencing factors can probably be found in more driver related factors, for example the distraction by work activities or the distraction due to a changed environment. Also comparing different situations in non-controllable environments with each other causes some uncertainties and part of the noise in this analysis can be addressed to that.

CHAPTER

6 Effects of External Variables

External variables are variables that are not part of the work zone environment and thus can be excluded by using proper data to ensure good comparison between estimated capacities. These external variables are excluded in the analysis in the previous chapters. Nevertheless, these external variables can have influence on the capacity of work zones. In this chapter the effect of the external variables rain and duration on work zone capacity are analyzed. Due to datarestrictions it was not possible to analyze other external variables.

6.1 EFFECT OF RAIN

The effect of rain on capacity is researched a lot and is logically a negative effect, i.e. in situations with rain the capacity of the road section is lower. Other research found a decrease between 5- 10% in normal situations.In this paragraph the effect of rain on the capacity of work zones is researched, because the effect of rain on work zones can be different from normal situations.

In this research rain is defined as precipitation of 2 mm per hour or more. The capacities in chapter 4 are estimated using dry situations only.These capacities are directly copied to this analysis. From seven of the thirteen cases, the capacity is estimated for situations with rain. In table 45 the capacities of the cases in situations with and without rain are showed. The other five cases are excluded based on the absence of rain in the research period. The capacity estimation and analysis results can be found in appendix 10.

Table45

Effect of rain on capacity

Case	Capacity w/ rain	No. of meas.	Capacity w/o rain	No. of meas.	Relative difference	Sig.
A58 Batadorp - Oirschot	3636	152	3318	18	-8.7%	0.006
A9 Uitgeest – Alkmaar	3744	206	3594	40	-4.0%	0.011
A2 Lage Weide – Utrecht Centrum	5292	53	5172	9	-2.3%	0.150
A12 Zoetermeer Centrum – Nootdorp	4518	34	4728	22	+4.6%	0.567
A50 Renkum – Heteren	2724	560	2562	168	-5.9%	0.000
A2 Zaltbommel - Kerkdriel	3516	128	3216	30	-8.5%	0.000
A16 ′s Gravendeel – Klaverpolder	3576	54	3288	15	-8.1%	0.020

In five of the seven cases the difference between the situations with and without rain is significant. In all these cases the capacity in situations with rain is lower than in situations without rain. The differences in capacity range from -4.0% till -8.7%. The literature review in chapter 2 shows that according to the CIA handbook the effect of rain on capacity in general is between -5% and -10% for moderate to heavy rainfall and this effect is no different for work zones. The results of this analysis are in line with the guidelines of the CIA handbook and thus there is no reason to expect different effects of rain at work zones compared to standard situations.

6.2 EFFECT OF DURATION

The effect of work zones on capacity can change over time, because road users will become more familiar with the situation. The effect of the duration of work zones is analyzed by comparing the capacity at the work zone in the first month with the capacity of the work zone in the second third month. The analysis for the second month is done with six work zones and the analysis for the third month is done with four work zones.

The capacities in the first month are estimated in the chapter 4. The statistics of the estimated capacities of month two and three are shown in appendix 11. All these capacity estimations are shown in table 46. In the table also the relative difference and the significance of the difference are shown. The difference is regarded significant if the significance value of the difference is lower than the confidence level of 5%.

Table46

Effect of duration on capacity

Case	Capacity month 1	No. of meas.	Capacity month 2	No. of meas.	Relative difference	Sig.
A9 Zaandijk – Zaandam	3030	18	3036	31	+0.2%	0.851
A9 Alkmaar - Uitgeest	3744	206	3564	33	- 4.8%	0.000
A2 Lage Weide – Utrecht Centrum	5292	53	5226	86	- 1.2%	0.583
A12 Zoetermeer Centrum – Nootdorp	4518	34	4458	30	- 1.3%	0.802
A2 Zaltbommel – Kerkdriel	3516	128	3456	123	- 1.7%	0.082
A12 Zoetermeer – Zevenhuizen	3660	259	3576	296	- 2.3%	0.060
Case	**Capacity month 1**	**No. of meas.**	**Capacity month 3**	**No. of meas.**	**Relative difference**	**Sig.**
A9 Zaandijk – Zaandam	3030	18	3084	23	+ 1.8%	0.402
A9 Alkmaar - Uitgeest	3744	206	4056	153	+ 8.3%	0.000
A2 Lage Weide – Utrecht Centrum	5292	53	5544	38	+ 4.8%	0.056
A12 Zoetermeer Centrum – Nootdorp	4518	34	-	-	-	-
A2 Zaltbommel – Kerkdriel	3516	128	3588	96	+ 2.0%	0.002
A12 Zoetermeer – Zevenhuizen	3660	259	-	-	-	-

The estimated capacities in the second month show that one case has a significant decrease in capacity, in the other five cases the differences cannot be regarded as significant. The decrease in capacity in that particular case is probably due to other influences than the duration of the work zone, because the effect of duration on work zones tends to be positive, see also the literature review in chapter 2. For five of the six cases in this analysis the capacities are not significantly different and that means that the capacities do not change in the second month compared to the first month. The conclusion can be drawn that in almost all cases, i.e. 83.3%, the capacity does not change in the second month.

In the analysis for the third month there can be seen that two of the cases show an increase in capacity of +2.0% and +8.3%. The other two cases show no significant increase in capacity. Thus in 50% of the cases in this analysis the capacity increases after more than two months, the other 50% show no significant difference in capacity. It looks like that in the third month the expected effect of duration is shown, but it goes a bit far to draw this conclusion from an analysis of four cases from which two show no significant difference.

This analysis of the effect of duration on work zone capacity shows no clear results. After one month almost all cases show no significant difference, one case shows a decrease in capacity. After two months half of the cases show an increase in capacity, but the other half of the cases show no significant difference. Thus a clear conclusion on the effect of duration cannot be drawn from this analysis; more research is needed.

CHAPTER 7 Conclusions and Recommendations

In this chapter the conclusions that are found in this research paper are written down. The main goal of the research was to gain more insight in freeway work zone capacity in the Netherlands. This main goal was split up in three objectives. The first objective of this research was to estimate the (decrease in) capacity of different work zone lay-outs in the Netherlands. The second objective was the analysis on situation specific variables that affect work zone capacity to explain differences in the estimated capacities. The third objective of this research was to analyze the effect of external variables.

The first section of this chapter contains the findings of the capacity estimation. The second section gives the most important findings from the analysis on the differences between these capacity estimations. In the third section the findings on the effects of external variables are described. Based on the findings in this research recommendations for future research and recommendations for traffic engineers working with traffic flows in freeway works zones in the Netherlands are presented in the last section.

7.1 MAIN FINDINGS OF CAPACITY ESTIMATION

The results of the capacity estimation show that work zone capacity differs a lot. In table 47 these results are shown. The decrease in capacity caused by work zones differs from 11% to 43% compared to the standard capacity of a freeway. The biggest decrease can be found by work zones with the 3 – 1 and the 4 – 2 lane shift system, which are, in respective order, -31.7% and -35.1%, and -35.2% and -43.2%. The other work zone lay-outs show decreases between 11% and 28%.

The relative decrease in capacity of the 3- 1 and the 4 – 2 lane shift system is significantly bigger than the other work zones and the only thing that both work zones differentiate from the others is that the lanes of these two work zone lay-outs are split. Thus, from this can be concluded that the capacity of work zones with split lanes is lower than the capacity of work zones where the lanes are not split.

THE CAPACITY OF WORK ZONES WITH SPLIT LANES IS SIGNIFICANTLY LOWER THAN THE CAPACITY OF OTHER WORK ZONES.

Table47

Capacities of work zones

Location	Work zone lay-out	Capacity	Relative difference with CIA work zone	Relative difference with CIA standard
A9 Uitgeest – Alkmaar	Lane narrow.2 lane	3744	+17,0%	-10,9%
A12 Zoetermeer – Zevenhuizen	4 – 0 shifted	3660	+7,7%	-12,9%
A58 Batadorp – Oirschot	Clos. hard shoulder	3636	+1,0%	-13,4%
A2 Lage Weide – Utrecht Centrum	Lane narrow.3 lane	5292	+17,6%	-16,0%
A2 Zaltbommel – Kerkdriel	4 – 0 shifted	3516	+3,4%	-16,3%
A12 Zevenhuizen – Zoetermeer	4 – 0 non-shifted	3366	-1,0%	-19,9%
A28 Hattemerbroek – Zwolle Zuid	4 – 2 non-shifted	4896	+8,8%	-22,3%
A15 Klaverpolder – 's Gravendeel	4 – 2 non-shifted	4704	+4,5%	-25,3%
A50 Heteren – Renkum	3 – 1 non-shifted	3105	-8,7%	-26,1%
A2 Roosteren – Echt	Clos. hard shoulder	3048	-15,3%	-27,4%
A7 Zaandijk – Zaandam	Clos. hard shoulder	3030	-15,8%	-27,9%
A12 Zevenhuizen – Gouwe	Lane narrow.2 lane	3018	-5,7%	-28,1%
A12 Zoetermeer Centrum – Nootdorp	Lane narrow.3 lane	4518	+0,4%	-28,3%
A2 Kerkdriel – Empel	3 – 1 shifted	2868	-4,4%	-31,7%
A50 Renkum – Heteren	3 – 1 shifted	2724	-9,2%	-35,1%
A28 Zwolle Zuid – Hattemerbroek	4 – 2 shifted	4080	-5,1%	-35,2%
A16 's Gravendeel – Klaverpolder	4 – 2 shifted	3576	-16,8%	-43,2%

Another finding is that there is great dispersion between estimated capacities. When comparing the guidelines for capacity of work zones from the CIA handbook and the estimated capacities for the work zones part of this research, this dispersion is very clear shown. Only four of the seventeen estimated capacities are not significantly different from the guideline from the CIA handbook. The others are significant different from the CIA handbook guideline and these differences range between -17% and +18%. There can be concluded that there is great variation possible in work zone capacity. And because of this dispersion no other differences between work zone lay-outs can be found.

THERE IS GREAT VARIATION POSSIBLE IN WORK ZONE CAPACITY, ALSO BETWEEN WORK ZONES WITH THE SAME LAY-OUT. THE DIFFERENCE WITH THE GUIDELINE FROM THE CIA HANDBOOK RANGE BETWEEN -17% AND +18%.

From a sensitivity analysis on estimated capacities can be concluded that the dispersion of the estimated capacities is caused by the work zones themself. The dispersion of the estimated capacities is not attributable to the used method for capacity estimation when looking at the expected influence of traffic related aspects of a work zone. The sensitivity analysis showed that the Empirical Distribution Method is a better method for estimating capacity for work zones than the Product Limit Method. For work zones with a high number of capacity measurements the Empirical DistributionMethod is a better method and for work zones with a low number of capacity measurements both methods are equal when respecting the influence of the traffic related aspects of a work zone. Hence, the dispersion of the estimated capacities found in the research is not attributable to the used method for capacity estimation, but to the work zones themselves.

7.2 MAIN FINDINGS OF ANALYSIS OF DIFFERENCES

The analysis of the differences in estimated capacities showed some interesting findings about which variables have significant influence on capacity of freeway work zones.

The most interesting finding is the significant relation found for work zones in general between four situation-specific variables and the relative difference in capacity compared to guidelines from the CIA handbook. These four variables are: the percentage of heavy vehicles, the presence of a nearby ramp upstream, the presence of a nearby ramp downstream and the length of a work zone. The other situation-specific variables, which were obtained from the literature review in chapter 2, do not have a significant or feasible influence on the relative differences in capacity in the cases of this research. Found in the analysis for work zones in general is the negative influence on capacity from an increasing percentage of heavy vehicles.Also the presence of nearby ramps upstream and downstream causes a negative effect on capacity. For the variable work zone length a positive influence is found in this analysis. This means that a long work zone has a higher capacity than short work zone.

FOUR VARIABLES HAVE SIGNIFICANT INFLUENCE ON WORK ZONE CAPACITY. THESE ARE: PERCENTAGE OF HEAVY VEHICLES, PRESENCE OF NEARBY RAMP DOWNSTREAM, PRESENCE OF NEARBY RAMP UPSTREAM AND THE LENGTH OF A WORK ZONE.

