Assessing Traffic Safety of Dutch Weaving Sections

Validation of the Surrogate Safety Assessment Model combined with VISSIM

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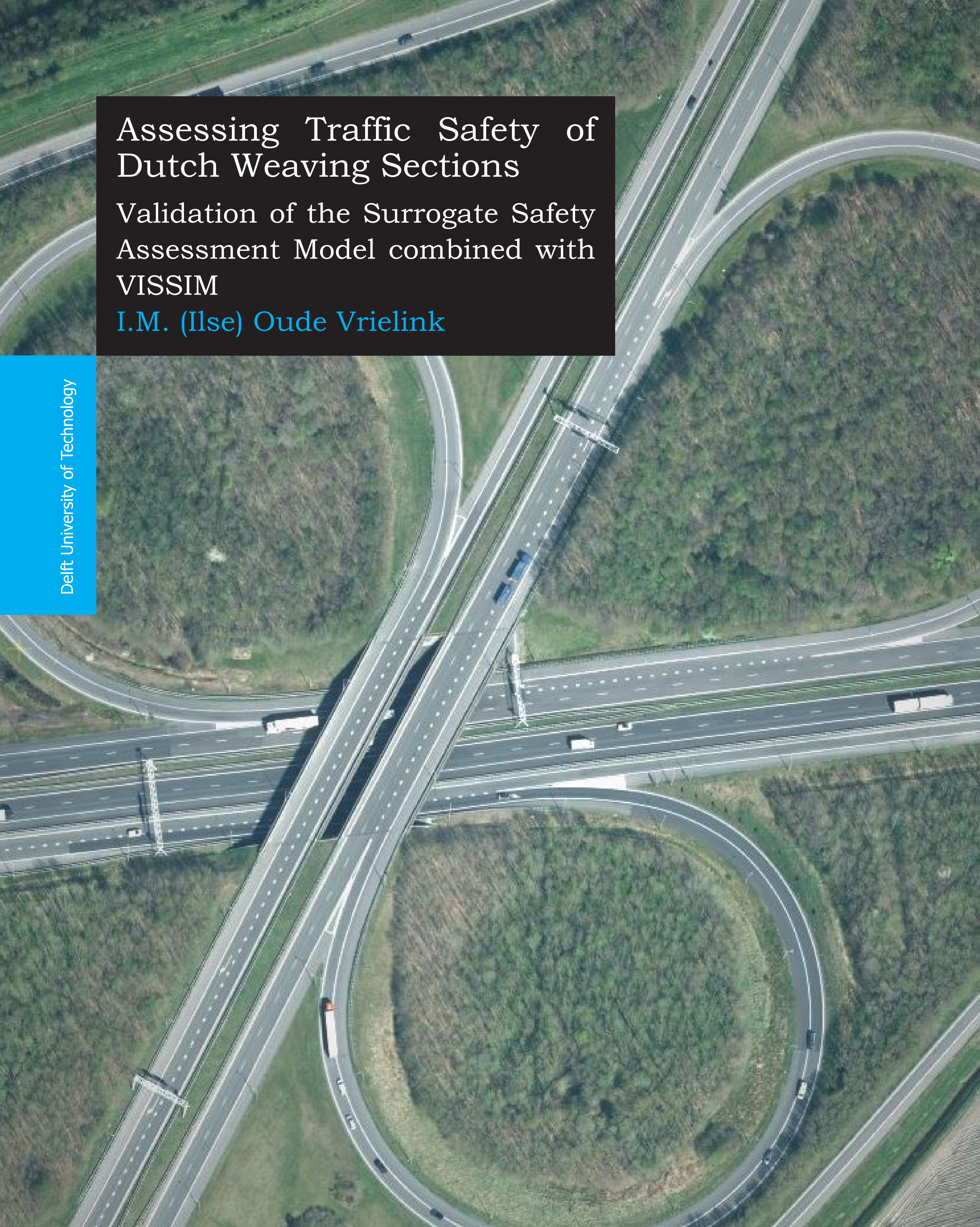

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Assessing Traffic Safety of Dutch Weaving Sections

Validation of the Surrogate Safety Assessment Model combined with VISSIM

by

I.M. (Ilse) Oude Vrielink

in partial fulfillment of the requirements for the degree of

Master of Science
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Abstract

Weaving sections are frequently applied on Dutch freeways. Guidelines are present for designing those freeway weaving sections. However, the origin of these guidelines is unclear and it is not always possible to apply the guidelines. Dutch road designers and road safety experts are searching for methods to evaluate the safety of a (proposed) design more quantitatively than is currently done by expert judgement. An alternative option would be to determine safety of Dutch weaving sections using VISSIM micro-simulation models in combination with the Surrogate Safety Assessment Model (SSAM).

SSAM is able to calculate the number of conflicts that occurred in a micro-simulation model using the surrogate safety measures time-to-collision (TTC) and post-encroachment-time (PET). A conflict is an observable situation in which two or more road users approach each-other such that there is a risk of collision if their movement remains unchanged. The goal of this master thesis research is to assess whether this number of conflicts observed from VISSIM micro-simulation models using SSAM is representing safety (crash rate) of Dutch weaving sections.

For that nine Dutch weaving sections were selected, and were ranked based on four criteria: (I) the crash rate from the BRON crash database, (II) the conflict rate (conflicts per number of vehicle kilometres) calculated from VISSIM micro-simulations using SSAM, (III) the expected number of crashes calculated using the crash prediction model developed by Iliadi et al. [29], and (IV) the judgement of road safety experts.
The Spearman Rank Correlation Coefficient was calculated between these rankings, to validate the ranking based on the conflict rate. For initial VISSIM and SSAM settings, a correlation of 0.567 was found between the crash rate and conflict rate ranking, indicating a reasonable fit. However, due to the small sample size this correlation is not significant (P-value is 0.112).

The effects of some micro-simulation settings, conflict analysis thresholds and the calibration method are assessed in a sensitivity analysis. Reducing the TTC threshold from 1.5 seconds to 0.5 seconds resulted improved the correlation between the conflict rate and the crash rate. However, changing other settings resulted in a weaker correlation. Although different than expected, extending the calibration process by adding calibration on speeds resulted in a weaker correlation. Hence care should be taken when using conflicts calculated by VISSIM and SSAM as (only) predictor for safety of Dutch weaving sections.

It is recommended to expand the selection of weaving sections to assess whether a larger sample results in a stronger, significant, correlation. Also, it can be assessed how a more extensive calibration of VISSIM parameters affects the correlation between the conflict rate and other measures. Furthermore, crash numbers might have more impact on policy makers and public perceptions than alternatives such as conflicts and surrogate safety measures.

Contents

Preface

This master thesis report ”Assessing Traffic Safety of Dutch Weaving Sections; Validation of the Surrogate Safety Assessment Model combined with VISSIM” has been written as the final part of the master Civil Engineering, track Transport & Planning at the Delft University of Technology. Via my daily supervisor at the TU Delft Haneen Farah and a colleague during a former internship at the municipality of The Hague I came in contact with my supervisor Patrick Broeren from Arcadis, where I wrote this master thesis research as part of a graduation internship. We found that the safety of weaving sections would be an interesting topic, and after researching literature on what already has been researched already we found that it would be interesting to validate the usability of SSAM in combination with VISSIM for determining the safety of Dutch weaving sections. Such method could lead to a more underpinned safety judgement of designs of weaving sections than is currently obtained by expert judgement. The possible practical usability is something which I like on the research topic.

The validation procedure comprised four methods that describe road safety: crash data analysis, expert judgement, crash prediction models and VISSIM micro-simulations in combination with SSAM. The use of multiple methods made the study interesting and alternating. Availability of data was a challenge. Completeness of the crash database is a well-known problem. Also, OD-matrices are not available for weaving sections, but should be calculated. However, each possible method has some disadvantages (and advantages). Also, video images which could be used for expert judgement and analysing driving behaviour on weaving sections are difficult to obtain due to privacy reasons. Although this resulted in difficulties, it was also challenging to find alternatives with help of the committee. I want to thank professor Serge Hoogendoorn for his guidance, comments, things to think about and warning that results might be different than you hope for. I want to thank my daily supervisor Patrick Broeren from Arcadis for his feedback and advices, useful suggestions and tips, visits to Delft and of course for making it possible to do this study at Arcadis. I want to thank Haneen Farah as my daily supervisor from the TU Delft for her feedback and advices on the report content and structure, enthusiasm and help in understanding outcomes of SSAM. I want to thank my external supervisor Pieter van Gelder for bringing suggestions and interesting different approaches.

Furthermore, I would like to thank my colleagues at Arcadis for facilitating a pleasant working atmosphere and their interest. Especially I would like to thank the colleagues that helped me with accessing and understanding databases, building VISSIM simulations and their expert judgement on the selected weaving sections.
I also want to thank Rijkswaterstaat and 4Cast for providing the OD matrices, the NDW for providing access to their database, PTV Group for providing me a student licence for VISSIM 9.0, and the FWHA for providing the SSAM software.

Last but not least, I would like to thank Matthijs and my family for their support in my study and for debating issues and challenges.

I.M. (Ilse) Oude Vrielink
Amersfoort & Delft, May 2017

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Introduction

On highways so-called weaving sections are applied when the point of convergence and point of divergence of two merging and splitting traffic streams are within a short distance. Figure 1.1 shows a simple example of such a weaving section. In these weaving sections many vehicles in close proximity switch lanes, which results in a complex driving task, disturbances and conflicts [24]. In general, the number of accidents showed to be higher on weaving sections than on other regular freeway sections [48].

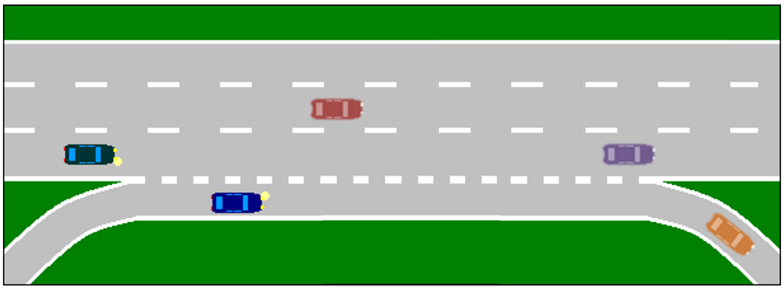


Figure 1.1: Example of a weaving section

The Dutch road authorities Rijkswaterstaat have guidelines on how to design weaving sections [25, 50]. However, there are multiple variations in the design, for example in number of lanes, (as)symmetry and length. Also, variable traffic characteristics such as intensity and vehicle composition do influence traffic flow [50]. Due to the high density of the Dutch road network, weaving sections are applied relatively frequently in the Netherlands, but due to lack of space it is often difficult to design the weaving sections exactly according to the guidelines.

It is generally accepted that safety is a fundamental design criteria, next to capacity, speed and other factors. Despite, relatively few studies have focused on the relation between design elements and safety [24]. Major part of these studies focused on predicting the number of accidents based on the road design and traffic flow factors. These studies mostly use accident counts, and focus less on the perspective of human behaviour.
The Dutch Institute for Road Safety Research (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid, SWOV) has made a list of topics and corresponding questions which need more attention in research. One of these questions is whether the inability to satisfy the required length of

a weaving section does influence the degree of traffic safety, and what is the minimal required distance between junctions and/or intersections [55]. Their question is based on the notion that in the Netherlands currently the length of a weaving section is based on a required 300 meters per lane change. However, it is unclear to the developers of the list what is the origin of this measure, and whether it holds for all design variations (i.e. number of lanes, (as)symmetry, speed, amount of freight traffic, major directions, intensities). This question indicates the need for more in-depth research on the required length and configuration of weaving sections in the Netherlands.

A international used method to determine the safety of a weaving section is using crash prediction models (CPM). Iliadi et al. [29] researched the effects of design elements and traffic flow characteristics on safety of symmetrical weaving sections in the Netherlands by developing such a CPM. The research mostly used accident frequency and type as independent variable for validation of the model, but did not focus on the vehicle interaction influencing the origin of the accident.

When redesigning or creating weaving sections often multiple design options are possible for one location, and currently in most cases a choice is made based on expert judgement. Therefore, it would be valuable to determine the degree of road safety from a microscopic simulation already during the design process. There is a possibility to derive the safety of a road section from a micro-simulation using surrogate safety measures. The FHWA (Federal HighWay Administration of the United States) developed the Surrogate Safety Assessment Model (SSAM) which can calculate surrogate safety measures from micro-simulations. However, it is uncertain whether SSAM can be used to assess the safety on Dutch weaving sections and how accurate the outcomes of SSAM in combination with VISSIM are.

1.1. Problem Definition

Safety of weaving sections is currently mostly assessed by expert judgement. Some attempts to develop crash modification factors (CMFs) and crash prediction models (CPMs) as alternatives have taken place.
However, the derivation of such factors and models is a complex task and not all relevant factors can be included. Next to analysing safety of existing weaving sections by looking at the configuration, also micro-simulations might be usable to determine the degree of safety. Using the Surrogate Safety Assessment Model (SSAM) it is possible to derive surrogate safety measures from vehicle trajectories generated by the VISSIM micro-simulation model. These surrogate safety measures might be a replacement for crashes. Thus, micro-simulations can be a good alternative when for a weaving section type no accident frequencies are available. A simulation is especially useful when designing a new weaving section as there is no accident data available at that time. However, such micro-simulations are developed for analysing traffic performance, and not for safety purposes which requires more details on vehicle interactions. Hence it is uncertain how well simulation results are representative for the Dutch traffic safety.

1.2. Research Goal

The goal of this master thesis research is to determine if the combination of the micro-simulation model VISSIM with SSAM is a reliable method to predict the traffic safety of Dutch weaving sections.

1.3. Research Question

To fulfil the research goal, the following research question is defined:

How representative are surrogate safety measures calculated from VISSIM micro-simulations with SSAM for predicting the safety of Dutch weaving sections?

A selection of Dutch weaving sections will be ranked based on crash frequency. Thereafter the same weaving sections will be put in micro-simulation models, and another safety ranking will be made based on the number of conflicts determined from the simulations using surrogate safety measures. The relation between safety estimations from micro-simulations and registered accidents will be assessed by comparing the two safety rankings. Rankings based on expert judgement and crash rates based on a crash prediction model will be used as reference. The strength of the relation between the rankings will be used to conclude whether micro-simulations can be used in future for assessing safety of weaving sections.

The results are expected to give an indication of how accurate safety estimations based on micro-simulations are, and what causes eventual differences. Another result is a better explanation why some weaving sections are unsafe, and thus what can be done to improve safety. More insight in traffic safety of weaving sections can lead to recommendations for changes in the design guidelines. If the SSAM model in combination with VISSIM proves to be valid, it can help Rijkswaterstaat to better describe the advantages and disadvantages of the different design options and hence provide aid in making a choice between the various configurations for weaving sections. Moreover, safety of new ideas can be tested using simulations before implementing it on roads, so no long testing period in practice is required. From the scientific perspective more insight will be gained in the relation between the number of crashes and number of conflicts and the characteristics of the used surrogate safety measures and the potential of SSAM for determining traffic safety.

1.4. Report Structure

Chapter 2 includes definitions and general terminology regarding weaving sections and safety. The reader can skip this chapter if the reader is familiar with this terminology. Chapter 3 gives a description of the available literature on safety of weaving sections and applications of SSAM. Chapter 4 describes the research steps and the data collection and modification. It also includes the selection procedure for the weaving sections and outcomes of some of the research steps. Chapter 5 presents the results of the research by first giving outcomes of some of the research steps and then performing the validation of the SSAM model. Chapter 6 closes with answering the research question and conclusions, a discussion and recommendations.

2

Definitions and Terminology

In this chapter general definitions and terminology regarding weaving sections and safety will be given. Section 2.1 focuses on weaving sections while section 2.2 includes definitions in the field of safety and conflicts.

2.1. Weaving Sections

This section includes definitions and terminology with respect to weaving sections. Paragraph 2.1.1 includes the definition of a weaving section and the primary functions. Paragraph 2.1.2 describes terminology and name-giving. Paragraph 2.1.3 focuses on the weaving manoeuvre. Paragraph 2.1.4 describes the most frequent used methods to classify the different types of weaving sections.

2.1.1. Definition

A weaving section is a facility where traffic streams with different destinations cross longitudinal. It is applied on freeways where two major traffic streams merge and split within a short distance. In a situation in which an onramp is followed closely by an off-ramp often a choice is made for a weaving section due to lack of space: the onramp and off-ramp are connected by one or more auxiliary lanes. When the distance between an onramp and the following off-ramp is limited, the application of a weaving section is even obligatory according to the Dutch design guideline [50].

The Dutch Design Guideline for Freeways (Richtlijn Ontwerp Autosnelwegen, ROA) describes a weaving section as [50]

a road section where two traffic streams weave, with limited distance between the point of convergence and point of divergence.

In this definition, weaving is understood as the crossing of two traffic flows travelling in almost the same direction, under a small angle and with a slight speed difference, without aid of traffic control devices [43, 50]. The limited distance between the point of convergence and point of convergence is specified at 1500 meters.

Weaving sections are, even as incoming and exiting lanes, special lanes with a limited length and are characterised by the blocking line between the two directions. They function as transition at locations where various lanes are connected or are adjacent to other lanes. A weaving section has the following primary functions [50]:

- Facilitating traffic flow and exchange of driving traffic with equal speed coming from multiple lanes and going to multiple lanes;
- Providing the required length for comfortable deceleration to the design speed of the deflecting lane in case of non-equivalent traffic flows;
- Providing space to vehicles to find a gap before switching to the other lane.

2.1.2. Terminology

Figure 2.1 shows the general layout of a weaving section. The exit and entry roadways are called legs, numbered from A to D. Legs A and B are incoming legs, while C and D are the outgoing legs. Traffic going from leg A to leg C does not have to change lanes, even as traffic going from B to D. These flows are called the non-weaving flows. On the contrary, the flow with origin leg B and destination leg C must change lanes, and similar for vehicles going from leg A to leg D. The latter flows are called crossing or weaving flows [43]. When at least three legs consist of multiple lanes, the weaving section is called a major weaving section. If this is not the case the weaving section is a ramp-weave (figure 1.1), which connects an onramp to an off-ramp in close proximity [48].
The triangular points where the two directions merge and split are called the convergence and divergence gores respectively. The length of the weaving section is measured between the end of the convergence gore and the beginning of the divergence gore, as indicated by the L in figure 2.1 [50]. The weaving width is defined as the total number of lanes of the road section between the two gores [48].

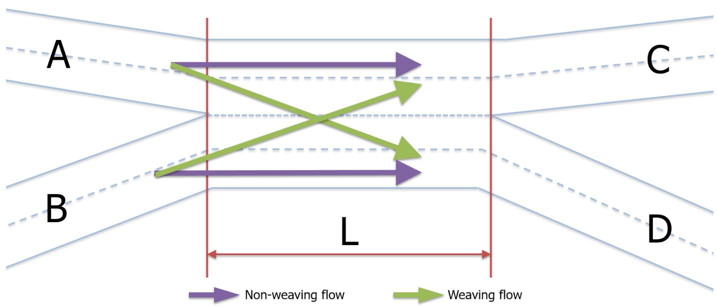


Figure 2.1: General layout of a weaving section (schematic, adapted from [43, p. 17])

A weaving section is applied if the points of convergence and divergence are within 1500 meters of each other. In case the distance in between is larger no weaving section is applied and the onramp should be followed by a separate off-ramp. If this leads to capacity problems, an auxiliary lane could be added in combination with a lane ending on the through-going lane, or a merging and splitting will be applied. Also, a combination of both is possible [50].

The capacity of a weaving section is determined by road factors and traffic flow characteristics. These road factors include the number of lanes per vehicle flow, the configuration of the weaving section and the length of the weaving section. Traffic flow characteristics comprise the traffic flow, vehicle composition and speed on the connector roadway [50]. The Dutch handbook on

capacity values of highway infrastructures (Capaciteitswaarden Infrastructuur Autosnelwegen, CIA [25]) can be used to determine the most appropriate configuration.
In general it holds that on longer weaving sections there is less turbulence, which leads to a higher capacity. However, as most weaving manoeuvres take place at the beginning of the section the extra length at the end has a relative limited effect.

The minimal applicable weaving section lengths for a certain traffic flow and truck percentage can be found in the ROA [25]. As a rule of thumb a minimum length of 300 meters per lane change is applied at a speed of 120 km/h. However, the length of the weaving section should always comply with the minimum required lengths for signage [64]. Standards for design and positioning of signage in the Netherlands can be found in the guidelines for signage [23]. The Dutch institute for road safety research (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid, SWOV) advices not to place weaving sections close to tunnels. Near a tunnel already more attention is required due to the changing road view, and the presence of a weaving section will lead to an even more difficult driving task [60].

2.1.3. Weaving manoeuvre

According to Wilmink [70] the lane change process consists theoretically of four phases, which are schematic shown in figure 2.2. These phases are

1. Search gap;
2. Adapt speed;
3. Change lanes;
4. Adapt following distance and speed.

After the driver makes the decision to changes lanes, the searching for an acceptable gap in the destination lane starts. This will be more difficult in a busy traffic situation as then the following distance is shorter and therefore less acceptable gaps occur. After a gap is found, the driver can accelerate or decelerate to the right speed and the lane change manoeuvre can be executed. Finally, the driving speed is adapted to the speed on the lane and a safe distance to the predecessor will be maintained.

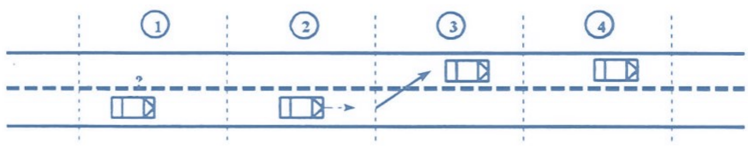


Figure 2.2: The four steps of the lane change process (adapted from [70, p. 7])

A weaving manoeuvre differs from a regular lane-change manoeuvres since vehicles from two lanes can make a lane change simultaneously as shown in figure 2.3. As both vehicles must find an acceptable gap at the same time, the needed space for this type of manoeuvre is considerable. At high densities, speeds may be reduced as drivers try to position their vehicle and find an acceptable gap, or other vehicles may reduce speed to create a gap for an adjacent vehicle that wants to merge [43].

The intensive lane change manoeuvres combined with the heavy traffic volume and high speed conditions at weaving sections often result in safety and operational problems. Besides, various

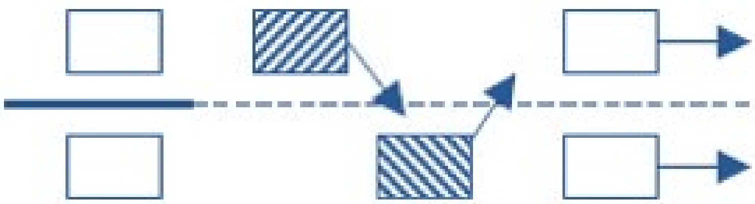


Figure 2.3: Weaving manoeuvre (adapted from [43, p. 17])

factors such as the design of the ramps, use of auxiliary lanes, and continuity of lanes have significant effects on the level of service and safety performance of the weaving sections [48].

The Dutch design guideline (ROA) recommend to avoid a combination of slower and faster driving traffic, such as a major roadway in combination with a weaving section and indirect connections (loops) with a low design speed, as this has a negative influence on traffic safety. When designing an interchange, this can be a reason to apply a collector/distributor lane or choose for a design different from the clover leaf [50].

2.1.4. Classifications

There are multiple options to classify the different types of weaving sections. A distinction can be made based on equivalent or non-equivalent traffic flows. Another distinction can be made based on symmetry of the design. In literature frequently a distinction is made based on the required number of lane changes. The latter is not generally used in the Netherlands, but is included to create a complete overview and is useful as background information for the discussion of research from other countries than the Netherlands.

Equivalent or Non-equivalent Traffic Flows

In the Netherlands sometimes weaving sections are distinguished into weaving sections having equivalent or non-equivalent traffic flows, or a combination of both [50].
A weaving section with equivalent traffic flows has no hierarchical difference on network level between the roads, thus the flows are at a similar level in the network. This means that the converging and diverging legs have the same design speed. The weaving section often is a combination of a merging and a splitting of two highways. For the dimensions of the gores and entering and deflecting roads, guidelines for regular merges and splits can be applied.
A weaving section for non-equivalent traffic flows is a combination of an entrance and exit. It is applied if there is a hierarchical difference between carriageways, thus if the carriageways have different design speeds. Here often exchange between a freeway and a more local road is facilitated. A well-known example of a weaving section with non-equivalent traffic flows is a ramp-weave.
A combination of both occurs if the traffic flows are equal at the convergence point and unequal at the divergence point, or vice versa.

Symmetrical or Asymmetrical Design

Another distinction which is often used in the Netherlands is between symmetric and asymmetric weaving sections [50].
In case of a symmetric weaving section the design at the point of convergence is symmetrical to the design at the point of divergence, as can be seen in figure 2.4. The number of lanes on leg A equals the number of lanes on leg C, and the number of lanes on leg B is equal to the number

of lanes on leg D (see figure 2.1 for the labelling of the legs). The blocking line connects the convergence gore to the divergence gore.
For an asymmetrical weaving section the number of lanes of the two legs at the point of convergence is different from the number at the point of divergence. Figure 2.5 shows two examples of asymmetrical weaving sections.
The symmetry of the weaving section influences the required number of lane changes for the weaving streams [25]. Most of the weaving sections in the Netherlands are symmetrical [70].

The type of symmetry follows from the notation that is used. For symmetrical weaving sections simply the number of lanes in the main carriageway and the weaving lanes are mentioned. The weaving sections drawn in figure 2.4 have a $3 + 1$ and $3 + 2$ configuration [25].
The notation $3 + 1$ indicates that leg A has 3 incoming lanes, and leg B consists of only 1 lane. The sections are said to be symmetrical as the number of lanes in legs C and D are equal to that of A and B respectively.

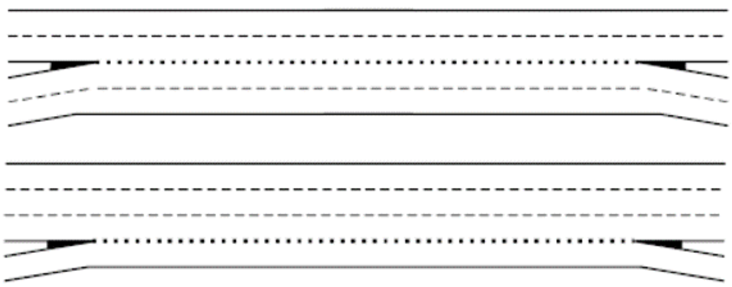


Figure 2.4: Two examples of symmetrical weaving sections [25, p. 38]

For asymmetrical weaving sections the number of lanes of the main carriageway are mentioned for the beginning and end of the weaving section. The weaving sections in figure 2.5 are notated as $4 + 1 > 3 + 2$ and $2 + 1 > 2 + 2$.
The notation $2 + 1 > 2 + 2$ indicates that leg A has 2 incoming lanes and leg B has 1 incoming lane, while legs C and D both have 2 lanes, thus the weaving section geometry is asymmetrical [43].

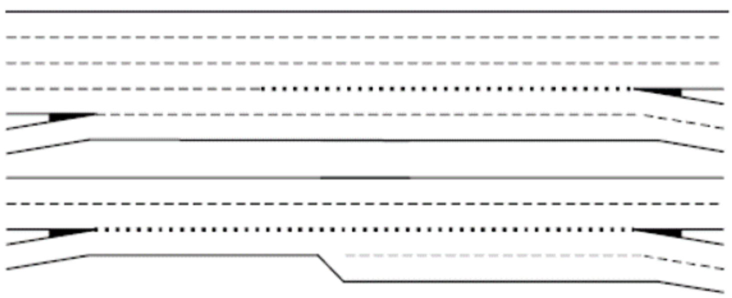
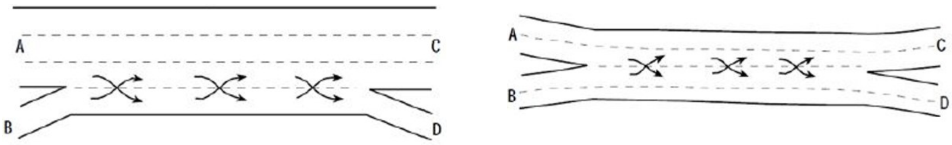


Figure 2.5: Two examples of asymmetrical weaving sections [25, p. 38]

In case of a taper entrance or taper exit a notation using a capital T is applied, for example: $2 + 2T > 2 + 1$ and $2 + 1 > 2 + 2T$.

Number of Required Lane Changes

The United States Highway Capacity Manual (HCM2000) makes a distinction into three types of weaving sections, mainly based on the minimum number of lane changes required for the weaving streams. In traffic engineering often the same distinction into type A, type B and type C is used [24, 48].
On a type A weaving section every merging or diverging vehicle must execute one lane change. All these lane changes pass the line that connects the entrance gore to the exit gore, the so-called crown line. Most common configuration is a pair of on- and off-ramps connected by an auxiliary lane. Example configurations can be found in figure 2.6. The left example is a ramp-weave. The right example is a major-weave, in which at least three of the entry and exit legs have multiple lanes.

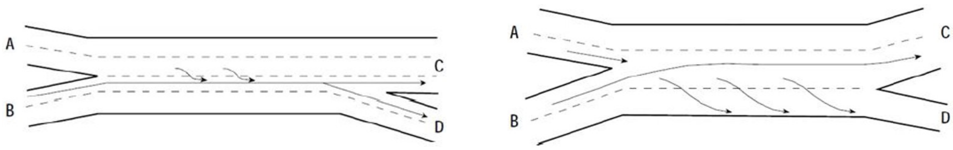


(a) Ramp-weave: all weaving drivers must execute a lane change across the crown line

(b) Major weave: three or more entry/exit legs have multiple lanes

Figure 2.6: Examples of type A weaving sections [48, p. 4]

On a type B weaving section either merging or diverging can be done without changing lanes while the other movement requires at most one lane change. All type B weaving sections are major weaving sections as they always have at least three legs with multiple lanes.
Most common configuration is a lane added at an onramp. In that case merging traffic does not need to change lanes, but traffic diverging downstream must change onto this added lane at the off-ramp. Two examples of this type of weaving section can be found in figure 2.7.



(a) Major weave with dual off-ramp

(b) Major weave with single off-ramp

Figure 2.7: Examples of type B weaving sections [48, p. 5]

On a type C weaving section one manoeuvre requires at least two lane changes, while the other weaving movement can be made without making any lane change. Examples of this type of weaving section can be found in figure 2.8.

A combination of two types, for example type A and B, is also possible. In the Netherlands type A is mostly used, while in the United States type B and C are more common.

The HCM2000 makes a distinction into the three types as described above, while the newer HCM2010 uses another distinction into one-sided or two-sided weaving sections. In a one-sided weaving section no manoeuvres require more than two lane changes to reach the desired destination. In a two-sided weaving section there is at least one manoeuvre which requires three or more lane changes. Most weaving sections are one-sided. As the categorisation according to the HCM2000 considers more details about the required number of lane changes, this older version is still used in research [48].

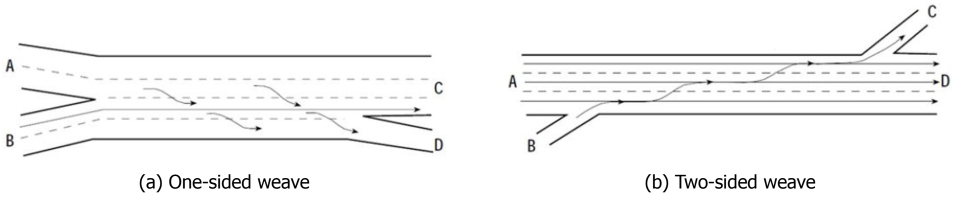


Figure 2.8: Examples of type C weaving sections [48, p. 6]

As the focus of the research is on Dutch weaving sections, the distinction into symmetrical and asymmetrical weaving sections will be used.

2.2. Safety, Conflicts and Surrogate Measures

This section focuses on road safety and describes how crashes and conflicts are used to express road safety. Paragraph 2.2.1 includes the definition of the safety of a traffic facility. Paragraph 2.2.2 describes factors that influence the occurrence of an accident. Paragraph 2.2.3 describes the reporting of accidents in the BRON database. Paragraph 2.2.4 includes the definition of a conflict, and paragraph 2.2.5 describes some surrogate safety measures that are available to indicate conflicts.

2.2.1. Definition of Safety and Crash

In general, the likelihood of being involved in a crash on a freeway is bigger on weaving sections than on other freeway sections. The extra high number of lane change manoeuvres in a road section with high traffic volume and speeds often results in an increased number of unsafe situations [48]. This is due to the weaving traffic resulting in more conflicts between the vehicles entering and exiting, leading to a more complicated driving task [45]. The demand-performance relationship shown in figure 2.9 describes that as long as the task demand remains within the attentional capacity of the person performing the task, no overload is experienced. The task performer may experience normal workload if the demands are not high. However, if the workload keeps increasing, performance may decrease unless the person invests more effort in executing the task correctly. If the task demand approaches the maximum resources available, thus the person invests maximum effort, the performance declines. A too high task demand might lead to almost-accidents, but sometimes also results in a crash. When the task demand is too low, also underload can occur [62].

In literature the safety of a traffic facility is defined by Gettman and Head [21] as

the expected number of crashes, by type, expected to occur on an entity in a certain period, per unit of time

in which a crash is defined as

an unintended collision between two or more motor vehicles.

In this definition thus single-vehicle crashes are excluded.

2.2.2. Occurrence of an Accident

The occurrence of an accident can be seen as a coincidence of influencing factors [1]. The road design and traffic flow characteristics are seen as given to the road users. Together with the characteristics of the road user such as age, gender and experience [64] these characteristics

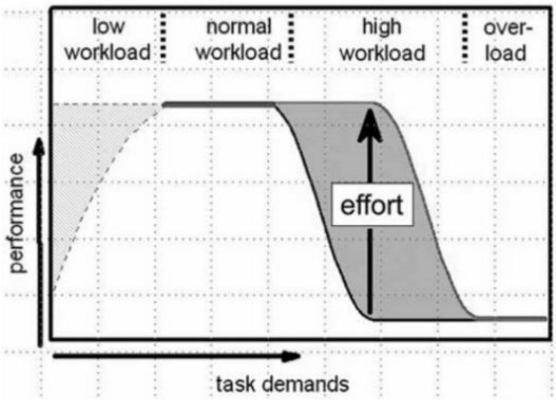


Figure 2.9: The task performance relationship [62, p. 59]

results in certain behaviour of the road users, which can result in an almost-accident or accident (figure 2.10). Due to specific design, traffic and personal characteristics and unfavourable circumstances the risk (change × effect) can be higher or lower at a location or moment than in the reference situation.

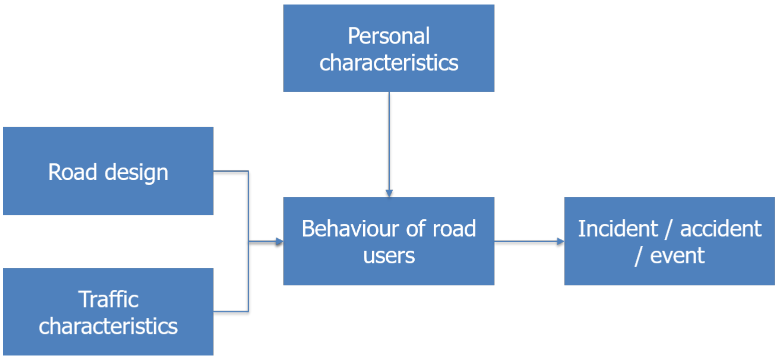


Figure 2.10: Conceptual model on the occurrence of a traffic incident (adapted and modified from [1, p. 9])

Due to the higher speeds on freeways, a collision on a freeway is more likely to cause a fatality or serious injury: the consequences of an accident are often more severe than roads with lower speeds [54].

2.2.3. Accident Data

There are two main methods to determine the safety of a road section. The most straightforward method is by analysing historical accident data such as from the BRON database as described in this paragraph. Another method is by calculating the number of conflicts using surrogate safety measures (paragraph 2.2.4 and paragraph 2.2.5).

It is a well-known problem that the official accident statistics are incomplete and biased [15]. Of all accidents that occur, some are not reported to for instance the police. And if the accident is reported, the data is often incomplete. Also, there can be errors or missing information in the data. The sources of error and data loss in official accident data can be seen in figure 2.11. This also is a problem in the Netherlands [13].

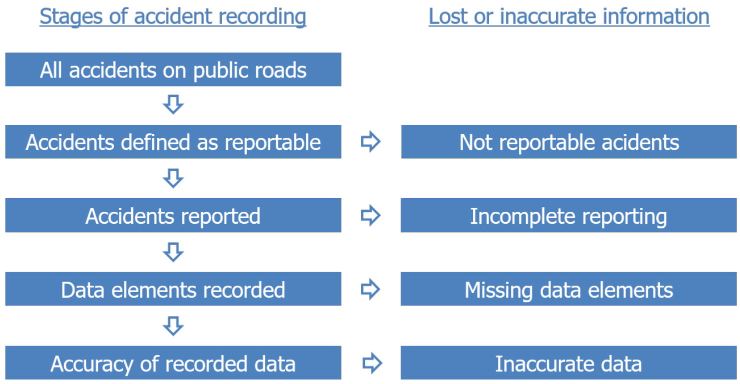


Figure 2.11: Sources of error and data loss in official accident records (adapted from [15, p. 48])

The database containing the accidents that occurred in the Netherlands is the BRON, which is an abbreviation for Bestand geRegistreerde Ongevallen in Nederland (Document Registered Accidents in the Netherlands). This document contains data on the accident on Dutch freeways for the years 2001 till 2015 which are reported to the police. The BRON defines a traffic accident as an event on public road, which relates to traffic and which causes damage to objects or injuries to people, and in which at least one driving vehicle is involved. Note that this definition differs from the definition by Gettman and Head [21] of a crash given before, as BRON also includes single-vehicle crashes. The database is composed by the Dienst Verkeer en Scheepvaart (DVS) of the Dutch Ministry of Infrastructure and Environment [61].

It is expected that 90% of the material damage only crashes are not registered, and that even not all fatal crashes are included [61]. If the police registers an accident, around 40 characteristics can be included. These are amongst others the date and time, the location (road number, left or right and hectometre position), the vehicle type, and characteristics of the victim and other vehicles involved. Many characteristics are objectively and can be determined after the occurrence of the event. If an accident cause is more difficult to determine (such as speeding) it is less frequent mentioned than a clear cause (such as giving no priority). Also, the severity of the accident is included using some abbreviations:

- *DOD* fatal crash;
- *GZH* injured and hospital stay;
- *GEH* injured with first help;
- *GOV* injured otherwise;
- *UMS* only material damage.

Many more characteristics can be included in the data file, however not everything is registered and therefore some cells are empty.

2.2.4. Definition of Conflicts

Next to accident counts, also surrogate safety measures can be used to assess safety. Surrogate safety measures are measures other than actual crash frequency that are representing the degree of safety [22]. Most surrogate safety measures use conflicts for that. A conflict is defined as [21] *an observable situation in which two or more road users approach each other in time and space for such an extent that there is a risk of collision if their movements remain unchanged*

Thus, conflicts also include events that do not lead to a real crash.

The pyramid of traffic events shown in figure 2.12 describes the various traffic events. The area of the layer describes the frequency, while the distance of the layer from the base represents the severity of the events. Thus, a majority of the traffic events are undisturbed passages. Conflicts already occur less frequent, and accidents are even rare, but have a high severity [35]. Benefit of analysing conflicts is that they are observed more frequent than crashes. However, the disadvantage of using conflicts as measure for safety is that conflicts do not directly give the number of accidents that occurs. However, there are some attempts to relate the number of conflicts and crashes by a formula [5]. A basic relationship between crashes and conflicts was initially hypothesised as [72]

$$\lambda = c \cdot \pi$$

where λ is the expected number of crashes, c is the number of conflicts and π is the crash-to-conflict ratio. Later these parameters were updated to λ being the number of crashes expected to occur on an entity during a certain period, c the number of crash surrogates occurring on an entity in that time and π the crash-to-surrogate radio for that entity [72]. Bared [5] proposes the following relationship between crashes and conflicts after simulating 83 four-leg urban signalised intersections:

$$\frac{\text{crashes}}{\text{year}} = 0.119 \cdot \left(\frac{\text{conflicts}}{\text{hour}}\right)^{1.419}$$

However, it is likely that another relationship is applicable for freeway weaving sections.

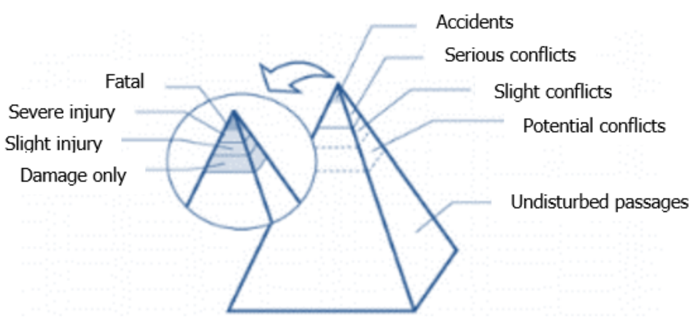


Figure 2.12: Pyramid of traffic events (adapted from [35, p. 2])

2.2.5. Surrogate Safety Measures

Conflicts are observed in practice when for example the braking-lights of a vehicle are lightning up. Surrogate safety measures can be calculated by analysing vehicle trajectories. These vehicle trajectories can be obtained from video data or from micro-simulation models. There are many surrogate safety measures, some of which will be discussed. Table 2.1 gives an overview of the described surrogate safety measures.

Table 2.1: Overview of Surrogate Safety Measures

Symbol	Description	Goal	SSAM
H	Time headway	Time between leading and following vehicle passing a point. Better for enforcement than for safety evaluation.	No
TTC	Time to collision	Time span left before two vehicles collide if nobody takes evasive action. Cannot be used if leading vehicle drives faster than following vehicle. Often mentioned for safety evaluation.	Yes
PICUD	Possibility index for collision with urgent deceleration	Probability that two consecutive vehicles collide under assumption that leading vehicle applies emergency brakes.	No
MTTC	Modified TTC	Alternative for TTC in which more situations can be included.	No
TET	Time exposed TTC	Includes duration of exposure to critical TTC	No
TIT	Time integrated TTC	Includes impact of the TTC value.	No
PET	Post encroachment time	Time difference between passage of road users over a conflict area.	Yes
DR	Initial deceleration rate	Initial deceleration rate of following vehicle.	Yes
MaxD	Maximum deceleration rate	Maximum deceleration rate of following vehicle.	Yes
DRAC	Deceleration rate to avoid crash	Minimum deceleration rate required by following vehicle to come to a timely stop.	No
CPI	Crash potential indicator	Compares DRAC to maximum available deceleration rate.	No
PSD	Proportion of stopping distance	Ratio of remaining distance to collision point to minimum acceptable stopping distance.	No
MaxS	Maximum speed	Maximum speed of vehicles involved in a conflict (i.e. situation in which TTC is below a threshold value).	Yes
DeltaS	Maximum speed differential	Maximum relative difference between speeds of two conflicting vehicles.	Yes
MaxDeltaV	Vehicle velocity change	Maximum change between conflict velocity and post-collision velocity for conflicting vehicle.	Yes

Vogel [66] makes a comparison between the time headway (H) and time to collision (TTC), which both are an indicator that can be used to estimate the criticality of a traffic situation. The *time headway (H)* is defined as the time between a vehicle passing a point and the following vehicle passing the same point:

$$H = t_F - t_L$$

where H is the time headway, t_F the time at which the following vehicle passes a certain point and t_L the time at which the leading vehicle passes the same location. However, it turned out that there was no direct relation between the occurrence of traffic conflicts.

The *time to collision (TTC)* indicates the time span left before two vehicles collide, if nobody takes evasive action, and thus is an indicator for conflicts. The TTC is calculated as [35, 42]

$$TTC = \frac{X_L - X_F - l_L}{v_L - v_F} \quad \forall\ v_F > v_L$$

where the subscript L is refers to the leading vehicle and the subscript F indicates the following vehicle. v_i denotes the speed of vehicle i at time t, X_i denotes the position of vehicle i at time t, l_i the length of vehicle i. However some definitions do not include the length of the vehicle [7, 44]. It is assumed that both vehicles continue without changing speed [66] and thus potential conflicts due to acceleration and deceleration of the vehicles are ignored [44]. The TTC cannot be used if the leading vehicle drives faster than the following vehicle as in that case no conflict occurs in future.
Vogel [66] concludes that the time headway is better used for enforcement purposes, while the TTC can be used to evaluate traffic safety.

As the TTC cannot be calculated when the leading vehicle is driving faster than the following vehicle, the *possibility index for collision with urgent deceleration (PICUD)* is introduced by Bin et al. [7]. The PICUD evaluates the possibility that two consecutive vehicles might collide under the assumption that the leading vehicle applies its emergency brakes. The PICUD is calculated as

$$PICUD(m) = \frac{v_L^2 - v_F^2}{2\alpha} + S_0 - v_F \Delta t$$

where v_L and v_F denote the speed of the leading vehicle L and following vehicle F respectively, S_0 is the distance between the vehicles, Δt the driver's reaction time and α the deceleration rate to stop.

The *modified TTC (MTTC)* is suggested as an alternative for the TTC by Ozbay et al. [44], such that more situations can be included. Table 2.2 shows the situations that can occur. Here v_F, a_F, v_L and a_L are the speed (m/s) and acceleration (m/s^2) of the following and leading vehicles respectively. The MTTC is calculated as follows [44]:

$$MTTC = \begin{cases} t_2 & \text{if } \Delta a \neq 0 \text{ and } t_1 \geq t_2 > 0 \\ t_1 & \text{if } \Delta a \neq 0 \text{ and } t_2 > t_1 > 0 \\ t_1 & \text{if } \Delta a \neq 0 \text{ and } t_2 \leq 0 < t_1 \\ t_2 & \text{if } \Delta a \neq 0 \text{ and } t_1 \leq 0 < t_2 \\ \frac{D}{\Delta v} & \text{if } \Delta a = 0 \text{ and } \Delta v > 0 \end{cases}$$

where

$$t_1 = \frac{-\Delta v - \sqrt{\Delta v^2 + 2\Delta a D}}{\Delta a} \qquad t_2 = \frac{-\Delta v + \sqrt{\Delta v^2 + 2\Delta a D}}{\Delta a}$$

and $\Delta v = v_F - v_L$ is the relative speed in m/s, $\Delta a = a_F - a_L$ is the relative acceleration in m/s^2, D is the initial relative distance.
The MTTC threshold value is set to 4 seconds in the study by Ozbay et al. [44]. However, even as for the TTC, this value is dependent on circumstances such as the performance of the vehicle and the traffic conditions. To determine the severity of the crashes they proposed a new crash

Table 2.2: Possible scenarios between two vehicles with one following the other [44]

v	$v_F > v_L$			$v_F \leq v_L$		
a	$a_L > 0$	$a_L < 0$	$a_L = 0$	$a_L > 0$	$a_L < 0$	$a_L = 0$
$a_F > 0$	P	C	C	P	C	P
$a_F < 0$	P	P	P	I	P	I
$a_F = 0$	P	C	C	I	C	I

C = conflict occurs; P = possible conflict; I = Impossible conflict with each other

index (CI), which is calculated based on the influence of speed on kinetic energy involved in collisions and the likelihood of a potential conflict. However, this measure is only useful for comparing alternatives, and not as absolute indicator for safety.

Many more variations on the TTC exist. The *time exposed TTC (TET)* describes the duration of the exposure to safety-critical TTC values over a specified time duration. It is found by summing up all moments over a considered period that a driver approaches a vehicle with a TTC value below a certain threshold TTC value. The lower the TET value, the safer the situation is. The *time integrated TTC (TIT)* takes into account the impact of the TTC value, and is calculated by integrating the TTC-profile of the driver to express the level of safety [42].

Another surrogate safety measures is the *post encroachment time (PET)*, which represents the difference in time between the passage of the 'offending' and 'conflicting' road users over a common area of potential conflict [72]:

$$PET = t_2 - t_1$$

Here t_1 is the time at which the first road user leaves the path of the second, and t_2 is the time at which the second road user reaches the path of the first vehicle. Debnath et al. [12] state that the two vehicles should have transversal trajectories. A collision occurs if the PET equals 0.

The *deceleration rate (DR)* is the initial deceleration rate of the following vehicle. It is recorded as the instantaneous acceleration rate. If the vehicle brakes (i.e. reacts), this is the first negative acceleration value observed during the conflict. If the vehicle does not brake, it is the lowest acceleration value observed during the conflict [22].

The *maximum deceleration (MaxD)* is the maximum deceleration rate of the following vehicle. It is recorded as the minimum instantaneous acceleration rate observed during the conflict. A negative acceleration value indicates a deceleration, thus in which brakes are used or the gas pedal is released. A positive value indicates that the vehicle did not decelerate during the conflict [22].

The *deceleration rate to avoid the crash (DRAC)* is a widely used surrogate measure, and is defined as the minimum deceleration rate required by the following vehicle to come to a timely stop (or match to the speed of the leading vehicle), and hence avoid a crash. It is calculated as

$$DRAC = \begin{cases} \frac{(v_F - v_L)^2}{D_{L-F}} & \text{if } v_L > v_F \\ 0 & \text{otherwise} \end{cases}$$

which equals

$$DRAC = \frac{v_F - v_L}{TTC}$$

In this, D_{L-F} is the gap between the two vehicles. A higher DRAC value indicates a more dangerous car-following scenario [32].

The *crash potential indicator (CPI)* is often used to evaluate the road risk in safety analysis. The CPI value is calculated by comparing the required deceleration rate (DRAC) and the maximum available deceleration rate (MADR). The MADR is vehicle- and scenario- specific [11].

$$CPI_i = \frac{\sum_{t=0}^{N} P(DRAC_i(t) > MADR_i) \cdot \Delta t}{T}$$

where $DRAC_i(t)$ and $MADR_i$ are the DRAC and MADR values of the ith car-following scenario at discrete time t, and N and Δt are the total number and duration of the time intervals and $T = N \cdot \Delta T$ is the total investigated time duration [32].