Another finding of the analysis of the differences between estimated capacities is that there are no peculiarities when looking at the differences in capacity for one work zone system only. From this analysis the conclusion can be drawn that in most cases the measurements belonging to a specific work zone system are not significantly different from the model for work zones in general. For two work zone types the percentage of heavy vehicles and the presence of a nearby ramp downstream had a significant influence on the differences in capacity. The degree of influence of these variables changed per system, but the coefficient of determination and the number of measurements was quite low in both work zone types, thus drawing a conclusion on the degree of influence per system is not feasible. The absence of the other variables can most of the times be addressed to insignificance caused by the low number of cases per work zone system.Hence the conclusion can be drawn that for none of the work zone systems there are other distinguished situation-specific variables with significant influence on capacity than the four that have significant influence on work zones in general.

FOR NONE OF THE WORK ZONE LAY-OUTS THERE ARE OTHER SITUATION-SPECIFIC VARIABLES WITH SIGNIFICANT INFLUENCE ON CAPACITY THAN THE ONES THAT HAVE SIGNIFICANT INFLUENCE ON WORK ZONES IN GENERAL.

The goodness of fit analysis showed that these four variables are all important for explaining differences in estimated capacities and together these variables explain the most of the variance. The coefficient of determination of these four variables together is 0.375, which means that these four variables explain 37.5% of the variance in estimated capacities. Thus there can be concluded that these four variables explain a considerable part of the variance in capacity, but there are also other variables that cause differences in capacities of freeway work zones.

TOGETHER THE FOUR VARIABLES EXPLAIN 37.5% OF THE VARIANCE IN CAPACITY AND ALL FOUR VARIABLES ARE IMPORTANT FOR EXPLAINING DIFFERENCES IN WORK ZONE CAPACITY.

7.3 MAIN FINDINGS OF EFFECTS OF EXTERNAL VARIABLES

The finding of this research on the effect of rain is that rain causes a drop in capacity between 4.0% and 8.7% in the work zones studied in this research. The literature review shows that the effect of rain on capacity in normal situations is between -5% and -10%. The conclusion of this research is that the effect of rain on the capacity of work zones is the same as the effect of rain on capacity in normal situations, there is no reason to assume otherwise.

THE EFFECT OF RAIN ON CAPACITY IS NOT DIFFERENT FOR WORK ZONES COMPARED TO NORMAL SITUATIONS.

The findings of this research on the effects of duration of a work zone on the capacity of that work zone are not clear. After more than one month almost all cases show no significant difference in capacity and after more than two months half of the cases show an increase in capacity and the other half of the cases show no significant difference. Thus a clear conclusion on the effect of duration of a work zone on the capacity of that work zone is not found in this research.

THIS RESEARCH SHOWED NO CLEAR RELATION BETWEEN THE DURATION OF A WORK ZONE AND THE CAPACITY OF THAT WORK ZONE.

7.4 RECOMMENDATIONS

This research shows some major findings on variables that have significant influence on work zone capacity. Nevertheless the variables found in this research explain only 37.5% of the variance in capacity of work zones. This means that there are other variables that affect the capacity of work zones that were in the scope of this research. The presumption is that these are mainly variables that are related to distraction of road users. A recommendation for future research on work zone capacity is to conduct a research that keeps track of the work activities and the changes in perception of road users simultaneously with the changes in capacity of that specific work zone. Because this research was set up after the road works took place, this precise information was not available. For future research it is thus recommended to research the effects of distraction due to work activities and changes in perception of drivers (change in surroundings etc.).

Another recommendation for future research is to conduct the same research again when a lot more work zones have been present. In this way more than two or three cases can be researched per work zone lay-out and maybe the differences between lay-outs can be unraveled better. When more cases can be researched also the difference between the effect on capacity of work zones and normal situations of other external variables can be analyzed. Interesting external variables are for example the effect on work zone capacity of darkness and the effect of sun glare when drivers are facing a low standing sun. Of course, also the effect of duration, for which this research showed ambiguous results, can be researched better when more work zones are part of a research.

A recommendation for traffic engineers working with work zone capacities is to keep in mind that work zone capacities can differ a lot. This research showed differences up to -16.7% and +17.6% when the estimated capacity of a work zone was compared to the guideline for capacity of the CIA handbook. Only four of the seventeen researched cases showed no significant difference with this guideline. This research also showed that 37.5% of the variance in estimated capacities could be explained by commonly used variables, and thus 62.5% of the variance cannot be assigned to the standard variables named in previous research.

CHAPTER 8 Discussion

In every research the choices made are affecting the results. In this chapter some aspects of this research are discussed. Firstly, the location choicesare discussed. After that the assumptions for the set-up of the analysis are discussed.

8.1 LOCATION CHOICES

The division of the work zones over the Netherlands is good. Most work zones are located in or near the Randstad, but also locations in Limburg, Noord-Brabant, Gelderland and Overijssel are part of the research. The location division over the Netherlands could have influence on the results of this research, because maybe people react in another way on work zones in rural areas than in urban areas. If this research contained only work zones located in one of the two areas, the estimated capacity could have been different.

Another topic for discussion is the effect of the chosen locations on the general conclusions of the specific work zone lay-out to which it belongs. Because there are only two or three locations researched per work zone lay-out, the effect of the chosen location can be big. If the work zone has very specific characteristics that influence the capacity and those characteristics are not part of the analysis, it can have influence on the research results. Therefore the recommendation is done for future research on the same topic over a few years. In that way more work zone locations can be part of the research and this noise can be ruled out.

8.2 ASSUMPTIONS

In this research there are also some assumptions made that can influence the results. First assumption to discuss is the chosen speed threshold of 50 km/h for congestion. Brilon & Zurlinden (2003) state that a good speed threshold for capacity estimation lies between 50 km/h and 70 km/h. If chosen for 70 km/h as threshold, there would be more measurements upstream and downstream of the bottleneck that fit the restrains, which can influence the estimated capacities. A speed threshold of 70 km/h is closer to free flow state and thus the estimated capacity can be influenced by free flow measurements. This is especially the case at work zones, because the speed limit is set to 70 km/h or 90 km/h. The effect of another speed limit is that there could be more or less measurements, but the estimated capacity shall not differ a lot. And because the speed threshold is the same for every location, the differences will stay the same.

Another assumption that can be discussed is the chosen time interval of five minutes. A five minute interval provides more measurements that fit the collection restrains than a time interval of ten or fifteen minutes. A disadvantage of a smaller time interval is that measurements are regarded as congestion measurements when there is no real congestion, but speed of some cars drop beneath the speed threshold. Bigger time intervals rule this effect out. The effect on the results of this research is again that measured capacities can differ, but the results of the comparison and analysis is the same because the measuring method is the same for all estimated capacities. Brilon & Zurlinden(2003) state that a time interval of five minutes is best for capacity estimation based on the consideration of number of measurements and the quality of the measurements.

The definition of the peak hours can also be discussed. In this research the peak hours are defined from 6.00 to 10.00 h for the morning peak hour and 15.00 an 19:00 h for the evening peak hour, which is pretty broad. Peak hours can also be defined smaller, for example a two hour range from 7:00 to 9:00 h and 16:00 to 18:00 h. The effect can be that the driver population in the edges of the defined peak hour period of this research differ from the driver population in the middle. The effect on the results of the broad peak hour period as defined in this research is regarded to be quite small. In the outer edges of the period almost none congestion measurements are made, and driver population in these edges is not very different.

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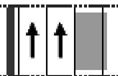
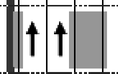
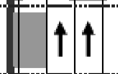
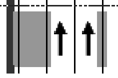
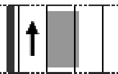
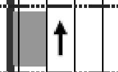
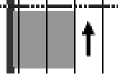
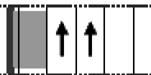
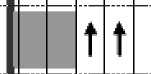
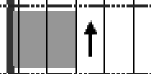
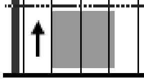
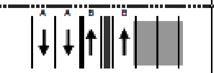
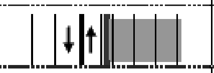
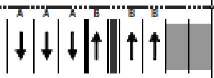
Appendices

ANNEX 1 CIA Capacity for Work Zones

Work zone lay-out	Description	Capacity
	Closure of hard shoulder without lane narrowing (90 km/h)	3600
	Lane narrowing two lanes (70 km/h)	3200
	Closure of left lane with usage of hard shoulder(90 km/h)	3400
	Closure of left lane with usage of hard shoulder and narrowed lanes (70 km/h)	3000
	closure of right lane (90 km/h)	1500
	closure of left lane (90 km/h)	1500
	Closure of all lanes with usage of hard shoulder (90 km/h)	1300

Work zone lay-out	Description	Capacity
	Closure of left lane (90 km/h)	3600
	Closure of middle and left lane with usage of hard shoulder (90 km/h)	3200
	Closure of middle and left lane without usage of hard shoulder (90)	1500
	Closure of middle and right lane (90 km/h)	1500

Work zone lay-out	Description	Capacity
	3 - 1 lane shift system (90 km/h)	3400 (A) 3000 (B)
	3 - 0 lane shift system (90 km/h)	3400 (A) 1500 (B)
	2 - 0 lane shift system (90 km/h)	1500
	4 - 0 lane shift system (90 km/h)	3400 (A) 3400 (B)
	4 - 2 lane shift system (90 km/h)	4500 (A) 4300 (B)

ANNEX 2 Weather Stations in the Netherlands

ANNEX 3 Capacity Estimation Methods

Empirical Distribution Method
The Empirical Distribution Method is a method that estimates the capacity by using intensities from the congestion-state of the traffic in a cumulative probability distribution. The description of this method in this appendix is based on a study of Minderhoud, Botma, & Bovy (1996).

The theory of the method is based on an explicit division of the flow observations that have been made over the observation period. The idea is that a capacity value can be derived from the distribution of capacity measurements.
It can easily be understood that a flow rate measurement can be divided into one of the following categories if the traffic state is observed upstream the measuring point:

- measurements representing the traffic demand (free flow intensity measurement)
- measurements representing the capacity-state of the road (congested flow intensity)

These categories are indicated with set {O} and {C} respectively. With this categorization the Empirical Capacity Distribution function, F(q), can be estimated. The definition of the capacity of a road according to the Empirical Distribution Method is:

A capacity distribution (and a capacity value at a certain location characteristic) may be derived using intensities observed at a bottleneck during upstream congestion conditions.

The Empirical Distribution Method is based on observations of traffic volumes at a well-chosen measuring point at a bottleneck, shown in figure 1. The data should be collected at or right after the bottleneck (location B) to obtain flow rate data that is representative for the variable that will be analyzed. Speed observations upstream of the bottleneck, location A, are required to determine the traffic state to distinguish congestion and non-congestion measurements of the flow in location *B*. And finally speed observations downstream the bottleneck, location *C*, are required to determine the possible occurrence of congestion. If congestion is measured at that point *C*, a bottle-neck further downstream the freeway affects the observed intensities at location *B*, so that roadway capacity at *B* is not yet reached. The bottleneck observations are then no longer representative for a capacity situation, and therefore the observations are included in neither set {O} nor {C}.

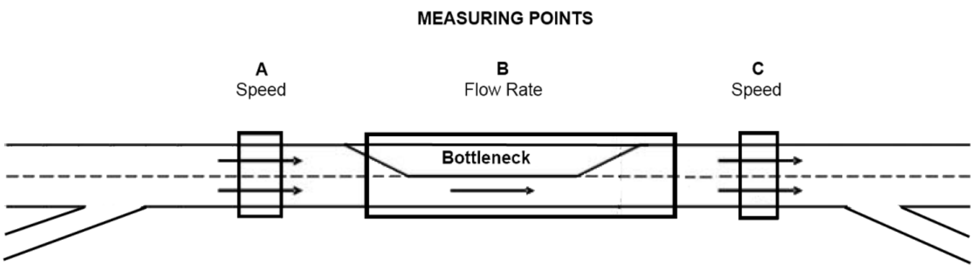
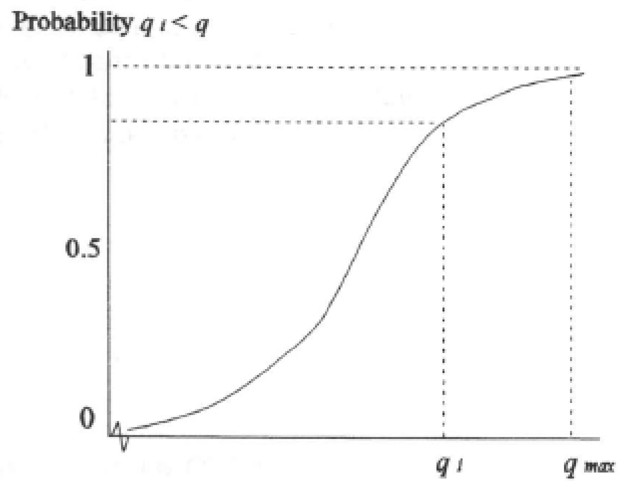


Figure 2 shows the general form of a continuous, cumulative Empirical Capacity Distribution function.



A discrete Empirical Capacity Distribution function can easily be determined with the following equation with applying only intensities that are element of the capacity set $\{C\}$.

$F(q) = P(q_i < q)$ $\quad , q_i \in \{C\}$ $\quad$ or more specific, $F(q) = \frac{N_c}{N}$

Whereby:

F(q) = cumulative distribution function of capacity
q = capacity value
q_i = intensity value counted at averaging interval *i*
N_c = number of observation in congestion-state with intensities $q_i<q$
N = total number of observation elements in congestion-state

For practical application of the Empirical Distribution Method, two things should be defined:

- Duration (Δt) of observation intervals; According to Brilon and Zurlinden (2003), who after experiments with different time intervals, came to the conclusion that a time interval of five minutes is the best for capacity analysis. Therefore a five minute interval is chosen for this research.
- Defining of congestion state; Brilon and Zurlinden (2003) state that the treshold for congestion can range from 50 km/h to 70 km/h. According to the Dutch CIA handbook, the congestion state of traffic is where the speed of traffic drops below 50 km/h. Also at 50 km/h the traffic is most certain to be in congestion state, compared to a boundary of 70 km/h. Therefore a speed of 50 km/h is set as boundary for congestion in this research.

The capacity is analyzed using SPSS. This software program calculates a probability distribution function of the capacity, and with this, the capacity at the specific work zone is analyzed. For estimating the capacity value, the median ($F_c(q) = 0.5$) of the cumulative distribution function is used.

Product Limit Method

Opposite to the empirical distribution method, the product limit method does not only use measurements from the congestion state of the traffic. Also the description of this method in is based on the study of Minderhoud, Botma, & Bovy (1996).

The product limit method uses intensities from periods with congestion as well as free flow periods. This method is based on the idea that every non-congestion observation with a higher intensity than the lowest observed intensity in congestion-state contribute to the determination of the capacity value.

The product Limit method determines the chance that the capacity is higher than a given intensity, with the following equation:

$G(q) = P(q_i > q)$or more specific, $G(q) = \prod q_i \frac{K_{q_q} - 1}{K_{q_i}}$

Where:

G(q) = cumulative distribution function of capacity

q = capacity value

q_i = intensity value counted at averaging interval *i*

K_q = number of observation elements total data set with intensity $q > q_i$

The intensities from the congestion-state are plotted with the cumulative distribution values (F(q) = 1- G(q)). The maximum value from the distribution function from the capacity will only be 1 if this intensity is from the congestion-state data, if it is from the free flow state, it will never be 1. For the product limit method also the median will be used for estimation of the capacity value, F(q) = 0.5.

The Product Limit Method uses the same definitions for data collection as the Empirical Distribution Method does.

ANNEX 4 Nonparametric Tests

Wilcoxon Signed-rank Test

The Wilcoxon signed-rank test is a test that is a non-parametric equivalent of a (1-Sample)t-test. The test is used to test whether a distribution differs from a given median or if the medians of two distributions are different. This description of the test is based on studies of Marcus (2011) and the Statistical Engineering Division (2011).

The Wilcoxon signed-rank assumes that the sample we have is randomly taken from a population, with a symmetric frequency distribution. The symmetric assumption does not assume normality, simply that there seems to be roughly the same number of values above and below the median. The Wilcoxon procedure computes a test statistic W that is compared to an expected value. W is computed by summing the ranked differences of the deviation of each variable from a hypothesized median above the hypothesized value.

To form the signed rank test, compute $d_i = X_i – d_0$where X is from the sample and d_0 is the value to which will be tested. Rank the di without regard to sign (plus or minus). Tied values are not included in the Wilcoxon test. After ranking, restore the sign to the ranks. Then compute W+ and W- as the sums of the positive and negative ranks respectively. If the population median is in fact equal to the value d0, then the sums of the ranks should also be nearly equal. If the difference between the sums of the ranks is too great, we reject the null hypothesis that the population median and d0 are equal. To test whether H_0 should be retained or rejected, the minimum of W+ and W- is compared to the critical value in the tables; the null hypothesis is rejected if W is less than or equal to the critical value.

More formally, the hypothesis test is defined as follows:

H_0: F(m) = d_0
H_a: F(m) ≠ d_0
Test statistic: W=MIN(W-,W+) where the calculation of W- and W+ is discussed above

Confidence level: 0.05

Critical value: For small samples (N ≤ 30) the critical value is tabulated[1].
For N > 30, the test statistic W approaches a normal distribution with an expected median and variance of:

$$\mathrm{E}_0 W = \tfrac{1}{4} n(n+1)$$
$$\mathrm{var}_0 W = \tfrac{1}{24} n(n+1)(2n+1)$$

Conclusion: If the calculated W is less than or equal to the critical value, than H_0 will be rejected.

[1]see e.g.: http://www.sussex.ac.uk/Users/grahamh/RM1web/WilcoxonTable2005.pdf

Kolmogorov-Smirnov Test

The Kolmogorov–Smirnov test (K–S test) is a nonparametric test for the equality of continuous, one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution (one-sample K–S test), or to compare two samples (two-sample K–S test). This description is based on Wikipedia (2011) and (Omey, 2007).

The Kolmogorov–Smirnov statistic quantifies a distance between the empirical distribution function of the sample and the cumulative distribution function of the reference distribution, or between the empirical distribution functions of two samples. The null distribution of this statistic is calculated under the null hypothesis that the samples are drawn from the same distribution (in the two-sample case) or that the sample is drawn from the reference distribution (in the one-sample case). In each case, the distributions considered under the null hypothesis are continuous distributions but are otherwise unrestricted.

The two-sample KS test is one of the most useful and general nonparametric methods for comparing two samples, as it is sensitive to differences in both location and shape of the empirical cumulative distribution functions of the two samples.

The test statistics of the KS test is as follows:

$$KS = \max_{\infty} |F_a(x) - F_0(x)|$$

Whereby:

$F_a(x)$ = a cumulative distribution function of the sample

Critical value: For small samples (N ≤ 30) the critical value is tabulated[2].
For N > 30, the critical valuecan be calculated with:

$$D(\propto) = \sqrt{(-\ln(\frac{\propto}{2}))/2n}$$

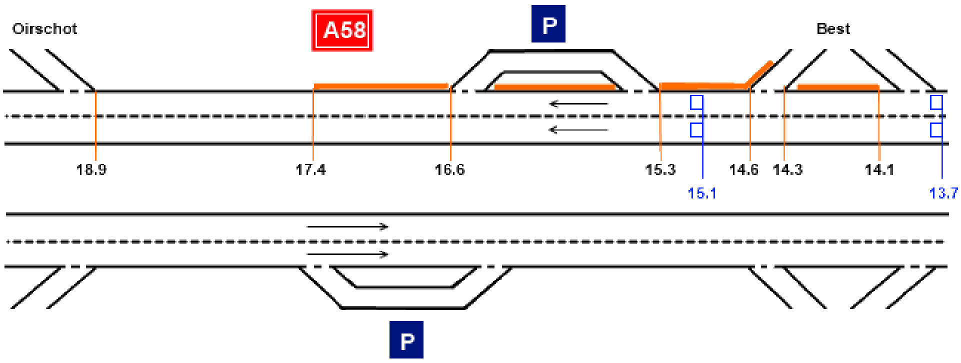
[2]see e.g.: http://www.eridlc.com/onlinetextbook/appendix/table7.htm

ANNEX 5 Work Zone Details

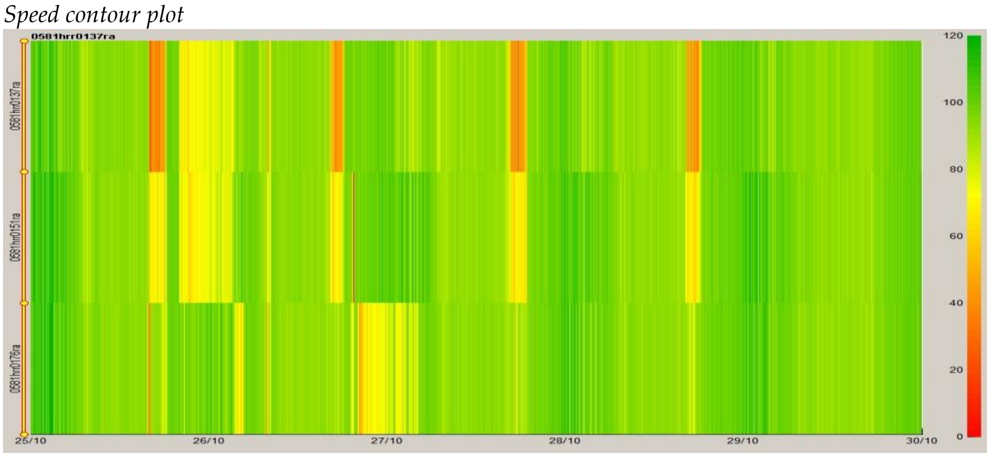
A58 Batadorp – Oirschot

Information	
Road	A58 (HRR)
Location	14.1 – 17.4
Work zone period	25October 2010 – 19 November 2010
Researched period month 1	25 October 2010 – 5 November 2010
Researched period month 2	-
Researched period month 3	-
Work zone lay-out	Closure of hard shoulder

Situation



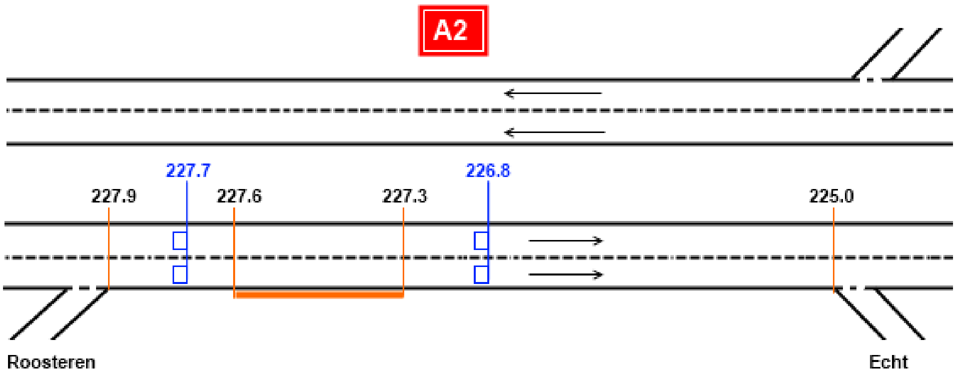
Speed contour plot



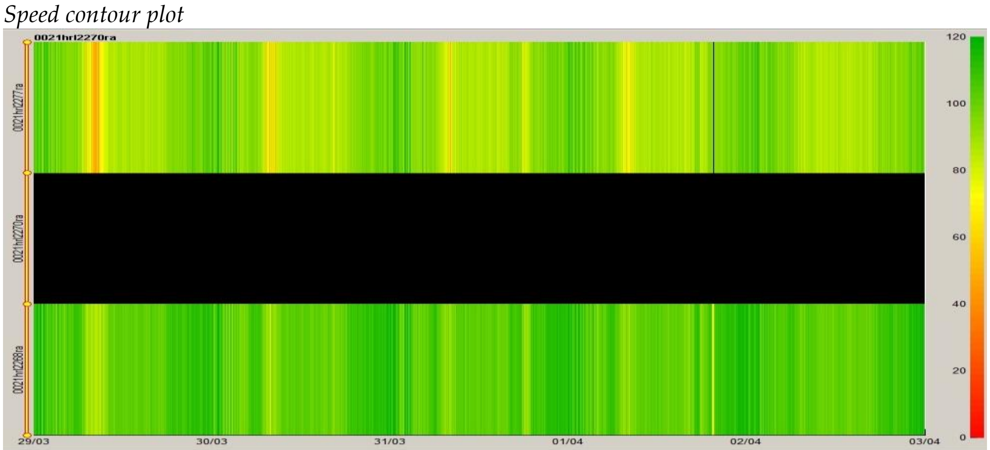
A2 Roosteren – Echt

Information	
Road	A2 (HRL)
Location	227.6 – 227.3
Work zone period	18 March 2010 – 2 June 2010
Researched period month 1	22 March 2010 – 2 April 2010
Researched period month 2	19 April 2010 – 3 May 2010
Researched period month 3	-
Work zone lay-out	Closure of hard shoulder