The *proportion of stopping distance (PSD)* is defined as the ratio of the remaining distance to the point of collision to the minimum acceptable stopping distance:

$$PSD = \frac{RD}{MSD}$$

where RD denotes the remaining distance to the potential point of collision and MSD represents the minimum acceptable stopping distance. The latter is based on the speed of the following vehicle and the maximum acceptable deceleration rate (calibrated as 3.92 m/s^2). Situations in which the PSD is less than 1 are regarded as unsafe as they indicate that even with maximum braking a collision cannot be avoided [32].

The *maxS* is the maximum speed of the vehicles involved in a conflict event, thus in a situation in which the TTC is below a certain threshold value.

The *DeltaS* is the maximum relative speed of the two vehicles involved in the conflict event, thus the difference between the speeds of the two vehicles. This surrogate is measured at the time at which the TTC was minimum. If $\vec{v}_L$ and $\vec{v}_F$ are the velocity vectors of the two vehicles, then

$$DeltaS = ||\vec{v}_L - \vec{v}_F||$$

Assume the two vehicles have equal speed v. Then, if they are travelling in similar direction, DeltaS equals 0. If they have a perpendicular crossing path then DeltaS equals $v\sqrt{2}$. If they are approaching each other head-on then DeltaS is $2v$ [22].

The *MaxDeltaV* is the maximum change between conflict velocity and post-collision velocity for either vehicle in the conflict. It is representing the severity of the conflict, assuming a hypothetical collision of the two vehicles in the conflict. Conflict velocity is determined from speed and heading on the moment that TTC was minimum.

Many more surrogate safety measures are available to detect conflicts. Although the TTC has some drawbacks, it is most frequently mentioned in literature according to Laureshyn et al. [36].

Pu and Joshi [46] distinguished between four *types of conflicts* (crossing, rear-end, lane-change and unclassified) by investigating the conflict angle and lane and link information. A very small (acute) angle indicates that the two vehicles were on nearly the same trajectories pointing on a rear-end conflict. Large angles (around 180 degrees) point on two vehicles being on head-on course. Two vehicles having a degree of around 90 degrees are on perpendicular paths. When expressing the angle from the perspective of the first car arriving at the collision point, a positive angle indicates that the second vehicle is approaching from the right and a negative angle indicates that the vehicle is coming from the left. Also, link and lane information may help to classify the type of conflicts. If two vehicles have a conflict on the same link and lane the conflict is a rear-end event regardless of the angle. If both vehicles are on the same link and one of the vehicles changes lanes, it is classified as a lane-change event regardless of the angle. However, the link and lane information is not always available and if vehicles are on different links and lanes the angle should be used to classify the conflict type. In such cases the classification is as follows (figure 2.13) [46]:

- *Unclassified* conflict angle unknown;
- *Crossing* conflict angle is larger than $85°$;
- *Rear-end* conflict angle is less than $30°$;
- *Lane-change* conflict angle is between $30°$ and $85°$.

These threshold values were found by limited experimentation, and in some situations it can be difficult to classify the type of conflict.

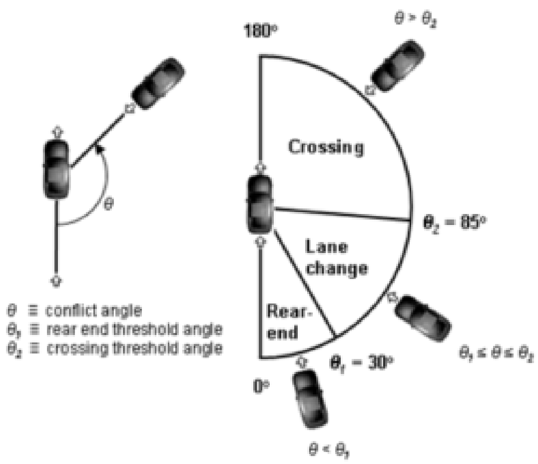


Figure 2.13: Conflict angle between two vehicles determines the type of conflict [46]

3
Literature Review

Several relations between road design and safety are described in literature. Section 3.1 describes some safety research on weaving sections in the Netherlands. Section 3.2 describes (international) researches that compare different types of weaving sections and analyse crash data to identify design and traffic flow factors that affect safety. Section 3.3 focuses on how micro-simulations and surrogate safety measures are used to assess road safety. Section 3.4 describes the research gaps.

3.1. Weaving Sections in the Netherlands

In the Netherlands some research is performed on the safety of weaving sections.

Arcadis [1] performed on behalf of the Dutch road authorities Rijkswaterstaat a traffic safety research on the weaving section on the A27 between nodes Lunetten and Rijnsweerd, on which extra lanes are added in the summer of 2012. In the research accident and traffic data before, during and after the road works were analysed, an assessment of the road design has taken place on the weaving section and a benchmark with similar weaving sections in the Netherlands is executed. The accident risk on the weaving section between Lunetten and Rijnsweerd decreased after building the extra lanes, due to extra capacity for performing weaving manoeuvres. However, the risk of this weaving section is still at the top of the range of risk numbers investigated for researched weaving sections in the Netherlands. Main reason for this is the complexity of the weaving section: a combination of high number of lanes, high traffic density and high number of weaving manoeuvres leads to a more difficult driving task.

In another research for Rijkswaterstaat, Arcadis [2] performed an analysis on the safety of the intersections at Hoogeveen and Drachten, which also includes an analysis of the weaving sections. Speeds, intensities and crash data are analysed, and a VOA-analysis is done. They found that weaving sections are shorter than is required according to the guidelines and that no collector/distributor lanes are present, which results in speed difference between traffic on the main road and weaving traffic. Also, sight is decreased due the positioning of trees, and signage is not always placed at the optimal location.

Iliadi et al. [29] included a sample of 110 symmetric weaving sections distributed over the motorway network in the Netherlands to develop a crash prediction model. After investigating several factors that might need to be included in the crash prediction model, the following factors were included in the final model:

- Length of the weaving section;
- AADT;
- Number of lanes on the main freeway;
- Percentage (share) of weaving cars;
- The location of the weaving section relative to an interchange (inside or outside);

This resulted in the following formula predicting the number of crashes for a three-year period:

$$N = 4.46 \cdot 10^{-5} \cdot LENGTH^{0.46} \cdot AADT^{0.88} \cdot e^{0.35LANES + 1.05SHARE - 1.67LOC}$$

Factors that were investigated but not included in the final model are the share of trucks, share of weaving trucks, the interchange type (i.e. cloverleaf, clover-turbine, etc.) and symmetry. Brouwer [8] concluded already in 1975 that the likelihood of a crash increases strongly for shorter weaving sections and weaving sections with a high traffic flow. The latter is not surprising as more vehicles lead to more conflicts and thus more crashes. It is mentioned that if the daily traffic flow (in one direction) is less than 10.000 vehicles the crash likelihood is low. It is stated that the number of crashes at cloverleaf on- and off-ramps is determined by (I) the likelihood of a conflict between entering and exiting vehicles and trough-going vehicles, (II) the ability of the driver to detect potential conflicts and (III) the ability and willingness of the driver to behave in such a way that conflicts are avoided. Another conclusion is that results from the United States may not be generalised to the Dutch situation due to other speed regulations, different acceleration and deceleration performances and a different driving style and willingness to cooperate.

Heikoop and Henkens [26] noticed that capacities of weaving sections are included in the fourth edition of the Dutch HCM in their analysis on the history and recent developments of the Dutch HCM (Highway Capacity Manual).

Also Minderhoud and Elefteriadou [43] reviewed the Dutch guidelines and made a comparison with the HCM2000 guidelines for the U.S. Highways. The most significant difference is that the HCM uses the volume-ratio for describing the proportion of weaving traffic, while the Dutch approach uses the weaving proportion of the leg with the smallest incoming flow. This makes a fair comparison between the guidelines difficult. However, both procedures also have similarities. Their analysis showed that it is important to consider the weaving proportions per leg, which neither the HCM nor the Dutch approach does. They also recommend to introduce an additional variable which includes the presence of asymmetrical weaving flows. However, the focus of the research is more on capacity and less on safety.

3.2. Relation between Configuration and Crash Data

In international literature, many researches can be found that discuss influences of different design characteristics of weaving sections on safety. Some of these researches compare the different types of weaving sections by analysing crash data. Part of them includes effects of design characteristics by for example developing Crash Modification Factors (CMFs).

Golob et al. [24] used accident data of 55 weaving sections in Southern California to compare the three types of weaving sections (A, B and C) distinguished in the HCM2000. They found no difference in accident rates, but there were differences in severity, location of the primary collision, the factors causing the accident and the period in which accidents are most likely to occur. There is no significant difference between accidents located within or outside weaving sections when considering the number of vehicles involved, the involvement of a truck, weather conditions, and distribution of accidents over time of the day and day of the week. Accidents on type A weaving sections are the least severe. Most conflicts occur at off-peak hours, but no collision type is predominant. Accidents on type B weaving sections are likely to be more severe and may be caused due to speed differences between weaving and non-weaving traffic. On type C weaving sections most conflicts occurred at the left lane during weekday rush hours, possibly due to speeding. These crashes are typical lane change crashes. Recommendations such as improving signage, lighting and speed limits are given.

Liu et al. [39] also compared for the three weaving section types A, B and C the crash frequency, crash rate, crash severity and includes next to that the collision type. Moreover, crash prediction models to relate crash counts to various explanatory variables such as traffic conditions and geometric characteristics are developed. As a result it was found that type C weaving sections have the lowest average crash frequency and crash rate, while also in this research type B weaving sections report the highest average crash frequency, crash rate and percentages of fatal and severe injuries. The most frequent are rear-end crashes. Crash data analysis results suggest that type B weaving sections should be used cautiously when entrance and exit ramps are closely spaced.

Qi et al. [48] reviewed literature, conducted data analysis on 16 weaving sections, developed a model for predicting safety impacts of geometric design elements for weaving sections and provided recommendations. They found that the crash frequency on a weaving section was significantly affected by the weaving section length, the minimum number of lane changes from freeway to onramp, the average daily onramp traffic and the average daily off-ramp traffic. Although counter-intuitive, an increase in merging traffic slightly reduces the crash risk. The interpretation of the CMFs according to the American Highway Safety Manual for length of the weaving section, length of the deceleration lane and modification of a two-lane to one-lane change area are explained, indicating that these factors are relevant for traffic safety. Qi et al. [48] refer to a research by Bauer and Harwood (1998) on ramp safety, which includes the FAADT, RAADT, area type, ramp type, ramp configuration, right shoulder width and lengths of ramp and speed change-lane as explanatory variables in the regression modelling. The RAADT explained most of the variability in the accident data: crash frequency increases when RAADT increases. Qi et al. [48] selected the following candidate variables for the development of a CMF: (I) weaving section length, (II) minimum number of lane changes from freeway to off-ramp, (III) average daily onramp traffic, (IV) average daily off-ramp traffic, (V) minimum number of lane changes from onramp to freeway and (VI) average daily through traffic. However, only the first four variables were found to be significant at the confidence level of 95%.

Park et al. [45] investigated the safety effects of two design elements: ramp density and horizontal curve. They had no specific focus on weaving sections. Five years of crash data is collected in Texas to apply negative binomial regression models to estimate the effects of independent variables on crashes. Their models reveal that crashes on freeway segments are associated with ADT, onramp density, degree of curvature, median with including the inside shoulder, number of lanes (for urban freeways) and whether the freeway is in urban or rural area. Off-ramp density was initially included in the model, but removed later as it was not significant. From this, CMFs were developed for onramp density and horizontal curves that can be used to predict safety.

Sarhan et al. [54] analysed 26 interchanges to quantify the effects of ramp terminal spacing and traffic volumes on safety performance through regression analysis. They developed negative binomial models which relate traffic volume and geometric features to collision frequency. A total of 18 statistically significant models was found. Safety performance depends on the behaviour and abilities of road users to adjust speeds without causing undue hazards to themselves and to other road users. Also, the spacing between onramp and off-ramp should be sufficient to provide enough length for acceleration, deceleration and executing the weaving manoeuvre. Also, the length of the speed-change lanes is an important factor. Ideally, drivers are able to complete the merging manoeuvre before reaching the end of the acceleration lane and not force themselves to merge in an inappropriate gap. They found that an increase in the number of vehicles that enter or exit the freeway leads to an increase in the number of collisions on the segment. Increasing the length of the speed change lane leads to a decrease in the number of crashes. However, in cases that warrant an increase or decrease in basic number of lanes, extending the speed change lane length is not helpful. In that case they advise to change the number of lanes away from the influence area of the speed change lane. They also advice to provide the speed-change lane with a tapered portion at the end and beginning of acceleration and deceleration lanes. Off-ramps designed for relative high speeds allow safer operational conditions compared to designs for relative lower speeds. Moreover, similar to other researches it is concluded that type A weaving sections have relative less collisions compared to type B.

Bared et al. [6] did not focus on weaving sections in particular, but developed a formula to predict the accident frequency at ramps as a function of speed change lane length and other ramp characteristics such as the AADT and design:

$$
\begin{aligned}
N = RAADT^{0.78} \cdot FAADT^{0.13} \cdot \exp(& -7.27 + 0.45DIA + 0.78PAR - 0.02FF + 0.69OC \\
& - 0.37RUR + 0.37DECEL - 2.59SCLEN + 1.62RLEN)
\end{aligned}
$$

Here,
- N is the expected number of accidents in a three-year period on the entire ramp combined with speed-change lane;
- $RAADT$ is the ramp AADT;
- $FAADT$ is the mainline freeway AADT;
- DIA, PAR, FF and OC are dummy variables being 1 if the ramp is a diamond, parclo loop, free-flow loop or outer connection ramp respectively, and 0 otherwise;
- RUR is 1 if the area type is rural and 0 otherwise;
- $DECEL$ equals 1 if the area is an off-ramp and 0 otherwise;
- $SCLEN$ and $RLEN$ are the speed change lane length and ramp length respectively.

All factors are significant in the model at the 10% level, except for the $FAADT$ which is significant at 20% but is included based on expert judgement. Next to that they evaluated the cost-effectiveness of extending speed change lanes. Special attention is asked for the deceleration lanes as these have higher accident rates. From a safety and economic perspective, they concluded that the minimum lengths of acceleration lanes are comparable to the lengths recommended by the AASHTO.

Le and Porter [37] also researched the relationship between ramp spacing and freeway safety. Data from 404 freeway segments in California and Washington State are used to develop models that predict the total number of crashes, the number of crashes with fatalities and injuries and the number of multiple-vehicle crashes for freeway ramps. They are all depending on several factors, but the coefficients differ per crash severity type. These influencing factors are the length of the segment, the average daily traffic volume upstream of the ramp in one direction, the average daily traffic volume on the entrance and exit ramp, the inverse of the ramp spacing and the ratio between ramp spacing and length of the auxiliary lane, the number of lanes, the relative vertical position of the mainline to the cross street associated with the entrance and exit ramp, the presence of a ramp metering installation, the presence of a lane for high occupancy vehicles and an indicator for the location of the ramp (i.e. Interstate 5 or 10 at California or Interstate 5 near Washington).

Pulugurtha and Bhatt [47] focused on evaluation the role of weaving section characteristics and traffic variables on number and type of crashes in weaving areas. They included as weaving section characteristics the configuration type, length and number of required lane changes. Traffic variables include entry volume, exit volume and non-weaving volume. They did this evaluation using data of 25 weaving sections around Las Vegas. Corresponding to other researches they found that the number of crashes tends to decrease when the length of the weaving section increases. An increased entry volume leads more crashes due to improper lane changes and ran off roadway crashes. Increase in exit-volume however leads to an increase in rear-end crashes and crashes due to a too close following distance and inattentive driving. Also, the non-weaving volume appears to play a role in explaining crash type and contributing factors. Again, type A weaving sections showed to be safer than the other types.

Kusuma et al. [33] did an analysis of driving behaviour at one weaving section in the United Kingdom by analysing traffic surveillance camera views and loop detector data. It was found that 25.25% of the weaving manoeuvres took place in the first 50-100 meters of the weaving section. Also, it is found that for movements that require more than one lane change, around a half is staggered and the other half is direct. However, a major part of the 408 observed vehicles performed no or only one lane change.

3.3. Surrogate Safety Measures and Micro-Simulations

A majority of the literature focuses on data analysis and subsequently comparing the three weaving section types A, B and C or on developing crash modification factors and formulae to predict the number of crashes based on certain road design and traffic flow characteristics. However, also simulation models are proposed for assessing traffic safety. Bared [5] emphasises that a major benefit of using simulation models is that there is no need for having a sufficient large accident data base. Moreover, the analysis of accident data is a slow process and results are influenced by the infrequent and random nature of crashes.

Yang et al. [71] also pointed on the benefit of using micro-simulations above other methods which are having limitations due to data availability. They propose a new time-based surrogate safety measure: the minimum time to collision (MTTC). Its application was demonstrated through micro-simulations of case studies on two highway sections in New Jersey Turnpike. The indicator was shown to be capable of highlighting real dangerous locations, but there are some underlying influential factors which cannot be explained by the indicator. However, it is suggested that the indicator has the capability to be applied for safety analysis using micro-simulations.

Bared [5] describes that it is possible to derive surrogate safety measures from micro-simulation results using the Surrogate Safety Assessment Model (SSAM). These surrogate safety measures include amongst others the time to collision (TTC) and minimum post-encroachment (PET). A relationship between conflicts per hour and crashes per year was found. However, there is need for further research on interpretation and comparison of such surrogate safety measures.

Gettman et al. [22] did an evaluation study of SSAM for the FHWA. They performed theoretical tests which compared pairs of simulated design alternatives and a field validation exercises which compared output from the real world to the simulation output. The comparison of design alternatives did not always lead to a clear design preference but rather a trade-off of surrogate safety measures. The simulation conflicts were found to correlate weakly but significant to the field crash data ($\rho_s = 0.463$). After a sensitivity analysis it is concluded that volume-based prediction models provide a better correlation to field data.

Fan et al. [18] used the micro-simulation model VISSIM in combination with SSAM to compare conflicts observed in the field with conflicts generated by the micro-simulation model. Their calibration model reduced the mean absolute prevent error for total conflicts from 78.1 to 33.4%.

Linear regression models and the Spearman rank correlation coefficient were used to study the relationship between simulated and observed conflicts. It was found that there was a reasonable consistency between simulated and observed conflicts, as a Spearman rank correlation coefficient of 0.898 was found between the safety ranks based on observed traffic conflicts and conflicts generated using the SSAM method.

Vasconcelos et al. [63] used SSAM to determine safety of different configurations for roundabouts. A strong relation between accidents predicted by regression models and conflicts predicted by simulation models was found by testing against variable demand flows. It was found that the safety performance of a turbo-roundabout is similar to a single-lane roundabout, with the advantage of offering much higher capacity levels.

In the research by Le [38] crash data is compared with the number of conflicts indicated by the DRAC-surrogate. A consistent and reliable link – although not strong – between conflicts and actual crash data has been found. Although simulating conflicts is not what the current simulation models are designed for, microscopic simulations have potential in applications in traffic safety studies. However more research with larger data sets is required for better understanding. Besides it is noted that crashes and fatalities have more impact on public perception and policy makers than alternatives such as surrogate safety measures.

Kim and Sul [30] listed some of the advantages and disadvantages of three traffic risk assessment approaches: Traffic Conflict Analysis, Accident Prediction Models and a Micro-simulation based Method. The latter method is used in combination with SSAM to evaluate the safety and consequences of some changes in design of urban intersections, such as changing the speed limit. They concluded that a good correspondence of the model with traffic conditions in terms of speeds and flows is not sufficient in the field of safety analysis. Microscopic models are more representative for calculating safety indicators than macroscopic models, but the usefulness depends on how well it replicates the real-world traffic flow and driver behaviour. Also, the threshold value settings of SSAM need to be further investigated for future use.

Also the research by Huang et al. [28] has as objective to identify if a combination of the VISSIM simulation model and the SSAM approach provides reasonable estimates for traffic conflicts. Their focus was on signalised intersections, and they compared the simulated conflicts with the conflicts in the field. Results of the data analysis showed that the goodness-of-fit was reasonable ($\rho_s = 0.916$) between the simulated and observed rear-end and total conflicts. However, the simulated conflicts were no good indicators for conflicts that occurred due to unexpected driving manoeuvres such as illegal lane-changes in the real world.

Also the objective of El-Basyouny [14] is to perform a field validation of SSAM by comparing predictive safety performance capabilities of SSAM with actual accident experience at Canadian signalised intersections. A poor relation was found, and it was concluded that traffic volumes can explain more variation in occurrence of accidents than simulated conflicts obtained from SSAM. The poor relation could be associated to the manner by which an intersection was modelled in VISSIM as changing model parameters resulted in considerable variations in number of conflicts.

In a study by Dijkstra et al. [13] a regional road network in the west area of the Netherlands was simulated and the number of conflicts is calculated and compared to crash data. A statistical relationship between the number of conflicts at priority junctions per number of passing vehicles and the number of observed crashes was found. However, there were clear differences between the number of frontal crashes and frontal conflicts.

Essa and Sayed [17] investigated the transferablility of calibrated parameters in VISSIM for safety analysis between different sites. Their main purpose was to assess whether parameters calibrated for one site provide reasonable results in terms of correlation between field-measured and simulated conflicts for another site. Six parameters were identified as important for the safety analysis. Two of them (CC1 and desired deceleration) were directly transferable, three (CC0, reduction factor for safety distance closed to stop line and start upstream of stop line) were transferable in some degree and one (CC4&CC5) was not transferable. They also mention that first calibrating on delay times and thereafter calibration of driving behaviour parameters results in a stronger correlation between field-measured conflicts and simulated conflicts. By transferring calibrated parameters this calibration procedure can be shortened.

Most researches thus apply simulation models and surrogate safety measures on controlled intersections, and not on freeways or weaving sections in particular. Some researches show a reasonable fit between simulated conflicts and observed crashes or conflicts, others indicate that the quality of the simulation model is important or emphasise that more research is required.

3.4. Conclusions and Research Gaps

As described in chapter 1 more research on the optimal length and configuration of Dutch weaving sections for safety is desired by the SWOV and road designers.

In previous sections some researches are listed that have researched the safety of freeway weaving sections. A majority did this by analysing crash data and comparing different types of weaving sections and developing crash modification factors. Only one of these researches focused on the Dutch situation.

The drawback of using crash data for safety evaluation is that it takes a long time before a sufficient large crash database is available. Hence it is suggested that surrogate safety measures are a good alternative for crash data. The Surrogate Safety Assessment Model (SSAM) is able to derive surrogate safety measures from vehicle trajectories generated using micro-simulations. Already some research is performed on the usage of surrogate safety measures as predictor for traffic safety as described in paragraph 3.3. However, these researches mostly focused on controlled intersections, and not on freeways and weaving sections in particular. Also, these researches were executed using field data from other countries than the Netherlands.

Thus, research on the applicability of micro-simulation models in combination with surrogate safety measures for estimating and predicting safety of Dutch weaving sections is needed. It is uncertain whether micro-simulation models are sufficient accurate are representing driving behaviour for safety analysis. Also deeper insight in the exact relation between surrogates and safety is needed. Therefore, the research question and sub questions as described in the next chapter 4 are defined.

4

Research Methodology

This chapter gives in section 4.1 a description of the research methodology. The procedure and outcomes of the first step, which is an initial analysis of traffic safety of Dutch weaving sections, will be presented in section 4.2. Section 4.3 describes which weaving sections are selected for further analysis and includes characteristics of these weaving sections. In section 4.4 it is described that expert judgement based on human factors analysis and a CPM can result in reference rankings. Section 4.5 describes the data collection and modification process required to perform the simulation, and how SSAM can be used to calculate the number of conflicts from a VISSIM simulation.

4.1. Methodology

The research question which is defined in section 1.3 is

How representative are surrogate safety measures calculated from VISSIM micro-simulations with SSAM for predicting the safety of Dutch weaving sections?

This research question will be answered after comparing safety predictions from VISSIM micro-simulations and SSAM with safety in the real situation. For that, answering the following sub-questions is required:

Q1 Which factors do influence the safety of a weaving section according to literature?

Q2 Which criteria are important for selecting a sample of weaving sections for this study?

Q3 What are the characteristics of accidents that occurred on the weaving sections?

Q4 How do road design and traffic characteristics contribute to the occurrence of crashes?

Q5 Is there a correlation between the ranking based on crash registrations, the ranking based on expert judgement, the ranking based on the crash prediction model and the ranking based on simulated conflicts?

Q6 What explains eventual differences between the rankings?

As a literature research is already included in chapter 3, the following steps are required to answer the sub-questions and research question:

Step 1. Initial analysis of traffic safety of Dutch weaving sections based on crash records;

Step 2. Selection of weaving sections for validation of VISSIM and SSAM;

Step 3. Detailed analysis of the selected weaving sections (crash data analysis, human factors analysis by road safety experts, risk calculation using a CPM);

Step 4. VISSIM simulation and SSAM analysis;

Step 5. Validation of SSAM results.

The process is shown in figure 4.1.

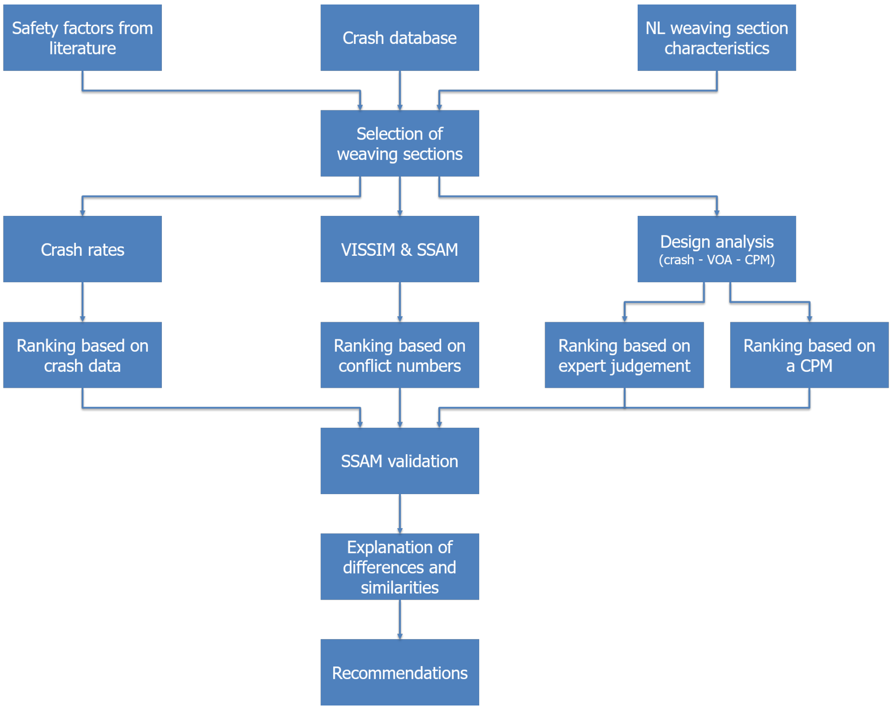


Figure 4.1: The research methodology

4.2. Analysis of Crash Records

The first step comprises an initial analysis of the safety of all weaving sections in the Netherlands. Therefore, first a crash database with all crashes that occurred will be created. Paragraph 4.2.1 describes how this database is created and what filters are applied. This paragraph also describes some characteristics of the included weaving sections. Thereafter this crash database is analysed in paragraph 4.2.2 by describing the occurrence of different crash characteristics.

4.2.1. Crash Database Development

For an initial analysis of the safety of all Dutch weaving sections a crash database with all crashes on the weaving sections should be created. Therefore, the BRON crash databases and INWEVA traffic intensities are coupled to a GIS work file. This work file contains an aerial view of the Netherlands and a layer which includes the locations of the weaving sections.

This layer with weaving sections is created by Rijkswaterstaat (WEGGEG data base) and represents all weaving sections as a line. This weaving section layer has some slight errors, as for example some weaving sections consisted of two lines while only one weaving section was found on the aerial view. Therefore, these split up weaving sections were connected into one weaving section. This required pre-processing was done by a GIS-expert within Arcadis. A total of 505 weaving sections were found on this layer after processing. All weaving sections received a unique identification number, ranging from 1 to 505.

For analysing the safety of the weaving sections in the Netherlands the crashes should be coupled to the weaving sections. Therefore, first the BRON crash database was modified such that it was suitable for importing into GIS. The crashes were coupled to the map using the X and Y coordinates, which are registered in BRON for all crashes.

Next, all crashes on locations other than the influence area of a weaving section were removed. Vermijs [64] defined the influence area of a weaving section as the road section starting 150 meters upstream of the convergence gore and ending 150 meters after the divergence gore, as shown in figure 4.2. All crashes that occurred on the weaving section within this influence area are connected to the weaving section using the unique identification number. Appendix A describes this connection procedure.

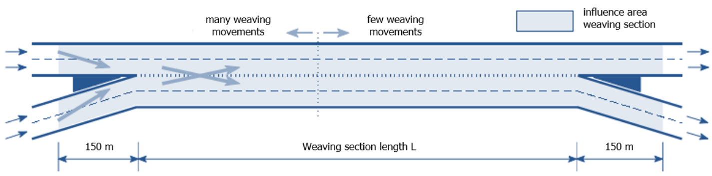


Figure 4.2: Influence area of a weaving section (adapted from [64, p.8])

A total of 28827 of all the registered crashes occurred on 502 of the road sections. On three road sections no crashes occurred. On the sections with a crash, the number of crashes ranges from 1 to 469, with an average value of 57.08 and standard deviation of 60.39. The median number of crashes per weaving section is 37. This is summarised in table 4.1.

Table 4.1: Descriptive statistics of all crashes and some weaving section characteristics (including non-weaving sections)

	Crashes	Length (m)	AADT (veh/day)	Vehicle km ($\times 10^3$ km)	Crash rate ($/10^3$ veh km)
Average	57.08	613.00	33564	23.30	4.01
Median	37	571.23	29950	17.19	2.16
Minimum	0	23.90	2775	0.43	0.00
Maximum	469	2073.00	99200	132.55	63.02
St. Deviation	60.39	348.73	19339	21.58	5.70
Sum	28827				

A major factor that is said to influence the number of crashes that occur on a weaving section is the number of lanes on the various legs. This number of lanes also determines the symmetry and influences the length of the weaving section. Therefore, this factor will be included in the weaving section database. A layer in GIS contains information about the number of lanes, but this information is not always correct. Therefore, the number of lanes is verified for each weaving section by looking at the aerial views. Figure 4.3 shows the frequencies of the different configuration types. It was found that 405 of the weaving sections have a symmetrical design, while only 67 weaving sections are asymmetrical. Most weaving sections have the 2+1 configuration, but also 3+1 and 1+1 configurations are applied frequently. It was found that 33 weaving sections were registered as weaving section while they are not according to the aerial view. In some cases these road sections ended in or started from a traffic light with multiple lanes for the different directions, in other cases these road sections were no longer weaving section due to changes in road design or due to incorrect registration. These 33 road sections are removed from the weaving sections database. Hence the final weaving sections database consisted of 472 weaving sections. Due to the exclusion of these 33 road sections also 2375 crashes were removed, such that 26452 crashes were remaining on the 472 weaving sections. Figure 4.4 shows the frequencies of the lengths of these 472 weaving sections.

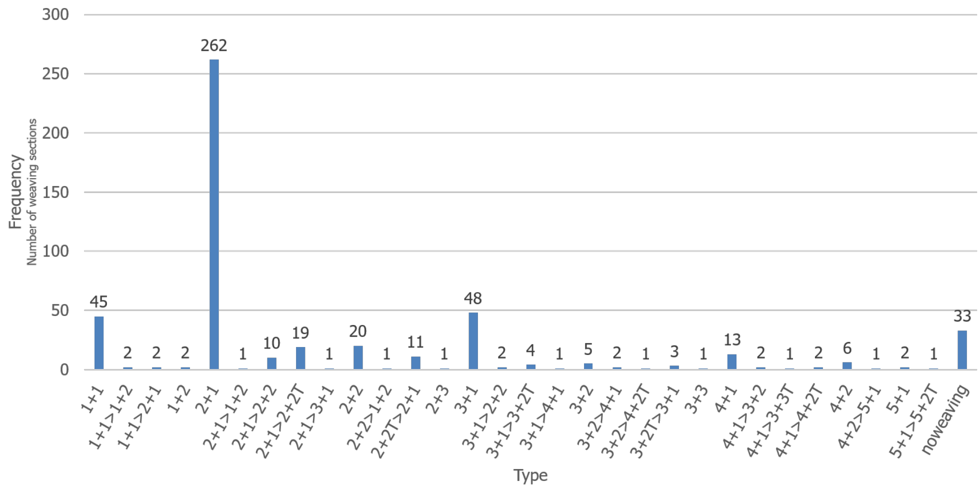


Figure 4.3: Occurrence of the various weaving section configurations

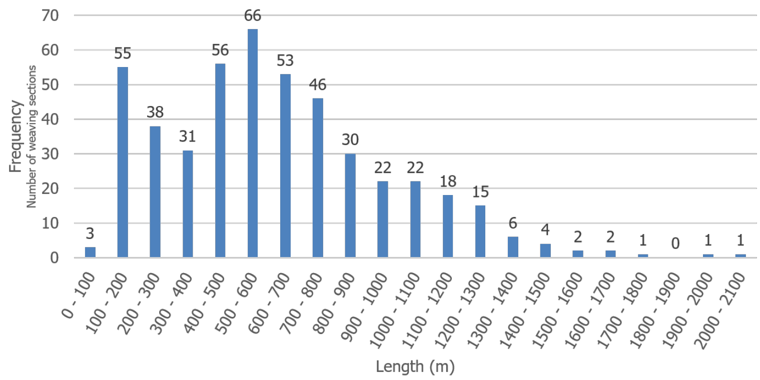


Figure 4.4: Occurrence of the various weaving section lengths

A measure for safety is the crash rate, which is calculated as the number of crashes per number of vehicle kilometres. Therefore, the number of passing vehicles will also be included in the database. For that the average amount of daily traffic for the years 2012 till 2015 is coupled to ArcGis. These intensities are obtained from the average number of passing vehicles on a weekday (MVT_E_WK_H) of the INWEVA database. The annual average number of passing vehicles (AADT) is found by averaging the intensities found for the years 2012 till 2015. The average number of daily vehicle kilometres is found by multiplying the intensity by the length of the weaving section. This results in large values, and is therefore expressed in thousands (10^3). From that the number of crashes per thousand vehicle kilometres is calculated. This results in a table of which a part is shown in table 4.2. A statistical summary of these values can be found in table 4.1.

Table 4.2: Part of the weaving sections database

ID	Crashes	Configuration	Length	AADT	Veh km ($\times 10^3$)	Crash rate	Crash rank	Rate rank
2	2	2+1	239.96	43750	10.50	0.19	375	386
3	8	2+1	1145.76	28750	32.94	0.24	233	358
4	0	1+2	141.46	6325	0.89	0.00	444	444
5	16	2+1	583.37	22375	13.05	1.23	135	81
6	0	1+1	186.77	6400	1.20	0.00	444	444
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

However not all 26452 crash registrations are suitable for further analysis, and hence some filtering is performed.

The accuracy of the location is indicated in the BRON database in the column called 'niveaukoppeling' (level of connection accuracy). It can be that the registration of the location is exact (E: Exact) or at an intersection level (K: Kruispunt), but it can also be that the registration is on street (S: Straat) level or even at municipality level (G: Gemeente). All crashes that occurred in a municipality of which the exact location is unknown are registered on one predetermined location in the network. Hence in such case it gives no information of the real location of the crash. Similar holds for streets: if only is known that a crash occurred on a street but the hectometre location is unknown, then it is assigned to a predetermined location on that street. It is advised not to include crashes with connection level S and G as it can be that such a crash occurred on another location which might be some kilometres away from the registered location, and hence not on the weaving section. All crashes with connection level S and G are removed, which leads to a reduction of 3457 crashes such that 22995 crashes are remaining.

Thereafter all crash types that clearly are not related to the design of the weaving section are removed, as these are not representative for the safety of the weaving section. This type of crash is described in the column 'AOL_OMS' of the crash database. Appendix E includes an overview of the used crash types. Crashes that are not related to the weaving section design are crashes with an animal, pedestrian, parked vehicle or flexible object. Side-swipe and rear-end crashes are typical weaving crashes and thus will be included in the analysis. After consulting a crash database expert at Arcadis it was found that side-swipe crashes sometimes are registered as head-on crashes in the database, and that also single-vehicle crashes and crashes with a fixed object could be related to the design of the weaving section. Crashes of which the cause is registered as 'unknown' will also be included in the database as this covers a very large part of the total number of crashes. This filtering on crash type reduced the number of crashes to 22347, which is another reduction of 648 crashes.

The crash database contains crashes that occurred between 2001 and 2015. As the road design is changed at some locations between these years, some crashes will be related to a weaving section configuration which was not designed that way at the time of the crash. Hence some years should be selected for further analysis.
It is preferred to remove the crashes in earlier years as more data on for example the road design and traffic intensities is available for more recent years. However, it is generally known that for the years 2009 till 2011 the degree of crash registrations was low in the Netherlands [61], which can also be concluded from figure 4.5, showing a lower number of crash registrations in these years. Therefore, it is not desired to select these years for further analysis. However, for the years 2012 till 2015 the degree of registration has improved again. Hence these years are selected for further analysis. Removing the crashes that occurred in the years 2001 till 2011 leads to another reduction of 15548 crashes, such that 6799 crashes remain in the final database.

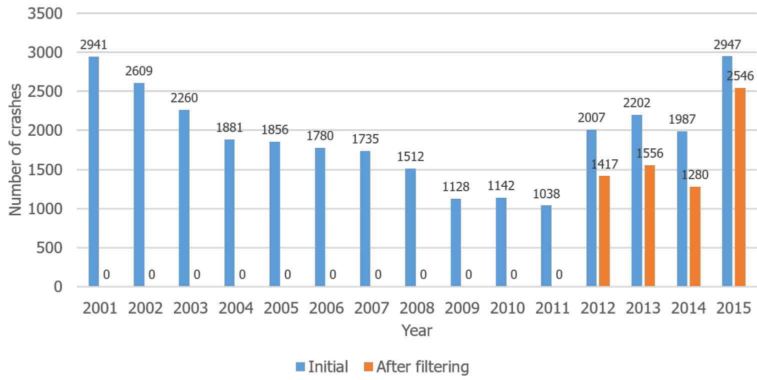


Figure 4.5: number of crash registrations between 2001 and 2015

4.2.2. Crash Database Analysis

The final crash database consists of 6799 crashes that occurred on 443 weaving sections. On 29 weaving sections no crashes (that satisfy the filter) occurred. Table 4.3 describes some statistics of this final data set after filtering. The total crash database including the ranking based on absolute number of crashes and on crash rate can be found in appendix B.

Figure 4.6 shows that on most weaving sections between 1 and 10 crashes occurred. The two weaving sections with the highest number of crashes had between 121 and 130 registered crashes. Figure 4.7 describes how many weaving sections have a certain crash rate. On most weaving sections between 0 and 1 crashes occurred between 2012 and 2015 per thousand daily vehicle kilometres.

Figure 4.8 shows how frequent the various crash types occurred in the initial crash data set and in the final data set after filtering. For most crashes the cause is unknown. Rear-end and side-swipe crashes occurred frequently in the initial data set, even as crashes with a fixed object. After filtering the share of unknown crashes increased clearly, and the share of single-vehicle crashes increased slightly, while the shares of side-swipe and rear-end decreased. This can

Table 4.3: Descriptive statistics of crashes after filtering and some weaving section characteristics

	Crashes	Length	AADT	Vehicle km ($\times 10^3$)	Crash rate
Average	14.40	624.12	33505	23.75	0.88
Median	8	580.63	30163	17.78	0.50
Minimum	0	23.90	2775	0.43	0.00
Maximum	128	2073.00	99200	132.55	27.15
St. Deviation	17.68	347.92	19458	21.91	1.85
Sum	6799	294583.24	15814475	11211.53	417.43

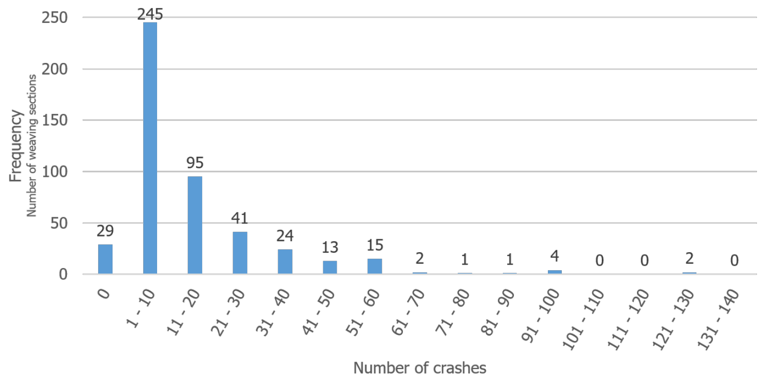


Figure 4.6: Number of crashes per weaving section

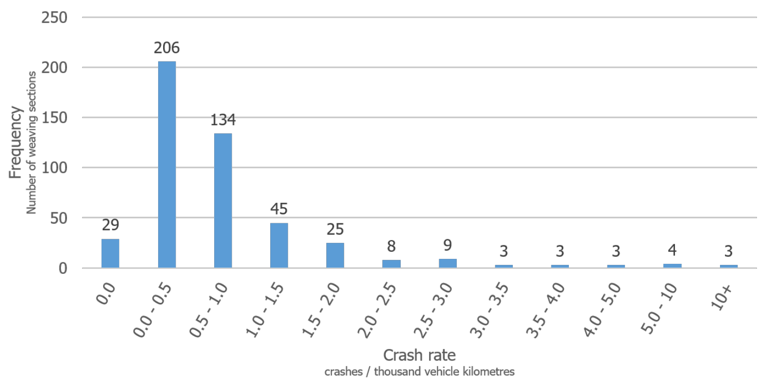


Figure 4.7: Crash rate per weaving section

be caused by the decreased crash registration quality in the last years, due to which for more crashes the type is registered as 'unknown'.

A majority of the crashes resulted in only material damage as can be seen in figure 4.9. Figure 4.9b makes a distinction into the type of injury in terms of hospital stay. The meaning of the (Dutch) abbreviations is as follows:

- *DOD* fatal crash;

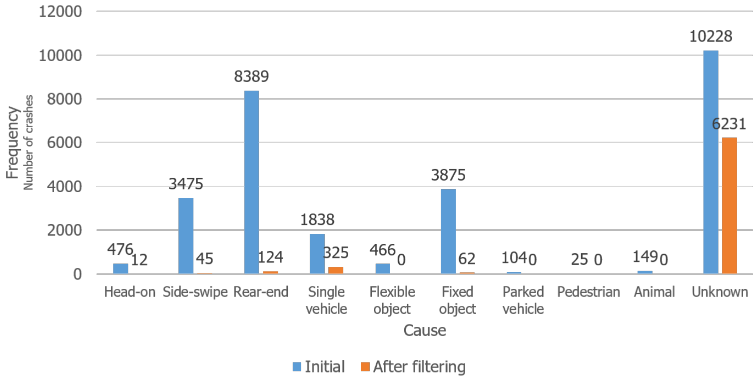
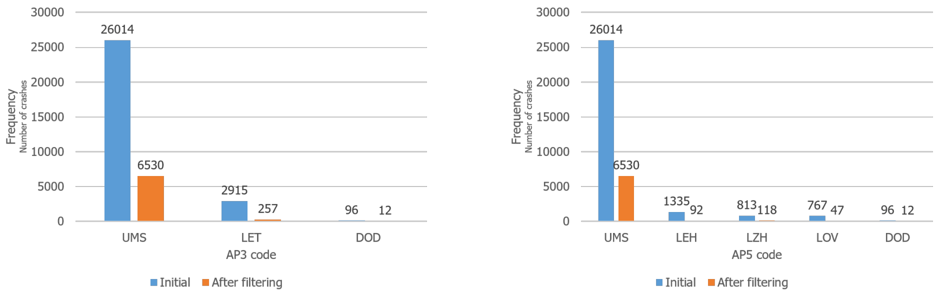


Figure 4.8: Occurrence of different crash types

- *GZH* injured and hospital stay;
- *GEH* injured with first help;
- *GOV* injured otherwise;
- *UMS* only material damage.

Only the severity of the person involved with the highest severity is registered. So, it might be that there is a fatality and also a person that went to the first help, then the crash is registered as a fatal crash.
However, research showed that although someone is registered as hospital injured this person is not necessary severely injured. According to the SWOV [61] the number of hospital injuries hence is not a good measure for the number of severe injuries, and it is better to determine the severity using the AIS-score (AIS stands for Abbreviated Injury Scale). In the Netherlands a person has a 'severe injury' if the person stayed in hospital, is treated in a (Dutch) hospital and has an injury with an AIS-score of 2 or higher.



(a) AP3 categories

(b) AP5 categories

Figure 4.9: Occurrence of different crash impacts

Figure 4.10 shows how many parties are involved in the crashes. In the majority of the crashes one or two vehicles were involved. In 759 of the registrations there was only one vehicle involved, and in 700 crashes two vehicles were involved. However, for a majority of the crashes (5198) it is not registered how many vehicles were involved.

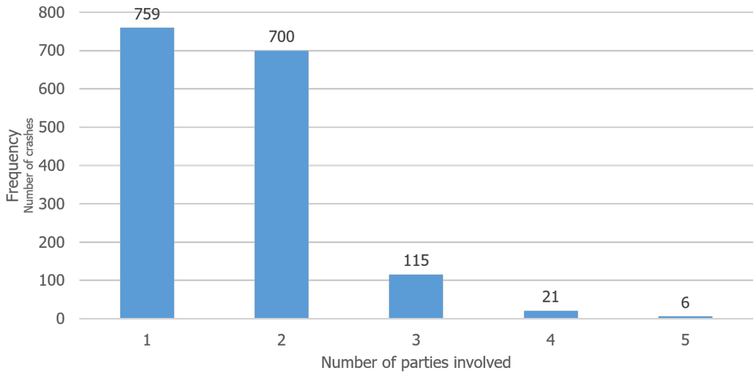


Figure 4.10: Number of parties involved

The blue bars in figure 4.11 show the type of vehicle that caused the crash. In most cases this is a passenger car. This is in line with the expectations as passenger cars have the largest share in the entire vehicle fleet on freeways. If two vehicles were involved, the type of the second vehicle is indicated by the orange bar, and in case of a third party the type is indicated using the grey bars. If more than three parties are involved the type is not registered. However, sometimes a third vehicle type is registered while the number of vehicles involved is not registered in the crash database, so the values in figure 4.10 and figure 4.11 do not correspond. Next to the most common vehicle types also trees, lightning poles, road furniture, bikes, mopeds, agricultural vehicles and other vehicles and fixed objects are involved in a few crashes. These are included in the graph as 'other'.

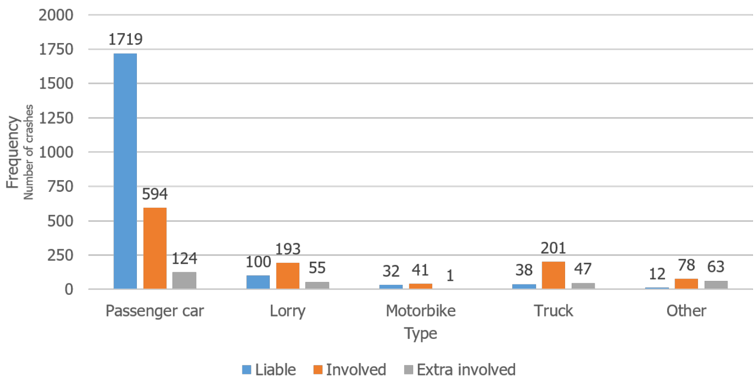


Figure 4.11: Type of vehicle involved

Figure 4.12 shows the age of the people involved in the crash and their role. The age is divided into categories. Most crashes are caused by people between 25 and 59 years old. However, this age group has a wide range and hence consists of many people who travel a lot for work. Also, people between 18 and 24 years are involved often, especially when considering the relative small size of the age group. In contrast to the other age groups older people are more often victim of the crash than liable. Note that not for all crashes an age is registered.

Figure 4.13 shows how many crashes occurred in each month. It is seen that in the winter

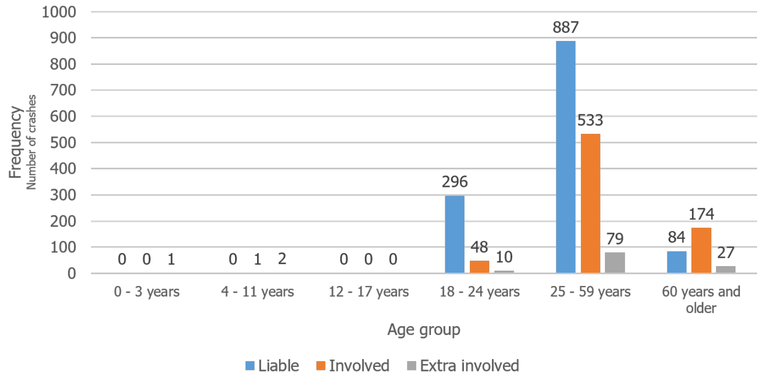


Figure 4.12: Age of the people involved

months more crashes occurred than during summer. Possible reasons for this are the weather circumstances, number of people using a car – which may be higher in winter due to less people using other modes such as a bike compared to the summer period – and decreased amount of daylight.

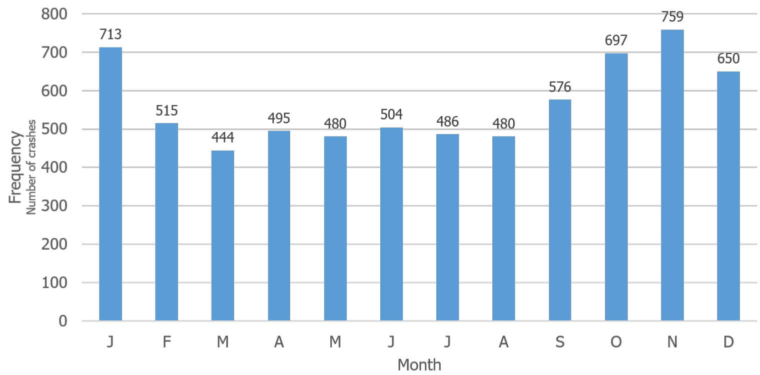


Figure 4.13: Distribution of crashes over the year; number of crashes per month

Also the time of the crash is registered. Figure 4.14 shows the number of crashes that occurred in each hour of the day. During the peak hours more crashes occurred, especially during the evening peak hour. At night-time only few crashes occurred. This suggests that the likelihood of a crash is influenced by the traffic intensity.

For some crashes the state of the weather at the moment of the crash is registered. Figure 4.15 shows that most crashes occurred during dry weather circumstances. Thereafter most crashes occurred during rain. However, these are also the most frequent occurring weather circumstances in the Netherlands. On the one hand a higher share of crashes during rainy weather might be expected due to decreased visibility and increased braking distance. On the other hand, drivers drive more careful and maintain a larger headway, resulting in larger gaps.

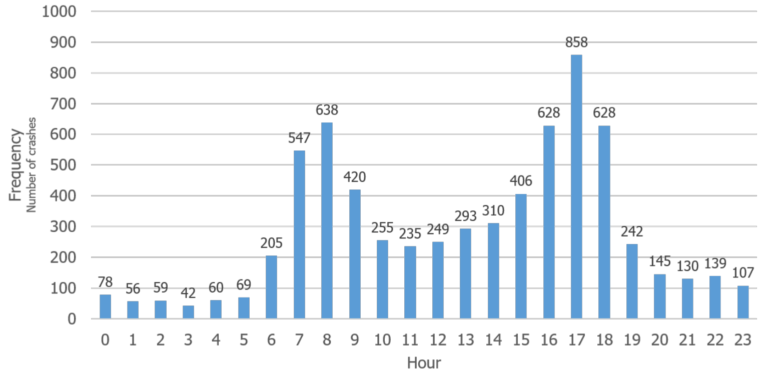


Figure 4.14: Distribution of crashes over the day; number of crashes per hour

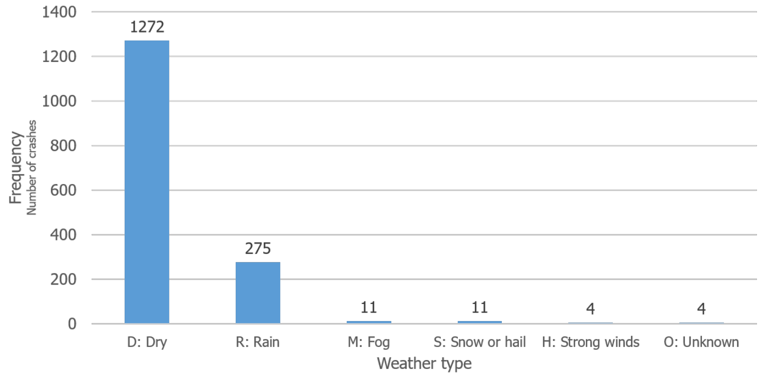


Figure 4.15: Weather circumstances at the time of the crash

4.3. Selection of the Weaving Sections

Paragraph 4.3.1 describes how a selection of weaving sections is obtained. Paragraph 4.3.2 describes these selected weaving sections.

4.3.1. Selecting the Weaving Sections

A selection of the weaving sections will be made for further analysis as it will be unnecessary to analyse and model all weaving sections into detail. This selection initially consists of 10 weaving sections. For selecting the weaving sections the factors that influence the number of crashes will be taken into account. These factors are obtained from the literature research in section 3.2. Iliadi et al. [29] included the following factors in the CPM developed for the Dutch situation: length of the weaving section, AADT, weaving width, share of weaving vehicles and location with respect to the interchange. Some other researches also include some configuration characteristics as symmetry or type and number of lanes on a specific leg as factors that influence safety. However, also other characteristics are relevant for making a selection.

At first it is important that the design of the weaving section did not change between 2012 and 2015 as then crashes are assigned to a design that did not exist at that time. Therefore, the design of the weaving section should be checked for each year by analysing aerial views.
Another consideration is that the safety of the weaving sections is determined by the weaving

section, and not by the surroundings. For example an upstream bottleneck might create spill-back onto the weaving section and hence influence the safety, but then this is no valid measure for the safety of the configuration of the weaving section. Hence weaving sections where safety is influenced by the situation upstream or downstream are not preferred.
Factors which cannot be included in a simulation model such as the position of the weaving section in relation to the interchange (inside or outside), the horizontal and vertical alignments and the type of area (rural or urban), should be more or less equal for all weaving sections in the selection.

The degree of safety is another important aspect, as on this factor a comparison between real and simulated weaving sections will take place. There are three options for the selection:

1. A half of the weaving sections is clearly safe and the other half is clearly unsafe;
2. The weaving sections are ranging from clearly unsafe to clearly safe, which thus also includes weaving sections which are moderate (un)safe;
3. All weaving sections have an almost similar degree of safety.

Benefit of the first option is that a distinction is made between safe and unsafe only, and thus the simulation also has to distinguish between safe and unsafe only. It will be more clear to see whether the simulation and real situation do match or not. On the contrary, the second option gives a more detailed view on how well the degree of safety estimated from the simulation matches reality, but it is more difficult to make a distinction between a 'reasonable' match and a 'good' match. The third option works the other way around, and if according to SSAM the weaving sections also have similar degrees of safety, micro-simulation and SSAM is expected to be a valid method.
The second option is preferred as this gives more detailed results than the first option and is more intuitive than the third approach.

Appendix C.1 describes how the selection of 10 weaving sections is obtained. The desired strategy as described was kept in mind but is not followed into detail. More attention was paid to have a selection with different configurations, no changes in design and variations in crash rates, and less to the surroundings of the weaving sections as then many weaving sections would be rejected due to environmental differences that cannot be included in a simulation model (such as urban or rural area, inside or outside interchange, vertical alignment, etc.). This resulted in the selection listed in table 4.4.

Table 4.4: Selected weaving sections

ID	Location	Road	BeginHM	EndHM	Direction	Letter
068	Interch. Heerenveen	A7	143.64	143.83	R	
077	De Bilt - Maarssen	A27	82.16	82.76	R	
156	Interch. De Baars - Tilburg Noord	A65	20.19	19.61	L	
173	Kralingen - Interch. Terbregseplein	A16	17.41	16.51	L	
256	Interch. Hoogeveen	A28	134.30	134.14	L	
269	Interch. Hattemerbroek	A28	85.15	85.33	R	m
369	Interch. Zaandam	A8	5.31	5.43	R	
412	Voorthuizen - Barneveld	A1	56.14	54.84	L	
454	Rotterdam Schiebroek - Interch. Kleinpolderplein	A20	30.31	29.84	L	
499*	Bavel - Interch. St. Annabosch	A58	54.91	55.67	R	

* Later this weaving section was removed from the selection as selected link data for another weaving section was received.

4.3.2. Description of the Selected Weaving Sections

In appendix C.2 a short description of each of the selected weaving sections is given. The appendix is summarised in table 4.5. Maps of these selected weaving sections are included in appendix C.3.

Table 4.5: Site description of selected weaving sections

ID	Between	Road	Configuration	Length	Urban	Congestion	Limit	Weaving	HGV
068	Cloverleaf loops	Main	2+1	188.75	Semi	No	130	25%	14%
077	Junctions	Main	3+1	607.58	Semi	Yes	100	32%	9%
156	Interch. & junction	Main	2+1	595.58	No	No	120	9%	14%
173	Junction & interchange	Main	3+2	888.19	Yes	Yes	100	43%	8%
256	Cloverleaf loops	Main	2+1	152.18	No	No	120	12%	26%
269	Cloverleaf loops	C/D	1+1	171.06	No	Yes	120*	100%	13%
369	Cloverleaf loops	Main	2+1	136.71	Semi	Yes	100	28%	7%
412	Junctions	Main	2+1	1306.10	Semi	Yes	120	27%	14%
454	Junction & interchange	Main	3+1>2+2	468.16	Yes	Yes	80	67%	9%
499	Junction & interchange	Main	2+1>2+2T	740.23	No	Yes	120	55%	13%

*At the divergence gore the speed limit changes to 100 km/h.

Appendix C.2 and table 4.5 include amongst others the location, speed limit and share of heavy good vehicles. The mentioned speed limits are from the speed limits database which is used for the implementation of the 130 km/h speed limit on freeways and harmonisation of the speed limits.
The INWEVA database provides traffic intensities and truck shares. The company 4Cast has determined the weaving shares from the NRM for the morning peak hour, evening peak hour and rest of the day, resulting into OD matrices. These OD matrices can be found in appendix D. From these OD matrices the percentage of weaving vehicles and percentage of trucks can be calculated. The share of weaving vehicles is found by dividing the number of weaving vehicles by the total number of vehicles. Similarly, the truck share is found by dividing the number of trucks by the total number of vehicles. The weaving and HGV shares per time period are included in the appendix. The weighted daily averages included in this paragraph are calculated from the OD matrices using equations 4.1 and 4.2:

$$\text{HGV share}_{day} = \frac{\sum_{i,j}\left(20\cdot \text{HGV}_{OP,ij} + 2\cdot \text{HGV}_{AM,ij} + 2\cdot \text{HGV}_{PM,ij}\right)}{\sum_{i,j}\left(20\cdot \text{veh}_{OP,ij} + 2\cdot \text{veh}_{AM,ij} + 2\cdot \text{veh}_{PM,ij}\right)}\cdot 100\% \tag{4.1}$$

$$\text{Weaving share}_{all,day} = \tag{4.2}$$
$$\frac{20(\text{veh}_{OP,AD} + \text{veh}_{OP,BC}) + 2(\text{veh}_{AM,AD} + \text{veh}_{AM,BC}) + 2(\text{veh}_{PM,AD} + \text{veh}_{PM,BC})}{\sum_{i,j}\left(20\cdot \text{veh}_{OP,ij} + 2\cdot \text{veh}_{AM,ij} + 2\cdot \text{veh}_{PM,ij}\right)}\cdot 100\%$$

In these equations $\text{car}_{t,ij}$ is the number of cars going from i to j at time period t and $\text{HGV}_{t,ij}$ is the number of HGVs going from i to j at time period t according to the selected link OD matrices. $\text{veh}_{t,ij} = \text{car}_{t,ij} + \text{HGV}_{t,ij}$ represents the total number of vehicles going from leg i to leg j at time period t. For most weaving sections the origin leg is $i = \{A, B\}$ and destination leg is $j = \{C, D\}$. Available time periods are AM, PM and OP.
The INWEVA database includes intensities of different vehicle types, from which also a truck share can be calculated. As different data is used, the truck shares calculated from INWEVA might differ from the share calculated from the selected link OD matrices. Table 4.5 includes the HGV shares according to INWEVA.

Within Google Maps it is possible to view the typical traffic per day and time on many road sections. The speed at the road section is indicated by colours, ranging from green for higher speeds to red for slow congested speeds. From this the state of congestion at the weaving section is determined.
Figure 4.16 shows that most of the selected weaving sections have a 2+1 configuration. Two weaving sections are asymmetrical. Figure 4.17 shows that four weaving sections have a length between only 100 and 200 meters, five weaving sections have a medium length and one weaving section is clearly longer than the others. Paragraph 4.5.1 includes information on how the traffic intensities and OD matrices of the selected weaving sections are retrieved. Section 5.1.2 focuses on describing crashes that occurred on the selected weaving sections.

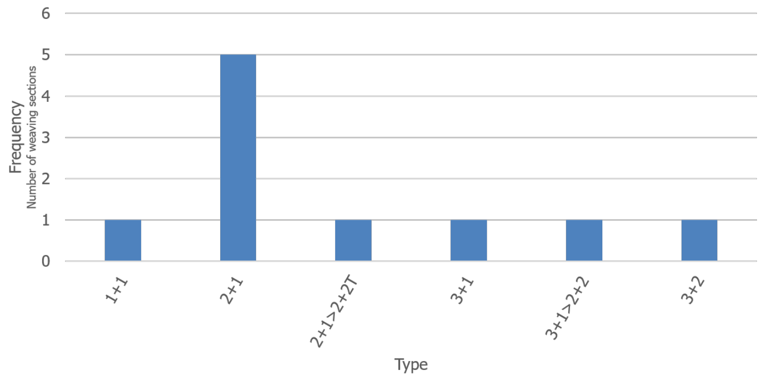


Figure 4.16: Configurations of the selected weaving sections

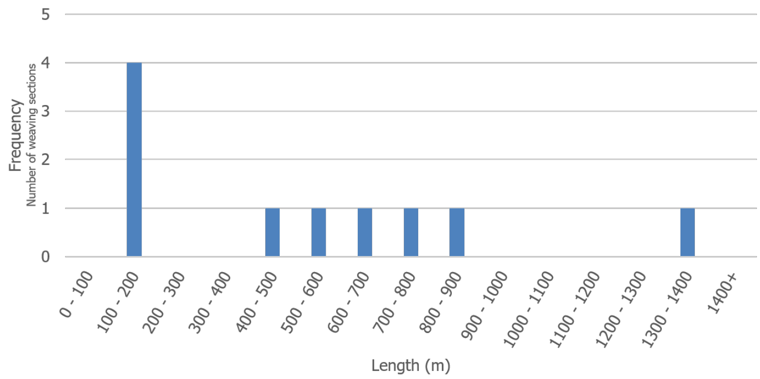


Figure 4.17: Lengths of the selected weaving sections

4.4. Reference Rankings

In the third step, some other methods to determine the safety of a weaving section will be used. These methods result in other rankings, which can be used to validate the rankings based on the crash database and conflict counts from SSAM. The first method based on expert judgement and a human factors analysis is described in paragraph 4.4.1, the second method uses the crash prediction model developed by Iliadi et al. [29] and is described in paragraph 4.4.2. In the third step, also the crashes that occurred on the selected weaving sections will be analysed, such that eventual patterns in the causes could be discovered.

4.4.1. Expert Judgement

Until the '90s of the previous century roads were designed mostly according to technical guidelines. Later, research showed that traffic safety has not only to do with infrastructure and safe vehicles, but that also the interaction between road users, infrastructure and vehicles can improve traffic safety. The five principles of sustainable safety show how road users, infrastructure and vehicles relate to each other. Figure 4.18 describes the five principles, which are functionality, homogeneity, predictability, forgivingness and state awareness. Sustainable safety specifies that also safety should be a design requirement when designing road traffic systems.

Sustainable Safety principle	Description
Functionality of roads	Monofunctionality of roads as either through roads, distributor roads, or access roads, in a hierarchically structured road network
Homogeneity of mass and/or speed and direction	Equality in speed, direction, and mass at medium and high speeds
Predictability of road course and road user behaviour by a recognizable road design	Road environment and road user behaviour that support road user expectations through consistency and continuity in road design
Forgivingness of the environment and of road users	Injury limitation through a forgiving road environment and anticipation of road user behaviour
State awareness by the road user	Ability to assess one's task capability to handle the driving task

Figure 4.18: The sustainable safety principles [68, p. 13]

Implementation of these principles has led to a decrease in number of accidents. The Netherlands has reached second position in the European Union for road safety [62]. However, updating old infrastructure and implementing these principles on all roads would be too costly. Therefore Rijkswaterstaat has developed the VOA-method (where VOA stands for Verkeersveiligheid op Auto(snel)wegen, which means traffic safety on highways). Figure 4.19 shows that this method consists of several building blocks to signalise safety risks in projects, ranging from the plan phase to the management and maintenance phase.

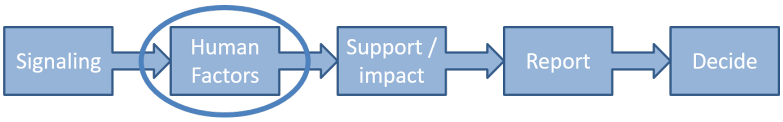


Figure 4.19: Building blocks in the VOA risk assessment method (translated from [67])

One of these building blocks includes the human factors. The field of human factors describes the interaction between people and the environment, based on five principles from traffic psychology and ergonomics [52]:

1. *Expectancy:* does the situation match with the expectation of the road users?
2. *Observing:* is the road user able to see the information important for the driving task?
3. *Understanding:* does the road user understand all this information?
4. *Ability (task complexity):* is the road user able to perform the desired/required traffic behaviour?

5. *Willingness (alacrity):* is the road user motivated to perform the desired traffic behaviour?

Sometimes also the principles *interaction of the vehicle* and *forgivingness* are added. These two are external characteristics from behavioural view, but play an important role [51].

This interaction between driver and environment can be analysed from the three driving task levels: the operational, tactical and strategic level, see figure 4.20. Operational tasks are executed almost automatically. Examples of such tasks are accelerating, decelerating and steering. The tactical level includes manoeuvres such as lane changing and overtaking, and also keeping a safe following distance. Strategic tasks include the planning of a movement and following a route to a destination, which needs conscious attention [52]. In a human factors analysis, the five principles are analysed for the three driving task levels.

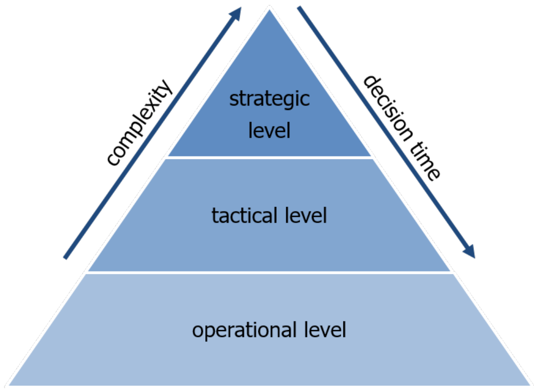


Figure 4.20: Three driving task levels and complexity and decision time (translated from [52])

Examples of observations for each of the five principles are listed below.
A driver has certain *expectations* about traffic situations. When driving on a freeway, or more specific on a weaving section, this activates schemata about what can be expected and what behaviour is required [62]. Based on experience the driver expects for example that the road course is in line with the course of the environment such as road furniture and forest. Similarly, drivers do not expect that there is a sharp curve after a long straight section [27]. A self-explaining road creates for almost all road users the correct expectations.
Observations can be top-down and bottom-up. Top-down observations include the controlled search based on expectations. Experienced drivers are more skilful than beginning drivers since scanning and searching is learnt more in practice. Bottom-up observations are observed because the object is standing out and therefore gets attention [52]. It should be taken into account that the time to look at traffic signs is limited. To prevent that drivers become distracted or confused by irrelevant signs such as advertisement, there are regulations on objects along Dutch highways [41].
The road user should *understand* the observed information, such that this can be translated into (changes in) traffic behaviour. Known and expected information is easier understood than unexpected or unknown information. This is already included in the expectancy-principle. However, understanding is also included as separate principle as information-elements such as signing should also be understandable and not contradicting to previous information.
To be *able* to execute a driving task safely it is important that the principles of expectancy, observing and understanding are met. Next to that overload and underload should be prevented. Tasks such as merging and splitting lead to an increase in workload. When the driver is doing

other tasks while driving (such as using a phone) or the time to execute the tasks is too short, this has a negative influence on performance and an overload can occur (see figure 2.9).
Willingness increases when the driver sees the benefit of the traffic situation or traffic rule. In that case the driver will be more likely to behave correct. It can be the case that the driver does not see the sign, but it also occurs that the driver is consciously ignoring a sign because there is a benefit in ignoring the sign. When a rule or situation is more understandable and credible, the compliance will be higher [52].

If traffic situations are analysed based on these five principles for the three driving task levels, different modes (vehicle types), movements and time slots, this gives more insight in how road users perceive the situation. Next to that it gives insight in how the traffic safety level can be increased [67].
The dynamics of the traffic should be included in such an analysis. Factors such as fluctuations in traffic composition due to events or facilities in the environment, but also expectations for future developments of the area and weather circumstances can be included, even as decreased visibility at night and longer reaction time of elderly people [52].

Also the Transportation Research Board noticed the importance of the human factor in roadway design and developed the Human Factors Guidelines for Road Systems [9]. There is no special focus on weaving sections, but for complex interchanges it is stated that these should be designed to give the drivers what they expect to see as the response time is faster for familiar information than for unexpected information. Thus, a more predictable design and operation leads to fewer errors. Important considerations for design (geometric elements, signing and sight distance) are listed, such that a route must be provided on which lane changing is not necessary to continue the through route and that information must be spread out by locating less relevant information upstream or downstream [9].

The human factors analysis is a generally accepted method to determine the safety of a road section in the Netherlands and in other countries, therefore this method will be used to create a third ranking of the weaving sections. Road safety experts will be asked to create a ranking of the selected weaving sections, and take into account the five principles expectancy, observing, understanding, ability and willingness.

4.4.2. Crash Prediction Model

Another method to determine safety of a road section is using a crash prediction model (CPM). As the focus of this research is on Dutch weaving sections, a CPM for the Dutch situation is preferred. Iliadi et al. [29] developed a crash prediction model after analysing configurations of weaving sections and crash data of these weaving sections. The focus of that research was on only symmetrical weaving sections in the Netherlands. The following formula was found for predicting the number of crashes that is expected to occur in a three-year period on symmetrical weaving sections in the Netherlands:

$$N = 4.46 \cdot 10^{-5} \cdot length^{0.46} \cdot AADT^{0.88} \cdot e^{0.35 \cdot lanes + 1.05 \cdot share - 1.67 \cdot location} \tag{4.3}$$

Here

- $length$ is the distance between the convergence gore and divergence gore in meters;
- $AADT$ is the average annual daily traffic on the weaving section expressed in vehicles per day;
- $lanes$ is the number of lanes on the main freeway;
- $share$ is the percentage of cars that is weaving during rush hours;

- $location$ is the location of the weaving section related to the interchange (if inside then $location = 0$ and if outside then $location = 1$);

In this the formula the length has a positive coefficient, indicating that a longer weaving section length is expected to result in more crashes. However, the number of crashes increases less than proportional with the length: if all other factors are left at similar level but the length is doubled then the number of crashes will be less than twice as high, as $2^{0.46} < 2$. Similar principle holds for the AADT. If the number of lanes increases by one, then the crash probability will increase by 42% $(\exp(0.35) = 1.42)$. For every 1% increase in weaving cars the number of crashes increases with 1.05%. The location coefficient indicates that weaving sections that are located outside an interchange have a lower crash likelihood than those located inside [29].

The values of the required variables will be calculated or searched for, and the expected number of crashes will be calculated using equation 4.3 for each weaving section. Subsequently, these expected number of crashes can be used to create a safety ranking.

4.5. VISSIM Simulation and SSAM Analysis

In this section it is described how the VISSIM simulations are created and performed in paragraph 4.5.1. Thereafter paragraph 4.5.2 describes how simulation results from VISSIM are analysed using SSAM.

4.5.1. Data Collection and Modification

A model of the selected weaving sections will be created in VISSIM in the fourth step. This section describes how important data was obtained. Appendix H describes in more detail how the simulation models were built.

The aim is to have as good as possible a match with the real weaving sections. Therefore, the simulation will be built on a technical drawing of the weaving section. These drawings are obtained from the DTB (Digitaal Topografisch Bestand) and scaled onto an aerial view which is available within VISSIM.

A choice was made to simulate one entire workday, as a whole day gives a better indication of the safety of a weaving section than simulating only the peak-hours. For that 25 time intervals are created, of which the first is a set-up hour, and the other 24 each represent one hour. Each time interval includes 900 simulation seconds, such that each hour is represented as 900 seconds (15 minutes) in the simulation models.

In VISSIM it is not possible to assign a speed limit to a road section. Instead, a desired speed should be assigned to a vehicle using a desired speed distribution. As described in appendix H.1.4, speeds measured by loop detectors at the weaving sections are used to create a desired speed distribution. Using box plots the speed intervals in which a predetermined percentage of vehicle drives are obtained, which are translated into the desired speed distributions.

The total number of vehicles entering the weaving section per unit of time is obtained from loop detector data available by the NDW (Nationale Databank Wegverkeersgegevens; Dutch National Data Warehouse for Traffic Information). The vehicle routes will be implemented by including origin-destination (OD) matrices as static vehicle routes. Shares of the different OD pairs are needed, but these are not directly available as empirical data.
An option is to estimate the shares from floating car data. Floating car data contains the position of a vehicle at every time step, so it is known via which leg the vehicle enters and leaves the weaving section. Not all vehicles are registered using floating car data, but it is assumed that the

number of registered vehicles is sufficient to generalise to all vehicles on the weaving section. Possible methods to obtain floating car data are via users of a particular smartphone apps in combination with the GPS position or via Bluetooth usage. However floating car data is not available currently for a sufficient number of weaving sections, and hence should be bought from an external company. The quality of the floating car data is not sufficient to determine individual vehicle trajectories and information on for example the selected lane and lane change position.
An alternative option is to derive the OD matrices from the Dutch regional model (NRM, Nederlands Regionaal Model). This can be done by executing a selected link analysis on the incoming legs of the weaving sections. Benefit of this option is that it is not based on one particular short time interval and that hence more detailed information is available such as a split into the time of day and type of vehicle. However, that is also a drawback, as it is a model based on expectations for social-economic circumstances and future growth and not on real measurements only [49]. Also for the NRM it is needed to derive the OD matrices via an external company (for example 4Cast), which brings costs. However, these costs are less than for deriving OD matrices from floating car data. Furthermore, already for some weaving sections the OD matrices are available as the NRM is used in other researches by Arcadis and in the research by Iliadi et al. [29].
It is not desired to use two different methods to obtain the data for the selected weaving sections, thus for similar budget data for more weaving sections and for multiple modes and time periods can be obtained using the NRM database. Hence a choice is made to derive the weaving percentages from the NRM, resulting in tables such as table 4.6. Here SL_{ij} is the result of the selected link analysis for vehicles going from leg i to leg j.
Per weaving section multiple tables are created, making similar distinction as the NRM into the time of day and modality. Three time periods are distinguished: the morning peak, the evening peak and off-peak. The morning peak is from 7:00 till 9:00, the evening peak hour from 16:00 - 18:00 and the off-peak from 9:00 - 16:00 and from 18:00 - 7:00. Two modalities are distinguished: passenger car vehicles and heavy good vehicles. This resulted in a total of six OD-matrices per weaving section.
Appendix D describes the principle of the selected link analysis and includes the shares of the different routes. Appendix H.1.6 describes how these OD matrices are implemented in VISSIM by means of *static vehicle routes*.

Table 4.6: Fill-in table for weaving percentages. See figure 2.1 for the numbering of the legs

From / To	Leg C	Leg D
Leg A	SL_{AC}	SL_{AD}
Leg B	SL_{BC}	SL_{BD}

However, intensities from the NRM are not fully trusted as they are from a model and not fully based on empirical data. Hence these OD matrices are used for the shares of the different routes only, and thus not for traffic intensities and vehicle compositions.
The vehicle compositions are calculated from vehicle intensities and truck intensities available per hour in the INWEVA database for weekdays. From this the share of trucks can be calculated as described in appendix H.1.3. In VISSIM for each simulated hour the corresponding truck share is included.

Variations in flows during peak hour and off-peak will be included by changing the vehicle inputs during the simulation period. For that information on the traffic flow pattern is required, which is available via the NDW historical traffic data documentation.

For each of the incoming links hourly vehicle intensities are determined from the NDW database. If no intensities were measured on a specific link, the number was calculated from other links assuming the law of conservation of vehicles [69]. However, it should be noted that vehicle counts are not 100% correct and that the error might increase after subtracting and adding intensities of multiple count locations.
These hourly intensities are used to simulate one average weekday. These intensities are obtained by averaging the intensities counted on weekdays in September 2015. A choice is made for the year 2015 as this year is part of the crash analysis period and in that year counts were more complete than in earlier years. The month September was selected as this is a representative month without holidays, special events and exceptional weather circumstances. Per weaving section this resulted in a table such as table 4.7. The number of columns might differ per weaving section, depending on the simulation area. Appendix H.1.5 includes the intensities used for creating the simulations.

Table 4.7: Fill-in table for traffic intensities

Hour	Leg A	Leg B
00	$I_{A,00}$	$I_{B,00}$
01	$I_{A,01}$	$I_{B,01}$
02	$I_{A,02}$	$I_{B,02}$
⋮	⋮	⋮
22	$I_{A,22}$	$I_{B,22}$
23	$I_{A,23}$	$I_{B,23}$

4.5.2. Conflict Analysis with SSAM

The fourth step also includes running the VISSIM simulations and conflict analysis using SSAM. The required number of simulation runs to obtain a statistical representation of the average is calculated in appendix H.4. This calculation is performed based on the average travel time on the weaving section and its standard deviation, and a desired confidence interval of 95% for the mean.

The vehicle trajectory files of these runs are analysed in SSAM. Appendix I describes the algorithm that SSAM uses to determine the number of conflicts and includes screenshots of the SSAM user interface. SSAM uses the surrogate safety measures TTC and PET to determine the number of conflicts. The angle is used to determine the type of conflict. Initial projection thresholds as shown in table 4.8 are used as projection thresholds for calculating the number and type of conflicts. These initial thresholds are the default values of SSAM, and are according to Gettman et al. [22] based on a literature research. The thresholds are explained in section 2.2.

Table 4.8: Conflict projection threshold values in SSAM

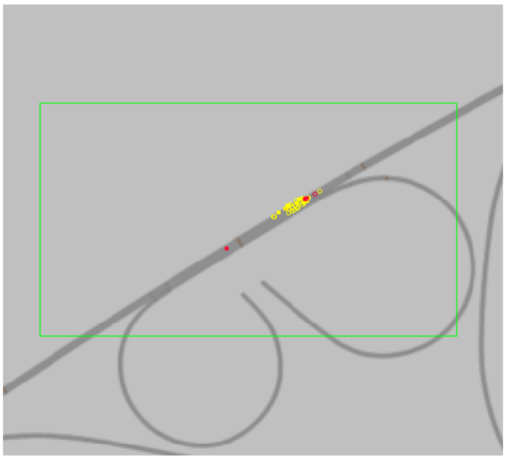
Conflict Threshold	Value
Maximum time-to-collision (TTC)	1.5 s
Maximum post-encroachment time (PET)	5.0 s
Rear end angle	30°
Crossing angle	85°

Similar values will be used as maximum conflict filter values. In the micro-simulation some 'virtual' crashes occur, which are identified in SSAM with a TTC of 0 seconds. According to Gettman and Head [21] and Gettman et al. [22] these crashes should be removed before analysing the results. This is done by setting the lower bound for the TTC to 0.05 seconds using a filter. Applied filter thresholds can be found in table 4.9. No filter is applied on the other surrogate safety measures, for the MaxS, DeltaS, DR, MaxD and MaxDeltaV values between -99 and 99 are accepted.
In the fifth step amongst others the sensitivity of these threshold values and the effects of some settings in the VISSIM simulation models are tested.

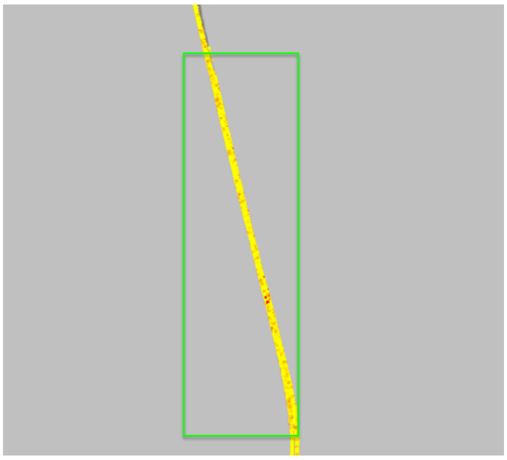
Table 4.9: Conflict filter threshold values in SSAM

Surrogate Threshold	Minimum	Maximum
TTC	0.05	1.50
PET	0.00	5.00
Area	Location specific	

Another filter will be applied on the conflict location, such that only the conflicts that occurred within the influence area of the weaving section are included and not the conflicts that occurred on other locations in the simulation model. This to have a fairer comparison to the crash rate, that is determined based on crashes that occurred within the influence area.
However, no measurement facilities are available in SSAM to determine whether the distance from the gore is exactly 150 meters, so an estimation is made. After analysing the trajectory files using SSAM and setting the filters, it is found that on most weaving sections an inaccuracy in this estimation does not influence the number of conflicts, as no conflicts are observed around these filter area boundaries (green line in figure 4.21a). However, at some locations this might result in a deviation as conflicts are located around the area boundaries, and it is uncertain whether this boundary is located correctly (figure 4.21b).



(a) No conflicts around the borders so no inaccuracy



(b) Conflicts around the borders might result in an inaccuracy

Figure 4.21: Area filter inaccuracy, green line represents filter area boundary

5
Results

The aim of this chapter is to come to the four rankings (crash rate, experts, CPM and VISSIM&SSAM), and understand the correlations between the four rankings.

Therefore, the first four sections of this chapter describe how the nine weaving sections listed in table 4.4 are ranked according to the four safety evaluation methods.
Section 5.1 gives the ranking of the selected weaving sections based on crash registrations in the BRON database. Also, characteristics of crashes per weaving section are included in this section. Section 5.2 describes the outcomes of the VISSIM simulation and SSAM analysis and concludes with a ranking based on the number of conflicts determined from the simulation. Section 5.3 describes outcomes of the judgement by the road safety experts and concludes with a third ranking based on this experts ranking. Section 5.4 predicts the number of crashes per weaving section from a CPM and includes a fourth ranking.

Thereafter these four rankings are compared by determining rank correlations. A strong relation between two rankings indicates that the one safety evaluation method is potentially representative for the other evaluation method. Section 5.5 starts with a global comparison of the simulation ranking with the crash rate, CPM rate and human factors rankings. Thereafter in section 5.6 a more in-depth validation is performed by means of a sensitivity analysis.

5.1. Crash Data Ranking and Crash Detail Analysis

In this section the crashes that are related to the selected weaving section will be analysed. In paragraph 5.1.1 the weaving sections are ranked based on the crash rates. This ranking is used to validate the ranking based on conflict numbers from VISSIM and SSAM.
In section 5.1.2 the crashes that occurred will be analysed in more detail. Section 5.1.3 describes per weaving section what crashes occurred, by summarising per weaving section the five W-factors: what, where, when, who and why.

5.1.1. Crash Data Ranking

Based on the analysis described in section 4.2 the selected weaving sections can be ranked on several characteristics. Table 5.1 ranks the weaving sections based on the number of registered crashes between 2012 and 2015. This ranking includes both vehicle-to-vehicle crashes and single-vehicle crashes.

Table 5.1: Ranking based on number of crash registrations

Ranking based on number of crash registrations (2012 - 2015)

Count rank	ID	Location	Crash count	Length	AADT	Veh. km ($\times10^3$)	Crash rate
1	173	Kralingen - Interch. Terbregseplein	128	888.19	89675	79.65	1.61
2	454	Rotterdam Schiebroek - Interch. Kleinpolderplein	94	468.16	76075	35.62	2.64
3	412	Voorthuizen - Barneveld	52	1306.10	36475	47.64	1.09
4	077	De Bilt - Maarssen	34	607.58	50275	30.55	1.11
5	369	Interch. Zaandam	31	136.71	30900	4.22	7.34
6	256	Interch. Hoogeveen	19	152.18	13175	2.00	9.48
7	499	Bavel - Interch. St. Annabosch	18	740.23	38200	28.28	0.64
8	156	Interch. De Baars - Tilburg Noord	12	595.58	27050	16.11	0.74
9	068	Interch. Heerenveen	5	188.75	20775	3.92	1.28
10	269	Interch. Hattemerbroek	4	171.06	6400	1.09	3.65

A generally used expression for road safety is the crash rate. This measure of safety is based on exposure, and expresses the number of crashes relative to the number of vehicle kilometres on a typical day.
In figure 5.1 the orange dots represent the AADT and crash rate of all weaving sections in the Netherlands, the blue triangles represent the selected weaving sections. It is seen that the AADT varies between a few thousand and $100\ 000$ daily vehicle kilometres at some weaving sections, but that at a majority of the weaving sections the AADT is between $10\ 000$ and $50\ 000$ daily vehicle kilometres. The crash rate varies between 0.0 and 3.0 for most weaving sections, but there are some weaving sections with higher crash rates. The little slope of the linear trend line indicates that expressing safety of weaving sections using the crash rate is indeed taking into account the exposure, and results in a fairer comparison than using only crash counts as representation of safety.

The crash rates at the selected weaving sections are also included in table 5.1. Table 5.2 includes the ranking of the weaving sections based on this crash rate. It should be noted that for weaving sections with a low crash count, one extra crash might already result in a major change in crash rate. Hence these crash rates are less trustful, and a change might also influence the ranking position.

Table 5.2: Ranking based on crash rate

Rate rank	ID	Location	Crash count	Length	AADT	Veh. km ($\times10^3$)	Crash rate
1	256	Interch. Hoogeveen	19	152.18	13175	2.00	9.48
2	369	Interch. Zaandam	31	136.71	30900	4.22	7.34
3	269	Interch. Hattemerbroek	4	171.06	6400	1.09	3.65
4	454	Rotterdam Schiebroek - Interch. Kleinpolderplein	94	468.16	76075	35.62	2.64
5	173	Kralingen - Interch. Terbregseplein	128	888.19	89675	79.65	1.61
6	068	Interch. Heerenveen	5	188.75	20775	3.92	1.28
7	077	De Bilt - Maarssen	34	607.58	50275	30.55	1.11
8	412	Voorthuizen - Barneveld	52	1306.10	36475	47.64	1.09
9	156	Interch. De Baars - Tilburg Noord	12	595.58	27050	16.11	0.74
10	499	Bavel - Interch. St. Annabosch	18	740.23	38200	28.28	0.64

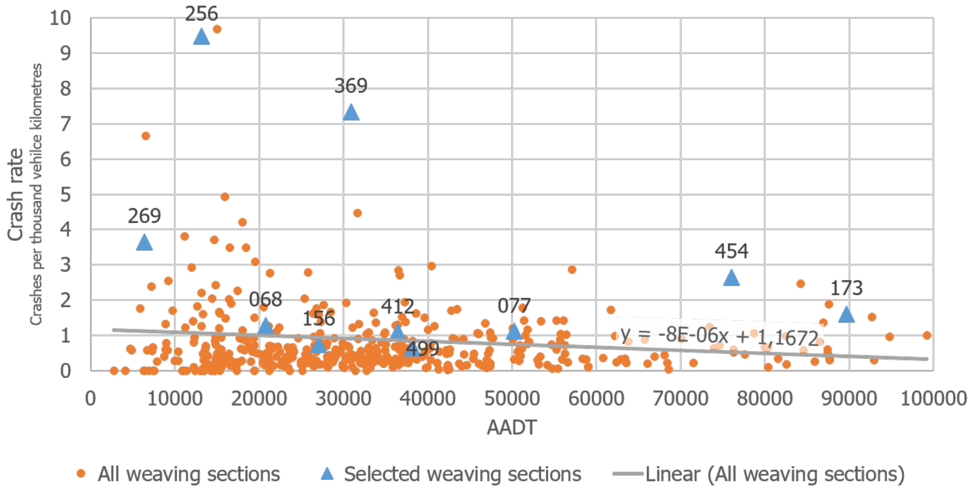


Figure 5.1: The relation between AADT and the crash rate

5.1.2. Detailed Crash Analysis

Next to analysing the crash counts and crash rates per weaving section a more detailed analysis of the crashes can be done, to get more insight in what might have caused the crash, when the crashes occurred, and where on the weaving sections the crashes occurred. Figure 5.2 shows the number of crashes on each of the weaving sections distinguished per year. Remarkable is that in 2015 many more crashes are registered on the selected weaving sections (158 in total) than in the years 2012 (83), 2013 (81) and 2014 (75). There might be several reasons for the higher number in 2015, such as the degree of registration, the influence of the weather and the economic growth resulting in more traffic and hence a higher crash likelihood.

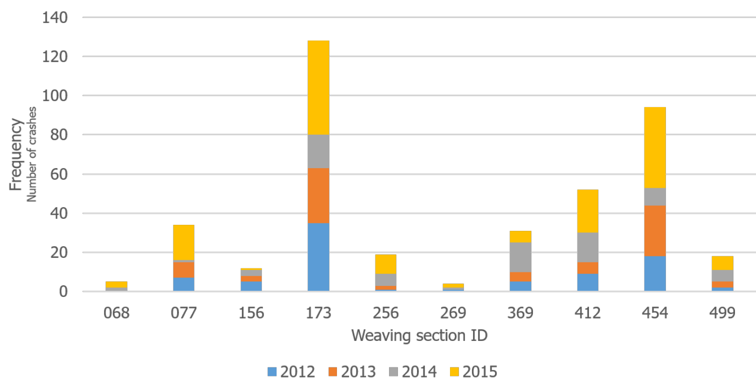


Figure 5.2: Number of crashes per weaving sections distinguished per year

On the selected weaving sections 397 crashes are registered, of which for 360 the crash type is described as 'unknown'. The frequencies of the other types are seen in figure 5.3. Most crashes are single-vehicle crashes, while only a few side-swipe, rear-end and fixed object crashes, and no head-on crashes are registered on the selected weaving sections.

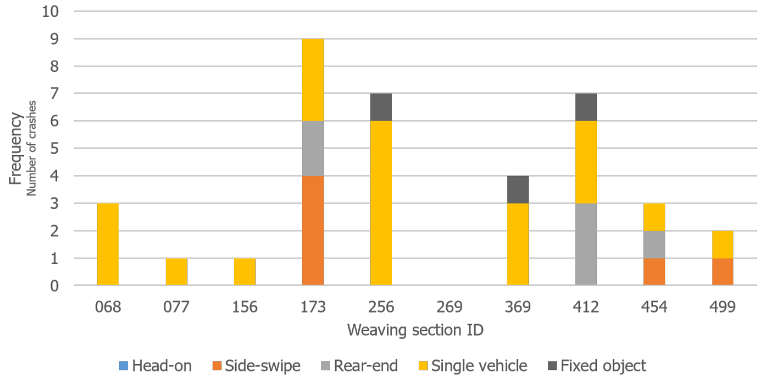


Figure 5.3: Registered crash types (crashes with unknown type are left out)

Figure 5.4 shows the severity of the crashes. On none of the weaving sections a fatal crash (DOD) occurred between 2012 and 2015. Eight crashes resulted in an injured person that needed first help (LEH), for three crashes a person had to stay in hospital (LZH) and three crashes had another injury type (LOV). For a majority of the crashes there was only material damage (UMS). The crashes with an injury occurred on weaving section ID173 (6), ID454 (5), ID156 (1), ID256 (1) and ID499 (1).

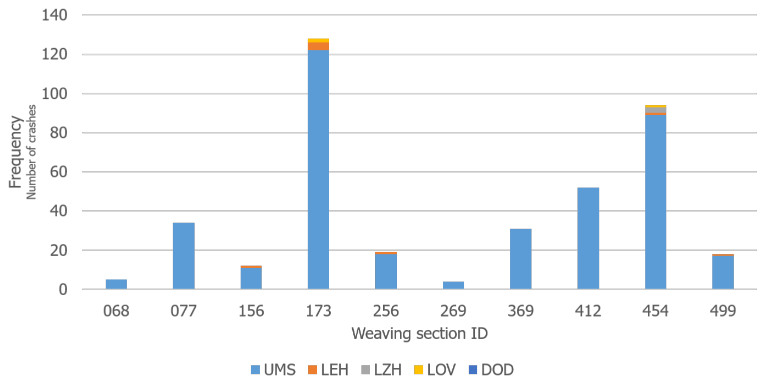


Figure 5.4: Occurrence of different crash impacts (see paragraph 2.2.3 for abbreviations)

Figure 5.5 shows the number of involved parties in a crash for each of the weaving sections. In a majority of the crashes one or two vehicles are involved. There are two crashes with four or five vehicles involved, and both occurred on weaving section ID454. Not for each crash the number of involved vehicles is registered.

Passenger cars are most often involved, which is not surprising as passenger cars have the highest share in the vehicle fleet. In only 4% of the crashes the liable vehicle was a truck, while in 32% of the multiple-vehicle crashes a truck was involved. Reasons for this relative high number are the high mass of trucks, the lower manoeuvrability, the decreased sight, and that other involved parties such as lightning poles and trees are not included as liable party.

Figure 5.6 shows the distribution of the crashes over the year. Some more crashes are observed during the winter months when looking at all selected weaving sections. However, when

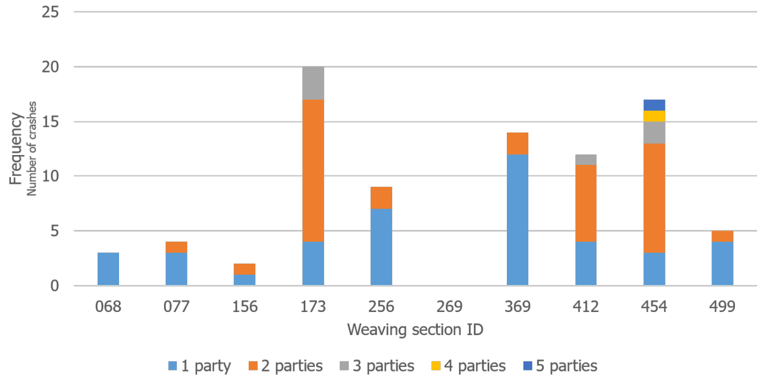
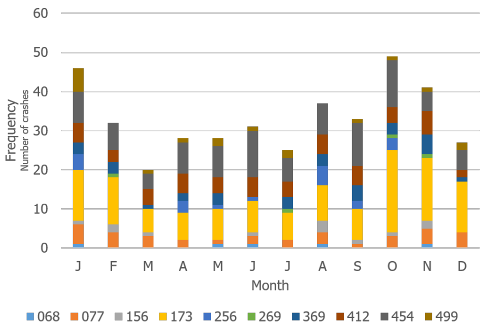
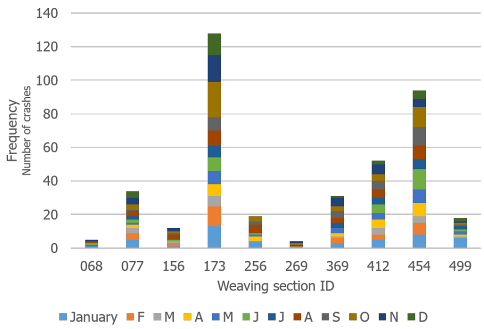


Figure 5.5: Number of parties involved

analysing 10 separate graphs – one for each weaving section, such as included in appendix F – this pattern was not observed due to the stochastic nature of crashes and lower number per weaving section.
Similar graphs are made for the time of day in figure 5.7. It is seen that around the peak hours clearly more crashes occurred. Less crashes occurred during daytime and only a few by night. Hence the vehicle intensities are assumed to be a factor influencing the number of crashes. When looking at individual graphs for each weaving section this pattern is better seen than a pattern in the distribution of crashes over the year. Hence, due to the relation to the traffic intensities, the time of day is expected to have a larger influence on the occurrence of a crash than the time of the year.
The graphs showing the distribution of the crashes over the day and year for each individual weaving section are included in appendix F.



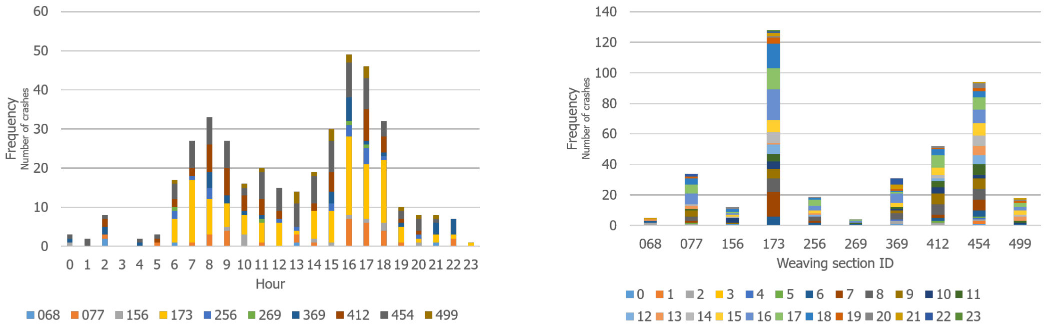
(a) Sorted per month



(b) Sorted per weaving section

Figure 5.6: Distribution of the crashes over the year

For only 85 crashes the weather circumstances are registered. 70 crashes occurred at dry weather and 15 while it was raining. No crashes are registered with fog, snow, hail or strong wind on the selected weaving sections, as can be seen in figure 5.8.



(a) Sorted per hour

(b) Sorted per weaving section

Figure 5.7: Distribution of the crashes over the day

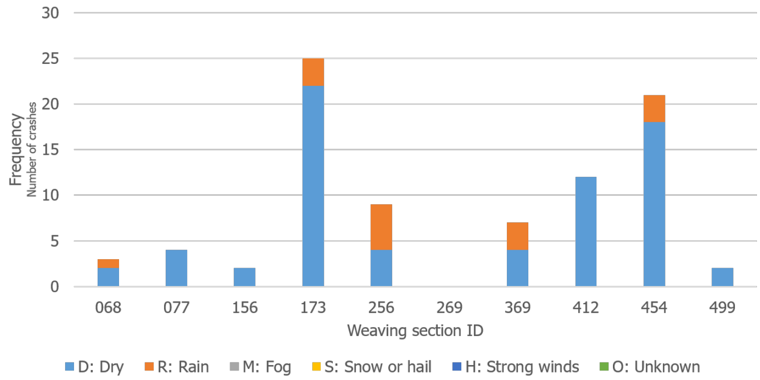


Figure 5.8: Weather circumstances at the time of the crash

5.1.3. Description per Weaving Section

Also for each individual weaving section crash characteristics can be analysed. For each crash the following characteristics will be analysed (if included in the database):

- *Location of the accident* It will be analysed if most accidents occur at the beginning of the weaving section or at the end, or somewhere in between. This is analysed by considering the hectometre location included in the crash database in the *'kilometrer'* column.
- *Time of the accident* The time is registered in the accident data in multiple ways: the exact time, the hour and the time period (interval). Also for some crashes it is registered whether there was daylight or darkness or whether lightning was in use. The time of day can be used to assess if factors such as darkness or peak hour intensities do influence the crash rate.
- *Type of accident* Which type of accident occurs the most? This type is included in the crash database in the *'AOL_OMS'* column. In the *'MNE_OMS'* column a more detailed specification of the manoeuvre is given. Appendix E includes an overview of all crash types used in the BRON database.
- *Severity of the accident* For most accidents the degree of severity of the most severe vehicle involved is registered. The severity is included in the data using the AP5 categories

DOD, GZH, GEH, GOV and UMS, as explained in section 2.2.3.