Situation



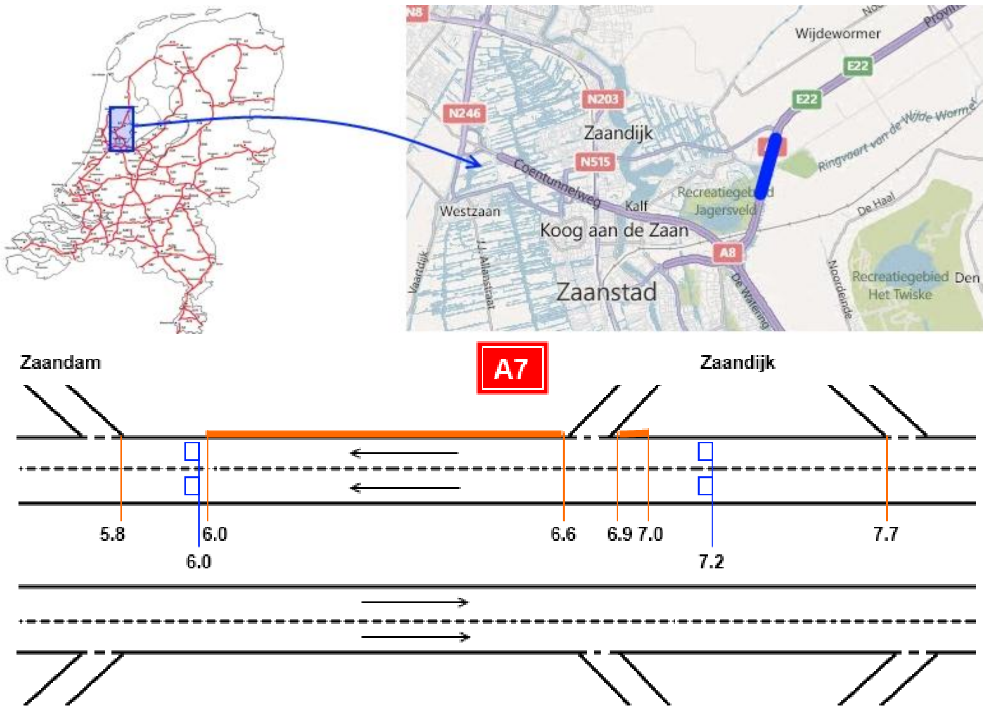
Speed contour plot



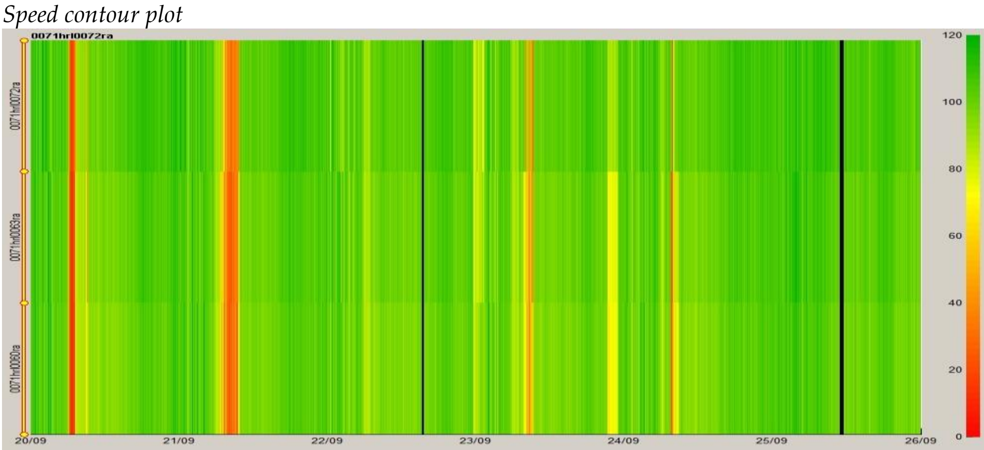
A7 Zaandijk – Zaandam

Information	
Road	A7 (HRL)
Location	7.0 – 6.0
Work zone period	13 September 2010 – 18 February 2011
Researched period month 1	13 September 2010 – 29 September 2010
Researched period month 2	11 October 2010 – 29 October 2010
Researched period month 3	1 November 2010 – 19 November 2010
Work zone lay-out	Closure of hard shoulder

Situation



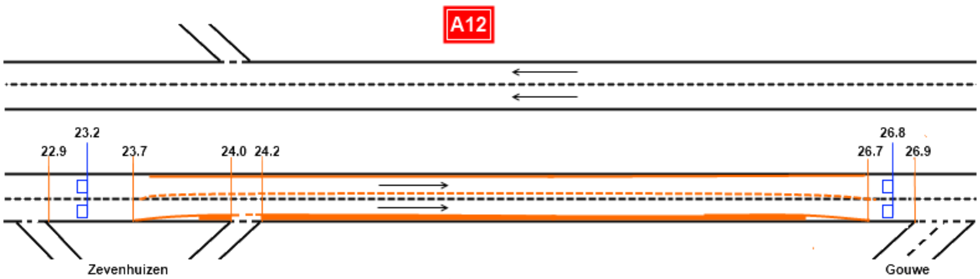
Speed contour plot



A12 Zevenhuizen – Gouwe

Information	
Road	A12 (HRR)
Location	23.7 – 26.7
Work zone period	11 August 2008 – 28 November 2008
Researched period month 1	1 September 2008 – 30 September 2008
Researched period month 2	-
Researched period month 3	-
Work zone lay-out	Lane narrowing on a two lane freeway

Situation

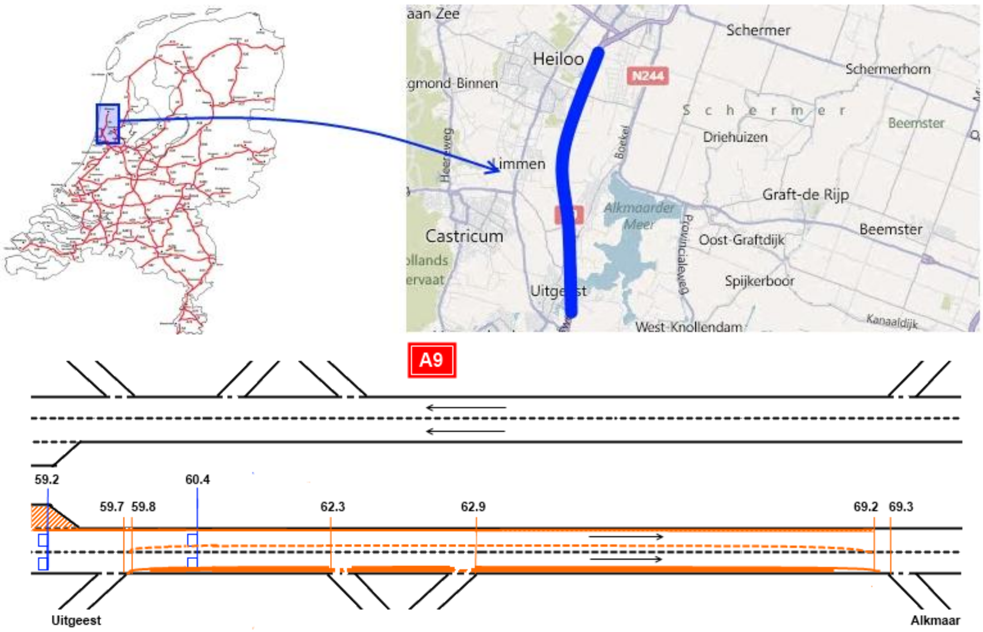


Speed contour plot

A9 Uitgeest – Alkmaar

Information	
Road	A9 (HRR)
Location	59.8 – 69.2
Work zone period	1 November 2010 – 25 February 2011
Researched period month 1	1 November 2010 – 12 November 2010
Researched period month 2	29 November 2010 – 10 December 2010
Researched period month 3	17 January 2011 – 28 January 2011
Work zone lay-out	Lane narrowing on a two lane freeway

Situation

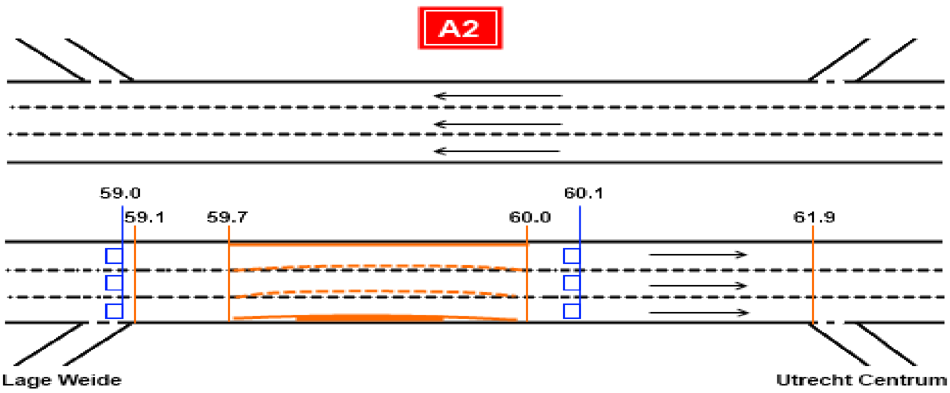


Speed contour plot

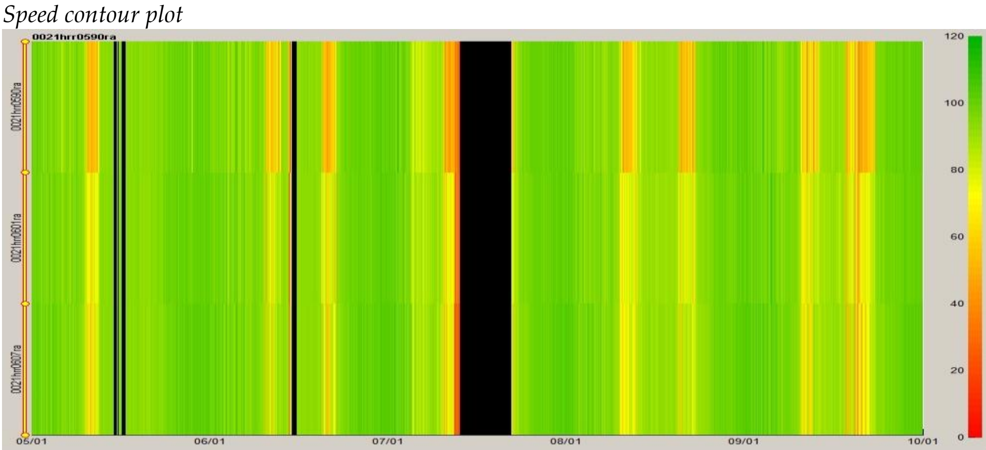
A2 Lage Weide – Utrecht Centrum

Information	
Road	A2 (HRR)
Location	59.7 – 60.0
Work zone period	1 January 2009 – 30 November 2010
Researched period month 1	5 January 2009 – 19 January 2009
Researched period month 2	2 February 2009 – 13 February 2009
Researched period month 3	2 March 2009 – 13 March 2009
Work zone lay-out	Lane narrowing on a three lane freeway