- *Origin of the accident* Is there something known about what caused the accident? Is it due to the weaving section itself, or probably due to a person using his or her cell phone while driving, or due to bad weather? What type of vehicles are involved? This additional data is not registered for all accidents.

After analysing all crashes per weaving section the five *W*-factors will be summarised:

- *What?* The number of events;
- *Where?* The locations of the events;
- *When?* The time of the events;
- *Who?* The involvement of freight traffic to the events and age of the driver;
- *Why?* The cause of the events;

Appendix F includes answers to the five *W*-factors that are supposed to give a better insight in what might have caused the crashes. Also some answers might be useful for comparison with times and locations of conflicts in the micro-simulation.
It is found that on most weaving sections clearly more crashes are found during peak hours than in off-peak hours. Also, sometimes the spread over the year shows that more crashes occur in winter months with unfavourable weather circumstances and less daylight, but this is not seen at all locations. No clear pattern is seen on the location of the crash within the weaving sections. On some locations more crashes are seen around the gores, but at other locations more crashes are observed in the middle. The quality and completeness of the crash database is too low to draw conclusions on what and who caused the crash and why. Data such as the crash type, weather circumstances and age of the driver are often described as 'unknown'.

5.2. Ranking Based on Simulation Conflict Numbers

A second ranking is based on the number of conflicts in the VISSIM simulation models. This section describes how this conflicts ranking is obtained.

After creating the VISSIM simulation models, performing a calibration by comparing simulated and field intensities and performing a visual inspection, and determining the required number of simulation runs to ensure that the outcomes are a true representation of the average as described in appendix H, the trajectory files that are obtained from the VISSIM simulation can be put into SSAM to determine the number of conflicts. While calibrating and performing a visual inspection it was found that the OD matrices for weaving section 499 did not correspond to the selected weaving section between Bavel and interchange St. Annabosch, but to the weaving section between interchange St. Annabosch and junction Ulvenhout. As no correct OD matrices were available, this weaving section was left out the selection.

The required number of simulation runs is calculated based on a 95% confidence interval using the travel time on the weaving section, as described in appendix H.4. For most weaving sections the trajectory files of 10 simulation runs with random seed 50 – 59 are used. For weaving section 369 12 runs are required to obtain a statistical representative result, here seed 50 – 61 are used. These random seeds are values that initialise a random number generator. According to the VISSIM user manual [65] two simulation runs using the same network file and same random start number look the same. However, if the random seed varies, the stochastic functions in

VISSIM are assigned a different value sequence and the traffic flow changes. This seed number for example determines the arrival pattern of the vehicles in the network.
Due to the different number of runs, summing up conflict counts would result in an unfair comparison, hence averages are used for the ranking.

Appendix I includes screenshots of the SSAM user interface, and describes how SSAM calculates the number of conflicts from the VISSIM trajectory files. Conflicts are calculated in SSAM using the projection thresholds values included in table 4.8. Thereafter a filter is applied on the TTC and PET as included in table 4.9. As described in paragraph 4.5.2 also an area filter is applied such that only conflicts that occurred in the influence area are included.

Table 5.3 includes the number of conflicts that is count within the influence area per weaving section. Also, the average number of conflicts per weaving section per run is included, and based on that value the weaving sections are ranked.

Table 5.3: Ranking based on number of conflicts in VISSIM & SSAM

Count	ID	Number of conflicts in filter area												Average
Rank		Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11	Run12	
1	173	30510	30928	27584	34397	30539	29543	30473	28374	30706	35177			30823.1
2	454	575	574	546	707	692	636	672	640	616	1121			677.9
3	369	290	195	99	143	202	86	155	87	108	139	182	82	147.3
4	077	34	27	17	34	42	49	46	35	31	809			112.4
5	068	1	8	0	7	3	4	2	6	8	11			5.0
6	256	3	2	5	4	5	4	3	6	1	6			3.9
7	412	3	3	4	2	3	4	2	2	2	3			2.8
8	269	0	4	2	0	3	3	1	0	4	5			2.2
9	156	2	1	0	1	0	1	1	0	1	0			0.7

It is seen that on weaving section 173 clearly more conflicts occurred than on the other weaving sections. Also, on the weaving sections with more than 100 conflicts more congestion is seen in the simulation than on the other weaving sections. However, the low number of conflicts at some weaving sections might be lower than the number that would occur in reality. For some weaving sections in one of the runs many more conflicts are observed than in other runs. On weaving section 077 in the tenth run, there was some spillback from congestion around the lane drop upstream the weaving section into the influence area of the weaving section, leading to more conflicts. On weaving section 454 in the tenth run some vehicles had troubles finding a gap to merge into, due to which a leading vehicle comes to a temporary standstill, forcing other following vehicles to brake. It might be that although the following vehicle is braking, the time to collision still becomes below the threshold of 1.5 seconds.
Note that for the weaving sections with only a few conflicts a slight increase or decrease in number of conflicts might already result in a major change in conflict ranking position. Similarly, a slight change in number of crashes might result in a major change in crash ranking position.

To have a fairer comparison between the different locations with different exposures, the number of registered crashes was expressed in crashes per thousand daily vehicle kilometres. Hence similar is done for observed conflicts. The number of vehicle kilometres is calculated using the number of vehicles in VISSIM and the length of the real weaving section derived from the ArcGis analysis. This results in the values and rankings as shown in table 5.4 in which the weaving sections are ordered on ranking position. It is seen that the more busy and congested weaving sections still have a higher conflict rate. As each hour is represented as 15 minutes in the simulation, also only 25% of the daily vehicles is included in the simulation, leading to the low number of simulated vehicles in the *'SimVeh'* column in table 5.4.

It should also be noted that a slight lower or higher conflict rate for some weaving sections might already result in a lower or higher ranking position.

Table 5.4: Ranking based on conflict rate in VISSIM & SSAM

Rate rank	ID	Location	Conflict count	Length	SimVeh	Veh. km ($\times 10^3$)	Conflict rate
1	173	Kralingen - Interch. Terbregseplein	30823	888	24623	21.87	1409.38
2	369	Interch. Zaandam	147	137	9235	1.26	116.70
3	454	Rotterdam Schiebroek - Interch. Kleinpolderplein	678	468	20829	9.75	69.52
4	077	De Bilt - Maarssen	112	608	13971	8.49	13.24
5	256	Interch. Hoogeveen	4	152	4410	0.67	5.81
6	269	Interch. Hattemerbroek	2	171	2286	0.39	5.63
7	068	Interch. Heerenveen	5	189	6362	1.20	4.16
8	412	Voorthuizen - Barneveld	3	1306	8249	10.77	0.26
9	156	Interch. De Baars - Tilburg Noord	1	596	8071	4.81	0.15

5.3. Human Factors Ranking

This section describes how road safety experts ranked the weaving sections on safety.

Paragraph 4.4.1 describes that a human factor analysis is a good method for safety experts to be used when predicting safety of a road section. Hence some road safety experts are asked to give their opinion on the weaving sections and rank them, based on the human factors method. Therefore, the experts received a description of each weaving section, included in appendix G. First each expert group member made a ranking of the weaving sections. These different rankings are included table G.1. Thereafter the individual rankings are compared and discussed in the expert group, such that one final ranking that all experts agreed on was obtained. This ranking is shown in table 5.5.

Table 5.5: Ranking based on expert judgement

Expert rank	ID	Location
1	454	Rotterdam Schiebroek - Interch. Kleinpolderplein
2	173	Kralingen - Interch. Terbregseplein
3	077	De Bilt - Maarssen
4	412	Voorthuizen - Barneveld
5	068	Interch. Heerenveen
6	369	Interch. Zaandam
7	156	Interch. De Baars - Tilburg Noord
8	256	Interch. Hoogeveen
9	269	Interch. Hattemerbroek

5.4. Crash Prediction Model Ranking

Another method to determine safety of weaving sections is using a crash prediction model (CPM). This section describes how a ranking is obtained using a CPM.

As described in paragraph 4.4.2 the CPM developed by Iliadi et al. [29] will be used to create another ranking of the weaving sections. For that equation 4.3 will be used, which calculates the expected number of crashes in a three-year period on symmetrical weaving sections in the Netherlands:

$$N = 4.46 \cdot 10^{-5} \cdot length^{0.46} \cdot AADT^{0.88} \cdot e^{0.35 \cdot lanes + 1.05 \cdot share - 1.67 \cdot location} \qquad \text{(4.3, repeated)}$$

The parameters are explained in paragraph 4.4.2. For developing the model, no distinction was made in crash type and crash severity, hence both vehicle-to-vehicle crashes and single-vehicle crashes are used. Note that the model was developed for symmetrical weaving sections, and weaving sections 454 and 499 are asymmetrical. However, as no formula was found for Dutch asymmetrical weaving sections, the formula for symmetrical weaving sections is used. This might give incorrect results for the two asymmetrical weaving sections.

Table 5.6 lists the variable values that are required for calculating the expected number of crashes per weaving section. In the calculation similar length from the GIS analysis is used here as in the analysis of the weaving sections. The AADT is determined from INWEVA, also similar as in section 4.2.
The number of lanes on the main freeway is found by observing aerial views of the weaving sections. Note that weaving section 454 has a 3+1>2+2 configuration, and hence not has a clear number of lanes on the main freeway. As the dotted line is located in the middle, so that it has two lanes at the left and two lanes at the right, the number of lanes on the main freeway is set to two. However, changing the number of lanes to 3 does not affect the ranking position of ID454.
The percentage of weaving traffic is calculated from the selected link analysis data from 4Cast. For developing the CPM only the percentage of weaving cars during rush hours was used by Iliadi et al. [29], so similar is used here. The share of weaving cars is calculated by adding the number of weaving cars in the morning peak and evening peak, and dividing this by the total number of cars in morning and evening peak such as in equation 5.1, where $t = \{AM, PM\}$.

$$share = \frac{\sum_t \left(car_{t,AD} + car_{t,BC}\right)}{\sum_t \left(car_{t,AC} + car_{t,AD} + car_{t,BC} + car_{t,BD}\right)} \qquad (5.1)$$

The value for location is set to 0 if the weaving section is located outside an interchange and 1 if the weaving section is inside an interchange. The latter is the case for four weaving sections, which are situated between two loops of a cloverleaf interchange.
The 'N' column includes the predicted number of crashes to occur in a three-year period according to equation 4.3. The column 'CPM rank' includes the corresponding ranking position. To have a fair comparison to the crash rate and conflict rate, which are expressed in number of crashes and conflicts per thousand vehicle kilometres, the CPM is expressed in similar units in the column 'CPM ratio'. The ratio is found by dividing the CPM value by the number of vehicle kilometres in thousands:

$$\text{CPM ratio} = \frac{CPM}{AADT \cdot length \cdot 10^{-6}} \qquad (5.2)$$

Here the $AADT$ is expressed in vehicles per day, and the $length$ of the weaving section is in meters. Table 5.6 ranks the weaving sections based on this CPM ratio.

5.5. Global Validation of VISSIM & SSAM

The four rankings that are obtained in the previous sections can be compared, to determine whether the number of conflicts in VISSIM & SSAM is representative for the safety of the weaving sections.

Table 5.6: Predicted number of crashes using a CPM

CPM ratio rank	ID	Length	AADT	Lanes	Share	Location	N	CPM rank	CPM ratio
1	454	468	76075	2	0.67	0	60.85	2	1.71
2	077	608	50275	3	0.30	0	45.86	3	1.50
3	499	740	38200	2	0.66	0	40.41	4	1.43
4	173	888	89675	3	0.46	0	107.31	1	1.35
5	156	596	27050	2	0.09	0	14.78	6	0.92
6	412	1306	36475	2	0.34	0	35.82	5	0.75
7	269	171	6400	1	1.00	1	0.81	9	0.74
8	369	137	30900	2	0.30	1	1.99	7	0.47
9	256	152	13175	2	0.10	1	0.80	10	0.40
10	068	189	20775	2	0.27	1	1.57	8	0.40

Table 5.7 includes the scores of the weaving sections on the four methods. Registered and predicted number of crashes and calculated conflicts are expressed in number per thousand daily vehicle kilometres, hence a higher number corresponds to a higher risk. In the experts ranking the weaving section on position 9 has lowest risk, while the weaving section on position 1 is judged as most dangerous.
Table 5.8 shows the ranking positions of the selected weaving sections based on those different methods and figure 5.9 visualises these ranking positions. As for weaving section 499 the OD matrix did not correspond to the location of the weaving section, this location was left out the rankings. Hence the maximum ranking position is 9. The lower the rank number, the more crashes are observed or expected at the weaving section, so the more unsafe the weaving section is (and hence the more attention it requires). Figure 5.10 visualises the ranking positions of the weaving sections when considering the crash rate and VISSIM and SSAM conflict rate. From the linear trendline is seen that a higher position on the crash rate ranking corresponds to a higher position on the VISSIM and SSAM conflict ranking.

Table 5.7: Ratio scores of the weaving sections on the various categories

ID	Location	Value (ratio)			
		Crash Rate	Experts	CPM	VISSIM/SSAM
068	Interch. Heerenveen	1.3	5	0.4	4.2
077	De Bilt - Maarssen	1.1	3	1.5	13.2
156	Interch. De Baars - Tilburg Noord	0.7	7	0.9	0.1
173	Kralingen - Interch. Terbregseplein	1.6	2	1.3	1409.4
256	Interch. Hoogeveen	9.5	8	0.4	5.8
269	Interch. Hattemerbroek	3.7	9	0.7	5.6
369	Interch. Zaandam	7.3	6	0.5	116.7
412	Voorthuizen - Barneveld	1.1	4	0.8	0.3
454	Rotterdam - Interch. Kleinpolderplein	2.6	1	1.7	69.5

The correlation between two rankings can be evaluated using the Spearman rank correlation coefficient. This is a non-parametric test which assesses the statistical dependence between two variables, and is often used to assess how well the relationship between two variables can

Table 5.8: Positions of the weaving sections in the various rankings

ID	Location	Ranking position			
		Crash Rate	Experts	CPM	VISSIM/SSAM
068	Interch. Heerenveen	6	5	9	7
077	De Bilt - Maarssen	7	3	2	4
156	Interch. De Baars - Tilburg Noord	9	7	4	9
173	Kralingen - Interch. Terbregseplein	5	2	3	1
256	Interch. Hoogeveen	1	8	8	5
269	Interch. Hattemerbroek	3	9	6	6
369	Interch. Zaandam	2	6	7	2
412	Voorthuizen - Barneveld	8	4	5	8
454	Rotterdam - Interch. Kleinpolderplein	4	1	1	3

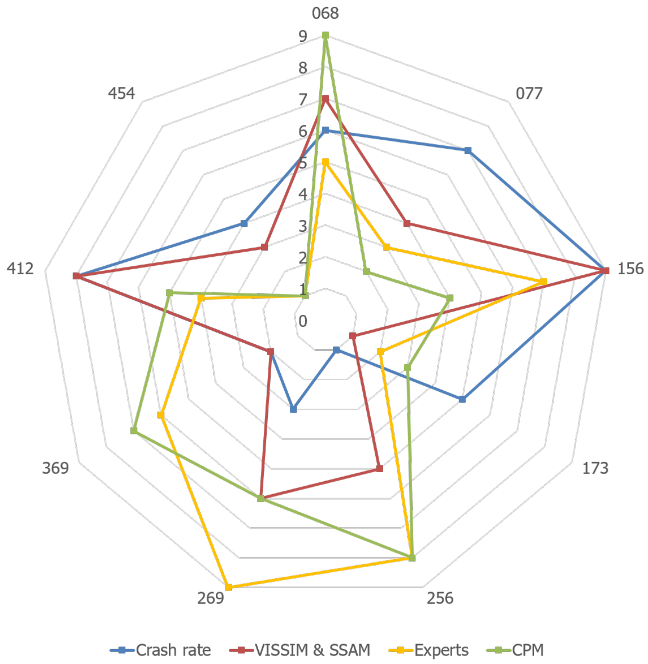


Figure 5.9: Positions of the weaving sections in the various ratio rankings

be described using a monotonic function. The coefficient is calculated as

$$\rho_s = 1 - \frac{6 \cdot \sum_{i=1}^{n} d_i^2}{n(n^2 - 1)} \tag{5.3}$$

where d_i is the difference between ranks for observation (i.e. weaving section) i and n represents the number of observations (weaving sections) in the validation data set. Similar to Pearson's correlation coefficient, the closer the coefficient is to ±1, the stronger the monotonic relationship [22, 28]:

- 0.00 - 0.19 – very weak

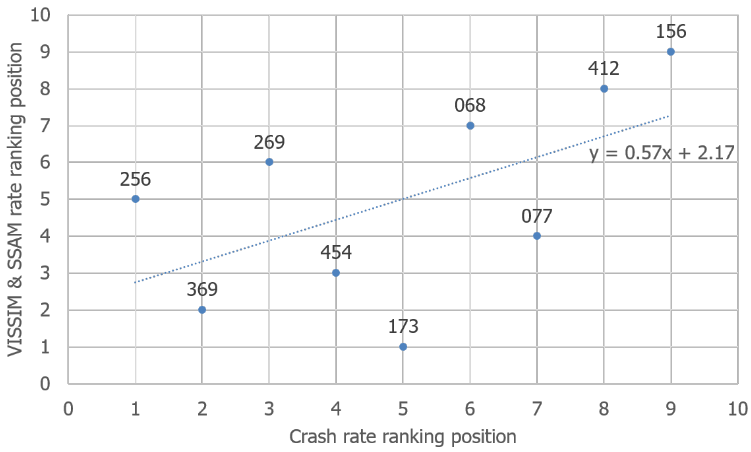


Figure 5.10: Relation between crash rate ranking position and VISSIM & SSAM rate ranking position

- 0.20 - 0.39 – weak
- 0.40 - 0.59 – moderate
- 0.60 - 0.79 – strong
- 0.80 - 1.00 – very strong

The Spearman rank correlation coefficient is calculated between each pair of rankings using equation 5.3 and the results are included in table 5.9. It is seen that the correlation between the VISSIM & SSAM ranking and the crash rate ranking is moderate. Also the correlation of the VISSIM & SSAM ranking with the experts ranking is moderate. The correlation with between VISSIM & SSAM and the CPM is weak, but positive. The correlation between the experts ranking and the CPM can be classified as strong.
There is a negative correlation between the crash rate and CPM ranking. This suggests that a higher number of conflicts corresponds to a lower expected number of crashes in the crash prediction model, and vice versa, which is not in line with the expectations. Similarly, there is a negative correlation between the crash rate ranking and the experts ranking.

Table 5.9: Spearman Rank Correlation Coefficients for ratios, and the P-values in brackets

	Crash Rate	Experts	CPM
Experts	-0.300 (0.433)		
CPM	-0.367 (0.332)	0.683 (0.042)	
VISSIM & SSAM	0.567 (0.112)	0.467 (0.205)	0.300 (0.433)

In order to assess whether or not the correlations between the rankings can be generalised from this sample of nine weaving sections onto the population of all weaving sections in the Netherlands, a test of significance can be performed. For that, the null hypothesis is that there is no correlation between the position on one ranking and on another. The alternative hypothesis states that there is a correlation between the two ranking positions.
A test of significance can be performed to test whether the calculated Spearman Rank Correlation is significant. Spearman's Rho Table [59] gives a critical value of 0.683 for $n = 9$ and $\alpha = 0.05$.

Since 0.567 is less than this critical value, the null hypothesis cannot be rejected. Hence the correlation is not statistically significant [59]. A P-value of 0.11163 is found. The correlation between the CPM and the experts ranking is significant.

Figure 5.9 visualises the positions of the selected weaving sections in the different rankings. It is seen that the various ranking methods do not exactly agree on the ranking positions. However, the four methods seem to agree on which location is more safe in comparison to another location (for example ID454 is more unsafe on all rankings than ID068, and ID156 is more safe than ID077 on all rankings). However, the crash rate rankings shows a somewhat different pattern in figure 5.9 than the other rankings, which corresponds to the negative correlations with the crash rates included in table 5.9. Furthermore it is seen that on weaving sections 256 and 269 there are large differences between the ranking positions on the four categories. Both are classified as relative unsafe from the crash rate ranking, which might be due to the low AADT resulting in a relative high crash rate. Also, the experts classified ID269 (which has the C/D-lane) as relative safe compared to the other rankings.

When considering absolute numbers instead of ratios, all correlations are stronger, as can be seen in table 5.10. Except for the correlation between VISSIM & SSAM and the CPM, all correlations are sufficient are significant as they are exceeding the critical value $\rho_{crit} = 0.683$. This is also seen in figure 5.11, in which the ranking positions are closer than in figure 5.9. This suggests that traffic intensity influences the number of crashes and number of conflicts. It might be that due to the relation to traffic intensities a correlation between VISSIM and SSAM and the crash counts is found, but that this is a spurious correlation and that the relation between crashes and conflicts is not causal.
Furthermore, the stronger correlations with the experts rankings suggest that experts seem to focus more on the road and traffic characteristics than on exposure when judging safety of weaving sections. Although the experts were asked to take into account the exposure and rank the weaving sections on the crash risk, from table 5.10 it seems that their rankings are based more on crash numbers than on crash rates.

Table 5.10: Spearman Rank Correlation Coefficients for counts, and the P-values in brackets

	Crash Count	Experts	CPM
Experts	0.850 (0.004)		
CPM	0.850 (0.004)	0.900 (0.001)	
VISSIM & SSAM	0.717 (0.030)	0.750 (0.020)	0.600 (0.088)

5.6. Detail Analysis

After the global validation of VISSIM & SSAM, a more detailed validation of the relation between the crash rates and conflict rates is presented in this section. First the effect of a different method to determine the correlation between two rankings is described. This is done in paragraph 5.6.1, which considers the Pearson correlation coefficient as alternative for the Spearman rank correlation coefficient.

Thereafter, paragraph 5.6.2 describes the effects of the weaving sections selection, as exceptional weaving sections or incorrect crash rates might influence the correlations.

Next, the effect of some settings in SSAM is assessed. In paragraph 5.6.3 the sensitivity of the choice for the PET threshold value is investigated. In paragraph 5.6.4 similar is done for the TTC threshold value.

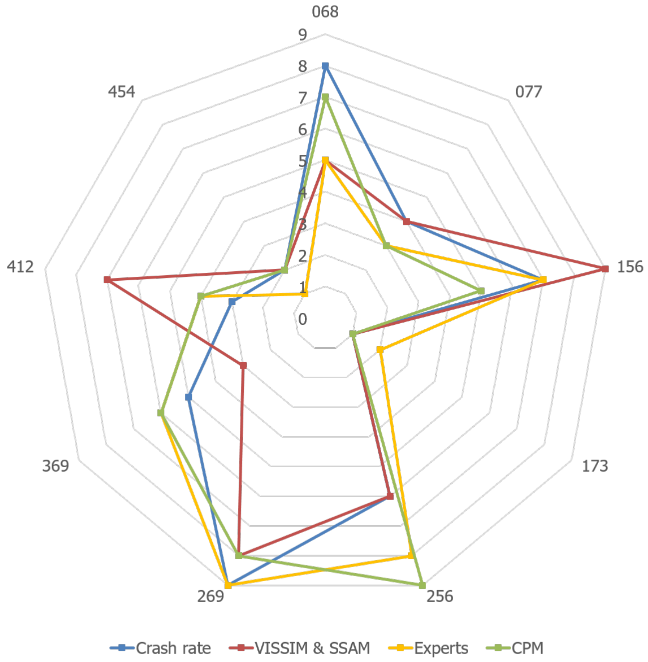


Figure 5.11: Positions of the weaving sections in the various count rankings

Also the effect of settings in the VISSIM micro-simulation model is investigated. Paragraph 5.6.5 tests the effect of the choice for a different Wiedemann car-following model. Thereafter, in paragraph 5.6.6 the effect of the desired speed distribution is tested. In paragraph 5.6.7 it will be assessed if a more extensive calibration on speeds results in a stronger correlation.

Lastly, a more detailed analysis on the correspondence between individual crash registrations and predicted conflicts is done. In paragraph 5.6.8 and 5.6.9 respectively it will be investigated if the time and location of the conflicts are corresponding to the time and location of the crashes. In paragraph 5.6.10 it is assessed whether the conflict type corresponds to the crash type.

5.6.1. The Pearson Correlation Coefficient

Instead of creating rankings and determining the Spearman Rank correlation coefficient it is also possible to calculate the correlation between the values included in table 5.7 using Pearson's Product Moment Correlation Coefficient. For this correlation coefficient it is not necessary to rank the entries, and hence the size of the variation in the scores is included in the correlation. This prevents that almost equal scores lead to a relative large difference in ranking position.

The correlation coefficient between a dataset $X = \{x_1, \ldots, x_n\}$ containing n values and another dataset $Y = \{y_1, \ldots, y_n\}$ also containing n values is calculated as

$$correl(X,Y) = r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (5.4)$$

where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, and analogous $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$.

Table 5.11 includes the calculated Pearson correlations between the various rankings. For most rankings the differences between the Pearson correlation coefficient and Spearman Rank correlation coefficient are only minor, except for the correlation between VISSIM & SSAM and the crash rate. The Pearson correlation between the CPM and the experts is significant.

Table 5.11: Pearson Correlation Coefficients for ratios, and the P-values in brackets

	Crash Rate	Experts	CPM
Experts	-0.485 (0.188)		
CPM	-0.501 (0.169)	0.756 (0.018)	
VISSIM & SSAM	-0.158 (0.685)	0.432 (0.246)	0.336 (0.377)

When removing weaving section 173 from the selection, which has an exceptional high conflict rate, Pearson correlation coefficients of 0.406 $(P = 0.318)$, 0.285 $(P = 0.494)$ and 0.110 $(P = 0.795)$ were found when comparing the VISSIM & SSAM conflict rates with the crash rates, experts score and CPM respectively. For the VISSIM & SSAM rate and crash rate this value is much closer to the calculated Spearman Rank correlations, indicating that the exceptional high number of conflicts at weaving section 173 largely influences the Pearson correlation coefficient.

5.6.2. Influence of Selection of Weaving Sections

As the correlations are calculated based on only nine weaving sections, one exceptional weaving section might considerably influence the rankings, and hence correlations in a large extent. The effect of possible exceptional weaving sections is discussed, even as the effect of incompleteness of the crash database and weaving sections having a very close crash rate.

Exceptional Weaving Section

A weaving section with a large likelihood of being exceptional is weaving section 256, which is the weaving section with the highest crash rate and has the largest distance to the linear trendline through the AADT and crash rate and in figure 5.1. This is a weaving section located within a cloverleaf interchange, hence having a short length. The relative low AADT leads to a low number of vehicle kilometres. Hence the low to medium number of crashes results in a very high crash rate. If this weaving section was not included in the selection, a correlation between the crash rate and VISSIM & SSAM rankings of 0.714 was found. This is higher than the original correlation of 0.567 in which ID256 was included, but still does not exceed the critical value 0.738 found in Spearman's Rho Table for $n = 8$ and $\alpha = 0.05$, which means that the correlation is still not significant.

Figure 5.10 suggests that also weaving section 173 might be an outlier weaving section. This weaving section has an extreme high number of conflicts, which might be due to congestion during the simulation being interpret by SSAM as conflicts. When removing this weaving section from the selection a correlation of 0.677 $(P = 0.071)$ is found. This correlation is below the critical value $\rho_{crit} = 0.738$, which means that the correlation is still not significant when removing ID173.

Removing both ID173 and ID256 results in a correlation of 0.821 $(P = 0.023)$. As the sample size is decreased, the critical value for having a significant correlation increases to 0.786 for $n = 7$ and $\alpha = 0.05$. As 0.821 exceeds $\rho_{crit} = 0.786$, the correlation is significant. However, taking care is required as the sample size is very small.

To reduce the effect of outlier weaving sections, the sample size could be increased. In that way, the influence of an exceptional value is less considerably. Another benefit of increasing the sample size is that the critical value reduces, and that hence for weaker correlations the correlation can be called significant.

Incomplete Crash Database

When selecting the weaving sections it was assumed that the percentage of non-registered crashes was equally spread over the weaving sections [13]. However, one could argue that on the busy weaving sections in urban area the crash registration degree is higher, as on those locations the crash is reported such that measures could be taken that reduce the nuisance as soon as possible and more police and road authorities pass that observe the crash than on locations with a lower traffic intensity. Hence on locations with a lower AADT more crashes could be missing in the database. To assess this hypothesis, the number of crashes is increased as function of the AADT according to equation 5.5:

$$\text{Crashcount}_{new} = \text{Crashcount}_{old} + \beta \cdot \frac{1}{AADT} \tag{5.5}$$

In figure 5.12 it is seen that for $\beta = 100\ 000$ on the weaving sections with a low AADT more crashes are added, and on the weaving sections with a high AADT only a few crashes are added.

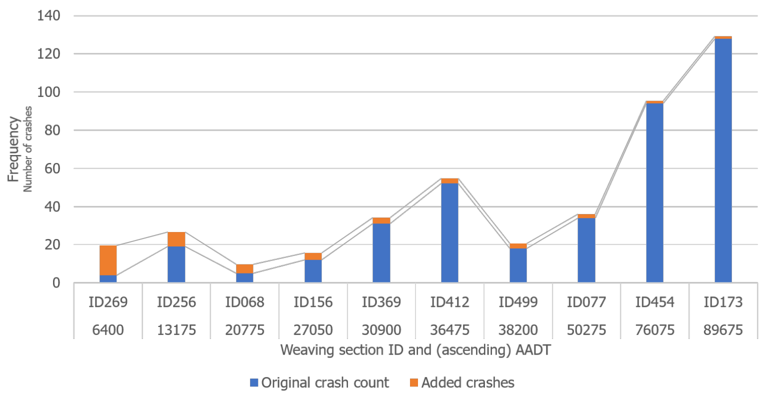


Figure 5.12: Crashes are added to weaving sections as function of the AADT

However, manually increasing the number of crashes does not improve the correlation between the crash rate and the VISSIM & SSAM rate rankings. Adding crashes according to equation 5.5 even leads to a decreased correlation of 0.383 ($P = 0.309$), as can be seen in table 5.12. Adding less crashes by replacing β by a lower number also does not result in an increased correlation. This suggests that the assumption that the crash registration is better at busy locations is incorrect, that the relation between simulated conflicts and crashes is not as expected or that simulated conflict rates are not representative for crash rates.

UDLS Crash Database

An alternative for the BRON crash database is the UDLS database. UDLS stands for Uniforme Droge Logging Systeem (uniform system for roadway incident logging) and is maintained by the Rijkswaterstaat traffic centres. There is a separate system for waterway incident logging. Also for this UDLS database it is uncertain if it is complete, as priority is given to solving the incident in the first place, and registration in the database occurs in a later stage. Furthermore, incidents are partially observed by cameras. The camera density is higher in more urban area such as the Randstad, and lower in the more rural areas of the Netherlands.

Table 5.12: Sensitivity of adding 'missing' crashes as function of the AADT (equation 5.5, $\beta = 100000$)

ID	VISSIM & SSAM		Original crash rate		Increased crash rate	
	Ratio	Rank	Ratio	Rank	Ratio	Rank
068	4.16	7	1.28	6	2.50	5
077	13.24	4	1.11	7	1.18	7
156	0.15	9	0.74	9	0.97	9
173	1409.38	1	1.61	5	1.62	6
256	5.81	5	9.48	1	13.26	2
269	5.63	6	3.65	3	17.93	1
369	116.70	2	7.34	2	8.10	3
412	0.26	8	1.09	8	1.15	8
454	69.52	3	2.64	4	2.68	4
Spearman				0.567		0.383
P-value				0.112		0.309

UDLS databases are received for the years 2012 till 2015. The crashes that satisfy the road number and hectometre range of the influence area of the selected weaving sections are selected. This resulted in the crash counts included in table 5.13. This table also includes the ranking based on the UDLS counts and rates.

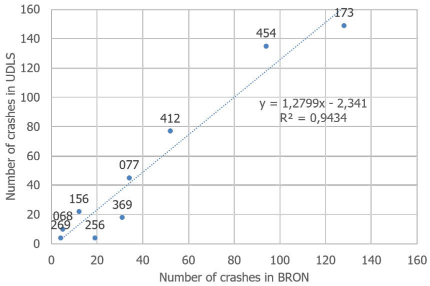
Table 5.13: Ranking based on crash rates in UDLS database

Rate rank	ID	2012	2013	2014	2015	UDLS count	Count rank	UDLS rate
1	369	8	3	5	2	18	6	4.26
2	454	16	36	34	49	135	2	3.79
3	269	0	2	0	2	4	8	3.65
4	068	3	1	4	2	10	7	2.55
5	256	0	0	2	2	4	8	2.00
6	173	37	26	33	53	149	1	1.87
7	412	13	12	30	22	77	3	1.62
8	077	9	11	6	19	45	4	1.47
9	156	10	6	6	0	22	5	1.37

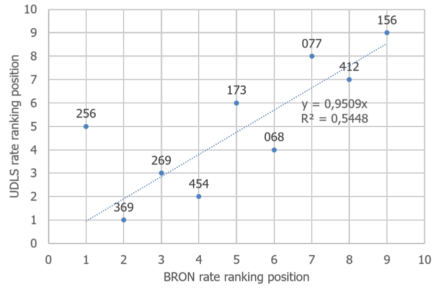
Figure 5.13a shows that the crash numbers in both databases are different, but that there is a strong correspondence between the two methods as the Pearson correlation between the BRON crash counts and UDLS crash counts is 0.971 ($P = 0.00001$). There is also a reasonable, but weaker, fit between the two crash rate rankings ($\rho_s = 0.767$, $P = 0.016$) shown in figure 5.13b. However, the Pearson correlation between the two crash rates is only 0.418 ($P = 0.262$). Table 5.14 includes the Spearman rank correlation coefficients for the rankings based on the ratios, including the ratio ranking based on the UDLS database. No major differences are observed for correlations with BRON crash rates and UDLS crash rate.

Close Crash Rate Scores

Three of the weaving sections have a very close crash rate, being 1.09, 1.11 and 1.28, resulting in ranking positions 6 till 8. Only a very slight change in number of crashes, length or AADT might already result in another ranking position, and thus in another correlation.



(a) Crash counts in BRON and UDLS database



(b) Crash rate rankings in BRON and UDLS

Figure 5.13: BRON and UDLS crash databases

Table 5.14: Spearman Rank Correlation Coefficients for ratios including UDLS, and the P-value in brackets

	Crash Rate	Experts	CPM	VISSIM & SSAM
Experts	-0.300 (0.433)			
CPM	-0.367 (0.332)	0.683 (0.042)		
VISSIM & SSAM	0.567 (0.112)	0.467 (0.205)	0.300 (0.433)	
UDLS	0.767 (0.016)	-0.050 (0.898)	-0.283 (0.460)	0.483 (0.187)

Assigning the average crash rate (1.16) to the three locations leads to a correlation of 0.559, which is only a slight decrease.
Manually changing the ranking positions leads to correlations varying from 0.483 to 0.617. For this specific selection of weaving sections a correlation of 0.567, which is in the middle of that range, was found. Hence in this case the slight differences between crash rates only have a minor effect on the acquired correlation coefficient.

Categories as Alternative for Rankings

Distributing the obtained crash rate, conflict rate, CPM rate and expert judgement values into three groups 'safe', 'medium' and 'unsafe' also results in a decreased influence of slight differences between scores. Distributing the nine weaving sections for each of the four safety methods evenly over the three groups results in the distribution as included in table 5.15. The obtained rank correlations are included in table 5.16. Note that distributing the weaving sections into different categories does not result in major differences with the Spearman rank correlation coefficients for ratios as included in table 5.9 for this selection of weaving sections.

5.6.3. Sensitivity of PET Threshold

The initial PET projection threshold value in SSAM is 5.0 seconds, and this value is also used as maximum for filtering conflicts. According to Gettman et al. [22] this value is selected based on a literature review. However, in literature also some lower PET threshold values are proposed. Archer [3] describes that the PET should be below a predetermined threshold value, which is typically 1 to 1.5 seconds. In his research the threshold value is set to 1.5 seconds. Kraay et al. [31] conclude that in general on roads within urban area only PET values below 1.0 seconds are perceived as possibly critical. Both have their focus in interchanges and not on weaving sections. Hence the number of conflicts is calculated for these PET threshold values, and for one extra value in between: 3 seconds. When using for the TTC the initial threshold of $0.05 \leq TTC \leq 1.5$, this results in the conflict rates and ranks as shown in table 5.17. In this table also the Spearman

Table 5.15: Distribution of the weaving sections into three safety groups (1 unsafe; 2 medium; 3 safe) according to different methods

ID	Location	Safety group (1 unsafe; 2 medium; 3 safe)			
		Crash Rate	Experts	CPM	VISSIM/SSAM
068	Interch. Heerenveen	2	2	3	3
077	De Bilt - Maarssen	3	1	1	2
156	Interch. De Baars - Tilburg Noord	3	3	2	3
173	Kralingen - Interch. Terbregseplein	2	1	1	1
256	Interch. Hoogeveen	1	3	3	2
269	Interch. Hattemerbroek	1	3	2	2
369	Interch. Zaandam	1	2	3	1
412	Voorthuizen - Barneveld	3	2	2	3
454	Rotterdam - Interch. Kleinpolderplein	2	1	1	1

Table 5.16: Spearman Rank Correlation Coefficients for distribution into safety groups, and the P-value in brackets

	Crash Rate	Experts	CPM
Experts	-0.333 (0.381)		
CPM	-0.500 (0.170)	0.667 (0.050)	
VISSIM & SSAM	0.500 (0.170)	0.500 (0.170)	0.333 (0.381)

Rank Correlation Coefficient with the crash rate ranking is included. It is seen that for lower PET filter values the correlation between the crash rate and VISSIM & SSAM rate ranking is less strong.

Table 5.17: Sensitivity of the PET threshold value

ID	Crash rate		$PET \leq 5.0$		$PET \leq 3.0$		$PET \leq 1.5$		$PET \leq 1.0$	
	Ratio	Rank	Ratio	Rank	Ratio	Rank	Ratio	Rank	Ratio	Rank
068	1.28	6	4.16	7	3.25	7	0.75	6	0.50	6
077	1.11	7	13.24	4	10.08	4	3.98	4	2.32	5
156	0.74	9	0.15	9	0.12	9	0.10	9	0.10	8
173	1.61	5	1409.38	1	1018.01	1	297.38	1	133.16	1
256	9.48	1	5.81	5	5.22	5	3.58	5	2.83	4
269	3.65	3	5.63	6	3.58	6	0.26	7	0.00	9
369	7.34	2	116.70	2	83.50	2	27.85	2	15.05	3
412	1.09	8	0.26	8	0.23	8	0.21	8	0.19	7
454	2.64	4	69.52	3	51.41	3	23.84	3	15.61	2
Spearman				0.567		0.567		0.517		0.400
P-value				0.112		0.112		0.154		0.286

5.6.4. Sensitivity of TTC Threshold

SSAM uses an initial value of 1.5 seconds for the TTC threshold, which is also proposed by amongst other Kraay et al. [31], recommended by Gettman et al. [22] and used by Shahdah et al. [56]. However, in literature also other values are proposed. Archer [3] uses a threshold TTC of 3.5 seconds, and Kuang et al. [32] mentions that the TTC varies between 1.5 and 4.0

seconds in various studies, and they apply a threshold value of 4.0 seconds in their research. Testing the sensitivity of larger TTC filter values in similar way as the PET filter value is not possible, as only values less than the projection threshold values can be used as filter upper bound. Maximum TTC filter values larger than 1.5 result in similar number of conflicts than for maximum TTC filter equal to 1.5, as the location of the vehicles is only projected 1.5 seconds in future since the conflict TTC threshold is set to 1.5 (see table 4.8).
For the in literature suggested TTC values larger than 1.5, conflict calculations should be performed with a larger TTC projection threshold. However, when using a larger time step different vehicle trajectories are projected by SSAM, leading to different conflicting vehicle pairs and locations. Hence this would lead to an unfair comparison with the original used threshold values. Hence sensitivity of the TTC threshold value is tested for TTC maximum values of 0.5, 1.0 and 1.5 seconds. This results in the conflict rates and ranking positions as shown in table 5.18. It is seen that the Spearman Rank Correlation Coefficient between the crash rate and the VISSIM/SSAM conflict rate increases when decreasing the maximum TTC. The correlation between the rankings is clearly stronger when filtering for only TTC values between 0.05 and 0.50. The lower the TTC value, the larger the likelihood that a conflict results in a crash.

Table 5.18: Sensitivity of the TTC threshold value

ID	Crash rate		$0.05 \leq TTC \leq 1.5$		$0.05 \leq TTC \leq 1.0$		$0.05 \leq TTC \leq 0.5$	
	Ratio	Rank	Ratio	Rank	Ratio	Rank	Ratio	Rank
068	1.28	6	4.16	7	0.75	7	0.58	6
077	1.11	7	13.24	4	2.59	6	0.31	7
156	0.74	9	0.15	9	0.08	9	0.06	9
173	1.61	5	1409.38	1	240.51	1	12.81	1
256	9.48	1	5.81	5	2.83	4	2.24	4
269	3.65	3	5.63	6	2.81	5	2.56	3
369	7.34	2	116.70	2	18.94	2	7.46	2
412	1.09	8	0.26	8	0.15	8	0.08	8
454	2.64	4	69.52	3	9.66	3	1.31	5
Spearman				0.567		0.733		0.783
P-value				0.112		0.025		0.013

According to Gettman and Head [21] and Gettman et al. [22, p. 36] a lower bound for the TTC larger than 0 should be used to remove 'virtual' conflicts. However, as not all SSAM users mention this measure, also the number of conflicts without setting a lower bound for the TTC is investigated. This results in the conflict rates as shown in table 5.19. As less conflicts are filtered out during the filtering process, higher conflict rates are obtained. However, only the ranking positions of weaving section 156 and 412 are switched as the crash rate increased more for weaving section 156 than for weaving section 412. Hence for this selection of weaving sections the effect of removing 'virtual' conflicts on the correlation between the rankings is only minor.

5.6.5. Effect of Wiedemann Car-Following Model

VISSIM includes two models for representing the car following behaviour of drivers, these are the Wiedemann 74 and Wiedemann 99 model. Initially the Wiedemann 99 car following model was used in all simulations, as Fan et al. [18, p. 71] writes "In this study, the Wiedemann 99 model was used since it was recommended by VISSIM user manual that the Wiedemann 99

Table 5.19: Sensitivity of filtering out 'virtual' conflicts

ID	Crash rate		$0.05 \leq TTC \leq 1.50$		$0.00 \leq TTC \leq 1.50$	
	Ratio	Rank	Ratio	Rank	Ratio	Rank
068	1.28	6	4.16	7	6.83	7
077	1.11	7	13.24	4	16.23	4
156	0.74	9	0.15	9	1.02	8
173	1.61	5	1409.38	1	1486.20	1
256	9.48	1	5.81	5	12.37	5
269	3.65	3	5.63	6	7.93	6
369	7.34	2	116.70	2	142.24	2
412	1.09	8	0.26	8	0.80	9
454	2.64	4	69.52	3	85.28	3
Spearman				0.567		0.550
P-value				0.112		0.125

model was mainly suitable for interurban traffic, whereas the Wiedemann 74 model was often used for urban traffic". Here it is referred to the manual for VISSIM 4.00. Similarly, Laufer [34] points out that the Wiedemann 74 model is now applied to urban and arterial roads, and that the Wiedemann 99 model is applicable to freeway conditions. However, when consulting the manual for VISSIM 9.0 – which is used for this research – it can be interpret that the Wiedemann 74 model is more suitable as it is written that the Wiedemann 74 is a "model suitable for urban traffic and merging areas" while the Wiedemann 99 is a "model for freeway traffic with no merging areas" [65, p. 247]. From this it can be concluded that the Wiedemann 74 model is a better choice. Hence in each simulation model the car following model at all links is changed to the Wiedemann 74 model and again the simulations are performed for multiple times (i.e. ID369 12 runs and all other locations 10 runs). Again, SSAM is used to calculate the number of conflicts. Initial projection threshold values described in table 4.8 and filter thresholds as in table 4.9 are used. Results can be found in table 5.20.

It is seen that on some locations the number of conflicts increased when using the Wiedemann 74 car following model, but that on most locations the number of conflicts decreased. However, the correlation between the crash rate and conflict rate with the Wiedemann 74 car following model is 0.300, thus changing the car following model did not lead to an improved correlation. When having as goal to obtain the highest correlation between the conflict rate from VISSIM & SSAM and the crash rate, based on this dataset it is recommended to use the Wiedemann 99 car following model. However, it is also desirable to determine the safety from a simulation model which is the best representing the real traffic behaviour. More detailed traffic data on vehicle trajectories is required to determine which model is best representing the real traffic behaviour. Data – such as floating car data – might also help to find the optimal parameter settings for the Dutch traffic behaviour. It might also be that another car following model which is not available in VISSIM might be better representing the real driving behaviour.

5.6.6. Effect of Desired Speed Limit

The desired speed limits used for the simulations are based on speeds observed by loop detectors, as described in appendix H.1.4. This data set also includes speeds during congestion. During congestion drivers are driving at a speed below their desired speed, and hence the used

Table 5.20: Sensitivity of the Wiedemann car following model

ID	Crash rate		Wiedemann 99		Wiedemann 74	
	Ratio	Rank	Ratio	Rank	Ratio	Rank
068	1.28	6	4.16	7	5.00	6
077	1.11	7	13.24	4	118.08	2
156	0.74	9	0.15	9	0.10	8
173	1.61	5	1409.38	1	575.80	1
256	9.48	1	5.81	5	3.58	7
269	3.65	3	5.63	6	11.25	5
369	7.34	2	116.70	2	68.18	3
412	1.09	8	0.26	8	0.08	9
454	2.64	4	69.52	3	21.53	4
Spearman				0.567		0.300
P-value				0.112		0.433

desired speed distributions are not sufficient representative for the real driving behaviour. Hence in all simulation models the desired speed distributions are adapted, such that the lowest 50% of the speeds are removed from the desired speed distributions. For weaving section 073 the desired speed distribution is changed such as shown in table 5.21. For the other weaving sections similar is done. For some weaving sections this resulted in clearly higher desired speeds, and at other weaving sections the changes are only minor. It is expected that this change leads to a better correlation between the rankings, as the speed distribution now is closer to the desired speed instead of the real speed.

Table 5.21: Adapted desired speed distribution for ID073 for sensitivity analysis

Original			Adapted		
X_{Car}	X_{HGV}	$F(X)$	X_{Car}	X_{HGV}	$F(X)$
35.5	28.8	0.00			
66.1	53.6	0.25			
80.8	65.6	0.50	80.8	65.6	0.00
90.7	73.6	0.75	90.7	73.6	0.50
120.4	97.8	1.00	120.4	97.8	1.00

Again, the required number of VISSIM simulation runs to obtain a statistical significant result are performed and the conflicts are calculated using SSAM. Initial projection threshold values described in table 4.8 and filter thresholds as in table 4.9 are used. This results in the conflict numbers and ranks as shown in table 5.22. It is seen that on most locations the number of conflicts, and hence the conflict ratio, decreased. However, the correlation between the crash rate ranking and conflict rate ranking did not improve, due to weaving section 156 now having a higher conflict ratio than weaving section 412, and the decrease in conflict rate of weaving section 269, which is not expected when considering the crash rate. Hence, the effect of the desired speed distribution on the correlation between the crash and conflict rate rankings is not as expected.

Table 5.22: Sensitivity of the desired speed distribution

ID	Crash rate		All speed data		Fastest 50%	
	Ratio	Rank	Ratio	Rank	Ratio	Rank
068	1.28	6	4.16	7	4.16	6
077	1.11	7	13.24	4	5.11	4
156	0.74	9	0.15	9	2.04	8
173	1.61	5	1409.38	1	390.82	1
256	9.48	1	5.81	5	3.13	7
269	3.65	3	5.63	6	4.60	5
369	7.34	2	116.70	2	152.67	2
412	1.09	8	0.26	8	0.12	9
454	2.64	4	69.52	3	69.51	3
Spearman				0.567		0.433
P-value				0.112		0.244

5.6.7. Effect of Calibration on Speeds

All previously presented results were based on a model that was calibrated by a visual inspection and calibrating on vehicle intensities. However, including also a calibration on vehicle speeds results in a model that is better representing the real traffic behaviour. For that calibration, hourly simulated vehicle speeds from three simulation runs with seed 43 - 45 are compared with average hourly field speeds measured by loop detectors retrieved from the NDW for working days in September 2015. According to Mai et al. [40] the spot speeds in the model should be within 10% of the observed real-world spot speed data.

At some weaving sections speeds were corresponding well at most hours. However, at some weaving sections the speed differences were larger at night time. This might be due to drivers violating the speed limit (at some hours average speeds between 130 and 150 km/h are observed), which is not the case in the simulation model. Another clarification is the low number of vehicles passing the data collection point in the simulation model, that accidentally might have received a desired speed from the lower part of the desired speed distribution. Hence at night-time larger deviations are accepted.

It is also seen that in the simulation the speeds on the acceleration lane after passing the convergence gore and on the deceleration lane before passing the divergence gore were higher than observed by the loop detectors. This indicates that vehicles in the simulation models are accelerating earlier and decelerating later than in the real situation. Hence the reduced speed areas that are applied to lower speeds in curves are extended, such that the speeds in the simulation model are decreased. Although this was not observed at every weaving section (due to absence of field speed data), this measure was applied in each simulation model.

At some locations (068, 156 and 269) the initial desired speed distributions resulted after extending the reduced speed areas in acceptable simulation speeds. At some other locations (256, 369 and 454) the adapted desired speed distributions as described in paragraph 5.6.6 in combination with extending the reduced speed areas resulted in acceptable simulation speeds deviating less than 10% from the field speeds as postulated by [40].

At weaving sections 077, 173 and 412 this did not lead to the desired results. At these locations the simulated speeds in the off-peak hours were too low. Hence the desired speed distributions are adapted again to increase the desired speed of the vehicles. At weaving sections 077 and

412 the simulated speeds during peak hours were higher than the field-speeds, indicating that in the simulation model there was less congestion. Here vehicle intensities are increased such that intensities were reaching simulation capacity, resulting into lower speeds. At weaving section 173 similar is done in the morning peak. However, in the evening peak the speeds in the simulation model were lower than speeds observed in the field. In these hours intensities are decreased, leading to a better correspondence of the speeds. When speeds are optimised for some locations and lanes, there are still deviations on the other lanes. However, optimising for the latter lanes in turn leads to differences on the first lanes. Hence some deviations are accepted.

After this calibration on speeds, again the required number of simulations is performed to obtain the trajectory files. Again these trajectory files are analysed using SSAM with the projection threshold values included in table 4.8 and filter thresholds described in table 4.9. The conflict numbers and correlation with the crash rate ranking as in table 5.23 are obtained.

Table 5.23: Sensitivity of performing calibration on speeds

ID	Crash rate		Initial calibration		Speed calibration	
	Ratio	Rank	Ratio	Rank	Ratio	Rank
068	1.28	6	4.16	7	4.58	8
077	1.11	7	13.24	4	932.21	1
156	0.74	9	0.15	9	0.31	9
173	1.61	5	1409.38	1	139.55	3
256	9.48	1	5.81	5	4.77	7
269	3.65	3	5.63	6	8.18	6
369	7.34	2	116.70	2	139.27	4
412	1.09	8	0.26	8	693.55	2
454	2.64	4	69.52	3	56.63	5
Spearman				0.567		-0.083
P-value				0.112		0.831

It is seen that performing a more extensive calibration leads to a weaker correlation than omitting this calibration on speeds. The correlation is so weak that it can be interpret as no correlation. Remarkable is that the conflict rate largely increased on weaving sections 077 and 412, where the amount of congestion is increased by adding vehicles, and that the conflict rate decreased on weaving section 173, where the evening peak congestion is decreased. This suggests that there is a relation between the amount of congestion and the number of conflicts calculated by SSAM.

For this selection of weaving sections, the effect of improving the calibration strategy is not as expected. It was expected that extending the calibration procedure results in the simulation better representing the real situation, which in turn was expected to have a stronger correlation between the conflict rate and the crash rate. Nevertheless, opposite result was found as the calibration on speeds even reduced the correlation.

5.6.8. Time of the Conflicts and Crashes

Next to comparing conflict rates and crash rates, also a more detailed analysis can be performed. Such an analysis might give insight in how well VISSIM and SSAM are able to predict the hour, location and type of crashes.

The hour of the crashes is known from the BRON crash database, and is described per weaving section in appendix F. Similarly, SSAM provides for each conflict the time at which it occurred. These times are categorised into bins, where each bin is representing one hour. From this, the graphs shown in figure 5.14 till figure 5.18 are created that visualise the time of the crashes and conflicts. Note that only crashes and conflicts that occurred within the influence area of the weaving section are included, and that the conflicts are calculated using the projection threshold values included in table 4.8 and satisfy the filter thresholds in table 4.9. The number of conflicts for weaving section 173 was too large to process, hence the conflicts in only two of the simulations are included in the graph.

The polynomial trend lines in the figures show the pattern in the occurrence of crashes and conflicts over the day. At some locations these patterns correspond reasonably, which is also indicated by a moderate to strong correlation in table 5.24. However, at some locations the patterns are clearly different, especially at weaving section 068 where a negative correlation is observed. Furthermore, it is seen that on locations with only a few crashes the correlation is weaker than on locations with more crashes. This is due to the stochastic nature of crashes. For a sample size of $n = 24$ and $\alpha = 0.05$ a correlation is significant if it exceeds the critical value of 0.407. Hence at most weaving sections the correlation between the hour of the crash and hour of the simulated conflicts is significant, except for locations with only a few crashes.

Table 5.24: Correlation between time of crash and time of conflict

ID	Correlation			Crashes	P-value
068	-0.300	negative	weak	5	0.156
077	0.806	positive	very strong	34	0.000
156	0.227	positive	weak	12	0.286
173	0.730	positive	strong	128	0.000
256	0.507	positive	moderate	19	0.011
269	0.636	positive	strong	4	0.001
369	0.475	positive	moderate	31	0.001
412	0.634	positive	strong	52	0.001
454	0.815	positive	very strong	94	0.000

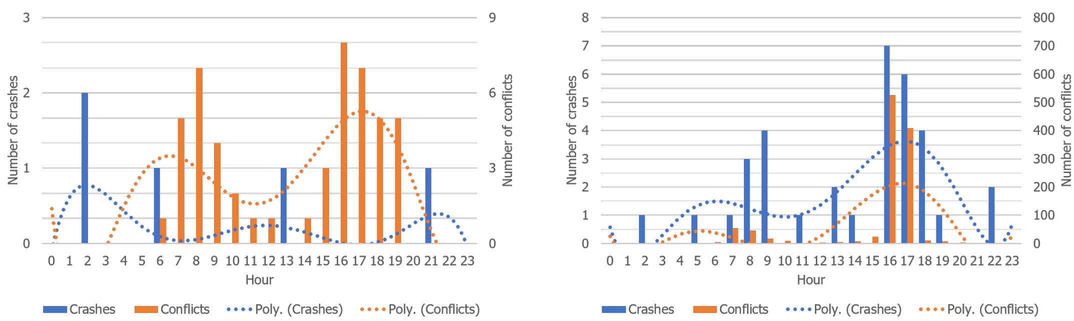


Figure 5.14: Crash and conflict hour at ID068 (left) and ID077 (right)

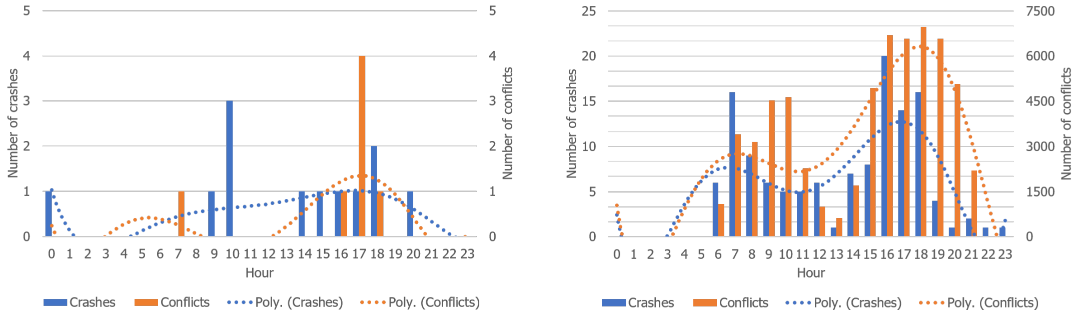


Figure 5.15: Crash and conflict hour at ID156 (left) and ID173 (right)

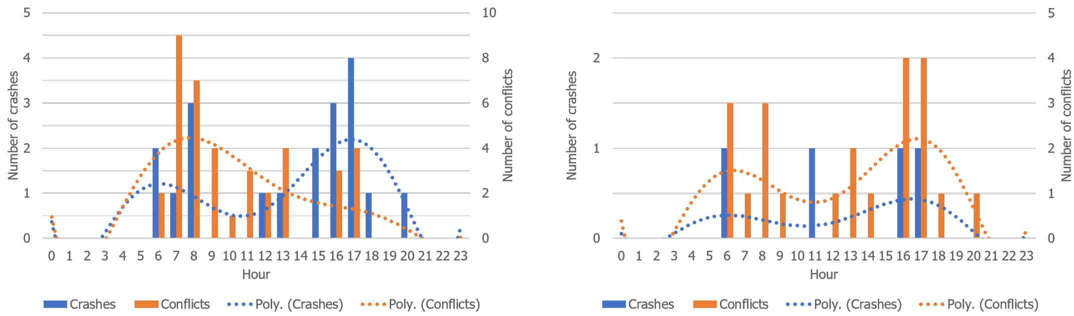


Figure 5.16: Crash and conflict hour at ID256 (left) and ID269 (right)

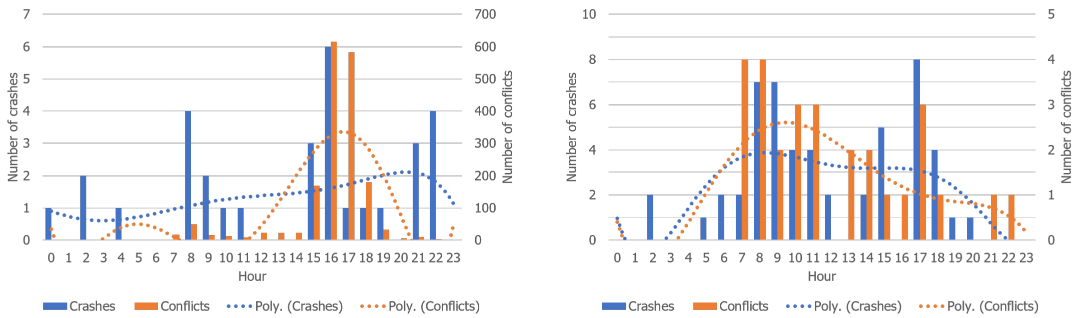


Figure 5.17: Crash and conflict hour at ID369 (left) and ID412 (right)

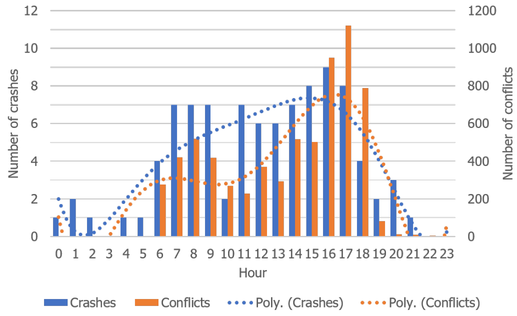


Figure 5.18: Crash and conflict hour at ID454

5.6.9. Location of the Conflicts and Crashes

In similar way as the times of the conflicts are compared to the times of the crashes, also the locations of the conflicts could be compared to the locations of the crashes. The locations of the crashes are included per weaving section in appendix F. SSAM provides the x and y coordinates of the location where the minimum PET was observed during the conflict. For each hectometre interval the begin and end coordinates are determined from the VISSIM simulation models manually, hence there might be a slight deviation from the real intervals. These intervals are measured such that the location where the DTB map indicated the hectometre number is in the middle of the interval. Subsequently the conflicts that occurred within such an interval are count.

The locations of the crashes and conflicts are visualised in figures 5.19 till figure 5.23. Again for weaving section 173 conflicts from only two simulation runs are used.

The polynomial trend lines show the pattern in the occurrence of crashes and conflicts over the weaving section. It is seen that the crash trend lines are corresponding less well to the conflict trend lines than when comparing the times of the crashes and conflicts. This is also seen in table 5.25 which includes the correlations between the locations of the crashes and locations of the conflicts. Correlations are very weak to moderate, and some correlations are negative. Hence it can be concluded from the available data that VISSIM and SSAM are not that good in predicting the most accident-prone locations within the weaving section. However, it might also be that the crash locations in the BRON crash database are not accurate, as it is uncertain whether the location of the collision is registered or the location at which the vehicles came to a stand-still.

Table 5.25: Correlation between location of crash and location of conflict

ID	Correlation			Crashes	P-value
068	0.126	positive	very weak	5	0.788
077	0.455	positive	moderate	34	0.160
156	0.015	positive	very weak	12	0.965
173	0.404	positive	moderate	128	0.152
256	-0.193	negative	very weak	19	0.678
269	-0.167	negative	very weak	4	0.720
369	-0.065	negative	very weak	31	0.903
412	-0.105	negative	very weak	52	0.788
454	0.306	positive	weak	94	0.390

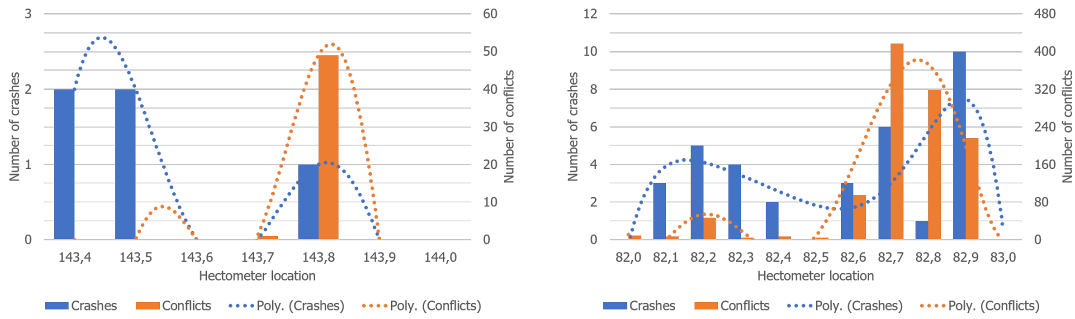


Figure 5.19: Crash and conflict location at ID068 (left) and ID077 (right)

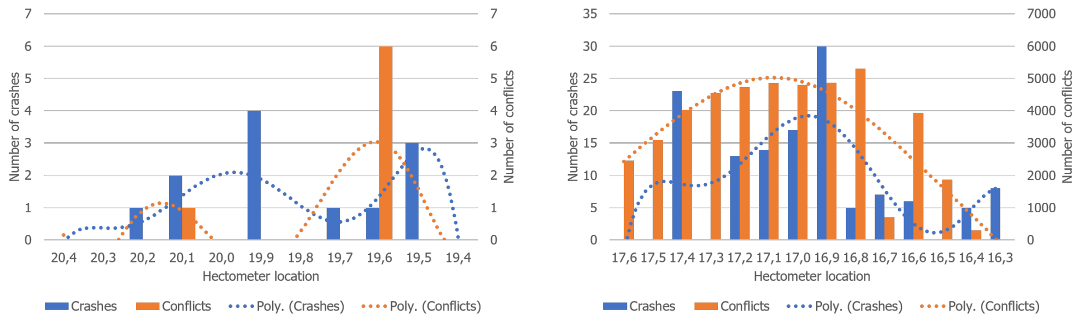


Figure 5.20: Crash and conflict location at ID156 (left) and ID173 (right)

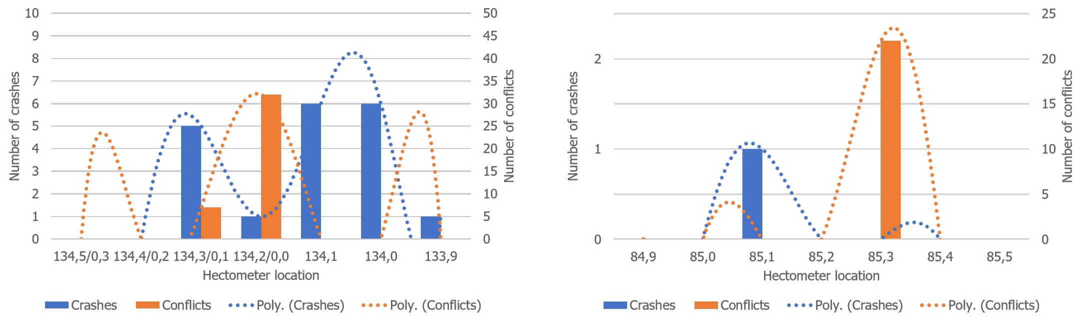
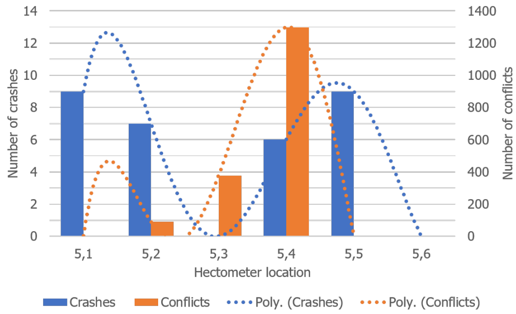


Figure 5.21: Crash and conflict location at ID256 (left) and ID269 (right)



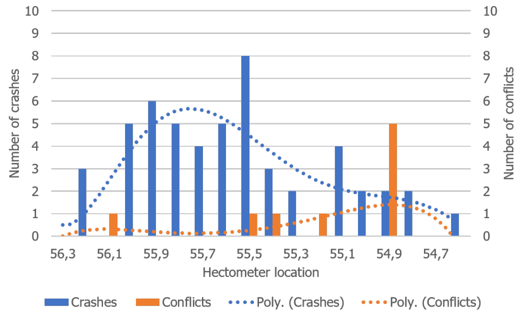


Figure 5.22: Crash and conflict location at ID369 (left) and ID412 (right)

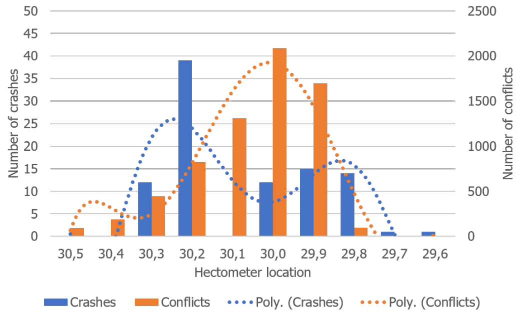


Figure 5.23: Crash and conflict location at ID454

5.6.10. Type of the Conflicts and Crashes

SSAM is able to distinguish between four conflict types based on the link on which vehicles are positioned and the angle between the conflicting vehicles, as described in paragraph 2.2.5. These conflict types are crossing, rear-end, lane-change and unclassified.
Also the BRON crash database includes information on the crash type. However, the crash database distinguishes between more crash types and uses different terminology than SSAM does, making it more difficult to have a straightforward comparison. The different crash types defined by BRON and SSAM are connected as described in table 5.26 to create the graphs in figure 5.24 till figure 5.28.
As described in paragraph 2.2.5 and table 4.8 a conflict is characterised by SSAM as lane change conflict if the conflicting vehicles were on a similar link and have an angle between 30 and 85 degrees, which is best corresponding to a side-swipe crash type in BRON. Vehicles conflicting at an angle between 85 and 180 degrees are characterised by SSAM as crossing conflicts, which is best corresponding to head-on crash type in BRON. As the crash database is not complete, for many crashes the type is registered as 'unknown'.

In figure 5.24 till figure 5.28 no relation between the type of conflict and type of crash is seen. This is also indicated by the negative correlations included in table 5.25. It should be noted that this might be influenced by the large share of crashes of which the type is unclassified. If for example a majority of these crashes were rear-end crashes, the correspondence would be better. However, based on this data set it is concluded that VISSIM and SSAM are not able to predict the most frequent occurring crash type.

Table 5.26: Crash and conflict types in BRON and SSAM related

Graph type	BRON crash type	SSAM conflict type
Lane change	Side-swipe	Lane change
Rear end	Rear end	Rear end
Crossing	Head-on	Crossing
Single vehicle & fixed object	Single vehicle	–
Single vehicle & fixed object	Fixed object	–
Unclassified	Unknown	Unclassified

Table 5.27: Correlation between type of crash and type of conflict

ID	Correlation			Crashes	P-value
068	-0.632	negative	strong	5	0.253
077	-0.285	negative	weak	34	0.642
156	-0.446	negative	moderate	12	0.452
173	-0.262	negative	weak	128	0.670
256	-0.605	negative	strong	19	0.280
269	-0.383	negative	weak	4	0.525
369	-0.370	negative	weak	31	0.540
412	-0.422	negative	moderate	52	0.479
454	-0.265	negative	weak	94	0.667

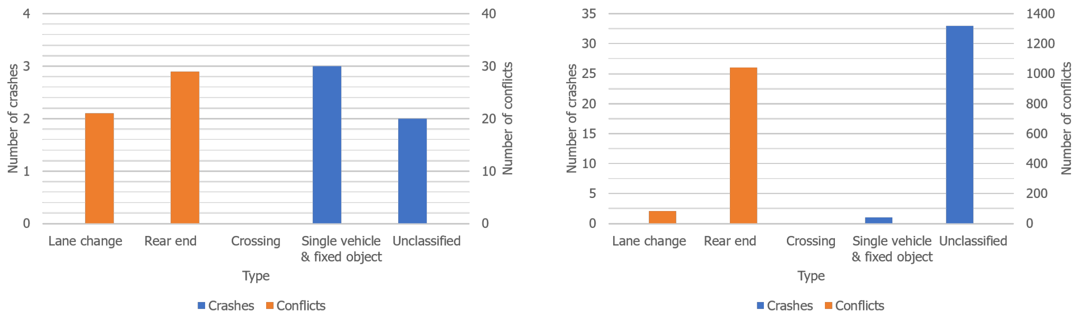


Figure 5.24: Crash and conflict type at ID068 (left) and ID077 (right)

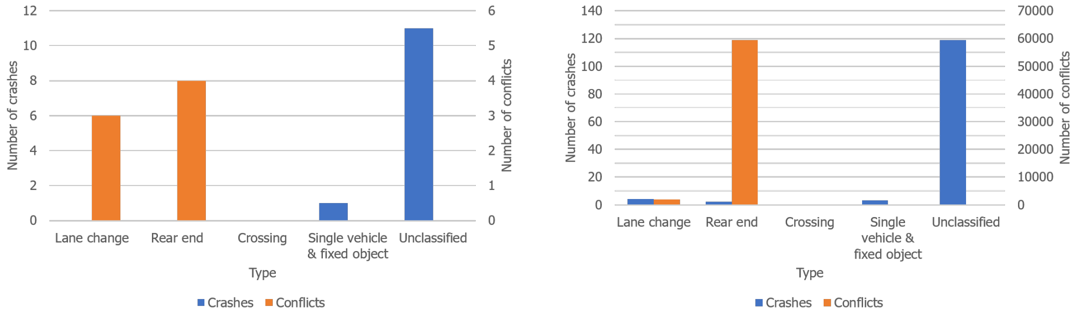


Figure 5.25: Crash and conflict type at ID156 (left) and ID173 (right)

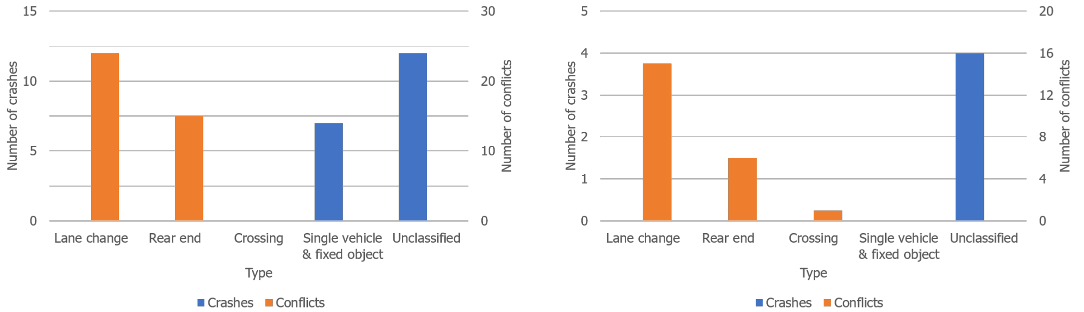


Figure 5.26: Crash and conflict type at ID256 (left) and ID269 (right)

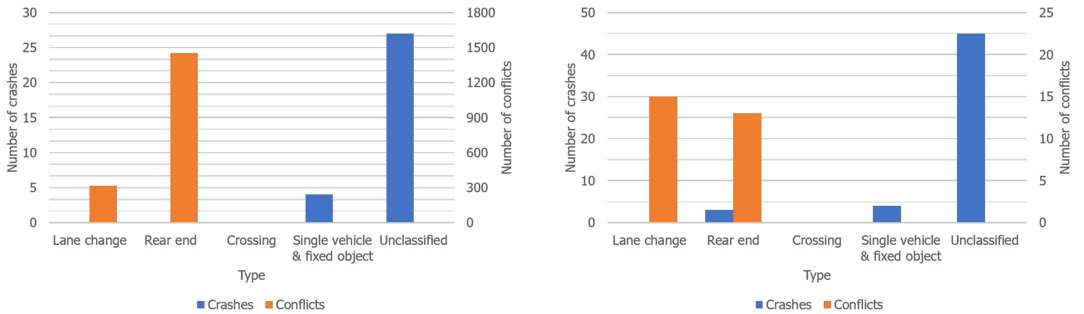


Figure 5.27: Crash and conflict type at ID369 (left) and ID412 (right)

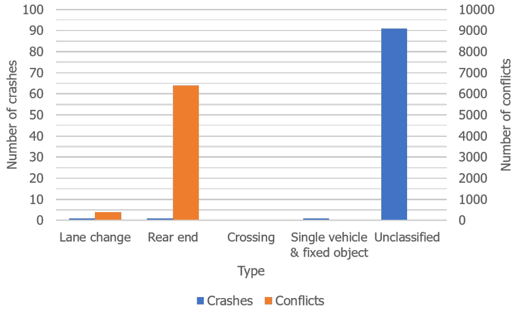


Figure 5.28: Crash and conflict type at ID454

6

Conclusions and Recommendations

This chapter includes conclusions in section 6.1, a discussion of the results in section 6.2 and some recommendations in section 6.3.

6.1. Conclusions

On highways so-called weaving sections are applied when the point of convergence and point of divergence of two merging and splitting traffic streams are within short distance of at maximum 1500 meters. The origin of the design guidelines is uncertain, and in some cases designing according to the them is difficult [50, 55]. Hence it is desired to have a more quantitative method to determine the safety of the design of weaving sections.

Therefore, the goal of this master thesis research was to determine whether the combination of the micro-simulation model VISSIM and the Surrogate Safety Assessment Model (SSAM) is able to determine the safety of Dutch weaving sections, such that safety could be evaluated in a more quantitative way than is currently done in the form of expert judgement and such that there is more focus on vehicle interaction than in crash prediction models. SSAM is able to calculate the number of conflicts that occurred based on the surrogate safety measures time-to-collision (TTC) and post-encroachment-time (PET) from trajectory files created by a micro-simulation model such as VISSIM [5]. To that extend the following research question was defined:

How representative are surrogate safety measures calculated from VISSIM micro-simulations with SSAM for predicting the safety of Dutch weaving sections?

For that a selection of weaving sections was ranked based on four criteria (crash rates, expert judgement, CPM and VISSIM & SSAM conflict rate), and the correspondence between these rankings was assessed. This was done by answering the sub-questions:

Q1 *Which factors do influence the safety of a weaving section according to literature?*
Frequent mentioned factors that are said to influence weaving section safety are the length of the weaving section, the AADT (on a specific leg or into a specific direction), the configuration (i.e. symmetrical or asymmetrical and type A, B and C distinguished in the US Highway Capacity Manual) and the number of required lane changes [6, 29, 37].

Q2 *Which criteria are important for selecting a sample of weaving sections for this study?*
It is desired that the selected weaving sections have differences in length, AADT and configuration, but also some similarities. Special attention is paid to obtain a selection of weaving sections with clear variations in crash rate (i.e. number of crashes that is registered in the BRON database between 2012 and 2015 per number of vehicle kilometres ranging from very high to low) and no changes in design since 2012. Initially ten weaving sections were selected, but as data for one weaving section was incorrect only nine weaving sections are used for the results.

Q3 *What are the characteristics of accidents that occurred on weaving sections?*
On all weaving sections in the Netherlands, rear-end crashes are most frequent occurring. On the selected weaving sections single-vehicle crashes are occurring more frequent. However, for a large part of the crashes no type is registered in the BRON database. Most crashes resulted in only material damage. The crash likelihood is higher in winter months and during peak hours. Due to incompleteness of the BRON crash database it is not possible to draw detailed conclusions on accident characteristics.
From the crash database the crash rates at the weaving sections are known, resulting in the crash rate ranking.

Q4 *How do road design and traffic characteristics contribute to the occurrence of crashes?*
Road safety experts analysed the road image to obtain the ranking based on expert judgement. After providing maps, photographs and traffic data of the weaving sections to road safety experts at Arcadis, they were asked to rank the weaving sections on safety. This resulted in the experts ranking.

Also road and traffic flow characteristics were included in the crash prediction model developed by Iliadi et al. [29] for symmetrical weaving sections in the Netherlands, which calculates the expected number of crashes to occur during a three-year period. This number was divided by the number of vehicle kilometres to obtain a ratio for each weaving section, which results in the CPM ranking.

Finally, for each weaving section a micro-simulation model was created, from which trajectory files were obtained. These files were processed by SSAM to calculate the number of conflicts in the simulation models. For that the TTC and PET projection thresholds were set to 1.5 and 5.0 seconds respectively, the conflicts were filtered such that $0.05 \leq TTC \leq 1.5$ and $0 \leq PET \leq 5.0$, and only the conflicts that occurred within the influence area of the weaving section were included. The obtained conflict numbers were expressed as ratio of the number of simulated vehicle kilometres, and the conflicts ranking was obtained from that ratio.

Q5 *Is there a correlation between the ranking based on crash registrations, the ranking based on expert judgement and the ranking based on simulated conflicts?*
A Spearman Rank Correlation Coefficient was calculated between each of the rankings [28], resulting in the correlations as included in table 6.1. A moderate correlation of 0.567 was observed between the conflict rate ranking and the crash rate ranking. However, this correlation is not significant at the 5% significance interval. A stronger correlation of 0.683 was observed between the CPM and experts ranking. Correlations between other rankings are weaker or even negative.

Q6 *What explains eventual differences between the rankings?*
There are multiple possible explanations for the differences between the rankings. It is generally known that the BRON crash database is incomplete. However, consulting the UDLS crash database as alternative for the BRON database did not result in very different crash rates and correlations. The crash rate ranking is affected by both the VISSIM and SSAM settings. There

Table 6.1: Spearman Rank Correlation Coefficients for ratios, and the P-value in brackets

	Crash Rate	Experts	CPM
Experts	-0.300 (0.433)		
CPM	-0.367 (0.332)	0.683 (0.042)	
VISSIM & SSAM	0.567 (0.112)	0.467 (0.205)	0.300 (0.433)

are many input variables within the VISSIM model, such as the desired vehicle speed, the car following model, the lane change distance and many parameter settings that influence the vehicle trajectories and hence the number of conflicts. Also the calibration procedure affects the number of conflicts. In SSAM the TTC and PET prediction and filtering threshold values affect the ranking.

Thus, depending on the VISSIM and SSAM settings, there seems to be a moderate correlation of 0.567 between the crash rate and conflict rate after performing a visual inspection and calibrating on intensities. However, this correlation is not significant at the 5% significance level ($P = 0.112$). Also it is generally known that the BRON crash database is not complete, which might lead to a weaker correlation with the crash rates than would be the case when the crash database was complete. Furthermore, due to calibrating on speeds more congestion is simulated at some locations, resulting in simulated traffic better representing the field, but also resulting in many more conflicts at some congested locations and a weaker correlation. Also the correlation of the conflict ranking with the other rankings is weaker or even negative. Hence, one should be very careful with using the number of conflicts calculated using VISSIM and SSAM as (only) predictor for safety of Dutch weaving sections.
In other countries crash prediction models are developed and used frequently. Such a CPM for symmetrical weaving sections in the Netherlands resulted in a weaker correlation to crash rates than VISSIM & SSAM, but the correlation between the CPM and the experts is stronger ($\rho_s = 0.683$, $P = 0.042$). Hence the CPM might be more appropriate for judging safety of a proposed design for a weaving section, although it gives no details on the location and severity of the conflicts and potential crashes.

6.2. Discussion

In this study a moderate correlation of 0.567 ($P = 0.112$) is found between the crash rate ranking and conflict rate ranking for initial settings, indicating that a VISSIM micro-simulation in combination with SSAM to determine the number of conflicts can give some insight in the safety of a weaving section. However, it should be noted that only a small sample of nine weaving sections was used in this research, and that hence care should be taken with generalising the results to all weaving sections in the Netherlands, and even more to weaving sections in other countries as there driving behaviour might be different [8]. Furthermore, in a sensitivity analysis it was found that making some changes in the simulation models to make them better representing the real situation, resulted in an unexpected weaker correlation between the observed crash rate and the simulated number of conflicts.

The VISSIM micro-simulation model is not developed for safety analysis, and also not for the Dutch traffic situation in particular. Attempts are made to make the traffic flow in the simulation models represent the observed traffic situation by using input values from empirical data, although the unavailability or incompleteness of data resulted in challenges:

- Vehicle intensities are retrieved from inductive loop detector data. However, not for each required input link loop detector data was available as the loop detector was not functioning properly or even not available. Hence in some cases vehicle inputs and off-ramp shares are estimated from other loop detectors using the law of conservation of vehicles. Also, there were some slight differences between the number of vehicles observed by a loop detector and the real number of vehicles, so calculating with slight incorrect numbers might result in some larger errors [69].

- OD matrices are needed for simulating representative weaving shares. As these are not directly available for weaving sections, a choice is made to retrieve OD matrices using a selected link analysis on the NRM. These matrices are partially model-based, and hence not fully based on empirical data.
- The used desired speed distributions are based on traffic speeds measured by loop detectors, which also include 'undesired' speeds due to congestion or vehicles driving below their desired speed due to a predecessor driving at a lower speed forcing following vehicles to drive below their desired speed. As it is impossible to make a distinction between desired and undesired speeds initially all speeds are included, and later in a sensitivity analysis only the fastest half of the speeds was used. Although this method results in only an approximation of the desired speed distribution, it is still used as alternative options for the desired speed distribution also have some drawbacks. Furthermore, contradicting to the field situation, the vehicles in the simulation model do not adapt their speed in curves. This deceleration in curves is manually implemented using reduced speed areas, and is thus depending on the model settings.
- Although not expected, extending the calibration method by calibrating on speeds, next to the initially performed visual inspection and calibration on intensities, resulted in a very weak correlation between the crash rate and conflict rate rankings. In response to the calibration, desired vehicle speeds and at some locations traffic intensities were changed, such that vehicle speeds and the amount of congestion are better representing the field situation. However, this increased congestion resulted in many more conflicts. This might indicate that the number of conflicts is more related to the amount of congestion than to the safety of the weaving section.
- In VISSIM many parameters and settings are available to replicate the traffic situation in the field. However, due to the large number of parameters, the unavailability of typical Dutch settings and unavailability of detailed vehicle trajectories to use for parameter calibration, most parameters are left at their initial value. Essa and Sayed [16, 17] conclude that parameter calibration leads to a better correlation between observed and simulated conflicts, and therefore also a better correlation between simulated conflicts and field crashes is expected. Hence a more in-depth calibration of these parameter values might be desired, which might be done in further research. A possible source for vehicle trajectories is floating car data (FCD). However, the usability of FCD for determining factors such as the lane change location, lane change speeds, following distance and gap acceptance depends on the penetration rate.

Not only the quality of the VISSIM simulation models affects the resulting correlation between the rankings. Also some care should be taken regarding the crash rates. It is generally known that the BRON crash database is incomplete, as both crashes and crash characteristics are missing [61]. This affects the crash counts and crash rates of some of the weaving sections, and possibly also the crash rates and ranking of the selected weaving sections. Therefore the UDLS database was used as alternative to BRON. However, this did not lead to a very different result.
Next to that, it should be noted that VISSIM and SSAM only determine vehicle to vehicle conflicts, while also single-vehicle crashes are included in the crash rates and CPM. This might lead to an unfair comparison.
Furthermore, the road safety experts ranked the weaving sections in only one hour. However,

when (re)designing a weaving section many more hours are spent on assessing the safety of the proposed design options as part of the design process. If the experts spent more time on ranking the weaving sections, they could have seen more minor details, which might have resulted in a different ranking. However, as the individual rankings are discussed to obtain one final ranking that everyone agreed on, the effect of missing details could be negligible as each expert might have observed other details. Also it turned out that road safety experts focused more on road and traffic characteristics, and less on including exposure.
Finally, the used crash prediction model is for symmetrical Dutch weaving sections [29]. However, one of the weaving sections (ID454) has an asymmetrical design, so the formula might not be applicable for that weaving section. As no formula for asymmetrical Dutch weaving sections is available, a choice is made to use the formula for symmetrical weaving sections for predicting the number of crashes on ID454.
Thus there are some marginal notes due to unavailability of data. However, it is tried find as good as possible alternatives.

Although the SSAM software is easy to use, there were some unclear and unexpected results, that are indeed correct after spending much effort on understanding the differences between various settings in SSAM. Although not clear from the SSAM manual [46], it was found that there is a difference between the TTC and PET threshold values selected in the configuration tab and the TTC and PET values in the filter tab (see appendix I). The threshold values in the configuration tab are used for projecting the vehicle positions after the selected time and calculating the number of conflicts, and the values in the filter tab are used for filtering only conflicts that have values of surrogate safety measures within a selected range [22]. This resulted in a better understanding of the SSAM conflict calculation algorithm.
TTC and PET prediction thresholds and filter values recommended in the SSAM manual [46] were used. However, in a sensitivity analysis it was found that other values lead to other conflict rates and different rank correlations.

The weaving sections were selected such that there was a clear variation in crash rates, resulting in a clear safety ranking. However, another option could be to select some weaving sections having almost equal crash rates. This prevents that weaving sections with extreme high or extreme low crash rates are selected, due to which the sample is not representative for the entire population.

In this research validation was performed by comparing only one ranking of a type to one ranking of another type. However, it can be desirable to perform cross-validation, in which multiple rankings of a type are compared to multiple rankings of another type. Then one ranking of each type can be used for training, the other ranking(s) for testing. This is a more fair way to estimate the prediction performance of a model.

Also other researchers investigated the correlation between simulated conflicts and the real situation. Those field conflicts were observed from video images. Fan et al. [18] found a Spearman rank correlation coefficient of 0.898 ($n = 88$) between simulated and observed traffic conflicts at seven freeway merge areas in the Nanjing area in China. Huang et al. [28] found a Spearman correlation of 0.916 ($n = 64$) between simulated and observed conflicts at ten signalised intersections in the Nanjing area. Their correlations are stronger, which might be due to comparing simulated conflicts with field conflicts, and not with field crashes. Gettman et al. [22] found a weaker correlation of 0.463 ($P < 0.05$) between conflicts per hour and crashes per year on 83 intersections in British Columbia, Canada. The latter corresponds better to the correlation of 0.567 between the crash rate and conflict rate found in this research, indicating that the resulting correlation might be correct. Le [38] compared the DRAC to the MADR to

determine the number of conflicts at freeway weaving sections. For two sites correlations of around 0.7 were found, while for another site the correlation was around 0.5 (declared by a low crash number at that site), depending on which surrogate measure is used and which crashes are included.
Hence stronger correlations are observed between field conflicts and simulated conflicts than between field crashes and simulated conflicts, thus VISSIM and SSAM might be better in predicting conflicts than in predicting crashes. Besides, the assumption that a location with more field conflicts than another location also has more crashes than the other location, might not be as trivial as expected.

A possible application of SSAM in combination with a simulation model such as VISSIM is to compare multiple design alternatives when (re)constructing a new weaving section. Hence for one site multiple designs are compared. In this research weaving sections at different types are compared, which thus differs from the proposed application. However, as no crash data is available for multiple proposed designs at one site (normally only one design is selected) it is not possible to compare different designs for one site, and hence the alternative was to compare different sites. This difference should be kept in mind.

In summary, the large number of model inputs and parameter values in the VISSIM simulation model and the calibration procedure are clearly influencing the conflicts ranking. Also the other rankings are influenced by some uncertainties. Although it is tried to find alternatives for the lack of data, it is unavoidable that the rankings and correlations are affected. Hence it might be desired to expand the sample of weaving sections to reduce the effect of weaving sections with exceptional or incorrect characteristics and values. It is also desired to get deeper insight in VISSIM parameter settings. Conflict rates from VISSIM & SSAM might give some insight in the safety of weaving sections, however care should be taken as there are many factors that influence the obtained correlation, a small sample of weaving sections was used, and the correlation was not significant.

6.3. Recommendations

From the correlation of 0.567 between the crash rate ranking and the conflict rate ranking it is concluded that VISSIM and SSAM can give some insight in the safety of a Dutch weaving section. However, this correlation is not significant ($P = 0.112$) due to the small number of only nine weaving sections, and hence care should be taken with generalising results to all weaving sections in the Netherlands. Therefore, it is advised to extend this research by including more weaving sections in the first place. Also, the correlation is based on many uncertainties, both on the crash rates and the simulated conflicts. Furthermore, it is surprising that expanding the calibration method leads to a weaker correlation between crash rate and conflict rate than the initial less extensive calibration. Hence assessing the influence of simulation parameters or considering another micro-simulation package than VISSIM would be a good second step. Recommendations are given for practice and for future research.

Recommendations for Practice

From the practice of road design and safety, it is desired to get more insight in how the values in guidelines such as the ROA are obtained and to have a more quantitative method to determine the safety of a proposed weaving section design. It is advised not to use VISSIM and SSAM as only predictor of safety for multiple reasons:

- The correlation of 0.567 between the conflict rate and crash rate is not strong, and not significant. Hence the safety judgement based on the conflict rate might be incorrect.

Adopting an unsafe design might have severe consequences such as injured or killed road users and high costs.

- The correlation of the conflict rate ranking with the experts ranking is even weaker ($\rho_s = 0.467$), indicating that road safety experts judge the safety different than VISSIM and SSAM do. As a strong correlation of 0.850 between the crash counts ranking and the experts ranking is found, this might be due to the road safety experts focusing more on road and traffic characteristics and less on exposure. However, it might also be that the experts ranking is incorrect. The correlation between the conflict rate ranking and CPM rate ranking is even weaker ($\rho_s = 0.300$).
- In the simulation model only vehicle-to-vehicle conflicts are included, but in real world also single-vehicle conflicts and crashes occur, that are not kept in the model. Also, in the field drivers make mistakes and violate traffic rules, which is not the case in a simulation model.
- According to Gettman and Head [21, p. 39] the objectives of SSAM are to (I) provide a tool for traffic engineers to perform comparative safety analysis, (II) be compatible with as many traffic simulations as possible, (III) use the best possible surrogate measures that are observable in simulation models and (IV) support flexible analysis. Hence SSAM is not developed for judging the safety of a singular weaving section design, but for comparing multiple design alternatives, and hence should be used for that purpose only.
- The correlation between the CPM rate ranking and the experts ranking ($\rho_s = 0.683$) is stronger than the correlation between the VISSIM & SSAM ranking and the crash rate ranking. This indicates that the CPM is better representing the judgement of the experts than the conflict rate is representing the crash rate. To get a more quantitative evaluation of safety the CPM might preferred, as application of the CPM is less time-consuming than application of VISSIM & SSAM. However, it is uncertain whether the crash rates or the experts are better representing the real safety, as the crash database is incomplete and hence not fully representative for safety of weaving sections.
- Although Le [38] is not using SSAM, he mentions that simulating conflicts is not what current microscopic simulation models are designed for, and that crash numbers might have more impact on policy makers and public perceptions than alternatives such as conflicts and surrogate safety measures.

Hence it is advised not to use conflict numbers as main method to judge the design of a weaving section, but more as argumentation in addition to the current expert judgement according to the human factors methodology. Road safety experts can judge the safety from the view of a road user, and are able to include factors that cannot be included in a simulation model. Hence road safety experts are valuable in the judgement of a proposed design for a weaving section.
The main added value of using conflict rates next to the current expert judgement methodology is that also the risk relative to the exposure and weaving shares are considered. But, also the crash prediction model can give this added value, and calculating the number of crashes from a CPM is less time consuming than creating a simulation model and calculating conflicts. However, in many design studies a simulation model is created for assessing traffic flow, and in such a case extending the simulation model for safety analysis is only a minor step.

It should be noted that the VISSIM micro-simulation model is not developed for safety evaluation, it has no specific focus on freeways and has no predetermined Dutch parameter settings. Hence it might be worth to assess the relation of other micro-simulation models in combination with SSAM to safety of weaving sections.
When using VISSIM and SSAM, care should be taken on the simulation settings and calibration. In the sensitivity analysis it is seen that using another car-following model results in a different conflict rate and correlation between the rankings. Furthermore, extending the cali-

bration method by calibrating on speeds resulted in a weaker correlation, probably due to more congestion resulting in more conflicts.
Kim and Sul [30] point out that a good correspondence of the model with traffic conditions in terms of flows and speeds is not sufficient for safety analysis, but that the usefulness depends on real-world traffic flow and driver behaviour. Also, Essa and Sayed [17] mention that first calibrating on delay times and thereafter calibration of driving behaviour parameters results in a stronger correlation between field-measured conflicts and simulated conflicts. Hence further research on the optimal parameter settings is desired, which can be done by comparing to vehicle trajectories in the field obtained from floating car data.

This research is performed using SSAM 2.1.6. Now a newer version SSAM 3.0 is available, which results in same conflicts for the tested trajectory files. The user interface of this newer version is more user-friendly, but trajectory files obtained using VISSIM 9.00.05 or later are not compatible with SSAM 2.1.6 anymore, as also the z-coordinate is included in the trajectory files. According to Bared [4] the SSAM 3.0 version has improved safety measures, 3D conflict graphics and advanced computing enhancements. The analysis time is reduced up to 50 percent, and the new parallel computing capabilities even decreases the computing time up to 90 percent. Also it is possible to illustrate conflicts by use of a bar chart, heat map and contour map. Furthermore the data export options are improved.

Recommendations for Research

From scientific point of view the relation between surrogate safety measures and crashes is more interesting. It is found that a weaving section with more simulated conflicts than another weaving section has not necessarily more crashes than the other weaving section. This can partially be explained by the incompleteness of the crash database and the quality of the simulation model. However, it can also be that the relation between crash rates and conflict rates is not as expected. It might be that other surrogate safety measures are better applicable, or that other threshold values should be used. It might also be that there are other boundary conditions that determine whether a conflict results in a crash or not. More research on that might be desired.

In this research SSAM is only used to determine conflict numbers by performing the analysis and filtering on TTC, PET and location. But next to providing frequencies of the different conflict types, SSAM also provides information on other surrogate safety measures and their mean, variance, minimum and maximum value. Research is required, but this might give information on the severity of the conflicts, and the probability of the conflict resulting in a crash. Furthermore, SSAM offers the possibility to perform a t-test between two SSAM case study files, which can be used for comparing two design alternatives in SSAM.

Within the VISSIM micro-simulation package there are many parameters that can be changed to make the driving behaviour better representing the field driving behaviour. In practice some major parameters such as the 'right side rule' versus the 'keep your lane' and the car-following model are changed, but most parameters are left at their initial value. In research more attention is paid to parameter calibration procedures. It is interesting to investigate whether parameter calibration to make the simulation model better representing the field situation indeed leads to a stronger correlation between simulated conflicts and field crashes. And if so, it might be desired to select important transferable parameters and determine the value best representing the Dutch situation, such that these values can be used in further research on the relation between conflicts and road safety.
SSAM is compatible with many other packages. Thus it might also be interesting to assess whether a different micro-simulation package results in different conflict rates.

Lastly, it might be interesting to assess the sensitivity of VISSIM & SSAM using the CPM. In the CPM developed by Iliadi et al. [29] for example increasing the AADT leads to more crashes, and it can be assessed whether that is also the case for the number of conflicts in the simulation model. And similarly for other parameters in the CPM. Another interesting research might be to determine a *conflict* prediction model and compare the significant parameters and their weights to the parameters in the crash prediction model.

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Nomenclature

AADT Annual Average Daily Traffic

ADT Average Daily Traffic

AIS Abbreviated Injury Scale

BRON Bestand geRegistreerde Ongevallen in Nederland (Document Registered Accidents in the Netherlands

C/D lane collector/distributor lane

CIA Capaciteitswaarden Infrastructuur Autosnelwegen (Dutch HCM)

CMF Crash Modification Factor

CPM Crash Prediction Model

DTB Digitaal Topografisch Bestand

GIS Geographic Information System

HCM Highway Capacity Manual

NDW Nationale Databank Wegverkeersgegevens (Dutch National Data Warehouse for Traffic Information)

NRM Nederlands Regionaal Model

PET Post Encroachment Time

ROA Richtlijn Ontwerp Autosnelwegen (Dutch Design Guideline for Freeways)

SSAM Surrogate Safety Assessment Model

SWOV Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (Dutch Institute for Road Safety Research)

TTC Time To Collision

UDLS Uniforme Droge Logging Systeem (uniform system for roadway incident logging)

VOA Verkeersveiligheid Op Auto(snel)wegen (traffic safety on freeways)

Appendices

A

ArcGis Processing

This appendix describes how crashes are assigned to the correct weaving section in ArcGis.

At first all crashes are connected to the map using the X and Y coordinates that are registered in the BRON crash database. These coordinates are derived from the road number, RPE code and hectometre position and therefore not representing the exact location but the hectometre position. Also the locations of the weaving sections are imported in another layer as lines (see the red line in figure A.1). The locations of the weaving sections are found in the WEGGEG mengstroken database. Each weaving section received a unique identification number (which is ID 184 for the weaving section shown in figure A.1).

Thereafter all crashes that occurred within less than 150 meters from the line representing the weaving section are selected, and the other crashes with a larger distance are removed. The crashes within this range of 150 meters are selected by creating a buffer, which is shown by the green line in figure A.1. As described in paragraph 4.2.1 a choice is made for this 150 meters as this is the influence area of a weaving section [64].

At third a new layer is created to which all relevant crashes will be copied in the next steps. First all crashes that are located within 3 meters from the weaving section lines are copied to this database and received the identification number of the corresponding weaving section. These crashes are indicated by the dark blue dots in figure A.1
However, on most of the weaving sections some crashes occurred within the influence area but outside the 3 meters, and hence these crashes had to be connected to the correct weaving section manually by copying them to the layer with relevant crashes and assigning the ID of the weaving section. In figure A.1 these crashes are shown in light blue.
The yellow triangles represent crashes that are not relevant for this weaving section and are therefore not included in the relevant crashes layer.

As can be seen in figure A.2 in some situations the crashes were displayed on the verge. These crashes are registered in early years. This indicates that the road is redesigned at those locations and that these crashes clearly did not correspond to the current design of the weaving section. Hence these crashes were not included as relevant crash.

While checking the configurations of the weaving sections it was found that some crashes were not included. These were later included manually in the crash database file. Also, some crashes were connected to one weaving section ID for multiple times. These doubles are removed from the crash database file.