Situation



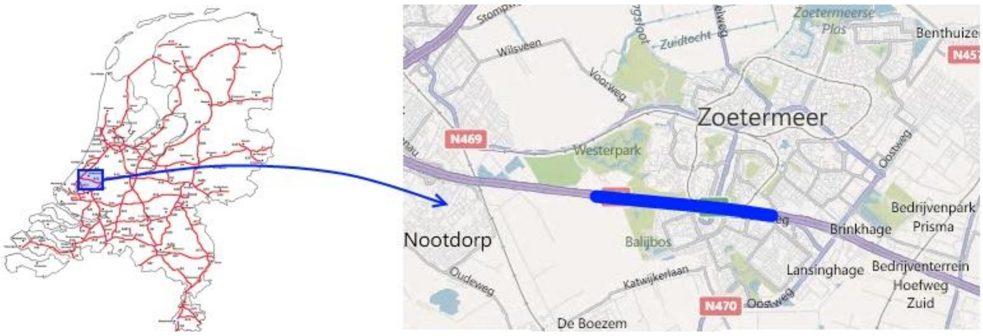
Speed contour plot

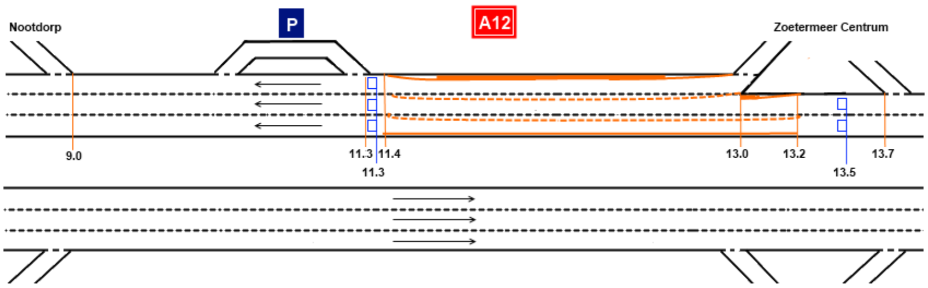


A12 Zoetermeer Centrum – Nootdorp

Information	
Road	A12 (HRL)
Location	13.2 – 11.4
Work zone period	7 January 2011 – 25 February 2011
Researched period month 1	10 January 2011 – 21 January 2011
Researched period month 2	7 February 2011 – 25 February 2011
Researched period month 3	-
Work zone lay-out	Lane narrowing on a three lane freeway

Situation



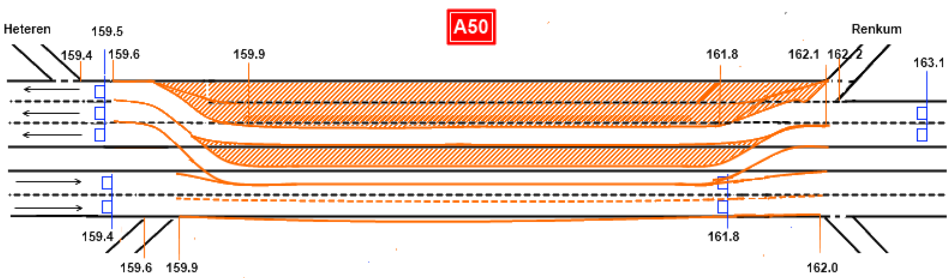


Speed contour plot

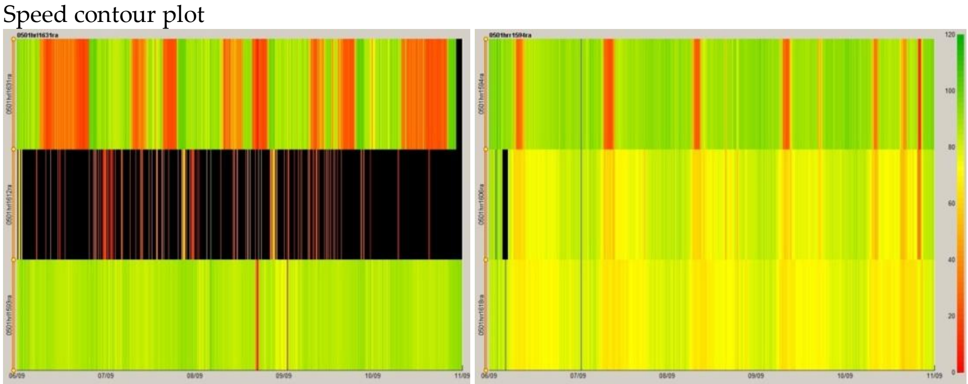
A50 Renkum – Heteren

Information	
Road	A50 (HRL shifted, HRR non-shifted)
Location	162.1 – 159.6
Work zone period	6 September 2010 – 17 September 2010
Researched period month 1	6 September 2010 – 17 September 2010
Researched period month 2	-
Researched period month 3	-
Work zone lay-out	3 – 1 lane shift system

Situation



Speed contour plot

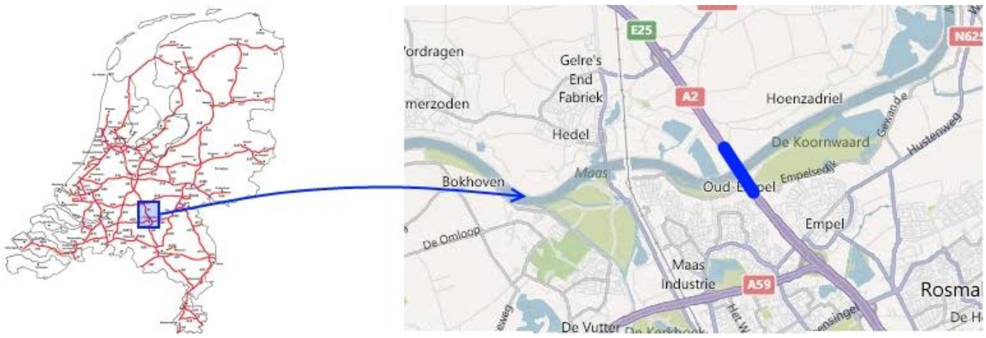


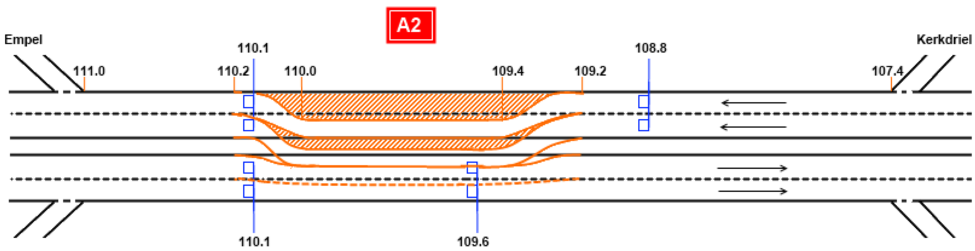
Shifted direction Non-shifted direction

A2 Kerkdriel – Empel

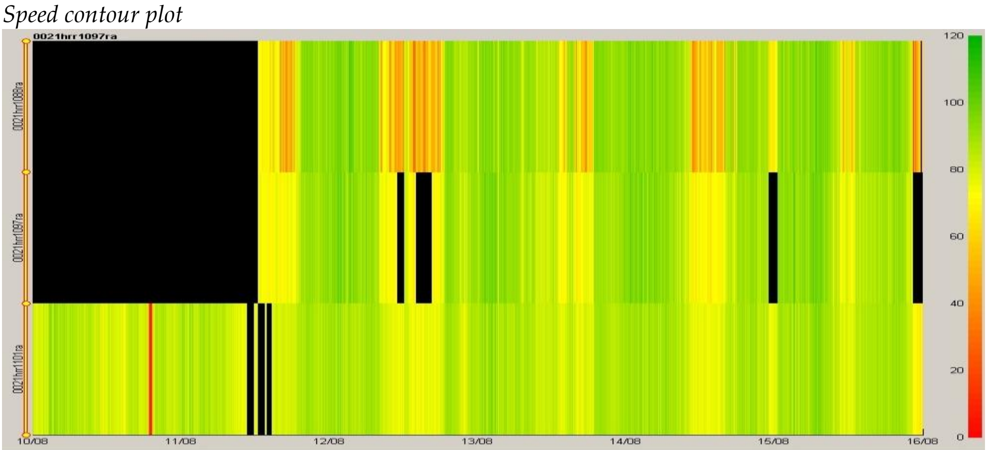
Information	
Road	A2 (HRR shifted)
Location	109.2 – 110.2
Work zone period	10 August 2010 – 15 August 2010
Researched period month 1	10 August 2010 – 15 August 2010
Researched period month 2	-
Researched period month 3	-
Work zone lay-out	3 – 1 lane shift system

Situation





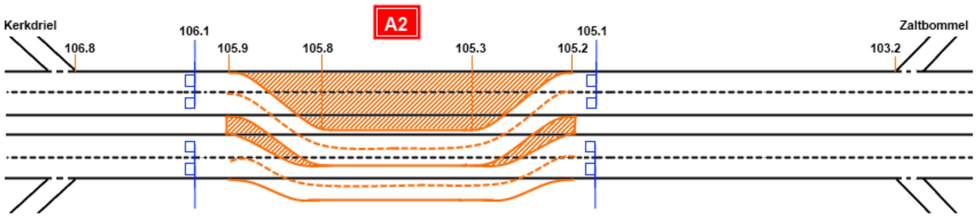
Speed contour plot



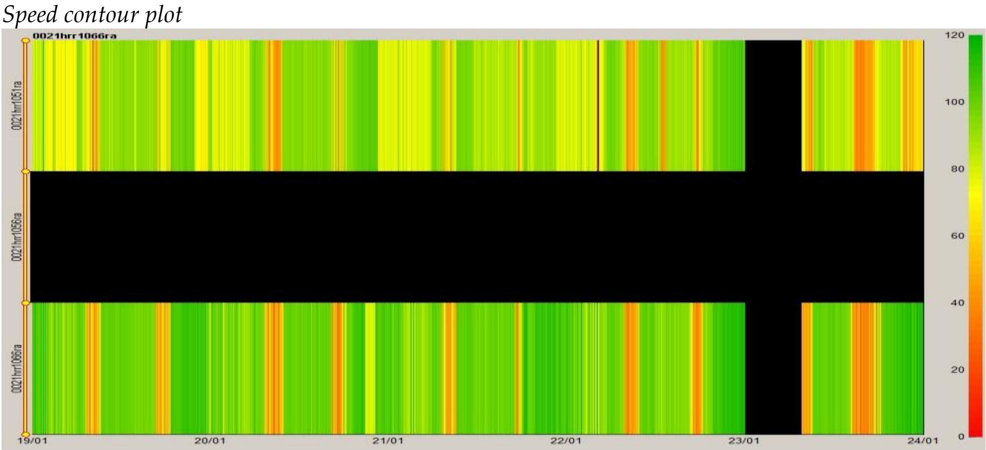
A2 Zaltbommel – Kerkdriel

Information	
Road	A2 (HRR shifted)
Location	105.2 – 105.9
Work zone period	16 January 2009 – 27 May 2009
Researched period month 1	19 January 2009 – 2 February 2009
Researched period month 2	16 February 2009 – 6 March 2009
Researched period month 3	16 March 2009 – 27 March 2009
Work zone lay-out	4 – 0 lane shift system

Situation



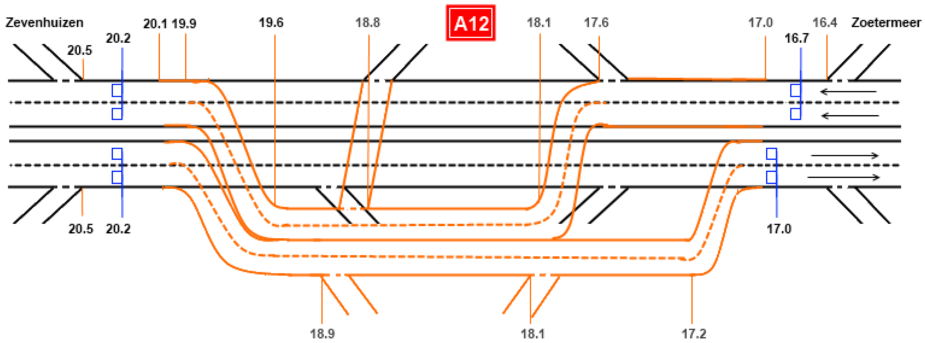
Speed contour plot



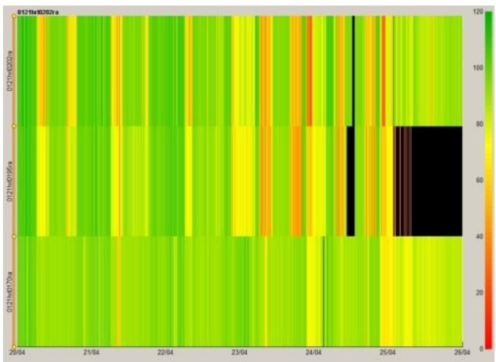
A12 Zoetermeer – Zevenhuizen

Information	
Road	A12 (HRR shifted, HRL non-shifted)
Location	17.0 – 20.1
Work zone period	15 April 2009 – 15 June 2009
Researched period month 1	20 April 2009 – 5 May 2009
Researched period month 2	18 May 2009 – 15 June 2009
Researched period month 3	-
Work zone lay-out	4 – 0 lane shift system