Figure A.1: Connecting crashes to weaving sections in ArcGis

Figure A.2: Crashes in the verge indicate that the road is redesigned

B

Weaving Sections Database

This appendix shows the weaving sections database for the initial safety analysis. It includes for each weaving section

- The number of crashes that occurred between 2012 and 2015 after filtering;
- The configuration;
- The length of the weaving section in meters;
- The annual average daily traffic (AADT) obtained by averaging the average workday traffic intensity from INWEVA for the years 2012 till 2015;
- The average daily number of vehicle kilometres in thousands, obtained by multiplying the weaving section length by the average daily traffic;
- The crash rate, which is the number of crashes that occurred between 2012 and 2015 divided by the average daily number of vehicle kilometres;
- The crash rank, which is the ranking position based on the number of registered crashes;
- The rate rank, representing the ranking position based on the crash rate. For both rankings it holds that the higher the position in the ranking, the more crashes occurred (per number of vehicle kilometres);
- The location of the weaving section, which can be derived from the road number, begin and end hectometre position and direction.

The weaving sections that are selected for the validation of SSAM are marked in blue.

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
2	2	2+1	239.96	43750	10.50	0.19	375	386	85.16	85.40	027	L
3	8	2+1	1145.76	28750	32.94	0.24	233	358	121.02	122.17	050	R
4	0	1+2	141.46	6325	0.89	0.00	444	444	25.90	26.04	010	R
5	16	2+1	583.37	22375	13.05	1.23	135	81	3.03	3.62	065	L
6	0	1+1	186.77	6400	1.20	0.00	444	444	206.14	206.33	050	R
7	15	2+1	523.22	27200	14.23	1.05	147	97	84.11	84.63	073	R
8	18	2+1	502.00	14850	7.45	2.41	120	27	233.60	234.11	004	L
9	12	2+1	557.36	27425	15.29	0.79	173	145	16.80	17.35	044	R
10	9	3+1>3+2T	152.00	39650	6.03	1.49	216	60	52.55	52.70	004	R
11	3	2+2	437.09	31975	13.98	0.21	350	377	35.40	35.84	002	R
12	2	2+1	563.22	22525	12.69	0.16	375	403	16.84	17.40	029	R
13	39	3+1>4+1	738.75	79975	59.08	0.66	40	176	12.99	13.73	010	R
14	33	4+1>4+2T	1213.21	92950	112.77	0.29	55	326	18.33	19.49	010	R
15	38	3+1	602.41	70125	42.24	0.90	43	124	22.36	22.96	010	R
16	22	3+1	661.10	55250	36.53	0.60	92	199	23.77	24.44	010	R
17	22	2+1	475.65	40075	19.06	1.15	92	87	127.70	128.18	059	R
18	13	3+1	609.10	51025	31.08	0.42	164	264	82.42	83.02	027	L
19	16	2+1	203.92	15925	3.25	4.93	135	8	48.28	48.48	032	L
20	1	2+1	447.00	16600	7.42	0.13	402	410	149.30	149.75	012	R
21	9	2+1	441.31	30700	13.55	0.66	216	173	5.41	5.86	027	L
22	14	3+1	401.86	77625	31.19	0.45	156	255	16.96	17.36	013	L
23	4	2+1	315.09	30500	9.61	0.42	323	265	68.74	69.05	001	L
24	0	1+1	642.88	23650	15.20	0.00	444	444	30.35	31.00	001	L
25	1	1+1	208.53	16650	3.47	0.29	402	331	87.44	87.65	001	L
26	0	1+1	206.49	10950	2.26	0.00	444	444	87.41	87.60	001	R
27	7	2+1	326.37	13350	4.36	1.61	251	55	30.80	31.12	002	R
28	7	2+1	428.84	17725	7.60	0.92	251	114	262.41	262.84	002	R
29	2	3+1	563.79	29950	16.89	0.12	375	417	250.12	250.66	002	L
30	26	2+1	179.41	14975	2.69	9.68	80	4	30.60	30.77	002	L
31	39	2+1	515.21	18000	9.27	4.21	40	10	262.28	262.80	002	L
32	12	2+1	409.04	14400	5.89	2.04	173	31	233.60	234.01	004	R

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
33	1	2+1	777.56	12225	9.51	0.11	402	423	54.37	55.15	004	L
34	31	3+2>4+2T	591.72	87400	51.72	0.60	58	202	2.68	3.27	004	L
35	1	2+1	149.31	20550	3.07	0.33	402	309	3.78	3.95	004	L
36	16	3+1	744.29	42525	31.65	0.51	135	236	57.11	57.86	009	L
37	31	3+2	1039.07	68100	70.76	0.44	58	256	39.96	41.01	009	R
38	16	3+1	645.97	42175	27.24	0.59	135	206	57.22	57.86	009	R
39	49	3+1	674.35	42825	28.88	1.70	26	47	58.34	59.02	009	R
40	14	3+1	687.47	62900	43.24	0.32	156	313	23.75	24.43	010	L
41	29	4+1	358.68	82475	29.58	0.98	64	107	13.32	13.68	010	L
42	18	4+1>3+3T	216.00	78725	17.00	1.06	120	96	12.37	12.58	010	L
43	12	2+1	326.28	20500	6.69	1.79	173	40	19.29	19.62	011	R
44	5	2+1	273.86	15300	4.19	1.19	299	85	149.32	149.60	012	L
45	4	2+2	498.56	54200	27.02	0.15	323	406	5.45	5.95	012	L
46	0	2+1	437.04	31400	13.72	0.00	444	444	61.74	62.19	012	L
47	0	2+1	434.87	12975	5.64	0	444	444	34.382	34.815	015	R
48	6	3+1	1085.05	26000	28.21	0.21	272	378	38.04	39.13	015	L
49	10	2+1	762.38	33100	25.23	0.40	199	275	43.36	44.12	015	L
50	38	3+1	414.05	51275	21.23	1.79	43	41	47.72	48.14	015	L
51	54	3+2	939.37	55800	52.42	1.03	20	101	51.66	52.58	015	L
52	10	3+1	737.13	47025	34.66	0.29	199	330	70.85	71.60	015	L
55	6	2+1	454.15	31500	14.31	0.42	272	263	62.45	62.91	015	L
56	5	2+1	636.74	28150	17.92	0.28	299	339	62.50	63.15	015	R
57	6	2+1	187.98	16700	3.14	1.91	272	36	95.65	95.84	015	R
58	0	1+1	188.85	13475	2.54	0.00	444	444	115.24	115.42	015	L
59	8	2+1	169.00	26850	4.54	1.76	233	42	63.73	63.91	015	R
60	4	2+1	287.76	19450	5.60	0.71	323	158	95.19	95.48	015	L
61	1	2+1	485.49	7875	3.82	0.26	402	349	104.18	104.67	007	L
62	2	2+1	156.57	18850	2.95	0.68	375	168	165.18	165.34	007	L
63	9	2+1	124.86	25800	3.22	2.79	216	21	165.21	165.33	007	R
64	5	2+1	568.49	23150	13.16	0.38	299	281	179.41	179.97	007	L
65	9	2+1	861.96	18275	15.75	0.57	216	214	213.26	214.13	007	R

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
66	1	2+1	350.71	4875	1.71	0.58	402	209	251.93	252.29	007	L
67	1	2+1	340.47	4725	1.61	0.62	402	191	252.07	252.41	007	R
68	5	2+1	188.75	20775	3.92	1.28	299	76	143.64	143.83	007	R
69	10	2+1	690.84	21575	14.90	0.67	199	170	15.03	15.72	017	R
70	0	1+1	481.66	10900	5.25	0.00	444	444	24.36	24.84	017	R
71	7	1+1	199.94	12000	2.40	2.92	251	18	24.32	24.52	017	L
72	6	2+1	830.94	28100	23.35	0.26	272	350	9.30	10.14	030	L
73	4	2+1	846.20	27200	23.02	0.17	323	397	9.35	10.19	030	R
74	9	1+1	1008.42	13650	13.76	0.65	216	179	3.43	4.44	036	R
75	9	1+1	1105.06	13550	14.97	0.60	216	200	3.44	4.55	036	L
76	1	2+1	134.53	26850	3.61	0.28	402	340	20.98	21.12	038	L
77	34	3+1	607.58	50275	30.55	1.11	52	89	82.16	82.76	027	R
78	12	2+1	765.54	29675	22.72	0.53	173	230	5.11	5.88	027	R
79	12	2+1	581.19	44275	25.73	0.47	173	250	84.98	85.56	027	R
80	11	2+1	1136.90	35900	40.81	0.27	189	342	98.63	99.79	027	L
82	5	1+1	484.01	5875	2.84	1.76	299	43	32.36	32.86	033	L
83	8	2+1	978.70	28325	27.72	0.29	233	328	128.71	129.72	050	L
84	22	2+1	1124.73	28000	31.49	0.70	92	162	128.31	129.47	050	R
85	6	2+1	1115.31	26825	29.92	0.20	272	382	228.11	229.22	050	L
86	8	2+1	729.43	30250	22.07	0.36	233	291	204.98	205.71	050	R
87	7	1+1	159.91	6575	1.05	6.66	251	7	238.33	238.50	050	R
88	1	1+1	203.97	7425	1.51	0.66	402	175	203.93	204.12	050	R
89	20	4+2	1260.91	71525	90.19	0.22	104	374	28.12	29.39	016	R
90	6	2+1	644.76	34250	22.08	0.27	272	341	18.32	18.98	016	R
91	1	2+1	190.79	9175	1.75	0.57	402	215	24.72	24.91	016	R
92	41	2+2	563.16	37300	21.01	1.95	36	34	22.50	23.07	020	R
93	3	2+1	778.06	15625	12.16	0.25	350	354	66.99	67.77	031	R
94	2	2+1	146.40	11250	1.65	1.21	375	82	75.56	75.70	031	R
95	2	2+1	775.80	14575	11.31	0.18	375	395	67.02	67.79	031	L
96	2	2+1	499.24	13425	6.70	0.30	375	324	57.14	57.64	032	L
97	3	2+1	813.16	16450	13.38	0.22	350	370	39.09	39.91	032	R

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
98	5	2+1	580.73	22000	12.78	0.39	299	278	6.13	6.71	032	R
99	16	2+1	1050.04	22225	23.34	0.69	135	166	9.02	10.07	032	R
100	12	2+1	490.12	22075	10.82	1.11	173	90	9.59	10.08	032	L
101	8	2+1	546.53	14825	8.10	0.99	233	105	42.70	43.25	035	L
102	1	2+1	758.87	14750	11.19	0.09	402	429	42.74	43.51	035	R
103	5	2+1	216.93	12650	2.74	1.82	299	39	22.75	22.97	037	R
104	8	2+1	696.52	25450	17.73	0.45	233	252	127.54	128.23	028	L
105	9	2+1	469.05	26550	12.45	0.72	216	156	189.73	190.19	028	L
106	29	2+1	675.07	26425	17.84	1.63	64	52	189.66	190.34	028	R
107	1	2+1	200.22	19050	3.81	0.26	402	348	27.36	27.54	028	R
108	0	1+1	502.19	13225	6.64	0.00	444	444	92.59	93.09	028	L
109	9	2+1	260.33	51100	13.30	0.68	216	169	1.25	1.34	028	L
110	3	1+1	168.98	19375	3.27	0.92	350	117	27.40	27.57	028	L
112	13	2+1	741.94	29050	21.55	0.60	164	196	16.71	17.45	044	L
113	4	2+1	730.42	16125	11.78	0.34	323	298	166.96	167.70	058	L
114	41	2+1	394.00	36525	14.39	2.85	36	20	100.75	101.15	058	L
115	10	2+1	426.46	29950	12.77	0.78	199	147	86.83	87.26	058	R
116	3	2+1	541.42	29950	16.22	0.19	350	388	85.51	86.08	058	R
117	10	2+1	491.70	38000	18.68	0.54	199	226	73.46	73.95	058	R
118	45	2+1	592.99	43500	25.80	1.74	31	44	13.42	14.00	058	L
119	7	2+1	508.80	21400	10.89	0.64	251	183	119.44	119.96	058	L
120	8	2+1	473.89	29075	13.78	0.58	233	211	85.52	85.99	058	L
122	6	2+1	814.31	32275	26.28	0.23	272	367	123.32	124.14	059	L
123	22	2+1	426.60	37400	15.95	1.38	92	68	127.44	127.86	059	L
124	14	2+1	568.82	37175	21.15	0.66	156	174	141.23	141.80	059	L
125	19	2+1	596.50	38200	22.79	0.83	111	134	141.20	141.80	059	R
127	4	2+1	386.59	21125	8.17	0.49	323	239	17.84	18.24	073	R
128	5	2+1	965.14	21125	20.39	0.25	299	355	18.91	19.88	073	L
129	7	2+1	1010.62	21125	21.35	0.33	251	306	18.87	19.87	073	R
130	3	2+1	983.22	26450	26.01	0.12	350	419	82.42	83.40	073	L
131	2	2+1	389.58	21125	8.23	0.24	375	357	17.73	18.12	073	L

ID	Crashes	Configuration	Length	AADT	Veh km ($\cdot 10^3$)	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
132	1	1+1	483.35	17025	8.23	0.12	402	415	45.16	45.67	073	L
133	0	2+1	153.95	14700	2.26	0.00	444	444	46.15	46.31	073	L
134	1	2+1	148.67	15700	2.33	0.43	402	260	46.20	46.34	073	R
135	5	2+1	554.96	25550	14.18	0.35	299	293	58.79	59.36	067	R
136	7	2+1	741.98	13675	10.15	0.69	251	165	71.71	72.44	067	R
137	1	2+1	443.91	15400	6.84	0.15	402	407	74.20	74.65	067	R
138	0	1+1	150.95	14775	2.23	0.00	444	444	68.62	68.76	067	L
139	28	3+1	1416.72	58350	82.67	0.34	68	300	91.87	93.30	002	R
140	10	2+1	807.56	33775	27.28	0.37	199	289	181.68	182.48	002	R
141	35	2+1	1257.65	34525	43.42	0.81	49	141	181.25	182.50	002	L
142	3	1+1	186.30	18300	3.41	0.88	350	128	36.77	36.96	027	R
143	21	4+1	518.64	56275	29.19	0.72	100	157	2.85	3.37	008	L
144	60	3+2	1036.13	65775	68.15	0.88	11	127	40.06	41.10	009	L
145	5	2+1	252.31	27325	6.89	0.73	299	153	33.89	34.14	009	L
146	19	4+2	1269.54	82575	104.83	0.18	111	391	5.00	6.27	004	R
147	0	2+1	397.61	15325	6.09	0.00	444	444	39.24	39.64	007	R
148	20	4+1	1050.88	58775	61.77	0.32	104	312	84.00	85.05	002	R
149	81	3+1	495.55	57150	28.32	2.86	7	19	41.93	42.44	009	R
150	6	2+1	225.96	21100	4.77	1.26	272	78	33.86	34.09	009	R
151	0	2+1	287.12	7525	2.16	0.00	444	444	76.07	76.36	031	R
152	1	1+1	240.89	7325	1.76	0.57	402	217	32.59	32.83	033	R
153	3	2+1	208.10	15475	3.22	0.93	350	113	26.67	26.88	076	R
154	4	2+1	119.94	16450	1.97	2.03	323	33	26.60	26.74	076	L
155	8	2+1	316.03	26450	8.36	0.96	233	109	19.61	19.93	065	R
156	12	2+1	595.58	27050	16.11	0.74	173	149	19.61	20.19	065	L
157	11	2+1	501.16	36800	18.44	0.60	189	203	100.75	101.25	058	R
158	13	2+1	856.09	23350	19.99	0.65	164	180	176.58	177.43	007	R
160	60	3+1	800.48	53425	42.77	1.40	11	65	16.26	17.06	001	L
161	13	2+1	497.54	40275	20.04	0.65	164	181	35.50	36.00	027	L
162	8	2+1	992.22	34725	34.45	0.23	233	365	100.37	101.36	027	L
163	4	2+1	814.86	14875	12.12	0.33	323	305	41.33	42.14	032	L

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
164	5	2+1	517.17	23650	12.23	0.41	299	270	47.20	47.71	032	R
166	11	2+1	696.16	23975	16.69	0.66	189	177	71.15	71.84	067	L
167	10	2+1	1176.49	32200	37.88	0.26	199	347	62.50	63.68	001	R
168	1	2+1	499.68	42550	21.26	0.05	402	440	18.65	19.17	016	L
169	13	3+1>3+2T	610.17	39650	24.19	0.54	164	224	51.84	52.47	004	R
170	3	2+1>2+2T	774.29	15650	12.12	0.25	350	353	54.37	55.15	004	R
171	2	2+2	438.06	42500	18.62	0.11	375	422	46.40	46.89	004	L
172	18	2+1	150.12	40450	6.07	2.96	120	17	198.26	198.41	007	R
173	128	3+2	888.19	89675	79.65	1.61	1	54	16.51	17.41	016	L
174	9	2+1	613.66	21175	12.99	0.69	216	164	118.85	119.46	058	R
175	6	2+1	369.51	17900	6.61	0.91	272	121	166.76	167.13	058	R
176	2	3+1	546.60	54775	29.94	0.07	375	438	27.66	28.22	009	L
177	17	3+1	654.77	42675	27.94	0.61	130	194	58.34	59.01	009	L
178	13	2+1	602.87	32975	19.88	0.65	164	178	7.82	8.43	009	R
179	11	2+1	748.82	32000	23.96	0.46	189	251	7.71	8.48	009	L
180	1	2+1	332.07	21700	7.21	0.14	402	409	165.63	165.96	002	R
181	8	1+1	203.02	17475	3.55	2.25	233	29	203.87	204.08	050	L
182	41	3+1	679.47	62200	42.26	0.97	36	108	7.12	7.80	001	R
183	6	2+1	1197.18	44025	52.71	0.11	272	420	93.60	94.80	001	R
184	3	2+1	656.32	20450	13.42	0.22	350	371	163.01	163.67	001	R
185	4	5+1	483.88	80400	38.90	0.10	323	426	48.62	49.10	002	L
186	0	1+2	142.18	11375	1.62	0.00	444	444	25.91	26.05	010	L
187	16	3+1	534.00	36800	19.65	0.81	135	140	22.58	23.11	020	L
188	7	4+1	1289.29	59075	76.17	0.09	251	428	81.74	83.03	002	L
189	3	2+1	532.68	10375	5.53	0.54	350	222	82.32	82.86	057	R
190	10	2+1	456.49	33850	15.45	0.65	199	182	36.61	37.06	028	L
191	5	2+1	532.06	30425	16.19	0.31	299	321	62.47	63.00	028	R
192	5	2+1	556.21	30900	17.19	0.29	299	327	62.46	63.01	028	L
193	7	2+1	1339.64	47375	63.47	0.11	251	421	94.20	95.57	028	R
194	15	2+1>2+2T	1685.73	46075	77.67	0.19	147	385	96.63	98.33	028	L
195	4	4+1	577.55	59075	34.12	0.12	323	418	83.92	84.50	002	L

ID	Crashes	Configuration	Length	AADT	Veh km ($\cdot 10^3$)	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
196	7	2+1	364.66	32925	12.01	0.58	251	210	12.30	12.66	044	L
197	11	2+1	499.27	28100	14.03	0.78	189	146	13.15	13.66	044	L
199	1	2+1	293.49	8725	2.56	0.39	402	279	76.06	76.36	031	L
200	18	4+1>3+2	829.05	60800	50.41	0.36	120	292	72.98	73.81	002	R
201	22	3+1	815.33	56275	45.88	0.48	92	245	33.29	34.08	012	L
202	5	2+1	1294.91	47000	60.86	0.08	299	432	94.18	95.49	028	L
203	6	2+1	661.36	21000	13.89	0.43	272	257	45.64	46.30	032	R
204	7	2+1	660.14	20900	13.80	0.51	251	234	45.67	46.33	032	L
205	29	2+1	621.17	36175	22.47	1.29	64	75	41.03	41.65	073	R
206	23	2+1	799.74	31775	25.41	0.91	90	122	43.50	44.30	073	R
207	6	2+1>2+2	550.72	17850	9.83	0.61	272	193	72.80	73.36	067	R
208	4	2+1	417.87	15250	6.37	0.63	323	188	74.19	74.60	067	L
209	55	4+2	1109.93	84600	93.90	0.59	16	208	5.01	6.13	004	L
210	37	4+2	795.23	73900	58.77	0.63	47	186	9.07	9.87	004	R
212	22	2+1	844.96	35025	29.59	0.74	92	150	41.01	41.85	073	L
213	19	2+1	1053.42	32100	33.81	0.56	111	218	42.83	43.88	073	L
214	6	2+1	525.02	29075	15.27	0.39	272	276	86.75	87.28	058	L
215	2	1+1	169.40	8900	1.51	1.33	375	72	36.68	36.85	027	L
216	7	2+1	280.03	15375	4.31	1.63	251	51	261.87	262.16	002	R
217	10	2+1	155.03	18475	2.86	3.49	199	14	261.86	262.02	002	L
218	3	2+1	497.07	25375	12.61	0.24	350	360	9.34	9.84	017	L
219	1	2+1	520.21	15625	8.13	0.12	402	414	9.87	10.40	079	L
220	1	2+1	440.89	15625	6.89	0.15	402	408	9.97	10.41	079	R
221	2	2+1	376.02	15975	6.01	0.33	375	303	13.57	13.94	079	R
222	12	2+1	504.43	16000	8.07	1.49	173	61	13.57	14.08	079	L
223	0	1+1	213.48	6850	1.46	0.00	444	444	16.82	17.04	079	R
224	60	3+1	752.54	56100	42.22	1.42	11	63	50.25	50.98	004	R
225	12	2+1	956.89	47175	45.14	0.27	173	344	34.29	35.25	001	L
227	6	2+1	637.94	28875	18.42	0.33	272	310	245.14	245.78	002	R
228	24	2+1	505.77	36450	18.44	1.30	85	74	10.82	11.30	009	R
229	1	1+1	142.21	8950	1.27	0.79	402	144	68.58	68.73	067	R

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231	46	2+1	586.97	55275	32.44	1.42	28	64	41.81	42.41	009	L
232	2	2+1	190.80	19175	3.66	0.55	375	220	0.88	1.06	028	R
233	4	2+2	437.07	41125	17.97	0.22	323	373	62.41	62.86	002	L
234	2	1+1	160.02	14750	2.36	0.85	375	133	70.71	70.89	027	L
235	1	1+1	172.90	13575	2.35	0.43	402	261	80.12	80.30	027	R
236	55	3+1	554.53	36725	20.37	2.70	16	23	3.93	4.48	076	R
237	6	2+2	352.47	39650	13.98	0.43	272	259	58.62	58.92	012	R
238	6	2+1	426.60	38225	16.31	0.37	272	287	59.27	59.70	012	R
239	1	2+1	197.47	27100	5.35	0.19	402	387	62.71	62.94	012	L
240	3	2+2	630.21	26750	16.86	0.18	350	393	57.11	57.74	002	L
241	6	2+2	680.44	26325	17.91	0.33	272	302	57.20	57.89	002	R
242	0	2+1	445.51	13300	5.93	0.00	444	444	241.92	242.37	002	L
243	11	2+1	1307.47	35675	46.64	0.24	189	363	91.64	102.98	012	L
244	1	2+2	368.71	33150	12.22	0.08	402	433	57.32	57.69	012	L
246	127	3+3	1197.27	61725	73.90	1.72	2	45	77.29	78.50	027	R
247	96	2+2	1349.59	86525	116.77	0.82	3	138	77.35	78.71	027	L
248	5	1+1	550.57	20200	11.12	0.45	299	253	80.51	81.06	027	L
249	5	1+1	314.18	18525	5.82	0.86	299	131	80.77	81.07	027	R
250	24	1+1	440.95	14675	6.47	3.71	85	12	1.82	2.28	028	L
251	9	2+1	717.99	36700	26.35	0.34	216	297	24.57	25.27	027	R
252	16	2+1	667.60	37875	25.29	0.63	135	185	142.95	143.62	059	R
253	9	2+1	494.74	33975	16.81	0.54	216	225	150.75	151.25	059	L
254	8	2+2	551.63	35125	19.38	0.41	233	268	63.04	63.59	002	R
255	1	2+2	282.82	28175	7.97	0.13	402	413	58.45	58.73	012	L
256	19	2+1	152.18	13175	2.00	9.48	111	5	134.14	134.30	028	L
257	12	2+1	862.02	31000	26.72	0.45	173	254	128.93	129.79	059	R
258	51	2+2	697.56	51400	35.85	1.42	24	62	70.51	71.22	004	L
259	7	2+1	541.45	24175	13.09	0.53	251	227	200.46	201.01	007	R
260	6	2+1	561.60	28525	16.02	0.37	272	286	20.08	20.66	020	L
262	4	2+1	770.27	21275	16.39	0.24	323	356	156.53	157.30	028	R
263	12	2+1	199.15	19525	3.89	3.09	173	16	48.19	48.39	032	R

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264	6	2+1	404.75	23775	9.62	0.62	272	190	47.18	47.58	032	L
265	28	2+1	197.82	31675	6.27	4.47	68	9	143.56	143.75	007	L
267	3	2+1	173.89	7225	1.26	2.39	350	28	22.90	23.08	037	L
268	30	4+2	767.84	76300	58.59	0.51	63	232	9.25	10.02	004	L
269	4	1+1	171.06	6400	1.09	3.65	323	13	85.15	85.33	028	R
270	31	2+1	699.49	47475	33.21	0.93	58	112	36.95	37.65	009	L
271	1	2+1	195.60	17950	3.51	0.28	402	334	38.76	38.95	009	L
273	11	2+1	188.58	3075	0.58	18.97	189	2	8.26	8.45	005	L
274	15	2+1	680.69	41350	28.15	0.53	147	228	223.51	224.19	002	L
275	7	2+1	575.20	33300	19.15	0.37	251	290	107.90	108.48	059	L
276	19	2+1	1962.03	47375	92.95	0.20	111	380	96.55	98.51	028	R
277	1	1+1	386.17	14025	5.42	0.18	402	389	92.61	93.00	028	R
278	2	2+2	512.42	31025	15.90	0.13	375	412	35.42	35.92	002	L
279	27	2+1	717.22	31050	22.27	1.21	75	83	235.71	236.44	004	L
280	10	2+1	280.00	32975	9.23	1.08	199	93	10.80	11.08	009	L
281	46	2+1	1681.67	47300	79.54	0.58	28	212	107.05	108.73	012	R
282	28	2+2	592.01	28475	16.86	1.66	68	48	136.90	137.51	012	R
283	6	2+1	728.20	33125	24.12	0.25	272	352	120.40	121.13	015	R
284	4	2+1	1072.54	35850	38.45	0.10	323	424	121.71	122.78	015	L
285	0	1+1	234.38	17350	4.07	0.00	444	444	162.08	162.32	015	L
286	11	2+1	811.77	21575	17.51	0.63	189	187	16.11	16.93	017	R
287	1	1+1	241.04	17400	4.19	0.24	402	359	12.90	13.13	325	R
288	0	1+1	204.18	2775	0.57	0.00	444	444	12.74	12.95	325	L
289	18	2+1	924.11	37650	34.79	0.52	120	231	97.18	98.12	058	R
291	6	2+1	806.12	23100	18.62	0.32	272	314	19.92	20.73	017	L
292	0	2+1	249.95	14250	3.56	0.00	444	444	46.75	47.00	073	R
293	2	2+1	702.22	33175	23.30	0.09	375	430	122.59	123.29	001	R
294	6	3+1	964.85	46475	44.84	0.13	272	411	70.55	71.52	015	R
295	2	2+1	183.06	14875	2.72	0.73	375	151	95.75	95.94	015	L
296	2	2+1	205.77	12225	2.52	0.80	375	142	95.11	95.32	015	R
297	7	2+1	1237.16	32425	40.11	0.17	251	396	56.29	57.53	035	L

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298	7	3+1	590.61	40350	23.83	0.29	251	325	158.14	158.72	050	L
299	16	2+1	424.30	43275	18.36	0.87	135	130	39.19	39.61	001	L
300	0	1+1	175.46	10875	1.91	0.00	444	444	154.68	154.85	015	R
301	0	1+1	124.33	4150	0.52	0.00	444	444	147.91	148.05	050	R
302	5	2+1	294.48	12150	3.58	1.40	299	66	3.29	3.59	065	R
303	4	1+1	137.75	13175	1.81	2.20	323	30	114.41	114.55	073	R
304	15	3+2>4+1	1017.33	62425	63.51	0.24	147	362	72.93	73.95	002	L
305	21	4+1	995.57	63400	63.12	0.33	100	304	79.90	80.90	002	R
306	16	4+1	1192.62	63600	75.85	0.21	135	379	79.74	80.94	002	L
307	17	3+1	943.32	55950	52.78	0.32	130	315	103.17	104.14	002	L
310	39	2+2	993.26	43000	42.71	0.91	40	120	47.41	48.41	004	L
311	3	3+1	747.10	39975	29.87	0.10	350	427	27.50	28.25	010	R
312	2	3+1>2+2	725.27	22925	16.63	0.12	375	416	27.58	28.28	010	L
313	3	1+1	198.82	18500	3.68	0.82	350	139	28.52	28.72	010	L
314	2	1+1	200.01	19700	3.94	0.51	375	233	28.53	28.72	010	R
315	33	4+1	1239.79	66950	83.00	0.40	55	274	31.11	32.35	016	R
316	17	4+1	1271.64	66050	83.99	0.20	130	381	31.33	32.61	016	L
317	46	3+1	766.63	50050	38.37	1.20	28	84	46.85	47.61	016	L
318	24	3+1	879.10	50700	44.57	0.54	85	223	47.50	48.40	016	R
319	4	2+1	603.66	25000	15.09	0.27	323	346	0.38	0.98	017	R
320	27	2+1	522.78	25375	13.27	2.04	75	32	0.46	1.00	017	L
321	3	2+1	580.15	22725	13.18	0.23	350	368	4.20	4.78	017	R
322	15	2+1>3+1	1590.78	53150	84.55	0.18	147	394	68.40	69.99	027	R
323	7	2+1	1035.35	44675	46.25	0.15	251	405	16.47	17.51	012	R
324	1	1+1	186.01	8925	1.66	0.60	402	198	90.40	90.59	002	L
328	56	4+2	967.48	56425	54.59	1.03	15	102	60.87	61.83	015	R
329	9	2+1	183.33	45925	8.42	1.07	216	95	44.49	44.64	001	L
330	1	1+1	175.82	13775	2.42	0.41	402	266	44.54	44.72	001	R
331	5	2+1>2+2	299.00	26650	7.97	0.63	299	189	56.49	56.78	006	R
332	7	2+1>2+2T	501.78	29025	14.56	0.48	251	244	40.05	40.55	073	L
333	5	2+1	669.87	26450	17.72	0.28	299	337	84.03	84.70	073	L

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334	21	2+1	406.79	27650	11.25	1.87	100	38	199.45	199.86	028	R
335	22	2+1	604.30	50950	30.79	0.71	92	159	18.71	19.31	028	R
336	20	2+1	632.45	51175	32.37	0.62	104	192	18.63	19.26	028	L
337	21	2+1	1009.50	53375	53.88	0.39	100	280	20.06	21.07	028	L
338	15	2+1	921.63	53050	48.89	0.31	147	322	20.15	21.07	028	R
339	52	2+1	1024.50	47425	48.59	1.07	22	94	21.52	22.54	028	L
340	19	2+1	1244.81	25625	31.90	0.60	111	204	126.95	128.19	028	R
341	16	2+1	1078.82	21300	22.98	0.70	135	163	140.45	141.54	028	R
342	3	1+1>2+1	441.28	16050	7.08	0.42	350	262	16.95	17.40	079	L
343	18	3+1	334.54	80425	26.91	0.67	120	171	12.07	12.42	001	R
344	26	2+1	1171.53	47175	55.27	0.47	80	248	37.63	38.80	001	R
345	22	3+1	502.77	50050	25.16	0.87	92	129	48.44	48.94	016	L
346	14	3+1	886.68	50225	44.53	0.31	156	319	52.15	53.04	016	R
347	27	3+1	1215.38	45500	55.30	0.49	75	240	59.38	60.60	016	R
348	45	3+1	869.62	51600	44.87	1.00	31	103	59.39	60.26	016	L
349	54	3+1	1133.88	46025	52.19	1.03	20	99	61.81	62.94	016	R
350	44	3+1	1007.60	47700	48.06	0.92	33	118	61.89	62.89	016	L
351	10	2+1	1246.03	36050	44.92	0.22	199	372	98.58	99.84	027	R
352	43	2+1	689.60	38600	26.62	1.62	35	53	54.28	54.97	058	L
353	3	2+1	649.58	25325	16.45	0.18	350	390	8.28	8.94	030	R
354	23	3+1	724.11	40350	29.22	0.79	90	143	121.63	122.37	002	L
355	2	3+1	1138.14	41325	47.03	0.04	375	441	132.37	133.50	002	R
356	38	2+2	742.45	40825	30.31	1.25	43	79	95.46	96.21	050	R
357	4	2+1	336.53	31625	10.64	0.38	323	283	242.45	242.79	002	R
358	2	1+1>2+1	171.09	12350	2.11	0.95	375	111	241.30	241.49	002	L
359	1	1+1	343.90	17375	5.98	0.17	402	398	28.73	29.08	001	R
360	1	1+1	159.88	13325	2.13	0.47	402	249	29.52	29.68	001	R
361	9	4+1	1029.84	37125	38.23	0.24	216	364	71.04	72.06	002	L
362	18	5+1	585.00	87675	51.29	0.35	120	294	13.97	14.56	004	R
363	24	2+1	685.00	87675	60.06	0.40	85	272	33.91	34.59	004	R
364	28	2+3	720.98	55475	40.00	0.70	68	161	74.57	75.30	004	R

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
365	1	1+1	355.47	55475	19.72	0.05	402	439	35.10	35.45	004	R
366	12	2+1	316.98	34900	11.06	1.08	173	92	31.59	31.91	058	L
367	1	2+1	60.00	13200	0.79	1.26	402	77	4.30	4.36	007	R
368	10	2+1	970.57	32450	31.50	0.32	199	318	15.04	16.03	007	R
369	31	2+1	136.71	30900	4.22	7.34	58	6	5.31	5.43	008	R
370	31	3+1	574.66	74575	42.85	0.72	58	155	11.78	12.36	013	R
371	38	3+1	771.30	55700	42.96	0.88	43	126	26.26	27.05	020	R
373	55	2+2	1044.01	63775	66.58	0.83	16	135	36.48	37.52	020	L
374	10	3+1	639.85	45375	29.03	0.34	199	296	121.73	122.37	002	R
375	60	2+1	957.00	46800	44.79	1.34	11	71	33.72	34.68	004	L
376	16	2+1	560.75	33425	18.74	0.85	135	132	21.36	21.93	020	R
377	7	2+1>1+2	119.53	21250	2.54	2.76	251	22	96.77	96.89	050	R
380	6	2+1	995.74	22700	22.60	0.27	272	345	56.91	57.90	067	L
381	11	2+1	843.95	25775	21.75	0.51	189	235	139.18	140.02	007	R
382	8	2+1	555.33	25825	14.34	0.56	233	219	142.61	143.17	007	R
383	6	2+1	206.02	19475	4.01	1.50	272	59	20.91	21.12	038	R
384	0	2+1	206.02	19475	4.01	0.00	444	444	20.91	21.12	038	R
385	9	2+1	1484.70	36550	54.27	0.17	216	399	105.20	106.69	001	L
386	74	3+1>3+2T	1233.32	51800	63.89	1.16	8	86	10.04	11.28	010	R
387	91	3+2T>3+1	646.23	92650	59.87	1.52	6	58	16.55	17.20	010	R
388	28	2+1>2+2T	840.52	37225	31.29	0.89	68	125	28.22	29.06	028	L
391	20	3+2T>3+1	731.58	81575	59.68	0.34	104	301	6.11	6.85	013	L
394	5	2+1	519.96	33625	17.48	0.29	299	332	59.08	59.60	012	L
395	25	3+1	624.03	54650	34.10	0.73	84	152	26.20	26.81	020	L
396	5	2+1	197.48	15275	3.02	1.66	299	49	75.07	75.26	031	R
397	61	3+1	673.57	73400	49.44	1.23	9	80	9.77	10.45	013	R
398	27	3+1	595.43	76275	45.42	0.59	75	205	9.78	10.37	013	L
399	51	3+2	518.96	99200	51.48	0.99	24	104	22.50	23.04	016	R
400	4	2+1	266.50	15250	4.06	0.98	323	106	75.09	75.36	031	L
401	0	2+1	682.74	13425	9.17	0.00	444	444	112.91	113.59	007	R
402	47	3+2T>3+1	1096.24	52050	57.06	0.82	27	136	10.07	11.17	010	L

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
403	13	2+1	709.17	37975	26.93	0.48	164	243	24.36	25.07	027	L
404	28	4+1>3+2	639.89	87425	55.94	0.50	68	237	2.75	3.40	004	R
405	12	2+2T>2+1	529.34	24675	13.06	0.92	173	115	200.47	200.99	007	L
406	8	2+1>2+2T	636.92	38725	24.66	0.32	233	311	35.51	36.15	027	R
407	17	2+1	830.52	34900	28.99	0.59	130	207	32.20	33.03	058	L
408	0	2+1	847.09	21200	17.96	0.00	444	444	93.32	94.18	004	R
409	6	2+2T>2+1	1403.30	27925	39.19	0.15	272	404	236.30	237.71	050	L
410	14	2+1	528.89	28925	15.30	0.92	156	119	142.51	143.05	007	L
411	20	2+1	1313.42	37200	48.86	0.41	104	269	105.43	106.75	001	R
412	52	2+1	1306.10	36475	47.64	1.09	22	91	54.84	56.14	001	L
413	1	2+1	307.08	20600	6.33	0.16	402	402	28.74	29.05	001	L
414	3	2+2T>2+1	878.01	42325	37.16	0.08	350	434	112.42	113.30	002	R
415	1	2+1>2+2T	1143.46	42350	48.43	0.02	402	443	113.65	114.81	002	R
416	2	2+1>2+2T	215.74	28300	6.11	0.33	375	307	3.81	4.05	004	R
417	44	3+1>3+2T	486.95	94800	46.16	0.95	33	110	16.68	17.17	010	L
418	61	4+1>4+2T	370.41	87625	32.46	1.88	9	37	14.92	15.29	010	R
419	93	4+1	449.50	84250	37.87	2.46	5	26	14.11	14.56	010	R
421	15	2+1	620.84	40075	24.88	0.60	147	197	119.70	120.32	012	R
422	11	2+1>2+2T	383.12	34900	13.37	0.82	189	137	61.76	62.14	012	R
423	12	3+1	1027.93	23600	24.26	0.49	173	238	38.03	39.06	015	R
424	7	2+1>2+2T	900.45	33575	30.23	0.23	251	366	58.01	58.90	006	L
425	3	2+1	1027.53	10425	10.71	0.28	350	338	54.49	55.52	007	R
426	0	2+1	448.62	7425	3.33	0.00	444	444	102.56	103.01	007	R
427	1	2+1	1019.67	13425	13.69	0.07	402	436	113.90	114.92	007	R
428	4	2+1	733.71	33100	24.29	0.16	323	400	30.40	31.13	007	R
429	2	2+1	741.58	10025	7.43	0.27	375	343	54.80	55.54	007	L
430	8	2+1>2+2T	617.75	35250	21.78	0.37	233	288	84.01	84.64	027	L
431	9	2+2T>2+1	873.06	30400	26.54	0.34	216	299	97.97	98.84	050	R
432	10	2+2T>2+1	794.88	36225	28.79	0.35	199	295	131.54	132.35	050	R
433	2	2+1>2+2T	804.48	30075	24.19	0.08	375	431	204.96	205.76	050	L
434	26	2+1>2+2	1211.07	30475	36.91	0.70	80	160	98.06	99.27	050	L

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
435	19	2+1>2+2	767.77	36100	27.72	0.69	111	167	131.43	132.23	050	L
436	3	1+1	181.41	9700	1.76	1.70	350	46	115.82	140.05	048	L
437	20	3+1	500.34	44200	22.12	0.90	104	123	13.45	13.94	058	R
439	8	2+1	498.56	33100	16.50	0.48	233	241	29.16	29.68	007	R
440	4	2+1	694.44	13950	9.69	0.41	323	267	42.18	42.87	007	L
441	9	2+1	1103.11	25625	28.27	0.32	216	316	141.44	142.56	015	L
442	4	2+1	893.19	25000	22.33	0.18	323	392	141.67	142.57	015	R
443	5	2+1	736.87	42375	31.22	0.16	299	401	229.40	230.14	002	R
444	6	2+1	777.67	23575	18.33	0.33	272	308	152.37	153.15	007	R
445	8	2+1	887.69	24000	21.30	0.38	233	285	152.31	153.21	007	L
446	16	2+1	422.62	27275	11.53	1.39	135	67	199.48	199.90	028	L
447	4	2+1	503.05	16450	8.28	0.48	323	242	25.81	26.31	076	L
448	4	2+1	426.33	15475	6.60	0.61	323	195	25.91	26.31	076	R
449	27	2+1>2+2T	1721.21	39350	67.73	0.40	75	273	37.62	39.36	027	L
450	13	2+1	489.57	36700	17.97	0.72	164	154	34.45	34.93	058	R
451	6	2+1	887.05	34725	30.80	0.19	272	383	102.09	102.99	027	L
452	10	2+1>2+2	721.49	36900	26.62	0.38	199	284	202.36	203.07	050	R
453	14	2+1	663.15	36675	24.32	0.58	156	213	202.34	203.01	050	L
454	94	3+1>2+2	468.16	76075	35.62	2.64	4	24	29.84	30.31	020	L
455	10	2+1	1106.94	31900	35.31	0.28	199	336	9.32	10.43	009	L
456	28	3+1	36.00	28650	1.03	27.15	68	1	4.34	7.60	009	L
457	8	2+1	711.11	36225	25.76	0.31	233	320	23.28	24.01	020	L
458	37	5+1>5+2T	1398.25	87675	122.59	0.30	47	323	15.33	16.67	004	R
459	1	1+1>1+2	261.60	16975	4.44	0.23	402	369	68.10	68.36	002	R
460	20	3+1	1489.74	56600	84.32	0.24	104	361	26.83	28.32	009	R
461	9	2+1	816.80	28050	22.91	0.39	216	277	1.19	2.02	044	R
462	15	2+1	355.72	31850	11.33	1.32	147	73	12.24	12.59	044	R
463	1	2+1	259.39	6750	1.75	0.57	402	216	7.27	7.53	031	L
464	17	2+2T>2+1	955.07	29675	28.34	0.60	130	201	39.70	40.65	073	R
465	5	2+1	23.90	18125	0.43	11.54	299	3	115.97	140.17	048	R
466	3	1+1	219.67	14875	3.27	0.92	350	116	133.97	134.19	028	R

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
467	15	2+1>2+2T	1229.43	28300	34.79	0.43	147	258	47.12	48.35	073	L
468	14	2+2T>2+1	982.25	26850	26.37	0.53	156	229	56.43	57.42	006	L
469	35	2+2T>2+1	961.05	34850	33.49	1.05	49	98	57.98	58.91	006	R
470	5	2+1	117.40	11200	1.31	3.80	299	11	4.75	4.87	007	R
472	33	2+2>1+2	571.23	16550	9.45	3.49	55	15	0.00	0.58	028	L
473	1	1+1>1+2	600.73	23500	14.12	0.07	402	437	1.69	2.30	028	R
474	2	2+1>2+2T	664.94	39800	26.46	0.08	375	435	60.05	60.72	012	R
475	2	2+1	690.23	28150	19.43	0.10	375	425	63.19	63.87	002	L
476	34	2+1	739.51	33875	25.05	1.36	52	69	43.38	44.13	015	R
477	3	1+1	128.16	9200	1.18	2.54	350	25	2.61	2.75	076	L
478	40	2+1>2+2T	712.67	36925	26.32	1.52	39	57	140.18	140.91	059	L
479	4	2+2	395.46	35050	13.86	0.29	323	329	155.24	155.63	002	R
480	24	2+2T>2+1	564.50	27050	15.27	1.57	85	56	140.25	140.82	059	R
481	4	2+1	563.32	15025	8.46	0.47	323	246	14.00	14.55	005	L
482	19	2+1>2+2	955.32	42250	40.36	0.47	111	247	221.67	222.65	002	L
483	18	2+1>2+2	737.16	36625	27.00	0.67	120	172	72.66	73.39	058	L
484	26	2+1>2+2T	446.77	30350	13.56	1.92	80	35	234.89	235.33	004	L
485	12	2+1	580.53	18025	10.46	1.15	173	88	235.68	236.26	004	R
486	0	2+1	590.37	12375	7.31	0.00	444	444	13.90	14.49	005	R
487	35	2+1	634.81	33600	21.33	1.64	49	50	120.02	120.66	012	L
488	12	2+2T>2+1	1126.61	33475	37.71	0.32	173	317	112.43	113.56	073	L
489	13	2+1>2+2T	910.19	37800	34.41	0.38	164	282	44.19	45.11	004	L
490	55	3+2>4+1	466.20	86950	40.54	1.36	16	70	14.92	15.38	010	L
491	1	4+1	487.10	68550	33.39	0.03	402	442	68.69	69.17	002	L
492	8	2+1>2+2	1091.02	25700	28.04	0.29	233	333	113.20	114.29	015	R
493	34	4+2>5+1	1542.16	85950	132.55	0.26	52	351	37.30	38.84	002	R
494	29	2+2T>2+1	727.95	51850	37.74	0.77	64	148	27.42	28.14	001	L
495	4	2+1	327.54	22450	7.35	0.54	323	221	45.03	45.35	001	L
496	10	2+2	693.34	50850	35.26	0.28	199	335	17.26	17.95	028	L
497	0	2+1>2+2	254.54	25175	6.41	0.00	444	444	30.25	30.50	001	R
498	3	2+1>2+2	361.82	37675	13.63	0.22	350	376	60.37	60.72	012	L

ID	Crashes	Configuration	Length	AADT	Veh km $(\cdot 10^3)$	Crash rate	Crash rank	Rate rank	BeginHM	EndHM	Road	Direction
499	18	2+1>2+2T	740.23	38200	28.28	0.64	120	184	54.91	55.67	058	R
500	19	2+1>2+2T	2073.00	47375	98.21	0.19	111	384	106.35	108.42	012	L
501	18	4+1	1189.31	68450	81.41	0.22	120	375	71.01	72.20	002	R
502	7	2+1	503.06	34125	17.17	0.41	251	271	14.08	14.61	007	R
503	14	2+1	414.80	32750	13.58	1.03	156	100	14.17	14.61	007	L
504	0	2+1	414.80	32750	13.58	0.00	444	444	14.17	14.61	007	L
505	0	2+1	106.34	19475	2.07	0.00	444	444	63.80	63.90	015	L

C

Selection of Weaving Sections

In this appendix it is described how the selection of 10 weaving sections is obtained in section C.1. In section C.2 these selected weaving sections are described in more details. Section C.3 includes maps of the selected weaving sections.

C.1. Selecting Weaving Sections

When considering the number of crashes per weaving section it becomes clear from figure 4.6 that there are two weaving sections having a clearly higher number of crashes than the other weaving sections. These weaving sections are ID173 on the A16 between Kralingen and Terbregseplein/Pr. Alexander and ID246 on the A27 between Lunetten and Rijnsweerd. Hence these weaving sections might be suitable so select as weaving sections with a high crash number. However, when looking at the aerial views of the different years it was found that ID246 has a 2+2 design on the view of 2012 and a 3+3 design on the view of 2013, indicating that the road section is redesigned between these years. Hence this weaving section is not suitable for further analysis. Weaving section 247 has the third position when looking at number of crashes, but this weaving section is also not suitable due to changes in design. Hence weaving section 454 which is located on the A20 between Rotterdam Schiebroek and node Kleinpolderplein/Overschie and has fourth position in the ranking has been selected.

Thereafter some weaving sections are selected based on the crash rate. Three weaving sections with a high crash rate will be selected, another three with a medium crash rate being between 1.0 and 3.0, and another two weaving sections with a crash rate below 1.0 but having sufficient crashes to analyse factors such as the location within the weaving section and the severity. The latter category thus has a relative high traffic intensity.
As weaving sections with a high crash rate initially ID456 on the A9 within interchange Diemen, ID273 on the A5 within interchange Raasdorp and ID465 on the A28 at interchange Hoogeveen were selected. However, ID456 and ID465 are included in the database with a length of 36.00 and 23.90 meters respectively, which is rather short and this might hence be an error in the data. Besides there has been some reconstruction in weaving section 456. ID273 has been created recently as this weaving section is not found on the aerial view of 2012 but is found since 2013. Hence it is decided not to select these weaving sections. The rejected weaving sections are on main carriageways and collector/distributor lanes between two loops, so it is searched for other weaving sections of this type. Weaving sections ID369 on the A8 within interchange Zaandam,

ID269 on the A28 within interchange Hattemerbroek and ID256 on the A28 within interchange Hoogeveen are selected.
As weaving sections with a medium crash rate ID068 on the A7 at interchange Heerenveen, ID077 on the A27 between interchange Rijnsweerd and junction Maarssen and ID412 on the A1 between Voorthuizen and Barneveld are selected. No design changes are observed for these weaving sections in the last years.
For weaving sections with a low crash rate the weaving sections ID156 on the A65 between interchange De Baars and Tilburg Noord and ID499 on the A58 between Basel and interchange St. Annabosch are selected. To come to this selection first ID166 on the A67 between Velden and the parking area and gas station called Reunen was rejected because it gives access to a parking space resulting in a different weaving pattern than other weaving sections and hence cannot be compared that accurate to the weaving sections with higher crash rates that do not head towards a parking lot. Also, ID161 was rejected as this weaving section is located on a bridge, leading to an environment that cannot be modelled. ID049 was rejected as the road markings have changed between 2012 and 2015.

Less attention has been paid to the surroundings (upstream traffic situation, vertical alignment, presence of trees and houses, etc.) as there are many factors and then for (almost) every weaving sections one can come up with an argument to reject that weaving section. However, if it turns out that the situation on a weaving section for example is influenced by an upstream bottleneck this can be included in the simulation by also modelling this upstream bottleneck. Furthermore, some attention is paid the environment of the weaving section as some weaving sections were not selected due to for example its position on a bridge.