Situation



Speed contour plot



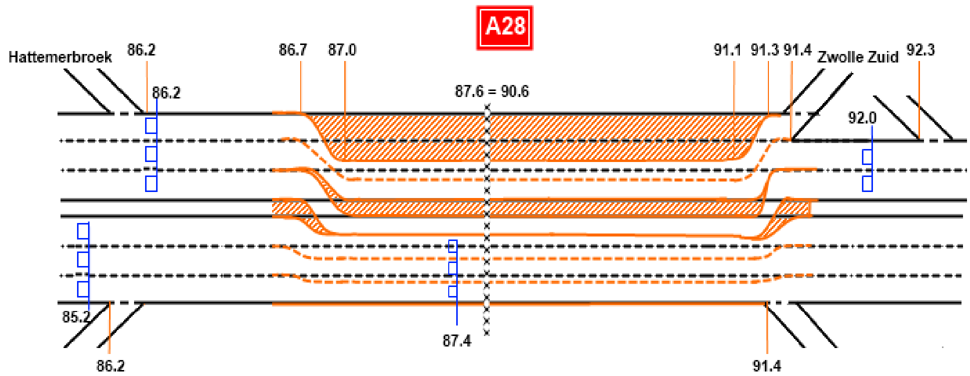
Shifted direction

Non-shifted direction

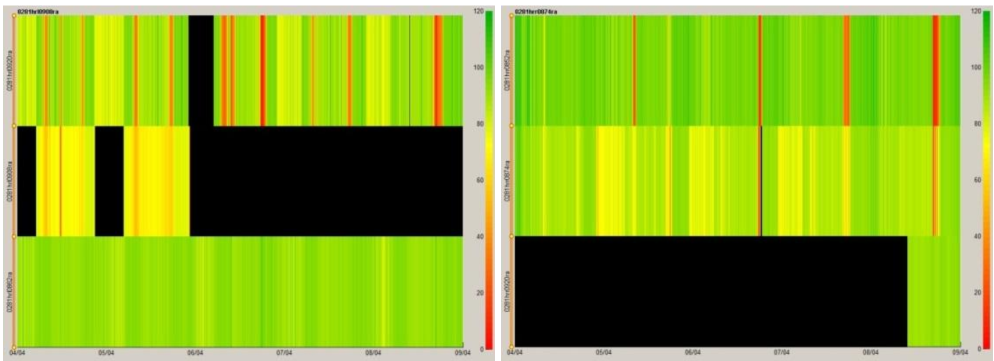
A28 Zwolle Zuid – Hattemerbroek

Information	
Road	A28 (HRL shifted, HRR non-shifted)
Location	91.3 – 86.7[3]
Work zone period	4 April 2011 – 8 April 2011
Researched period month 1	4 April 2011 – 8 April 2011
Researched period month 2	-
Researched period month 3	-
Work zone lay-out	4 – 2 lane shift system

Situation



Speed contour plot



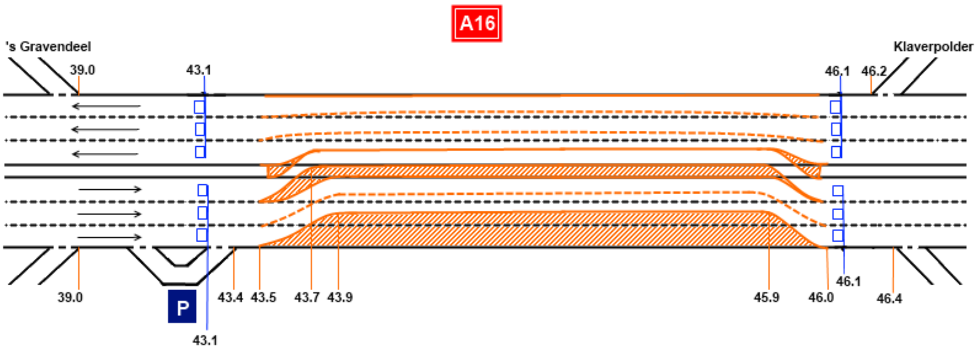
Shifted direction Non-shifted direction

[3] In this trajectory the route markers move up from 87.5 to 90.6

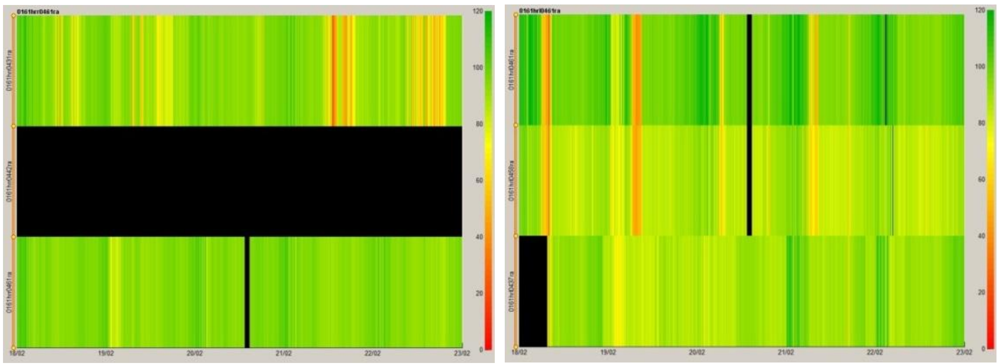
A15 's Gravendeel – Klaverpolder

Information	
Road	A16 (HRR shifted, HRL non-shifted)
Location	43.1 – 46.1
Work zone period	16 February 2008 – 15 August 2008
Researched period month 1	18 February 2008 – 29 February 2008
Researched period month 2	-
Researched period month 3	-
Work zone lay-out	4 – 2 lane shift system

Situation



Speed contour plot



Shifted direction Non-shifted direction

ANNEX 6 EDM Statistics for Capacity Estimation

Case A58 Batadorp - Oirschot

Statistics

Agg_Flow_Downstream_5min

N	Valid	152
	Missing	1
Mean		3586,11
Median		3636,00
Std. Deviation		381,246
Percentiles	5	2899,20
	95	4172,40

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,600.	One-Sample Wilcoxon Signed Rank Test	.801	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A2 Roosteren – Echt

Statistics

Agg_Flow_Downstream_5min

N	Valid	16
	Missing	1
Mean		3122,25
Median		3048,00
Std. Deviation		256,819
Percentiles	5	2820,00
	95	.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,600.	One-Sample Wilcoxon Signed Rank Test	.001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A7 Zaandijk – Zaandam

Statistics

Agg_Flow_Downstream_5min

N	Valid	18
	Missing	0
Mean		3023,33
Median		3030,00
Std. Deviation		238,210
Percentiles	5	2604,00
	95	.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,600.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A12 Zevenhuizen – Gouwe

Statistics

Agg_Flow_Downstream_5min

N	Valid	18
	Missing	0
Mean		3045,33
Median		3018,00
Std. Deviation		268,030
Percentiles	5	2568,00
	95	.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,200.	One-Sample Wilcoxon Signed Rank Test	.022	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A9 Uitgeest – Alkmaar

Statistics

Agg_Flow_Downstream_5min

N	Valid	206
	Missing	0
Mean		3721,22
Median		3744,00
Std. Deviation		185,648
Percentiles	5	3424,80
	95	3991,80

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A2 Lage Weide – Utrecht Centrum

Statistics

Agg_Flow_Downstream_5min

N	Valid	53
	Missing	0
Mean		5217,06
Median		5292,00
Std. Deviation		420,625
Percentiles	5	4436,40
	95	5762,40

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,500.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Flow_Downstream_5min equals 6,300.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A12 Zoetermeer Centrum – Nootdorp

Statistics

Agg_Flow_Downstream_5min

N	Valid	34
	Missing	1
Mean		4397,29
Median		4518,00
Std. Deviation		605,395
Percentiles	5	3402,00
	95	5193,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,500.	One-Sample Wilcoxon Signed Rank Test	.402	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Flow_Downstream_5min equals 6,300.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A50 Renkum – Heteren

Shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	560
	Missing	0
Mean		2706,71
Median		2724,00
Std. Deviation		241,478
Percentiles	5	2316,00
	95	3060,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,000.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Non-shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	220
	Missing	0
Mean		3070,55
Median		3105,00
Std. Deviation		309,247
Percentiles	5	2502,00
	95	3563,10

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,400.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A2 Kerkdriel – Empel

Shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	39
	Missing	1
Mean		2869,23
Median		2868,00
Std. Deviation		220,132
Percentiles	5	2448,00
	95	3204,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,000.	One-Sample Wilcoxon Signed Rank Test	.001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A2 Zaltbommel – Kerkdriel

Shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	128
	Missing	1
Mean		3507,00
Median		3516,00
Std. Deviation		229,909
Percentiles	5	3076,20
	95	3841,20

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,400.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A12 Zoetermeer – Zevenhuizen

Shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	259
	Missing	0
Mean		3629,33
Median		3660,00
Std. Deviation		332,058
Percentiles	5	3144,00
	95	4164,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,400.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Non-shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	76
	Missing	0
Mean		3351,00
Median		3366,00
Std. Deviation		353,184
Percentiles	5	2658,60
	95	3877,80

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 3,400.	One-Sample Wilcoxon Signed Rank Test	.453	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,200.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A28Zwolle Zuid - Hattemerbroek

Shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	114
	Missing	0
Mean		4015,16
Median		4080,00
Std. Deviation		366,374
Percentiles	5	3261,00
	95	4584,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,300.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Flow_Downstream_5min equals 6,300.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Non-shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	34
	Missing	0
Mean		4856,47
Median		4896,00
Std. Deviation		321,377
Percentiles	5	4254,00
	95	5373,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,500.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Flow_Downstream_5min equals 6,300.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Case A16 's Gravendeel – Klaverpolder

Shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	54
	Missing	0
Mean		3476,44
Median		3576,00
Std. Deviation		437,497
Percentiles	5	2445,00
	95	3954,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Agg_Flow_Downstream_5min equals 4,300.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Flow_Downstream_5min equals 6,300.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Non-shifted direction

Statistics

Agg_Flow_Downstream_5min

N	Valid	69
	Missing	0
Mean		4563,65
Median		4704,00
Std. Deviation		513,442
Percentiles	5	3480,00
	95	5322,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of V3 equals 4,500	One-Sample Wilcoxon Signed Rank Test	.085	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Flow_Downstream_5min equals 6,300.	One-Sample Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

T-test outcome of difference in decrease between lay-outs

Difference between 3 – 1 and 4 – 2 lane shift systems and all others

Group Statistics

	VAR00002	N	Mean	Std. Deviation	Std. Error Mean
VAR00001	1,00	4	36,3000	4,87921	2,43960
	2,00	13	21,1385	6,53128	1,81145

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00001	Equal variances assumed	2,338	,147	4,252	15	,001	15,16154	3,56556	7,56174	22,76134
	Equal variances not assumed			4,990	6,710	,002	15,16154	3,03859	7,91299	22,41009

ANNEX 7 Sensitivity Analysis on Estimated Capacities

Location	No. Meas. EDM	Capacity EDM	No. Meas. PLM	Capacity PLM	Relative diff. PLM w. EDM	Sig. Of diff.	Cap. CIA work zone	relative diff. PLM w. CIA work zone	relative diff. EDM w. CIA work zone	Capacity CIA standard	relative diff. PLM w. CIA stand.	relative diff. EDM w. CIA stand.
A2 Roosteren – Echt	16	3048	609	3552	16,54%	0.078	3600	-1,30%	-15,33%	4200	-15,40%	-27,43%
A12 Zevenhuizen – Gouwe	18	3018	1021	2892	-4,17%	0.100	3200	-9,60%	-5,69%	4200	-31,10%	-28,14%
A7 Zaandijk – Zaandam	18	3030	347	3132	3,37%	0.036	3600	-13,00%	-15,83%	4200	-25,40%	-27,86%
A28 Hattemerbroek – Zwolle Zuid	34	4896	205	4740	-3,19%	0.030	4500	5,30%	8,80%	6300	-24,80%	-22,29%
A12 Zoetermeer Centrum – Nootdorp	34	4518	763	4788	5,98%	0.020	4500	6,40%	0,40%	6300	-24,00%	-28,29%
A2 Kerkdriel – Empel	39	2868	303	2892	0,84%	0.628	3000	-3,60%	-4,40%	4200	-31,10%	-31,71%
A2 Lage Weide – Utrecht Centrum	53	5292	663	5544	4,76%	0.026	4500	23,20%	17,60%	6300	-12,00%	-16,00%
A16 ‘s Gravendeel – Klaverpolder	54	3576	753	3528	-1,34%	0.232	4300	-18,00%	-16,84%	6300	-44,00%	-43,24%
A15 Klaverpolder – ‘s Gravendeel	69	4704	836	4590	-2,42%	0.294	4500	2,00%	4,53%	6300	-27,10%	-25,33%
A12 Zevenhuizen – Zoetermeer	76	3366	671	3480	3,39%	0.027	3400	2,40%	-1,00%	4200	-17,10%	-19,86%
A28 Zwolle Zuid – Hattemerbroek	114	4080	358	3840	-5,88%	0.000	4300	-10,70%	-5,12%	6300	-39,05%	-35,24%
A2 Zaltbommel – Kerkdriel	128	3516	608	3516	0,00%	0.913	3400	3,40%	3,41%	4200	-16,29%	-16,29%
A58 Batadorp – Oirschot	152	3636	572	3408	-6,27%	0.000	3600	-5,30%	1,00%	4200	-18,86%	-13,43%
A9 Uitgeest – Alkmaar	206	3744	459	3612	-3,53%	0.000	3200	12,90%	17,00%	4200	-14,00%	-10,86%
A50 Heteren – Renkum	220	3105	658	2952	-4,93%	0.000	3400	-13,20%	-8,68%	4200	-29,71%	-26,07%
A12 Zoetermeer – Zevenhuizen	259	3660	576	3540	-3,28%	0.000	3400	4,10%	7,65%	4200	-15,71%	-12,86%
A50 Renkum – Heteren	560	2724	711	2712	-0,44%	0.457	3000	-9,60%	-9,20%	4200	-35,43%	-35,14%

ANNEX 8 Situation-Specific Variables

Closure of hard shoulder

Variable	CIA handbook	Case A58 Batadorp - Oirschot	Case A2 Roosteren - Echt	Case A7 Zaandijk - Zaandam
Capacity	3600	3636	3048	3030
Relative difference with CIA	-	+1.0%	-15.3%	-15.8%

Percentage of heavy vehicles	15%	9 – 14%	22 – 25%	5 – 11%
Left lane width	3.50	3.50	3.50	3.50
Right lane width	3.50	3.50	3.50	3.50
Distance to ramp upstream (nearby ≤ 500 m)	-	400	300	700
Distance to ramp downstream (nearby ≤ 500 m)	-	1500	2700	200
Length of work zone	-	3300	300	1000
Familiarity with congestion in normal morning peak hour	-	No (0)	No (0)	No (0)
Familiarity with congestion in normal evening peak hour	-	No (0)	No (0)	No (0)
Road gradient	0%	0%	0.3%	0%

Lane narrowing on a two lane freeway

Variable	CIA handbook	Case A12 Zevenhuizen - Gouwe	Case A9 Uitgeest - Alkmaar
Capacity	3200	3018	3744
Relative difference with CIA	-	-5.7%	+17%

Percentage of heavy vehicles	15%	6 – 10%	6 – 9%
Left lane width	2.75	2.75 m	2.50 m
Right lane width	3.00	3.25 m	2.85 m
Distance to ramp upstream (nearby ≤ 500 m)	-	800 m	100 m
Distance to ramp downstream (nearby ≤ 500 m)	-	200 m	100 m
Length of work zone	-	3000 m	9400 m
Familiarity with congestion in normal morning peak hour	-	No (0)	No (0)
Familiarity with congestion in normal evening peak hour	-	No (0)	Yes (1)
Road gradient	0%	0.7%	1.5%

Lane narrowing on a three lane freeway

Variable	CIA handbook	A2 Lage Weide – Utrecht Centrum	A12 Zoetermeer Centrum - Nootdorp
Capacity	4500	5292	4518
Relative difference with CIA	-	+17.6%	-

Percentage of heavy vehicles	15%	11 – 17%	5 – 7%
Left lane width	2.80	3.05	2.95
Middle lane width	2.80	3.15	3.05
Right lane width	3.25	3.25	3.50
Distance to ramp upstream (nearby ≤ 500 m)	-	600	500
Distance to ramp downstream (nearby ≤ 500 m)	-	1900	100
Length of work zone	-	300	1800
Familiarity with congestion in normal morning peak hour	-	No (0)	No (0)
Familiarity with congestion in normal evening peak hour	-	No (0)	No (0)
Road gradient	0%	0%	0%

3 – 1 lane shift system

Variable	CIA handbook	A50 Renkum - Heteren	A2 Kerkdriel - Empel
Capacity	3000	2727	2868
Relative difference with CIA	-	-9.2%	-4.4%

Percentage of heavy vehicles	15%	12 – 22%	9 – 16%
Left lane width	3.00	2.85	2.75
Right lane width	3.25	3.30	3.25
Distance to ramp upstream (nearby ≤ 500 m)	-	0	1800
Distance to ramp downstream (nearby ≤ 500 m)	-	200	800
Length of work zone	-	2700	1000
Familiarity with congestion in normal morning peak hour	-	No (0)	No (0)
Familiarity with congestion in normal evening peak hour	-	Yes (1)	No (0)
Road gradient	0%	0.7%	0.8%

4 – 0 lane shift system

Variable	CIA handbook	Case A2 Zaltbommel – Kerkdriel	Case A12 Zoetermeer - Zevenhuizen
Capacity	3400	3516	3660
Relative difference with CIA	-	+3.4%	+7.6%

Percentage of heavy vehicles	15%	9 – 14%	5 – 10%
Left lane width	3.00	3.25	3.00
Right lane width	3.25	3.25	3.25
Distance to ramp upstream (nearby ≤ 500 m)	-	2000	400
Distance to ramp downstream (nearby ≤ 500 m)	-	900	600
Length of work zone	-	700	2900
Familiarity with congestion in normal morning peak hour	-	No (0)	No (0)
Familiarity with congestion in normal evening peak hour	-	No(0)	Yes (1)
Road gradient	0%	1.7%	1.7%

Non-shifted direction 3 – 1 and 4 – 0 lane shift systems

Variable	CIA handbook	Case A50 Heteren – Renkum	Case A12 Zevenhuizen - Zoetermeer
Capacity	3400	3105	3366
Relative difference with CIA	-	-8.6%	-

Percentage of heavy vehicles	15%	10 – 18%	4 – 10%
Left lane width	3.00	3.50	3.00
Right lane width	3.25	3.50	3.50
Distance to ramp upstream (nearby ≤ 500 m)	-	300	400
Distance to ramp downstream (nearby ≤ 500 m)	-	0	600
Length of work zone	-	2100	3100
Familiarity with congestion in normal morning peak hour	-	No (0)	Yes (1)
Familiarity with congestion in normal evening peak hour	-	No (0)	No (0)
Road gradient	0%	0.5%	1.6%

4 – 2 lane shift system

Variable	CIA handbook	A28 Zwolle Zuid – Hattemerbroek	A16 ‘s Gravendeel – Klaverpolder
Capacity	4300	4080	3576
Relative difference with CIA	-	-5.1%	-16.8%
Percentage of heavy vehicles	15%	9 – 14%	10 – 22%
Left lane width	3.00	3.00	3.00
Middle lane width	2.80	3.00	3.00
Right lane width	3.00	3.25	3.25
Distance to ramp upstream (nearby ≤ 500 m)	-	0	100
Distance to ramp downstream (nearby ≤ 500 m)	-	500	400
Length of work zone	-	1700	2500
Familiarity with congestion in normal morning peak hour	-	No (0)	No (0)
Familiarity with congestion in normal evening peak hour	-	No (0)	No (0)
Road gradient	0%	1.5%	1.9%

Non-shifted direction 4 – 2 lane shift system

Variable	CIA handbook	A28Hattemerbroek – Zwolle Zuid	A16Klaverpolder – ‘s Gravendeel
Capacity	4500	4896	4704
Relative difference with CIA	-	+8.8%	-
Percentage of heavy vehicles	15%	10 – 11%	12 – 14%
Left lane width	2.80	3.00	3.25
Middle lane width	2.80	3.25	3.25
Right lane width	3.25	3.50	3.50
Distance to ramp upstream (nearby ≤ 500 m)	-	500	200
Distance to ramp downstream (nearby ≤ 500 m)	-	0	4500
Length of work zone	-	1700	2500
Familiarity with congestion in normal morning peak hour	-	No (0)	No (0)
Familiarity with congestion in normal evening peak hour	-	No (0)	No (0)
Road gradient	0%	1.7	1.5

ANNEX 9 Multiple Linear Regression Analysis Results

Work zones in general

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,618[a]	,382	,362	9,8338033111
2	,612[b]	,375	,359	9,8547852760

a. Predictors: (Constant), congestionfamiliarity, close to ramp downstream, % heavy vehicles, close to ramp upstream, work zone length

b. Predictors: (Constant), close to ramp downstream, % heavy vehicles, close to ramp upstream, work zone length

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	10,642	2,984		3,566	,000
	% heavy vehicles	-,757	,216	-,249	-3,509	,001
	close to ramp upstream	-7,064	2,149	-,244	-3,287	,001
	close to ramp downstream	-7,718	1,792	-,314	-4,308	,000
	work zone length	,002	,001	,327	3,759	,000
	congestionfamiliarity	2,873	2,225	,100	1,291	,199
2	(Constant)	10,695	2,990		3,577	,000
	% heavy vehicles	-,777	,216	-,256	-3,607	,000
	close to ramp upstream	-6,609	2,124	-,229	-3,111	,002
	close to ramp downstream	-8,183	1,759	-,333	-4,652	,000
	work zone length	,002	,000	,377	4,841	,000

a. Dependent Variable: relative difference with CIA

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
2	congestionfamiliarity	,100[a]	1,291	,199	,103	,661

a. Predictors in the Model: (Constant), close to ramp downstream, % heavy vehicles, close to ramp upstream, work zone length

b. Dependent Variable: relative difference with CIA

Closure of hard shoulder

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VAR00001 is the same across categories of VAR00002.	Independent-Samples Kolmogorov-Smirnov Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,720[a]	,518	,398	8,8624013138
2	,714[b]	,510	,435	8,5818577665

a. Predictors: (Constant), work zone length, % heavy vehicles, close to ramp downstream

b. Predictors: (Constant), % heavy vehicles, close to ramp downstream

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	21,884	30,890		,708	,492
	% heavy vehicles	-1,590	1,212	-,719	-1,312	,214
	close to ramp downstream	-24,307	15,789	-,952	-1,539	,150
	work zone length	-,003	,006	-,290	-,436	,671
2	(Constant)	8,702	6,089		1,429	,177
	% heavy vehicles	-1,103	,454	-,498	-2,429	,030
	close to ramp downstream	-17,842	5,239	-,699	-3,405	,005

a. Dependent Variable: relative difference with CIA

Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	close to ramp upstream	.[a]	.	.	.	,000
2	close to ramp upstream	.[b]	.	.	.	,000
	work zone length	-,290[b]	-,436	,671	-,125	,091

a. Predictors in the Model: (Constant), work zone length, % heavy vehicles, close to ramp downstream

b. Predictors in the Model: (Constant), % heavy vehicles, close to ramp downstream

c. Dependent Variable: relative difference with CIA

Lane narrowing on a two lane freeway

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VAR00001 is the same across categories of VAR00002.	Independent-Samples Kolmogorov-Smirnov Test	.237	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Lane narrowing on a three lane freeway