C.2. Description of the Selected Weaving Sections

In this section each of the selected weaving sections is described in more details. Amongst others the location with respect to the environment is described, even as some traffic characteristics and the crash rate. Paragraph 4.3.2 describes how some of the included numbers are obtained. Maps of the weaving sections can be found in appendix C.3.

Weaving Section 068

Weaving section 068 is located on the A7 between two cloverleaf loops of interchange Heerenveen and passes underneath the A32. The weaving section has a symmetrical 2+1 design, where two lanes of the A7 continue and the other lane comes from one of the loops and goes to another loop. The weaving section has a length of 188.75 meters and is located partially in urban area.
Some distance before the weaving section the junction Heerenveen-West is located which is connected via another 2+1 weaving section to an off-ramp for the connector road towards the A32L. Downstream of the weaving section there is an onramp from the connector road coming from the A32R and the freeway continues with two lanes till the junction Tjalleberd.
The speed limit on the weaving section is set at 130 km/h. In 2015 the AADT was 22500 vehicles per day. For the period 2012 till 2015 the average AADT was 20775 vehicles per day. In 2015 the truck share was 14% according to INWEVA. Based on the OD matrices from the selected link analysis it is found that 25% of the daily traffic is weaving and that the share of trucks is 17%.
While analysing the typical traffic, only free flow speeds are observed.
In the years 2012 till 2015 only five crashes occurred, resulting in a crash rate of 1.28 crashes per thousand vehicle kilometres.

Weaving Section 077

On the A27 between the diamond junction De Bilt and trumpet Maarssen weaving section 077 is located. The weaving section has a 3+1 configuration and has a length of 607.58 meters. The west side of the weaving section is urban area while the east side is rural area.
Upstream of the weaving section junction Rijnsweerd is located, where traffic can change between the A27 and A28. Thereafter the off-ramp towards De Bilt is located and the main carriageway and parallel carriageway merge. Right after the divergence gore an extra lane is opened on leg D at the left side, while on leg C a lane drops after some distance of a lane change prohibition. Traffic coming from the N230 merges with leg C after passing a ramp metering installation.
On the weaving section the speed limit is 100 km/h. The AADT was 50500 in 2015, and 50275 vehicles per day in the period 2012 – 2015. In 2015 the truck share was 9% according to INWEVA and 10% according to the selected link analysis. From the latter it is calculated that 32% of the vehicles are weaving on an average working day.
In the morning peak slower traffic is observed on leg A, leg C and leg D and on the weaving section itself. The severity differs per day. In the evening peak also congestion occurs, being even worse than in the morning peak.
With 34 registered crashes in the analysed period, a crash rate of 1.11 is found.

Weaving Section 156

Weaving section 156 is located on the A65 between interchange De Baars and the half cloverleaf junction Tilburg Noord. The weaving section has a 2+1 configuration and has a length of 607.58 meters, and passes through rural area.
Upstream of the weaving section the interchange De Baars is located where exchange between the A58 and A65 is facilitated. The parallel road and main road merge within this interchange and continue as a two-lane carriageway into leg A. Leg B is the connector road coming from the A58R. Leg D ends in a clover leaf loop of the junction and leg C continues after merging with traffic coming from the junction as a two-lane freeway towards junction Berkel-Enschot.
The speed limit was 120 km/h, but is set to 130 km/h since February 2016. In the period 2012 – 2015 on average 27050 vehicles passed per day, with in 2015 a number of 28800. 14% of these vehicles were heavy good vehicles according to INWEVA, and 15% according to the selected link analysis. 9% of the vehicles are weaving.
Congestion is observed during the morning peaks on Tuesday and Thursday on the connector road from the A65 towards the A58. However, this connector road is not included in the simulation model and does not have spill back onto the modelled area. On the modelled area no slow traffic is observed.
12 crashes occurred between 2012 and 2015, resulting in a crash rate of 0.74 crashes per thousand vehicle kilometres.

Weaving Section 173

On the A16 between the merging of the main freeway and parallel carriageway between junction Kralingen and interchange Terbregseplein and junction Alexander weaving section 173 is located. This 3+2 weaving section is located in urban area and has a length of 888.19 meters.
Upstream of the weaving section the A16 consists of the main carriageway and a parallel carriageway to which the junctions Capelle a/d IJssel and Kralingen are connected. On leg B a merge is situated close to the convergence gore. Downstream of the weaving section leg C splits into two lanes for all vehicles and one lane which is only allowed for heavy good vehicles and merges onto the A20 in west direction. Leg D splits via off-ramp Alexander into a cloverleaf loop of one lane and two lanes towards the east onto the A20.

On the weaving section the speed limit is 100 km/h. This is a busy road section with 90400 vehicles passing per day in 2015, and 89675 in the period 2012 – 2015. Only 8% of the vehicles were trucks according to INWEVA and 7% according to the NRM. However, the share of weaving vehicles is 43%.
This road section is heavy congested during peak hours. In the morning peak the congestion starts at leg C, the connector road towards the A20/A13 in the west, and has spill back onto the weaving section. In the evening peak similar pattern is seen, but even worse. Leg B becomes more congested in the evening peak than in the morning peak hour.
On the weaving section 128 crashes are registered between 2012 and 2015. This number resulted in a crash rate of 1.61, which is relative low due to the high number of vehicle kilometres.

Weaving Section 256

Weaving section 256 is located between two cloverleaf loops within interchange Hoogeveen. Here traffic can interchange between the A28 and A37. The interchange is located in rural area. The 2+1 weaving section has a length of 152.18 meters.
Some distance before the interchange a junction called Hoogeveen-Oost is located. At the interchange one lane is added as connector road towards the A28R. Thereafter the weaving section is located between two cloverleaf loops and traffic coming from the A28L merges such that the main road continues as two-lane road towards junction Zuidwolde.
Until September 2012 the speed limit was 120 km/h, and since then it is changed to 130 km/h. This is the weaving section with the highest truck share: 26% according to INWEVA and 27% according to the NRM. In 2015 13700 vehicles passed per day, with an average of 13175 in the period 2012 – 2015. 12% of these vehicles are categorised as weaving traffic.
At this weaving section no slow traffic is observed in the typical traffic viewer.
In this period 19 crashes are registered. The crash rate is 9.48 crashes per thousand vehicle kilometres.

Weaving Section 269

The 1+1 weaving section 269 is located on a collector/distributor lane (C/D lane) within interchange Hattemerbroek. At this interchange the A28 and A50 cross. The weaving section has a length of 171.06 meters and is situated in rural area.
This C/D lane road starts from an off-ramp as a one lane road, and right after another off-ramp is located providing access to the connector road towards the A50L. Thereafter the two cloverleaf loops which are connected via the weaving section are positioned and the C/D lane merges back onto the main freeway. Thereafter another carriageway coming from the A50R merges onto the A28 and another 2+2T>2+2 weaving section is located ending in the junction Zwolle-Zuid.
The speed limit changes on the weaving section. Upstream of the divergence gore the speed limit was set at 120 km/h and increased to 130 km/h since February 2016, and downstream of the divergence gore the speed limit is 100 km/h. Only 6500 vehicles passed per day in 2015, and 6400 in the period 2012 – 2015. 13% of these vehicles were trucks according to INWEVA and 19% according to the selected link analysis. All vehicles were weaving.
At this location almost no congestion is observed. Only during the Thursday evening peak some slower traffic is observed during a short period on leg C, which merges from the weaving section on the parallel roadway onto the main roadway.
Only 4 crashes occurred, but due to the low number of vehicle kilometres this results in a rate of 3.65 crashes per thousand vehicle kilometres.

Weaving Section 369

Weaving section 369 is a 2+1 weaving section located within interchange Zaandam. Here the A7 and A8 are connected. The weaving section has a length of 136.71 meters and is partially

located in urban area.
Upstream of the weaving section a gas station is located. The A8 here has 4 lanes, but splits into a connector road of two lanes towards the A7R and two lanes through the interchange as leg A of the weaving section. Leg B comes from a clover leaf loop and leg D results in a cloverleaf loop. A connector road coming from the A7L merges with leg B and continues as a two-lane road towards junction Zaandijk.
The speed limit is set at 100 km/h. Between 2012 and 2015 on average 30900 vehicles passed per day, of which 33200 per day in 2015. In this year 7% of the vehicles were heavy good vehicles according to INWEVA and 9% according to the NRM. 28% of the traffic is weaving.
According to the typical traffic analysis some congestion occurs in the evening peak on leg A and between the weaving section and the downstream onramp.
The number of registered crashes is 31, and the crash rate is 7.34.

Weaving Section 412

Weaving section 412 is located on the A1 between two half-cloverleaf junctions: Voorthuizen and Barneveld. The south side of the weaving section is urban area while at the north side agricultural fields are located. The weaving section has as 2+1 configuration and has a length of 1306.10 meters.
Upstream of the weaving section junction Stroe and a gas station are located. The A1 here has two lanes. At junction Voorthuizen an off-ramp is located followed by an onramp. This onramp results in leg B of the weaving section. Leg D is an off-ramp for traffic with destination Barneveld and the A30. Leg C continues as a two-lane freeway onto which traffic from junction Barneveld and the A30 merges and to which later some gas stations are connected before the interchange of Hoevelaken is reached.
Initially the speed on the weaving section and upstream and downstream was set at 120 km/h. However, since February 2016 the limit is changed to 130 km/h upstream and on the weaving section. From the onramp of Barneveld the limit is still set at 120 km/h. In 2015 36500 vehicles passed per day, which is slightly more than the average of 36475 in the period 2012 – 2015. The truck share in 2015 was 14% according to INWEVA and 20% according to the selected link analysis from the NRM. The share of weaving traffic was 27%.
The weaving section is frequently congested during the morning peak. This congestion starts at the onramp of Barneveld and spills back onto the weaving section. Similar is seen during the evening peak on some days.
52 crashes occurred between 2012 and 2015. The crash rate is 1.09 crashes per thousand vehicle kilometres.

Weaving Section 454

Between junction Rotterdam Centrum and interchange Kleinpolderplein and junction Overschie weaving section 454 is located on the A20. This weaving section has an asymmetrical configuration: 3+1>2+2. The length of the weaving section is 468.16 meters and the environment is an urban area.
Leg A comes from interchange Terbregseplein and passes junction Crooswijk such that at the weaving section it consists of three lanes. Leg B is an onramp and merges from two lanes to one before it reaches the convergence gore. The dotted line between the two directions already starts before the convergence gore. Downstream the convergence gore it is forbidden for drivers on the left-most lane to change lanes. On top of the regular signage, it is indicated with text on the asphalt towards which freeway (A13 or A20) the concerned lane heads. Leg C continues with two lanes on the A20 and passes underneath interchange Kleinpolderpein. On leg D another off-ramp is located going to Overschie, the continuing two lanes reach a curve and go towards the A13.

On the road section the speed limit is set at 80 km/h. At this busy road section 75500 vehicles passed per day in 2015, and 76075 in the years 2012 – 2015. According to INWEVA 9% of these vehicles were trucks while the percentage is 13% according to the NRM selected link analysis. The weaving share is 67%.
According to the typical traffic only the ramp upstream the weaving section towards Rotterdam has some slow traffic. No other slow traffic is observed. Although similar follows from the ROVM viewer, this is not in line with the expectations as this road section is frequently mentioned in radio traffic information and the opposite direction is heavy congested.
Between 2012 and 2015 94 crashes are registered, which corresponds to 2.64 crashes per thousand vehicle kilometres.

Weaving Section 499

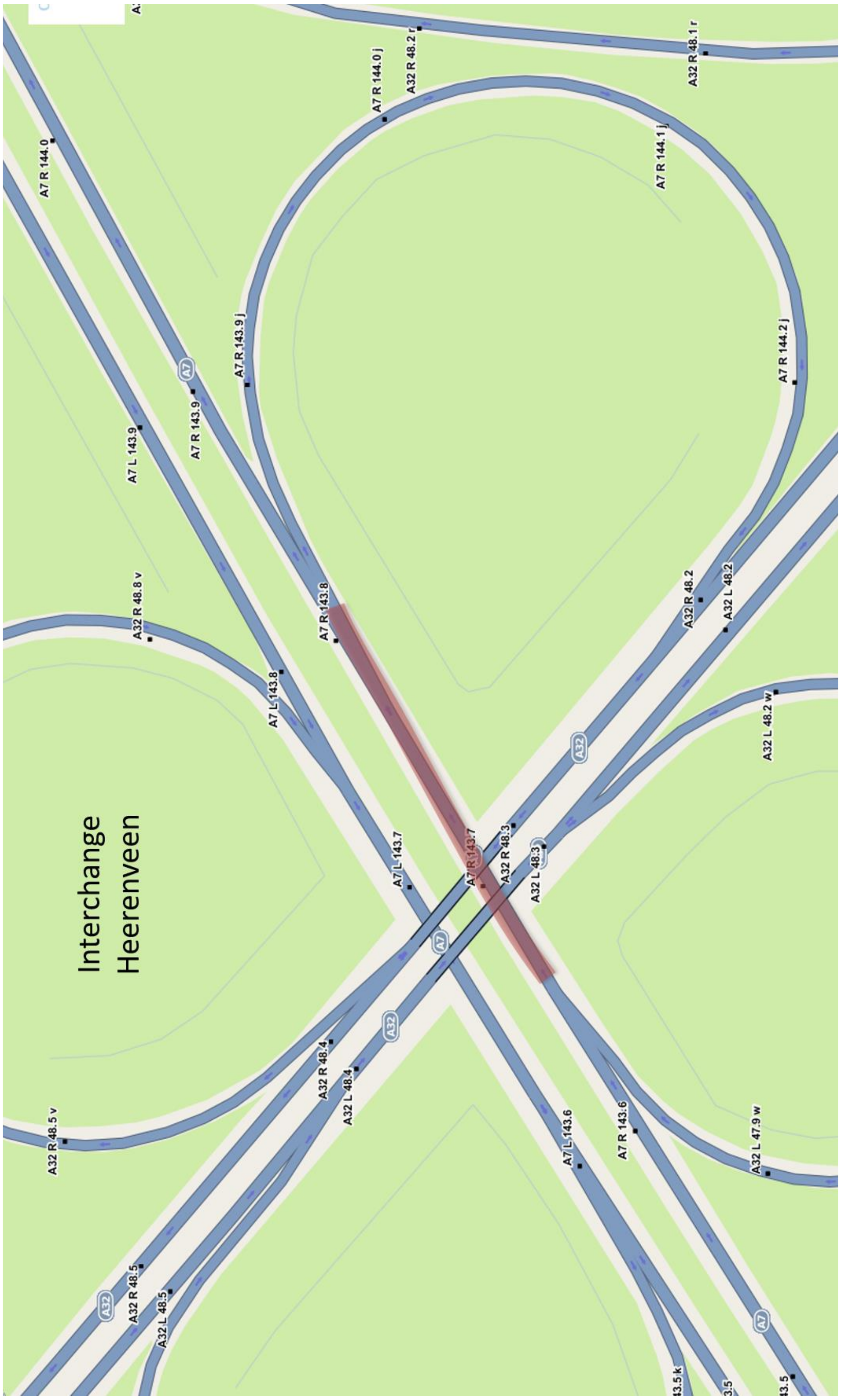
Weaving section 499 is a 2+1>2+2T weaving section located on the A58 between junction Bavel and trumpet interchange St. Annabosch in rural area. Here the A27 and A58 are connected. The weaving section has a length of 740.23 meters.
Upstream of the weaving section junction Gilze is located, and some service areas are passed before junction Bavel is reached. At junction Bavel the A58 consists of two lanes. An off-ramp is located upstream of the onramp. This onramp results in leg B of the weaving section. At the divergence gore leg C consists of two lanes, merges with traffic coming from the A27 and continues towards junction Ulvenhout. Leg D consists of two lanes of which one is created by a taper. The left lane drops before combining with one lane coming from the other direction of the A58 into the A27.
A speed limit of 120 km/h was applied, but this is changed to 130 km/h since February 2016. In 2015 39400 vehicles passed per day, and 38200 in the period 2012 – 2015. The share of trucks was 13% in 2015 according to INWEVA and 24% according to the NRM. 55% of the vehicles were weaving.
In both the morning and evening peak the off-ramp towards Bavel upstream of the weaving section is somewhat congested. Also leg C is congested in the evening peak on some days, which has some spillback onto the weaving section.
On this weaving section 18 crashes occurred. The crash rate was 0.64.

As incorrect selected link data was obtained, this weaving section is excluded from the selected weaving sections.

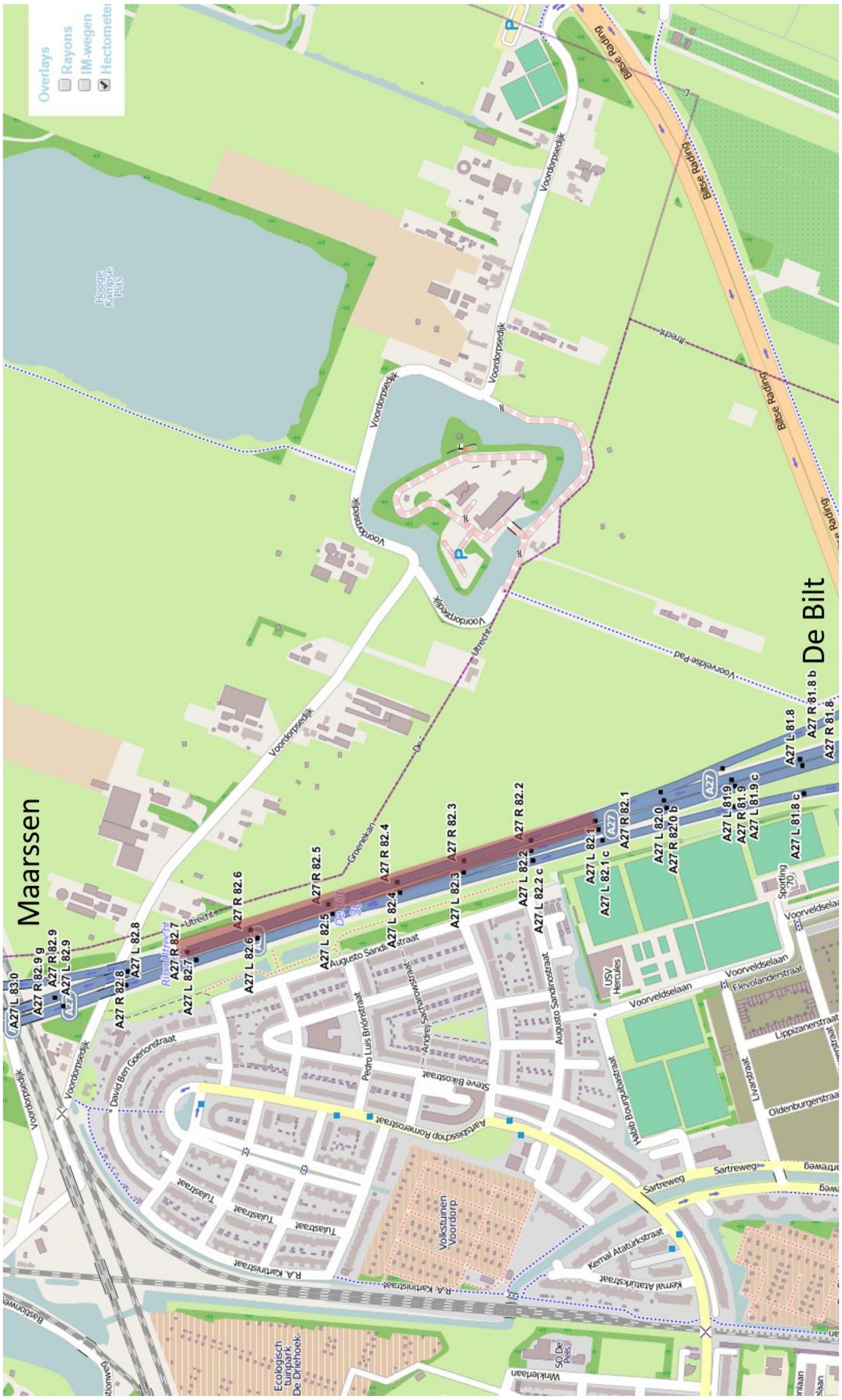
C.3. Maps of the Selected Weaving Sections

This section includes a map of all selected weaving sections. The particular location of the weaving section is marked in red.

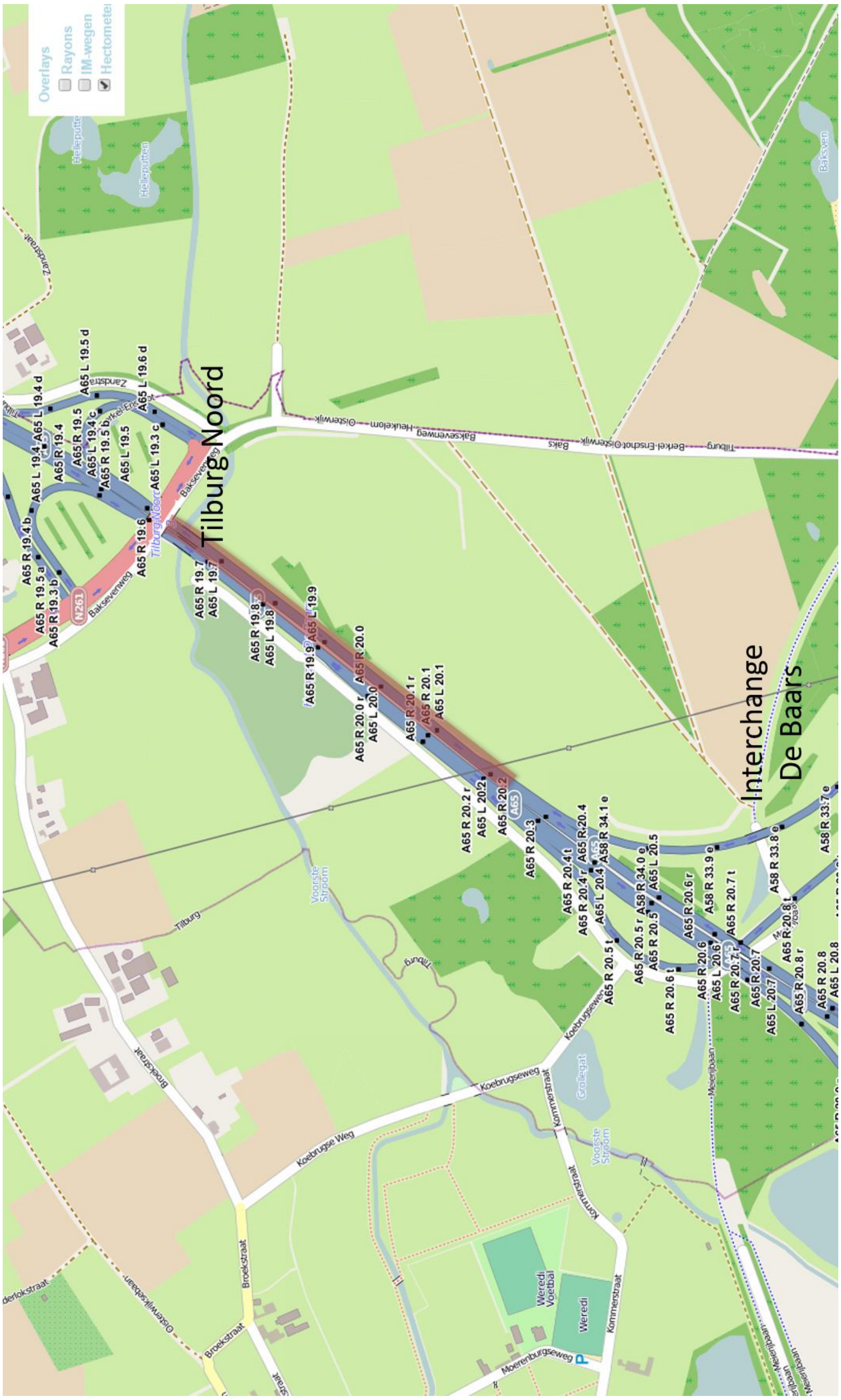
068 Interch. Heerenveen



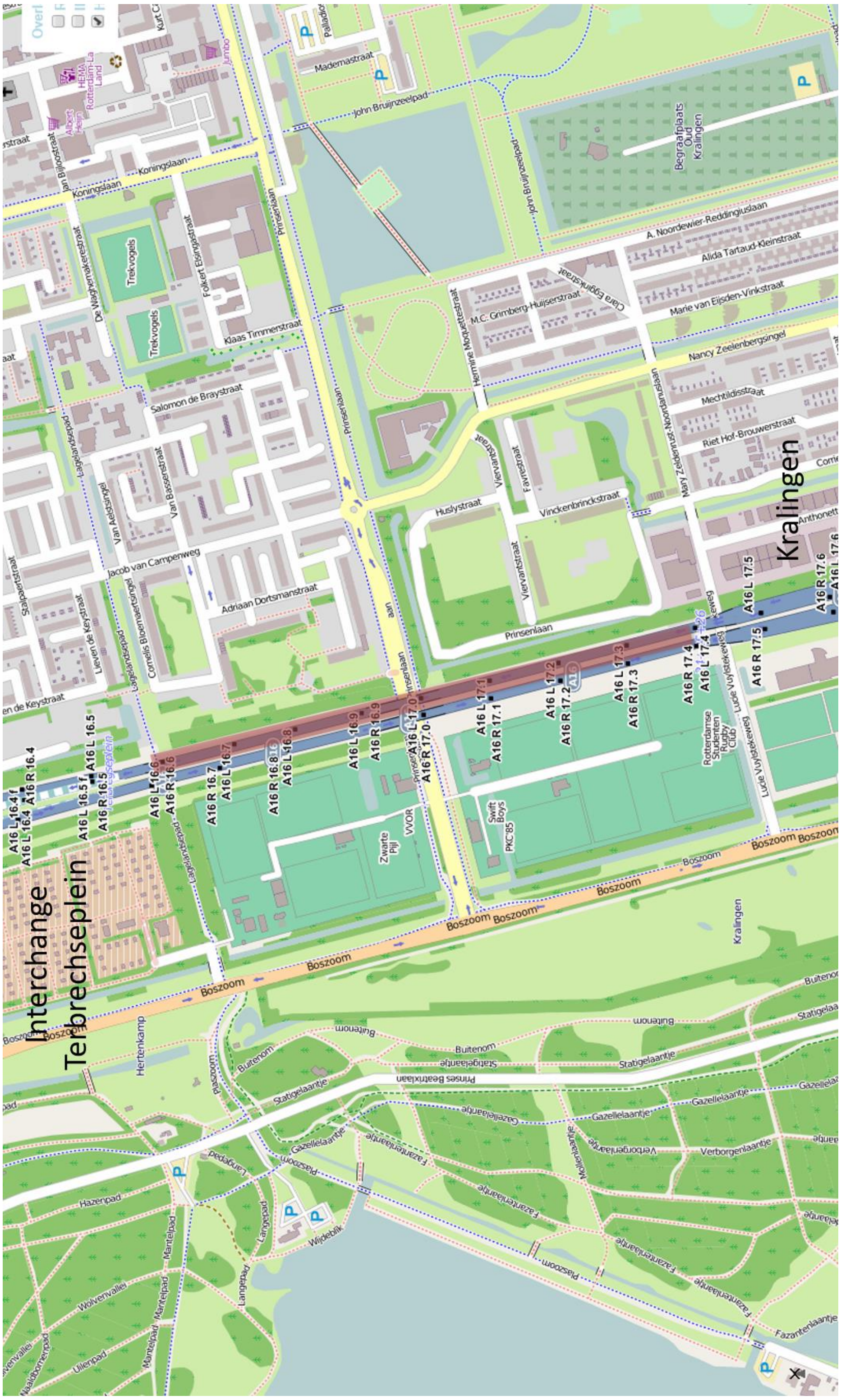
077 De Bilt – Maarssen



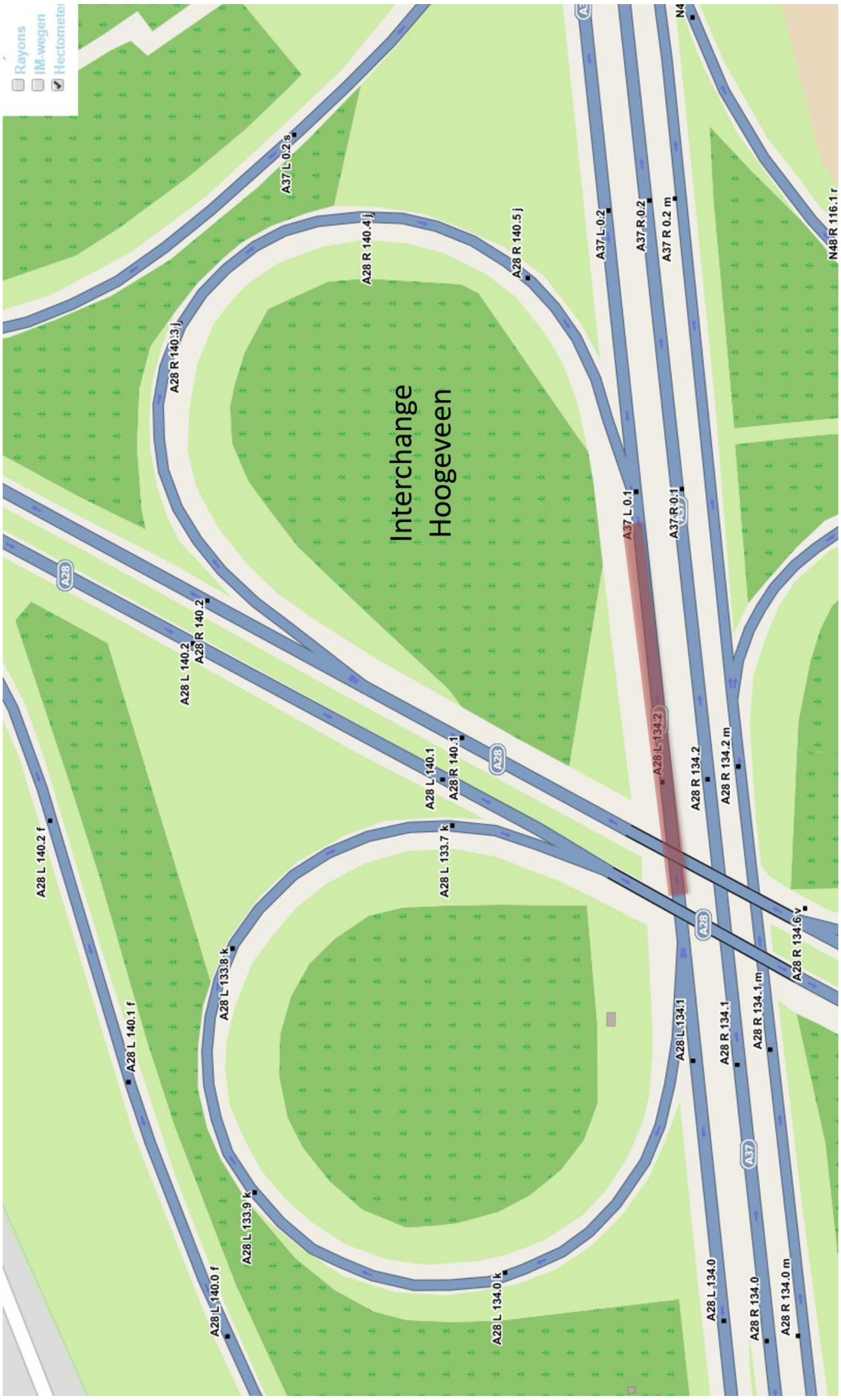
156 Interch. De Baars – Tilburg Noord



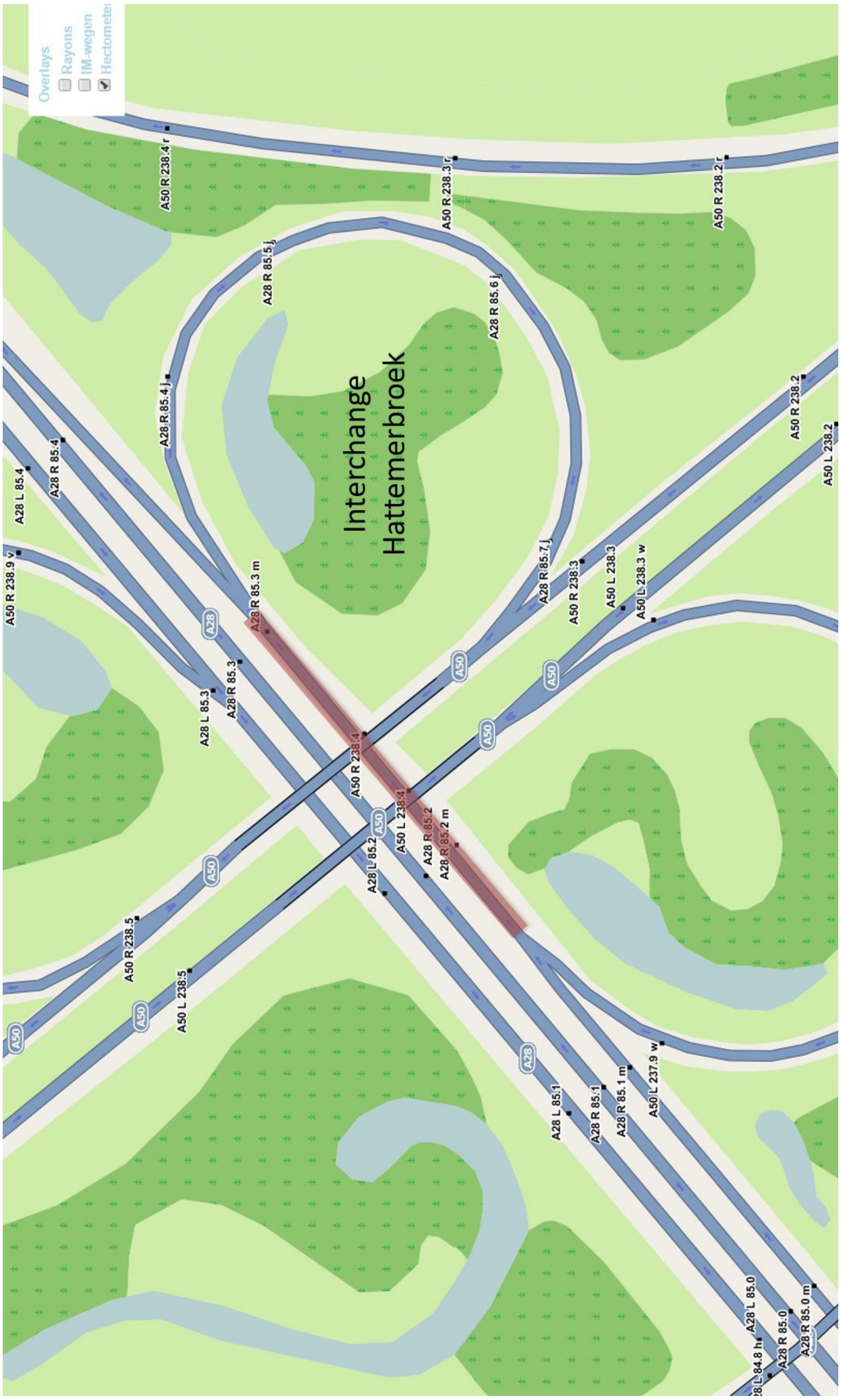
173 Kralingen – Interch. Terbrechseplein



256 Interch. Hoogeveen

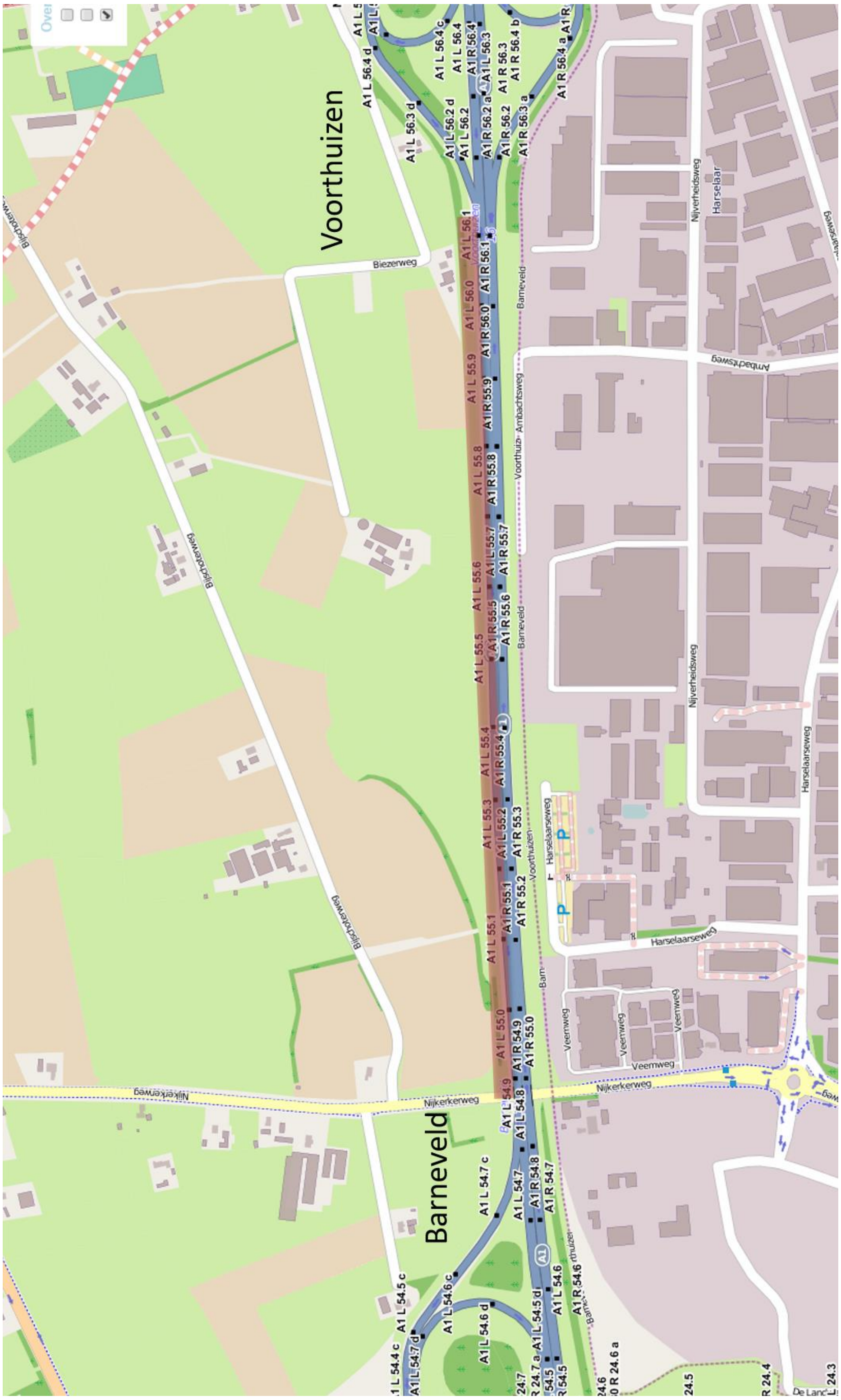


269 Interch. Hattemerbroek

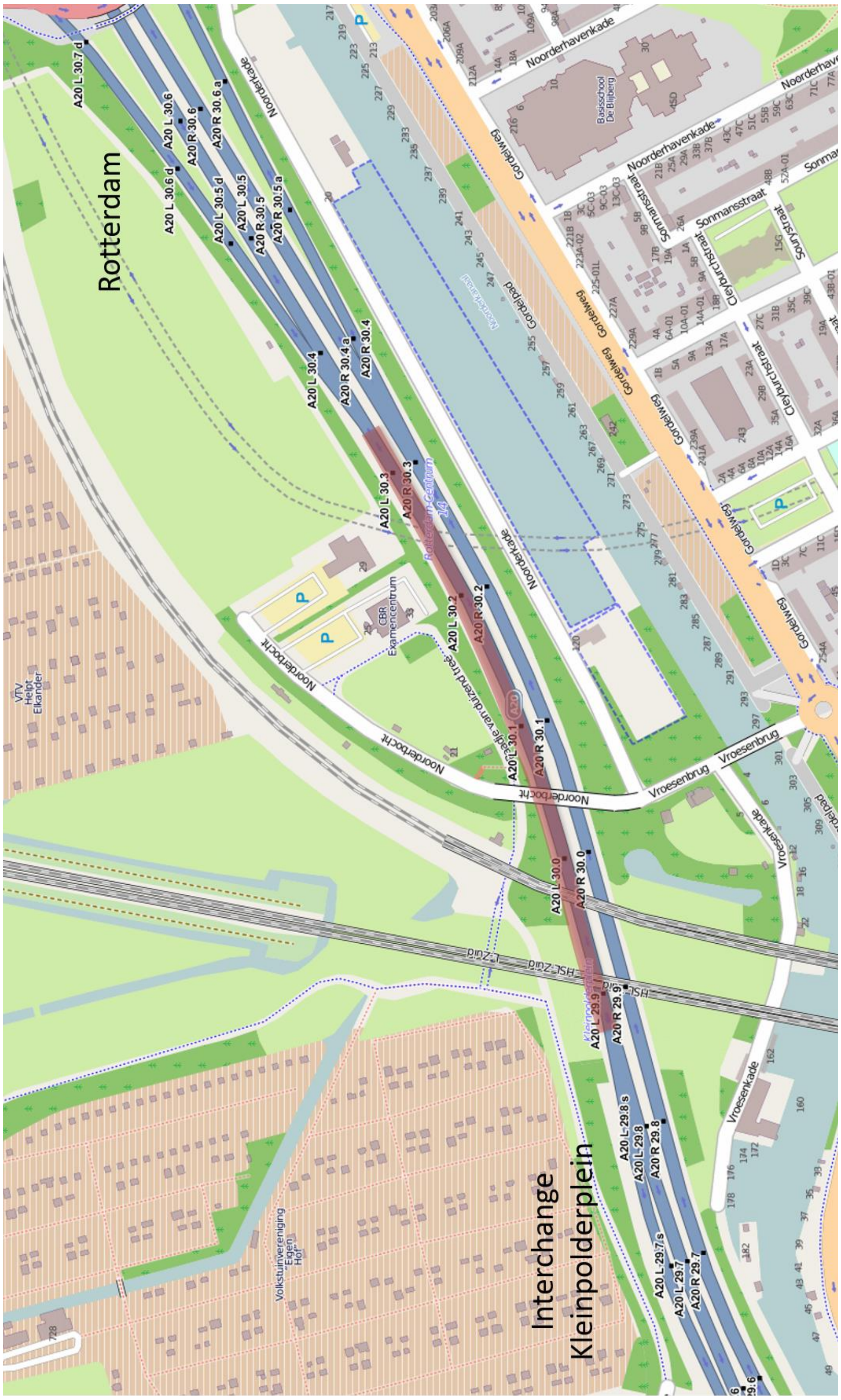


369 Interch. Zaandam

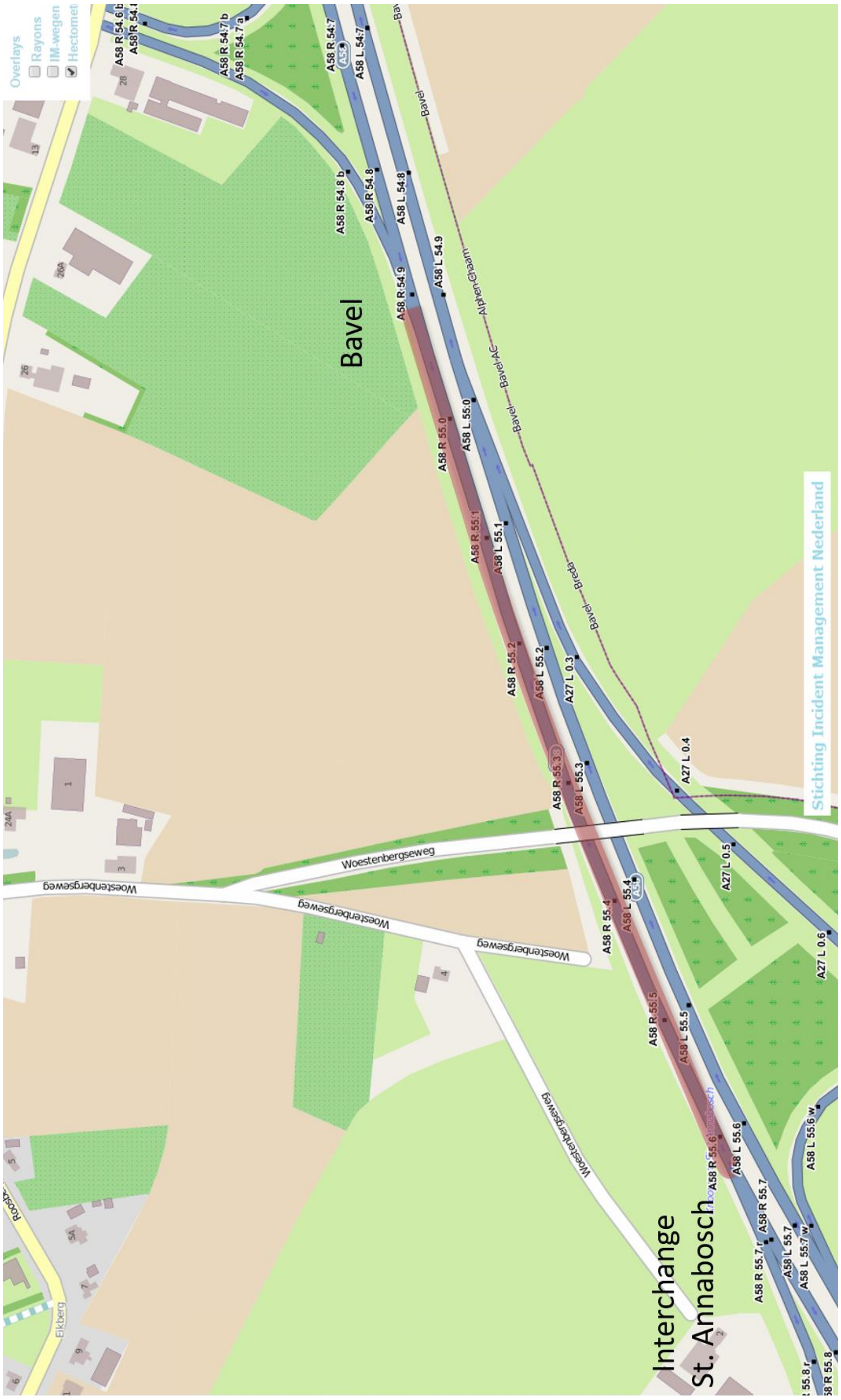
412 Voorthuizen – Barneveld



454 Rotterdam Schiebroek – Interch. Kleinpolderplein



499 Bavel – Interch. St. Annabosch



D

Route and Vehicle Shares

This appendix includes the shares of the different routes through the weaving sections and the vehicles shares. These are obtained from the selected link analysis that 4Cast did on the NRM. For each entry link a selected link analysis is carried out. Figure D.1 shows the selected link analysis on leg A of weaving section 068 in the morning peak hour for cars. In the example 1260.94 vehicles reach the weaving section via leg A. 928.97 of these vehicles go to leg C and 331.97 vehicles towards leg D. In similar way, selected links analyses are carried out for other time periods and for heavy good vehicles.

These selected link analyses give information on the movement of vehicles through the weaving sections in the form of OD-matrices. These OD-matrices are reformulated into route shares through the weaving sections which are listed for each weaving section in this appendix in table D.1 till table D.10.
Note that on weaving section 173 dedicated lanes are present which are only accessible for heavy good vehicles and that later on it was found that the data for weaving section 499 was collected for another weaving section and that hence no selected link data is available for weaving section 499.

In VISSIM each vehicle passes a routing decision. For these route decision points it is indicated which share of vehicles goes in which direction, and in that way the route decision point assigns a destination leg C or D to each passing vehicle.

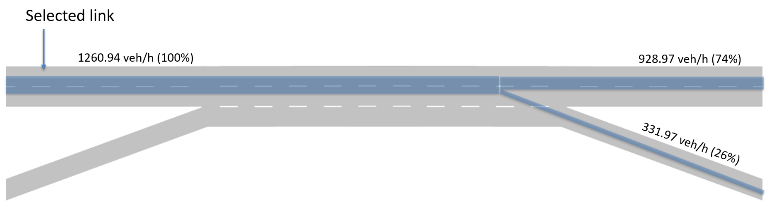


Figure D.1: Selected link analysis on leg A of weaving section 068

Also, the vehicle composition on each weaving section is included in this appendix. Different vehicle shares are calculated from the selected link analysis data for the different times of the day (AM, PM, OP) using the following formulae:

$$\text{car share}_t = \frac{\sum_{i,j} \text{car}_{t,ij}}{\sum_{i,j} \left(\text{car}_{t,ij} + \text{HGV}_{t,ij}\right)} \cdot 100\% \qquad \text{HGV share}_t = \frac{\sum_{i,j} \text{HGV}_{t,ij}}{\sum_{i,j} \left(\text{car}_{t,ij} + \text{HGV}_{t,ij}\right)} \cdot 100\%$$

where $\text{car}_{t,ij}$ is the number of cars going from i to j at time period t and $\text{HGV}_{t,ij}$ is the number of HGVs going from i to j at time period t. Here $i = \{A, B\}$ and $j = \{C, D\}$.
Note that it is also possible to derive the vehicle shares from the INWEVA database, and that these shares are used in the simulations as shares from the selected link are only available per time of day while shares from INWEVA are available per hour.

The percentage of weaving traffic is also calculated from the selected link analysis data by dividing the number of weaving traffic by the total amount of traffic. Weaving traffic steams are on the route from A to D and the route from C to B. The percentage is calculated according the following equations for time period t:

$$\begin{aligned}
\text{weaving share}_{car,t} &= \frac{\text{car}_{t,AD} + \text{car}_{t,BC}}{\sum_{i,j} \text{car}_{t,ij}} \\
\text{weaving share}_{HGV,t} &= \frac{\text{HGV}_{t,AD} + \text{HGV}_{t,BC}}{\sum_{i,j} \text{HGV}_{t,ij}} \\
\text{weaving share}_{all,t} &= \frac{car_{t,AD} + car_{t,BC} + HGV_{t,AD} + HGV_{t,BC}}{\sum_{i,j} \left(\text{car}_{t,ij} + \text{HGV}_{t,ij}\right)}
\end{aligned}$$

where $share_{car,t}$, $share_{HGV,t}$ and $share_{all,t}$ are the shares of weaving cars, HGVs and all vehicles respectively, at time period t.