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VAR00001 is the same across categories of VAR00002.	Independent-Samples Kolmogorov-Smirnov Test	.031	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,754[a]	,569	,491	8,9275953
2	,748[b]	,559	,522	8,6448817

a. Predictors: (Constant), close to ramp downstream, % heavy vehicles

b. Predictors: (Constant), close to ramp downstream

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	28,282	19,975		1,416	,184
	% heavy vehicles	-,800	1,594	-,217	-,502	,626
	close to ramp downstream	-22,916	10,532	-,941	-2,176	,052
2	(Constant)	18,381	3,056		6,014	,000
	close to ramp downstream	-18,215	4,669	-,748	-3,902	,002

a. Dependent Variable: relative difference with CIA

Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	close to ramp upstream	.[a]	.	.	.	,000
2	close to ramp upstream	.[b]	.	.	.	,000
	% heavy vehicles	-,217[b]	-,502	,626	-,150	,210

a. Predictors in the Model: (Constant), close to ramp downstream, % heavy vehicles

b. Predictors in the Model: (Constant), close to ramp downstream

c. Dependent Variable: relative difference with CIA

3 – 1 lane shift system

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VAR00001 is the same across categories of VAR00002.	Independent-Samples Kolmogorov-Smirnov Test	.459	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

4 – 0 lane shift system

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VAR00001 is the same across categories of VAR00002.	Independent-Samples Kolmogorov-Smirnov Test	.486	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Non-shifted direction 3 – 1 and 4 – 0 lane shift systems

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VAR00001 is the same across categories of VAR00002.	Independent-Samples Kolmogorov-Smirnov Test	.546	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

4 – 2 lane shift system

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VAR00001 is the same across categories of VAR00002.	Independent-Samples Kolmogorov-Smirnov Test	.216	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Non-shifted direction 4 – 2 lane shift system

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VAR00001 is the same across categories of VAR00002.	Independent-Samples Kolmogorov-Smirnov Test	.012	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,260[a]	,068	-,049	281,1295215
2	,000[b]	,000	,000	274,4970183

a. Predictors: (Constant), work zone length

b. Predictor: (constant)

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	5151,753	555,208		9,279	,000
	work zone length	-,185	,242	-,260	-,762	,468
2	(Constant)	4734,251	86,804		54,540	,000

a. Dependent Variable: capacity

Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	width left lane	.[a]	.	.	.	,000
	close to ramp downstream	.[a]	.	.	.	,000
2	width left lane	-,260[b]	-,762	,468	-,260	1,000
	close to ramp downstream	,260[b]	,762	,468	,260	1,000
	work zone length	-,260[b]	-,762	,468	-,260	1,000

a. Predictors in the Model: (Constant), work zone length

b. Predictor: (constant)

c. Dependent Variable: capacity

Combinations of variables

Heavy vehicles – Nearby ramp upstream – Nearby ramp downstream

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,530[a]	,281	,267	10,5352757150

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	16,978	2,880		5,895	,000
	% heavy vehicles	-1,192	,211	-,392	-5,637	,000
	close to ramp upstream	-2,586	2,090	-,089	-1,237	,218
	close to ramp downstream	-6,062	1,821	-,247	-3,329	,001

Heavy vehicles – Nearby ramp downstream – Work zone length

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,580[a]	,336	,324	10,1235052021

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8,429	2,979		2,829	,005
	% heavy vehicles	-,840	,220	-,276	-3,811	,000
	work zone length	,002	,000	,282	3,833	,000
	close to ramp downstream	-9,371	1,764	-,381	-5,313	,000

Heavy vehicles – Nearby ramp upstream – Work zone length

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,537[a]	,288	,275	10,4826437032

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	12,899	3,141		4,107	,000
	% heavy vehicles	-1,083	,218	-,356	-4,958	,000
	close to ramp upstream	-8,754	2,206	-,303	-3,969	,000
	work zone length	,002	,000	,287	3,574	,000

Nearby ramp upstream – Nearby ramp downstream – Work zone length

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,568[a]	,323	,310	10,2247401044

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	1,752	1,734		1,010	,314
	close to ramp upstream	-7,326	2,194	-,254	-3,339	,001
	close to ramp downstream	-10,114	1,738	-,412	-5,818	,000
	work zone length	,003	,000	,489	6,589	,000

Heavy vehicles – Nearby ramp upstream

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,480[a]	,230	,221	10,8661224397

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	17,531	2,965		5,912	,000
	% heavy vehicles	-1,355	,212	-,446	-6,384	,000
	close to ramp upstream	-5,041	2,017	-,174	-2,499	,013

Heavy vehicles – Nearby ramp downstream

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,524[a]	,274	,265	10,5529596464

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	15,201	2,500		6,079	,000
	% heavy vehicles	-1,173	,211	-,386	-5,552	,000
	close to ramp downstream	-6,857	1,707	-,279	-4,017	,000

Heavy vehicles – Work zone length

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,466[a]	,217	,207	10,9610557653

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10,194	3,206		3,180	,002
	% heavy vehicles	-1,232	,225	-,405	-5,475	,000
	work zone length	,001	,000	,137	1,848	,067

Nearby ramp upstream – Nearby ramp downstream

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,368[a]	,136	,125	11,5155350910

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	4,083	1,912		2,136	,034
	close to ramp upstream	-1,724	2,278	-,060	-,757	,450
	close to ramp downstream	-8,435	1,937	-,343	-4,355	,000

Nearby ramp upstream – Work zone length

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,421[a]	,177	,166	11,2376088206

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-,030	1,876		-,016	,987
	close to ramp upstream	-10,632	2,329	-,368	-4,565	,000
	work zone length	,002	,000	,425	5,276	,000

Nearby ramp downstream – Work zone length

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,524[a]	,275	,266	10,5479790948

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-1,591	1,461		-1,089	,278
	work zone length	,002	,000	,393	5,568	,000
	close to ramp downstream	-11,617	1,732	-,473	-6,707	,000

ANNEX 10 EDMStatistics for Effect of Rain

A58 Batadorp – Oirschot

Statistics

Agg_Flow_Downstream_5min

N	Valid	18
	Missing	0
Mean		3306,00
Median		3318,00
Std. Deviation		404,293
Percentiles	5	2688,00
	95	.

Hypothesis Test Summary

Null Hypothesis	Test	Sig.	Decision
The medians of Agg_Flow_Downstream_5min are the same across categories of V7.	Independent-Samples Median Test	.006	Reject the null hypothesis.

ymptotic significances are displayed. The significance level is .05.

A9 Uitgeest - Alkmaar

Statistics

Agg_Flow_Downstream_5min

N	Valid	40
	Missing	0
Mean		3522,90
Median		3594,00
Std. Deviation		270,205
Percentiles	5	3072,00
	95	3899,40

Hypothesis Test Summary

Null Hypothesis	Test	Sig.	Decision
he medians of ıgg_Flow_Downstream_5min are ne same across categories of V7.	Independent-Samples Median Test	.011	Reject the null hypothesis.

mptotic significances are displayed. The significance level is .05.

A2 Lage Weide – Utrecht Centrum

Statistics

Agg_Flow_Downstream_5min

N	Valid	9
	Missing	0
Mean		5161,33
Median		5172,00
Std. Deviation		231,171
Percentiles	5	4836,00
	95	.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Flow_Downstream_5min are the same across categories of V7.	Independent-Samples Median Test	.150	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A12 Zoetermeer Centrum – Nootdorp

Statistics

Agg_Flow_Downstream_5min

N	Valid	22
	Missing	0
Mean		4707,27
Median		4728,00
Std. Deviation		525,855
Percentiles	5	3402,00
	95	5332,80

Hypothesis Test Summary

Null Hypothesis	Test	Sig.	Decision
The medians of Agg_Flow_Downstream_5min are the same across categories of V7.	Independent-Samples Median Test	.568	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A50 Renkum – Heteren

Statistics

Agg_Flow_Downstream_5min

N	Valid	168
	Missing	2923
Mean		2584,00
Median		2562,00
Std. Deviation		219,079
Percentiles	5	2304,00
	95	2946,60

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Flow_Downstream_5min are the same across categories of V7.	Independent-Samples Median Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A2 Zaltbommel – Kerkdriel

Statistics

Agg_Flow_Downstream_5min

N	Valid	30
	Missing	0
Mean		3230,00
Median		3216,00
Std. Deviation		207,489
Percentiles	5	2890,20
	95	3593,40

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Flow_Downstream_5min are the same across categories of V7.	Independent-Samples Median Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A16 's Gravendeel – Klaverpolder

Statistics

Agg_Flow_Downstream_5min

N	Valid	15
	Missing	4002
Mean		3284,80
Median		3288,00
Std. Deviation		224,933
Percentiles	5	2928,00
	95	.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Flow_Downstream_5min are the same across categories of V7.	Independent-Samples Median Test	.020	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

ANNEX 11 SPSS Statistics for Effect of Duration

A9 Zaandijk – Zaandam

Month 2

Statistics

Flow_Downstream_5min

N	Valid	31
	Missing	0
Mean		3062,32
Median		3036,00
Std. Deviation		340,251
Percentiles	5	2143,20
	95	3612,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
	The medians of Flow_Downstream_5min are the same across categories of month.	Independent-Samples Median Test	.851	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Month 3

Statistics

Agg_Flow_Downstream_5min

N	Valid	23
	Missing	9
Mean		3193,04
Median		3084,00
Std. Deviation		286,105
Percentiles	5	2733,60
	95	3871,20

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Flow_Downstream_5min are the same across categories of VAR00001.	Independent-Samples Median Test	.420	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A9 Uitgeest – Alkmaar

Month 2

Statistics

Flow_Downstream_5min

N	Valid	33
	Missing	0
Mean		3558,91
Median		3564,00
Std. Deviation		135,301
Percentiles	5	3334,80
	95	3831,60

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Flow_Downstream_5min are the same across categories of months.	Independent-Samples Median Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Month 3

Statistics

Flow_Downstream_5min

N	Valid	153
	Missing	0
Mean		4033,88
Median		4056,00
Std. Deviation		372,209
Percentiles	5	3472,80
	95	4471,20

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Flow_Downstream_5min are the same across categories of month.	Independent-Samples Median Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A2 Lage Weide – Utrecht Centrum

Month 2

Statistics

Agg_Flow_Downstream_5min

N	Valid	86
	Missing	741
Mean		5164,47
Median		5226,00
Std. Deviation		743,633
Percentiles	5	2947,80
	95	6055,20

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Flow_Downstream_5min are the same across categories of VAR00001.	Independent-Samples Median Test	.583	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Month 3

Statistics

Flow_Downstream_5min

N	Valid	38
	Missing	0
Mean		5499,16
Median		5544,00
Std. Deviation		446,580
Percentiles	5	4317,00
	95	6216,60

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Flow_Downstream_5min are the same across categories of month.	Independent-Samples Median Test	.056	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A12 Zoetermeer Centrum – Nootdorp
Month 2

Statistics

Agg_Speed_Upstream_5min

N	Valid	30
	Missing	0
Mean		4090,40
Median		4458,00
Std. Deviation		1108,971
Percentiles	5	2334,60
	95	5333,40

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Speed_Upstream_5min are the same across categories of VAR00001.	Independent-Samples Median Test	.802	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A2 Zaltbommel – Kerkdriel
Month 2

Statistics

Agg_Flow_Downstream_5min

N	Valid	123
	Missing	0
Mean		3432,88
Median		3456,00
Std. Deviation		338,398
Percentiles	5	2997,60
	95	3828,00

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Flow_Downstream_5min are the same across categories of VAR00001.	Independent-Samples Median Test	.087	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Month 3

Statistics

Flow_Downstream_5min

N	Valid	96
	Missing	0
Mean		3548,00
Median		3588,00
Std. Deviation		316,839
Percentiles	5	3056,40
	95	4011,60

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Flow_Downstream_5min are the same across categories of month.	Independent-Samples Median Test	.002	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A12 Zoetermeer – Zevenhuizen

Month 2

Statistics

Agg_Flow_Downstream_5min

N	Valid	296
	Missing	0
Mean		3526,22
Median		3576,00
Std. Deviation		335,361
Percentiles	5	2922,60
	95	3973,80

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of Agg_Flow_Downstream_5min are the same across categories of VAR00001.	Independent-Samples Median Test	.060	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.