Table D.1: Route and vehicle shares at weaving section 068

Passenger cars	OP	AM	PM
A >C	714	929	1482
A >D	252	332	387
B >C	40	89	66
B >D	0	0	0

Heavy good vehicles	OP	AM	PM
A >C	197	203	237
A >D	23	42	26
B >C	0	0	0
B >D	0	0	0

Weaving share	OP	AM	PM
Cars	29%	31%	23%
HGVs	10%	17%	10%
All	26%	29%	22%

Vehicle composition	OP	AM	PM
Cars	82%	85%	88%
HGVs	18%	15%	12%

Table D.2: Route and vehicle shares at weaving section 077

Passenger cars	OP	AM	PM
A >C	1729	2351	2653
A >D	502	712	498
B >C	465	446	713
B >D	131	401	30

Heavy good vehicles	OP	AM	PM
A >C	284	296	301
A >D	47	61	101
B >C	5	13	37
B >D	2	21	20

Weaving share	OP	AM	PM
Cars		30%	31%
HGVs	15%	19%	30%
All	32%	29%	31%

Vehicle composition	OP	AM	PM
Cars	89%	91%	89%
HGVs	11%	9%	11%

Table D.3: Route and vehicle shares at weaving section 156

Passenger cars	OP	AM	PM
A >C	937	1641	1462
A >D	41	41	108
B >C	57	127	118
B >D	288	618	434

Heavy good vehicles	OP	AM	PM
A >C	131	140	103
A >D	23	24	17
B >C	12	15	23
B >D	92	115	92

Weaving share	OP	AM	PM
Cars	7%	7%	11%
HGVs	13%	13%	17%
All	8%	8%	11%

Vehicle composition	OP	AM	PM
Cars	84%	89%	90%
HGVs	16%	11%	10%

Table D.4: Route and vehicle shares at weaving section 173

Passenger cars*	OP	AM	PM
A >C	1083	1682	2053
A >D	534	1083	736
B >C	1467	2316	1681
B >D	1681	1467	1572

Heavy good vehicles*	OP	AM	PM
A >C	225	0	15
A >D	0	179	465
B >C	163	0	35
B >D	0	82	187

Weaving share	OP	AM	PM
Cars	42%	52%	40%
HGVs	42%	69%	71%
All	42%	53%	43%

Vehicle composition	OP	AM	PM
Cars	92%	96%	90%
HGVs	8%	4%	10%

Table D.5: Route and vehicle shares at weaving section 256

Passenger cars	OP	AM	PM
A >C	477	1039	592
A >D	70	80	100
B >C	2	4	7
B >D	0	0	0

Heavy good vehicles	OP	AM	PM
A >C	200	271	153
A >D	9	93	114
B >C	1	7	0
B >D	0	0	0

Weaving share	OP	AM	PM
Cars	13%	7%	15%
HGVs	5%	27%	43%
All	11%	12%	23%

Vehicle composition	OP	AM	PM
Cars	72%	75%	72%
HGVs	28%	25%	28%

Table D.6: Route and vehicle shares at weaving section 269

Passenger cars	OP	AM	PM
A >C	0	0	0
A >D	88	108	142
B >C	192	317	300
B >D	0	0	0

Heavy good vehicles	OP	AM	PM
A >C	0	0	0
A >D	12	10	9
B >C	57	58	89
B >D	0	0	0

Weaving share	OP	AM	PM
Cars	100%	100%	100%
HGVs	100%	100%	100%
All	100%	100%	100%

Vehicle composition	OP	AM	PM
Cars	80%	86%	82%
HGVs	20%	14%	18%

Table D.7: Route and vehicle shares at weaving section 369

Passenger cars	OP	AM	PM
A >C	1237	836	2874
A >D	344	543	741
B >C	120	169	144
B >D	0	0	0

Heavy good vehicles	OP	AM	PM
A >C	119	81	195
A >D	28	34	7
B >C	28	26	59
B >D	0	0	0

Weaving share	OP	AM	PM
Cars	27%	46%	24%
HGVs	32%	42%	25%
All	28%	46%	24%

Vehicle composition	OP	AM	PM
Cars	91%	92%	94%
HGVs	9%	8%	6%

Table D.8: Route and vehicle shares at weaving section 412

Passenger cars	OP	AM	PM
A >C	1162	1804	1432
A >D	235	655	332
B >C	205	436	310
B >D	17	88	113

Heavy good vehicles	OP	AM	PM
A >C	332	414	262
A >D	29	122	167
B >C	40	19	5
B >D	34	13	24

Weaving share	OP	AM	PM
Cars	27%	37%	29%
HGVs	16%	25%	38%
All	25%	35%	31%

Vehicle composition	OP	AM	PM
Cars	79%	84%	83%
HGVs	21%	16%	17%

Table D.9: Route and vehicle shares at weaving section 454

Passenger cars	OP	AM	PM
A >C	1114	1401	1232
A >D	2089	2434	3202
B >C	626	946	1229
B >D	207	928	229

Heavy good vehicles	OP	AM	PM
A >C	192	251	167
A >D	302	441	477
B >C	92	46	22
B >D	61	38	15

Weaving share	OP	AM	PM
Cars	67%	59%	75%
HGVs	61%	63%	73%
All	66%	60%	75%

Vehicle composition	OP	AM	PM
Cars	86%	88%	90%
HGVs	14%	12%	10%

Table D.10: Route and vehicle shares at weaving section 499

Passenger cars	OP	AM	PM
A >C	746	774	855
A >D	1147	2034	2164
B >C	24	5	10
B >D	141	340	200

Heavy good vehicles	OP	AM	PM
A >C	399	257	275
A >D	297	307	222
B >C	7	3	12
B >D	16	19	14

Weaving share	OP	AM	PM
Cars	57%	65%	67%
HGVs	42%	53%	45%
All	53%	63%	64%

Vehicle composition	OP	AM	PM
Cars	74%	84%	86%
HGVs	26%	16%	14%

E

Crash Types

This appendix includes the different crash types that are available in the BRON crash database. Note that not all crash types occurred within the influence area of one of the (selected) weaving sections.

Table E.1: Specification of possible crash types

AOL_OMS Category	MNE_OMS Detailed description
Head-on	Head-on without lane change
	Head-on with erroneous enter/exit
	Head-on with one vehicle changing lanes
	Head-on with both vehicles changing lanes
	At railway crossing with train from left or right
	Other crashes with oncoming traffic without turning
	Other with train or tram
	Other
Side-swipe	Side-swipe crash on crossing
	Side-swipe crash on crossing with lane change
	Side-swipe crash on crossing with vehicle at standstill
	Two left-turning vehicles
	Two right-turning vehicles
	Left side with turning left
	Left side with turning right
	Left side with reversing vehicle to the left
	Right side with turning left
	Right side with turning right
	Right side with reversing vehicle to the left
	Right side with crossing vehicle
	Graze
	Other side-swipe crashes
	Other with train or tram
	At railway crossing with train from left or right

AOL_OMS Category	MNE_OMS Detailed description
Rear-end	Rear-end with erroneous enter/exit
	Rear-end with incorrect overtaking
	Rear-end with vehicle at standstill
	Rear-end with lane changing left
	Rear-end with lane changing right
	Rear-end with turning left
	Rear-end with turning right
	Rear-end without turning
	Other crashes with oncoming traffic without turning
	Other with train or tram
	Other
Single vehicle	Not off the road
	Into the water
	Other single vehicles
Flexible object	Crash with flexible object
Fixed object	Crash with lightning pole
	Crash with three or another fixed object
	Collision with other road furniture
Parked vehicle	Parked vehicle hit from behind
	Parked vehicle hit at front
	Other with parked vehicle
Pedestrian	Pedestrian at pedestrian crossing
	Pedestrian on sidewalk or roadside
	Pedestrian on cycle track / cycle lane
	Pedestrian on roadway
	Pedestrian at bus or tram stop
	Pedestrian at other crossing location
	Incorrect crossing pedestrian
	Other crash with pedestrian
Animal	Crossing animals
Unknown	Other

F

Crash Analysis: What, Where, When, Who and Why?

As described in paragraph 5.1.3 per weaving section five *W*-factors will be summarised to get a better insight in what factors might cause a crash. Location, time and type of the crash are used in paragraphs 5.6.8, 5.6.9 and 5.6.10 for evaluating accuracy of SSAM.

- *What?* The number of events;
- *Where?* The locations of the events;
- *When?* The time of the events;
- *Who?* The involvement of freight traffic to the events and age of the driver;
- *Why?* The cause of the events;

The answers to these questions are described in this appendix.

Weaving Section 068

- *What?* Only five crashes are registered between 2012 and 2015. All took place in 2014 and 2015 and resulted in only material damage. The three crashes that occurred in 2015 were single vehicle crashes. As described in appendix E, single vehicle crashes are further distinguished in the database into 'into the water', 'not off the road' and 'other single vehicle'. All three crashes are classified as 'other single vehicle'. The two crashes that occurred in 2014 are classified as 'unknown'.
- *Where?* Figure F.1 shows where on the weaving section the crashes took place. Note that the convergence gore of the weaving section is located at hectometre 143.64 and the divergence gore at 143.83, thus a majority of the crashes occurred already in the influence area upstream of the weaving section.
- *When?* Figure F.2 shows in which month and during which hour the crashes occurred. Due to the low number of crashes no conclusions can be drawn on this.
- *Who?* Two drivers involved in the single vehicle crashes in 2015 were aged between 18 and 24 years and one driver was aged between 25 and 59 years. They all were driving a passenger car. No information is available on the other crashes.

- *Why?* For the crashes in 2014 no detailed data is available on the crashes. For two of the crashes that took place in 2015 the weather type was dry while for one crash it was raining and the road surface was wet. Lightning poles were not in use, which is not remarkable as it is assumed from the date and time that the crashes occurred by daylight.

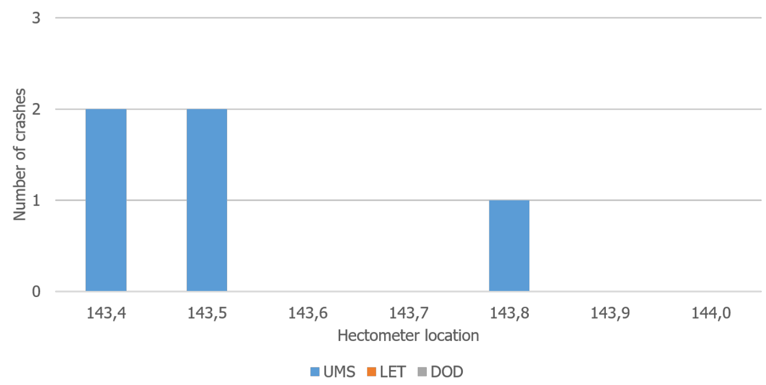


Figure F.1: Locations of the crashes at weaving section 068

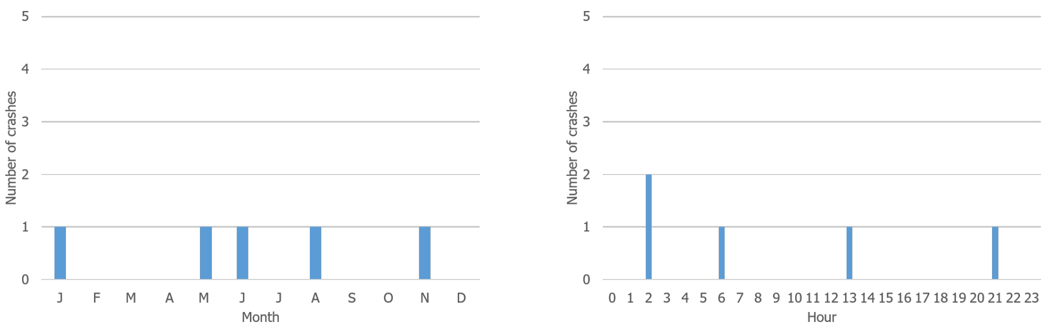


Figure F.2: Distribution of the crashes at weaving section 068 over the year (left) and day (right)

Weaving Section 077

- *What?* Thirty-four crashes are registered on weaving section 077. Seven of these crashes are registered in 2012, eight in 2013, only one in 2014 and 18 in 2015. All these crashes resulted in only material damage. Only one crash is registered as a single vehicle crash (others), for the others the type is categorised as 'unknown'.

- *Where?* Figure F.1 shows where on the weaving section the crashes took place. Crashes mostly occurred at the beginning or end of the weaving section.

- *When?* Figure F.2 shows in which month and during which hour the crashes occurred. It is seen that more crashes occurred in the winter months and during the peak hours.

- *Who?* For those four crashes with extensive details in three cases only one passenger car was involved, in the other crash a passenger car and a truck were involved. One of the drivers was older than 60 years, three were aged between 25 and 59 and of one of the drivers the age is unknown.

- *Why?* For four crashes the weather is described as dry, although the road surface is registered as wet for those crashes and for the other crash no state of the road surface is given. During two crashes lightning was on, during one crash lightning was off and at another crash no lightning was present, which contradicts to information on the crash that took place two days before.

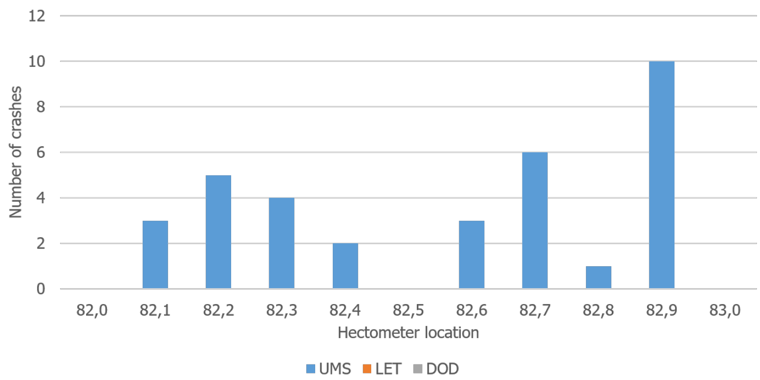


Figure F.3: Locations of the crashes at weaving section 077

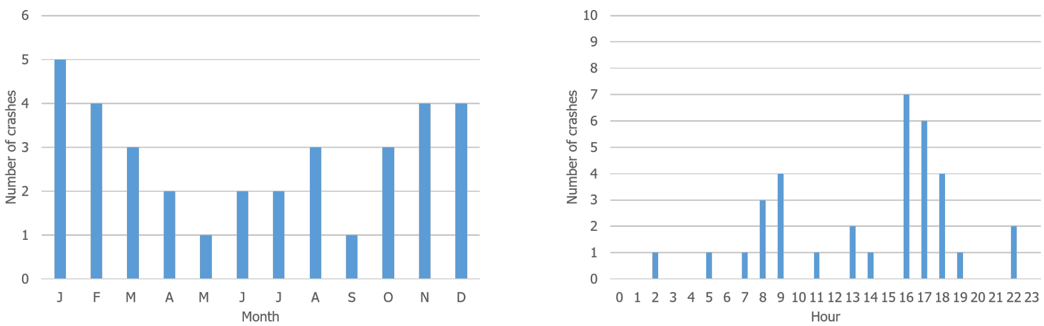


Figure F.4: Distribution of the crashes at weaving section 077 over the year (left) and day (right)

Weaving Section 156

- *What?* On this weaving section 12 crashes occurred. Five of them took place in 2012, in both 2013 and 2014 three crashes occurred and only one crash occurred in 2015. Eleven of these crashes resulted in only material damage, but in one crash there was an injury which needed first help. Only the crash that occurred in 2015 is characterised as single vehicle (others), and this crash resulted in only material damage. All crash types in previous years are registered as 'unknown'.

- *Where?* Figure F.5 shows where within the weaving section the crashes occurred. Some crashes occurred around the convergence and divergence gore, and some crashes occurred exactly in the middle. The crash with an injury occurred in the middle of the weaving section.

- *When?* Figure F.6 shows the spread of the crashes over the year and day. Slight more crashes are observed in the winter months and during the peak hours.

- *Who?* For only two crashes more detailed information is given. In one crash a passenger car and another vehicle were involved, the driver of the passenger car was between 25 and 59 years and the age of the other driver is unknown. The other crash was registered as single vehicle crash, hence only one passenger car with a driver aged between 25 and 59 years was involved.
- *Why?* For both these crashes the weather was dry and lightning poles were in use. The crash with two parties occurred on a dry road surface while the single vehicle crash occurred on wet asphalt.

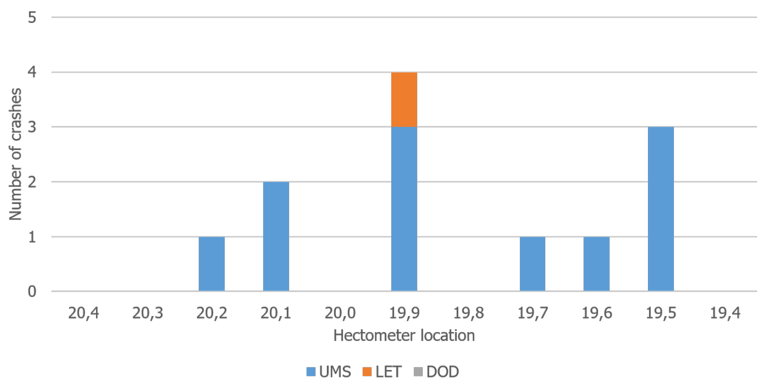
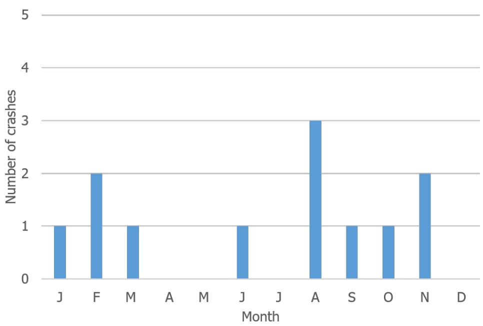


Figure F.5: Locations of the crashes at weaving section 156



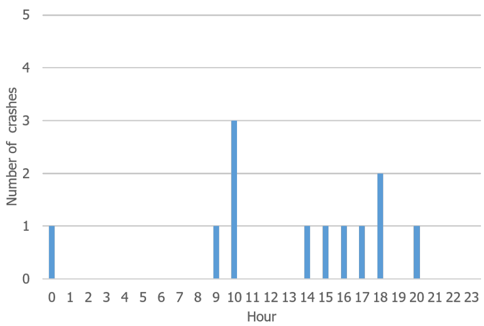


Figure F.6: Distribution of the crashes at weaving section 156 over the year (left) and day (right)

Weaving Section 173

- *What?* This weaving section has the highest number of crashes. In 2012 and 2013 respectively 35 and 28 crashes occurred. In 2014 the number of crashes decreased to 17 and the number increased to 48 in 2015. This adds up to a total of 128 crashes. The majority of these crashes only resulted in material damage (122). Six crashes resulted in an injury, of which four needed first help and two were injured otherwise. Four side-swipe crashes were registered of which one was a graze collision and three other side-swipe crashes. Two rear-end crashes are registered, one due to wrong overtaking and one without turning off. Three of the crashes were single vehicle and the other 119 were registered as unknown. One of the crashes with an injury was a side-swipe crash, one another was a rear-end crash and the other four are categorised as unknown.

- *Where?* Figure F.7 shows that the crashes are spread over the entire weaving section, but that there is a peak in the middle and more crashes occurred at the beginning than at the end.
- *When?* Figure F.8 shows the spread of the crashes over the year and day. A slight peak is seen in the winter months and clear peaks during peak hours.
- *Who?* In 21 of the 28 crashes of which the mode of the presumed liable driver was registered this was a passenger car. One crash was caused by a lorry, one by a motorbike, two by a truck and three by a tractor. Of four crashes it is registered that one vehicle was involved, in 13 crashes two vehicles were involved and in three crashes three vehicles were involved. For the other crashes this is not registered. Most of the other involved vehicles were passenger cars and trucks. In 15 crashes the liable driver was aged between 25 and 59 years, in three crashes between 18 and 24 years and in three crashes the liable driver was 60 years or older. Al victims were between 25 and 59 years old.
- *Why?* During 19 crashes the lightning poles were not in use and during six crashes they were switched on, indicating that the latter crashes occurred at twilight or darkness. 22 crashes occurred during dry weather and during three crashes it was raining. However, during some of the crashes at dry weather the asphalt was wet. For one crash it is included that it occurred due to a too short following distance. For five crashes it is registered that there was an error with overtaking and cutting in on someone.

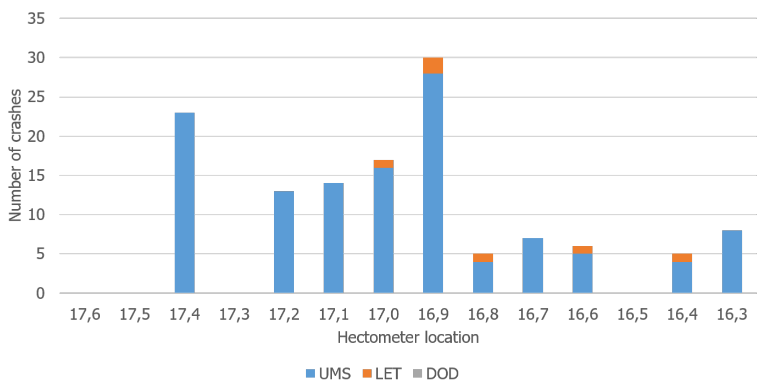


Figure F.7: Locations of the crashes at weaving section 173

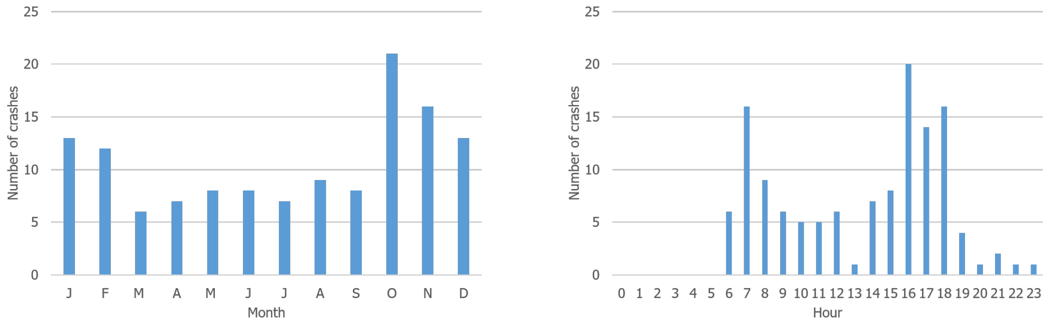


Figure F.8: Distribution of the crashes at weaving section 173 over the year (left) and day (right)

Weaving Section 256

- *What?* On weaving section 256 19 crashes are registered. One occurred in 2012, two in 2013, six in 2014 and ten in 2015. One of these crashes resulted in an injury that needed first help. The other crashes resulted in only material damage. Six crashes were single vehicle and one crash was with a fixed object. Crashes with a fixed object are further distinguished in a crash with a lightning pole, a crash with a three or other fixed object or a crash with other roadside furniture. This crash was with other roadside furniture. The other crashes – including the crash with an injury – were categorised as unknown.

- *Where?* Figure F.9 shows how the crashes are distributed over the weaving section. Note that the convergence gore is located at hectometre 134.30 and the divergence gore at 134.14, thus a relative large share occurred downstream of the weaving section.

- *When?* Figure F.10 shows the yearly and daily pattern in the crashes. Again, clearly more crashes are registered during peak hours.

- *Who?* For seven crashes it is registered that only one vehicle was involved. In all cases this was a passenger car. In two crashes two vehicles were involved, these crashes occurred due to a mistake of a passenger car driver. In one of these crashes another passenger car was involved while in the other crash a truck was involved. The age of the drivers is almost equally spread over the age categories.

- *Why?* For nine crashes the weather type is registered. Four crashes occurred during dry weather, the others during rain. Nine crashes occurred while the lightning poles were switched off, in one case they were switched on and in one case they are registered as not present.

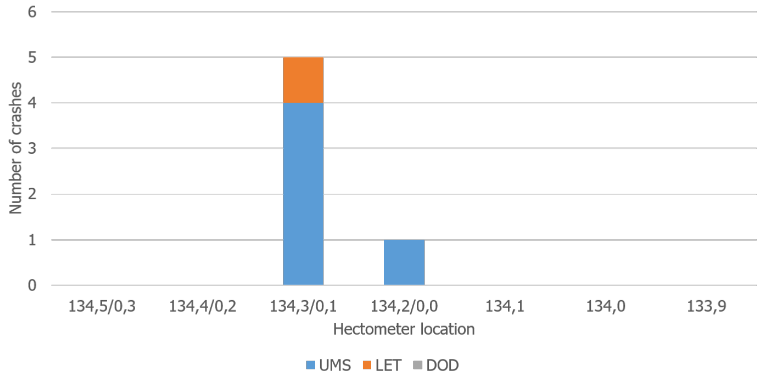


Figure F.9: Locations of the crashes at weaving section 256

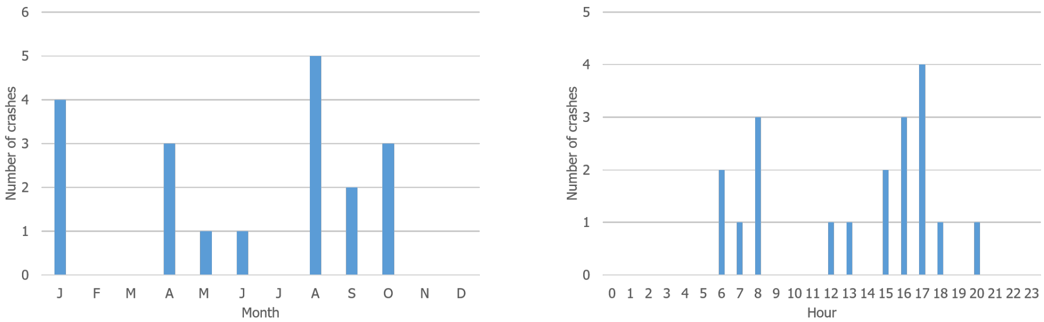


Figure F.10: Distribution of the crashes at weaving section 256 over the year (left) and day (right)

Weaving Section 269

- *What?* Only four crashes are registered on this weaving section. One occurred in 2012, another in 2014 and two in 2015. All resulted in only material damage and the type of crash is categorised as unknown.
- *Where?* Figure F.11 shows where the crashes occurred. Based on the registered hectometre location it is expected that three crashes occurred on the A50 which passes above the weaving section, and hence these three crashes should not have been assigned to the weaving section.
- *When?* In figure F.12 the spread of the crashes over the year and day is shown. Due to the low number of crashes no pattern can be distinguished.
- *Who?* No detailed information is registered for the crashes.
- *Why?* No detailed information is registered for the crashes.

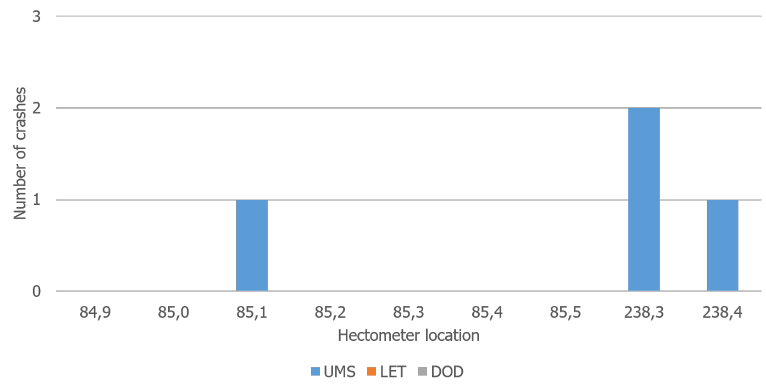
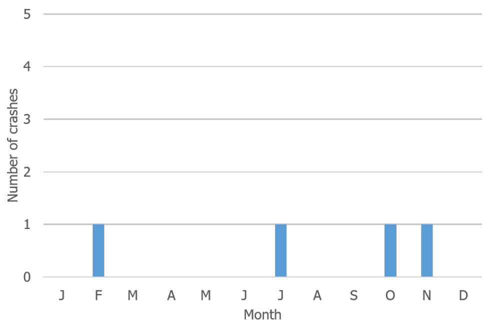


Figure F.11: Locations of the crashes at weaving section 269



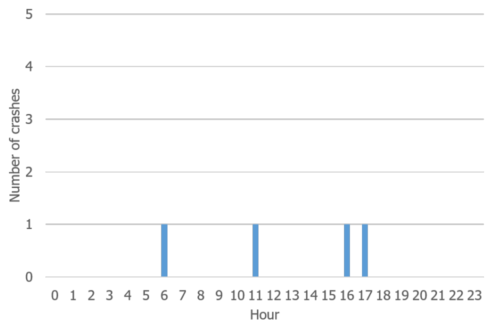


Figure F.12: Distribution of the crashes at weaving section 269 over the year (left) and day (right)

Weaving Section 369

- *What?* On this weaving section 31 crashes are registered. Five of them occurred in 2012, another five in 2013, 15 in 2014 and six in 2015. All resulted in only material damage. Three crashes were single vehicle (other), and one crash was with a fixed object (other road furniture). The other 27 crashes are labelled as unknown.
- *Where?* Figure F.13 shows that most crashes occurred upstream of the weaving section and around the divergence gore.
- *When?* Figure F.14 shows the spread of the crashes over the year and day. No clear pattern over the year is found, but it is seen that during peak hours more crashes occurred.
- *Who?* In most crashes (12) only one vehicle was involved. For two crashes it is registered that two vehicles were involved. A majority (15) of the crashes is caused by a passenger car, and one crash by a lorry. Seven of the liable drivers are aged between 25 and 59 years, and three drivers between 18 and 24 years.
- *Why?* For six crashes it is registered that the lightning poles were on, indicating that there was not sufficient daylight. For eight crashes the lightning poles were off. Four crashes occurred during dry weather while three crashes occurred during rain. For the other crashes no weather type is registered. However, for one of the crashes that occurred during dry weather the road surface was wet.

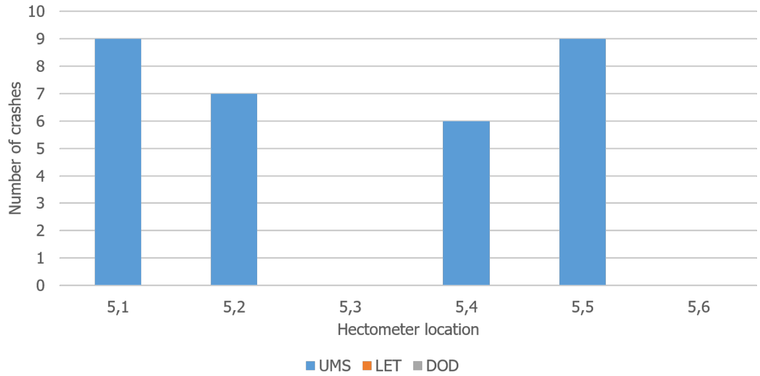
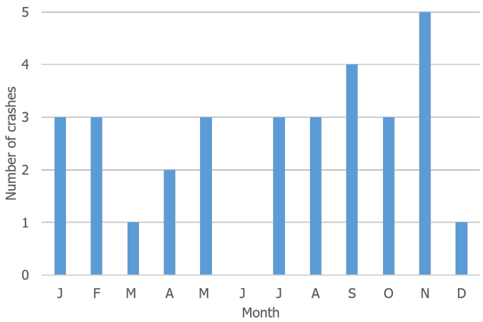


Figure F.13: Locations of the crashes at weaving section 369



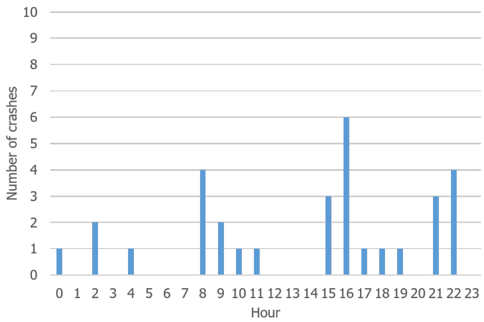


Figure F.14: Distribution of the crashes at weaving section 369 over the year (left) and day (right)

Weaving Section 412

- *What?* On weaving section 412 there are 52 crashes registered between 2012 and 2015. Nine of them occurred in 2012, six in 2013, another 15 in 2014 and 22 in 2015. All crashes only had material damage. Three crashes are registered as rear-end collisions of which two were without turning off and one with changing lanes to the left. Another three crashes are registered as single vehicle (others), one crash was with a fixed object described as other road furniture and 45 crashes are registered as unknown.
- *Where?* Figure F.15 shows the locations of the crashes within the weaving section. It is seen that more crashes occurred at the beginning than at the end of the weaving section.
- *When?* The crashes are almost equally spread over the year as can be seen in figure F.16. However clearly more crashes occurred at busy times than at off-peak hours.
- *Who?* Again, for most the crashes no detailed information is given. For four crashes it is registered that only one vehicle was involved. These all had to do with a passenger car of which one driver was aged above 60 and the others were aged between 25 and 59 years. In seven crashes two parties were involved. In all cases a passenger car was the liable party, five were with a passenger car, one with a truck and one with another vehicle type. One liable driver was aged between 18 and 24 years, three drivers between 25 and 59 years and for three drivers the age is not included. In one crash three vehicles were

involved. The passenger car was marked as liable, and the other vehicles were a truck and a vehicle of another type.

- *Why?* During all crashes of which the weather is registered it was dry. However, in two of the twelve cases the road surface was wet. For one rear-end crash with two passenger cars it is described that it occurred due to a too short following distance. The crash with the road furniture occurred due to illness and feeling unwell and losing control over the steering wheel.

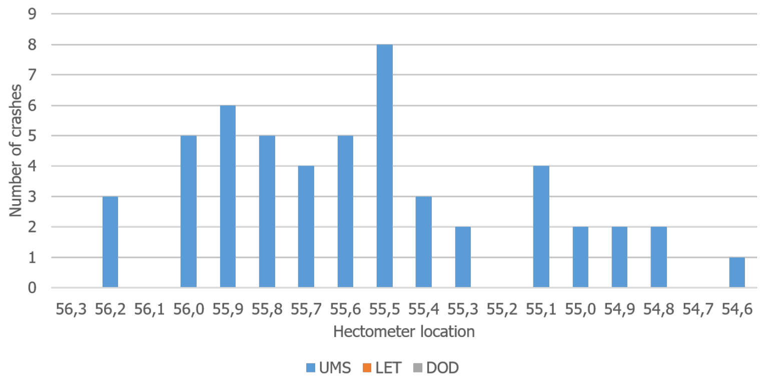


Figure F.15: Locations of the crashes at weaving section 412

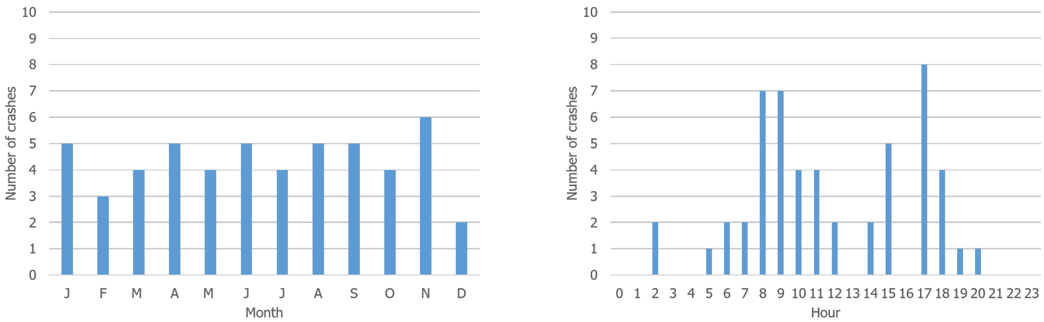


Figure F.16: Distribution of the crashes at weaving section 412 over the year (left) and day (right)

Weaving Section 454

- *What?* On weaving section 454 94 crashes are registered. Of these 18 occurred in 2012, 26 in 2013, nine in 2014 and 41 in 2015. A majority resulted in only material damage, but five crashes have led to an injury. For one injury first help was sufficient, three needed hospital stay and one had another injury type. One crash was registered as a side-swipe crash (others), and that crash resulted in an injury which needed first help. Another crash was a rear-end crash without turning off, leading to material damage only. Another crash was registered as single vehicle (other) and resulted in an injury with hospital stay. For the other 91 crashes the type is unknown.

- *Where?* Figure F.17 shows where on the weaving section the crashes occurred. It is seen that the crashes with an injury occurred at the end of the weaving section.

- *When?* In figure F.18 the spread of the crashes over the year and day can be seen. More crashes occurred by day than at night-time.
- *Who?* In most (10) crashes two vehicles were involved. In all these crashes the liable vehicle was a passenger car. In six cases the other vehicle was also a passenger car, in three cases it was a truck and in one case it was a lorry. One-third of the liable drivers was aged between 18 and 24 years. The others were aged between 25 and 59 years. In three crashes only one vehicle was involved. These vehicles were a passenger car, a truck, and a lorry. Two drivers were aged between 25 and 59 years and of one driver the age is unknown. Two crashes with three vehicles are registered, both with two passenger cars and a lorry. Also, one crash with four vehicles and one crash with five vehicles is registered. The crash with five vehicles resulted in four people with a hospital stay injury.
- *Why?* Eighteen of the crashes occurred during dry weather and three during rain. Of the five crashes with an injury four were during dry weather and on a dry road surface. One crash was during rain and with a wet road surface. During 19 crashes the lightning poles were off, during two crashes they were in use. For the rear-end crash it is registered that the following distance was too short. In the side-swipe crash with an injury the speed was too high.

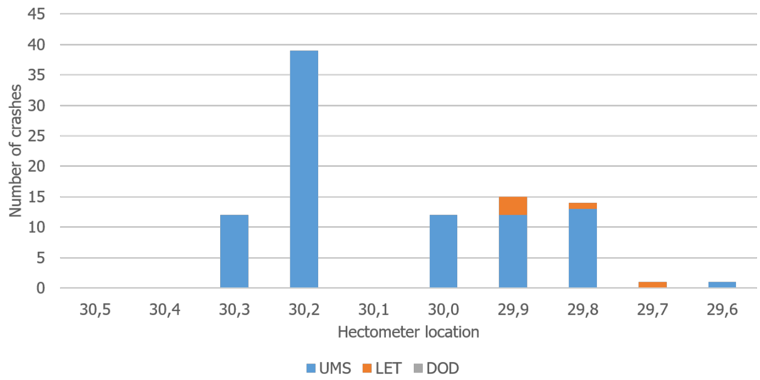


Figure F.17: Locations of the crashes at weaving section 454

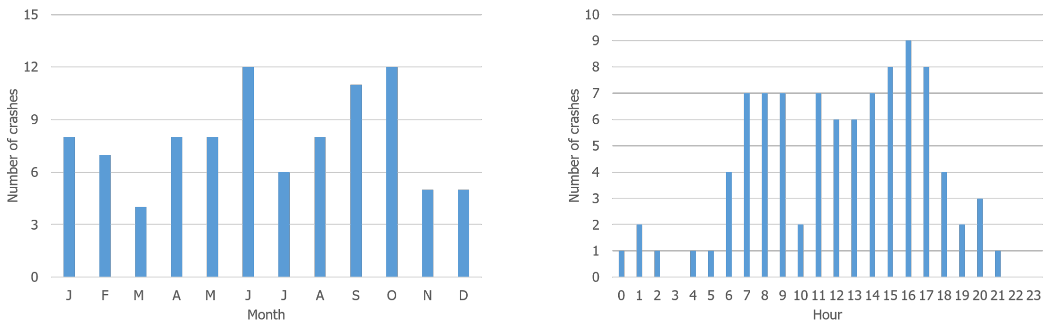


Figure F.18: Distribution of the crashes at weaving section 454 over the year (left) and day (right)

Weaving Section 499

- *What?* On this weaving section 18 crashes are registered. Two of them occurred in 2012, three in 2013, six in 2014 and seven in 2015. One crash resulted in an injury with hospital stay, for the others only material damage was registered. One crash was a side-swipe crash with a graze, another crash was a single vehicle crash, and for the other 16 the crash type is registered as unknown.
- *Where?* Figure F.19 shows where within the weaving section the crashes occurred. There is no clear pattern visible.
- *When?* In figure F.20 it is seen how the crashes are spread over the year and day. Only a few crashes occurred in the morning.
- *Who?* In all crashes for which the type of the liable vehicle is registered this is a passenger car. The crash with two parties was between a passenger car and a lorry. One liable driver was aged between 18 and 24, two others between 25 and 59 and for the others the age is unknown.
- *Why?* The crash that led to an injury was the side-swipe crash. It was between two passenger cars, and also a lightning pole was involved. It occurred due to driving too much on the right. The weather was dry but the road surface was wet. For one other crash the weather and road surface were dry. For other crashes no information is available.

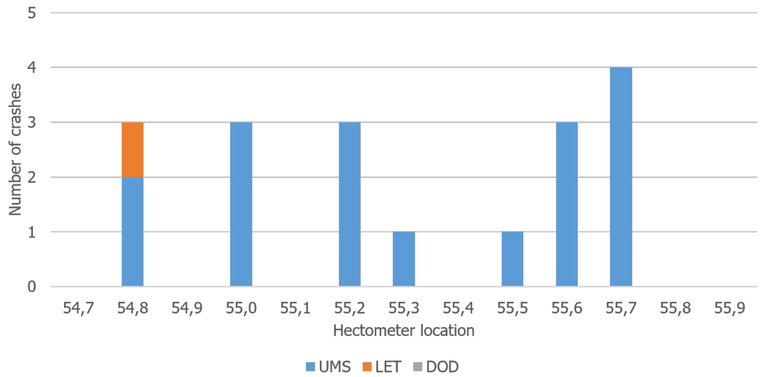


Figure F.19: Locations of the crashes at weaving section 499

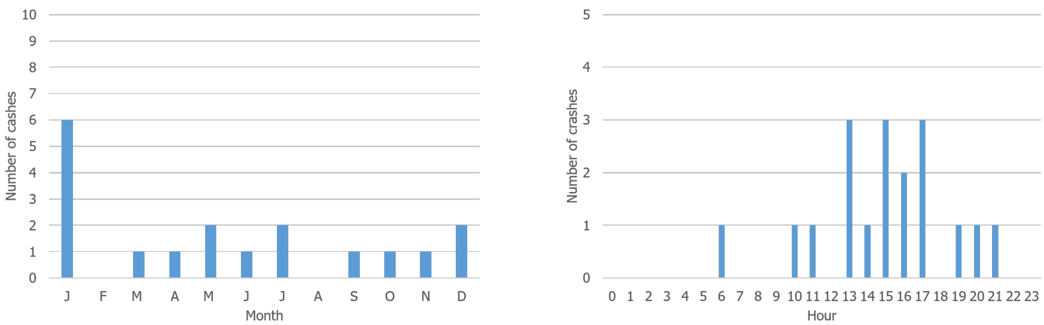


Figure F.20: Distribution of the crashes at weaving section 499 over the year (left) and day (right)

G

Expert Judgement

This appendix includes the data given to the experts for the expert judgement. As the experts are all Dutch, the weaving sections are described in Dutch as well. Also three maps were given to the experts:

- A road map on which the location of the weaving section is indicated with a coloured arrow;
- An aerial view on which the weaving section and some upstream and downstream freeway section is visible and on which the locations of the figures are indicated;
- Another aerial view zoomed in onto the weaving section.

The experts first made their own ranking, and after that all rankings were discussed such that one final ranking that all experts agreed on was obtained. These individual rankings and final ranking are included in table G.1.

Table G.1: Safety rankings of the road safety experts

ID	Ranking position						
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average	Final
068	7	4	2	6	3	4.4	5
077	3	5	8	4	4	4.8	3
156	8	8	6	3	7	6.4	7
173	2	1	7	1	4	3.0	2
256	6	6	4	9	8	6.6	8
269	9	9	5	5	9	7.4	9
369	4	7	1	8	5	5.0	6
412	5	3	9	7	2	5.2	4
454	1	2	3	2	1	1.8	1

Veiligheidsanalyse weefvakken

Fijn dat je wilt helpen om de verkeersveiligheid van 9 weefvakken te beoordelen. Zou je deze op volgorde willen leggen van meest veilig naar meest onveilig? Denk hierbij aan de zeven VOA-verkeersveiligheidsprincipes *verwachtingspatroon, waarnemen, begrijpen, kunnen, willen, interactie voertuig* en *vergevingsgezindheid* en de drie rijtaakniveaus *strategisch*, *tactisch* en *operationeel*.

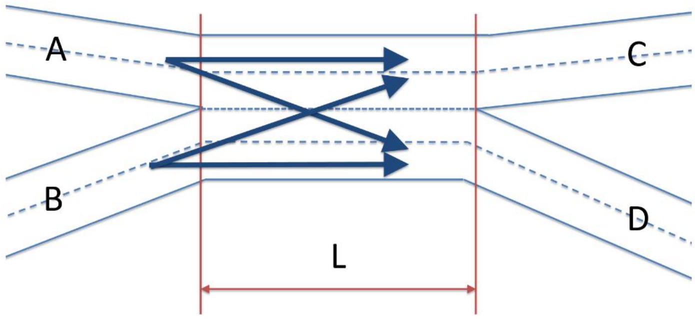
Van iedere locatie zijn er drie kaarten: de wegenkaart, een globale luchtfoto en een luchtfoto ingezoomd op het weefvak. De gekleurde pijl in de wegenkaart geeft de locatie/richting van het weefvak aan. Ook zijn relevante gegevens over onder andere de configuratie, de verkeerssamenstelling, congestie en bewegwijzering bijgevoegd.

Ik heb van dezelfde weefvakken een simulatie in VISSIM gemaakt, en met SSAM het aantal conflicten dat op een gemiddelde werkdag zou gebeuren bepaald. Met behulp van het aantal conflicten heb ik de weefvakken ook gerangschikt. Nu is de vraag of deze ranking overeenkomt met de ranking van jullie.

Weefvak	*Locatie*		*Positie* 1=onveilig, 9=veilig
068	A7	Knooppunt Heerenveen	……
077	A27	De Bilt – Maarssen	……
156	A65	Knooppunt De Baars – Tilburg Noord	……
173	A16	Kralingen – Knooppunt Terbrechseplein	……
256	A28	Knooppunt Hoogeveen	……
269	A28	Knooppunt Hattemerbroek	……
369	A8	Knooppunt Zaandam	……
412	A1	Voorthuizen – Barneveld	……
454	A20	Rotterdam Schiebroek – Knooppunt Kleinpolderplein	……

Definities

De benen van een weefvak zijn zoals in de afbeelding. Been A is dus altijd links van been B, en been C is altijd links van been D.
Wevend verkeer gaat van been A naar been D, of van been B naar been C.



Overzicht

Onderstaande tabel geeft een overzicht van een aantal kenmerken van de weefvakken. De kolom knooppunt geeft aan of het weefvak in een knooppunt tussen twee klaverbladlussen ligt of niet. De lengte is gemeten tussen de puntstukken. De lengte-eis is bepaald m.b.v. de ROA op basis van turbulentielengtes en minimale lengtes voor bewegwijzering en verkeersafwikkeling. De gemiddelde weekdag intensiteit komt uit INWEVA 2015. Ook het vrachtwagenpercentage komt uit INWEVA 2015 en is het gemiddelde percentage overdag. Het percentage wevend verkeer is een ochtend- en avondspits gemiddelde op basis van een *selected link analyse* op het NRM.

	CONFIGURATIE	KNOOPPUNT	LENGTE	LENGTE-EIS	GEM. WEEKDAG INTENSITEIT	% VRACHT-WAGENS	% WEVEND VERKEER	SNELHEIDS-LIMIET
068	2 + 1	Ja	189	500	22500	15 %	27 %	130/100
077	3 + 1	Nee	608	600	50500	9 %	30 %	100
156	2 + 1	Nee	596	500	28800	15 %	9 %	130
173	3 + 2 *	Nee	888	700	90400	9 %	46 %	100
256	2 + 1	Ja	152	500	13700	27 %	10 %	130
269	1 + 1	Ja	171	225	6500	14 %	100 %	(130/)100
369	2 + 1	Ja	137	500	33200	7 %	30 %	100
412	2 + 1	Nee	1306	500	36500	15 %	34 %	130
454	3 + 1 > 2 + 2	Nee	469	750	75500	10 %	67 %	80

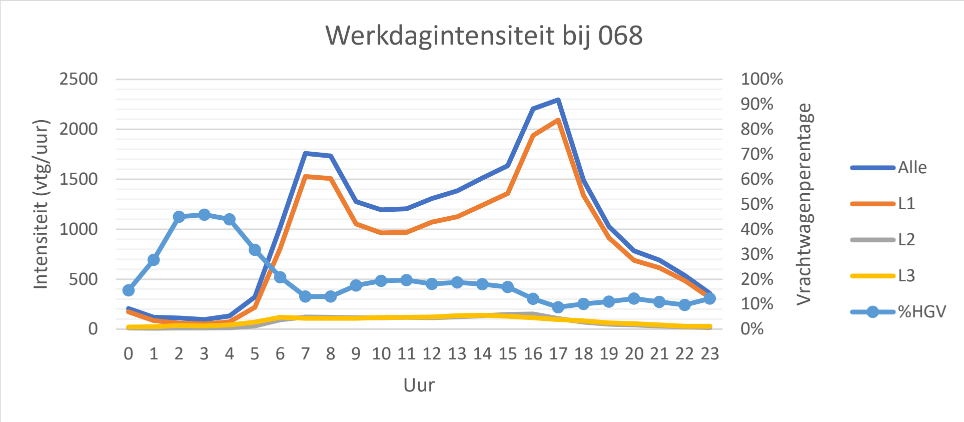
* Voor en na het weefvak is er een vrachtwagenrijstrook, dus je zou dit ook kunnen zien als een (2+1)+2 weefvak.

Tijd-weg diagrammen

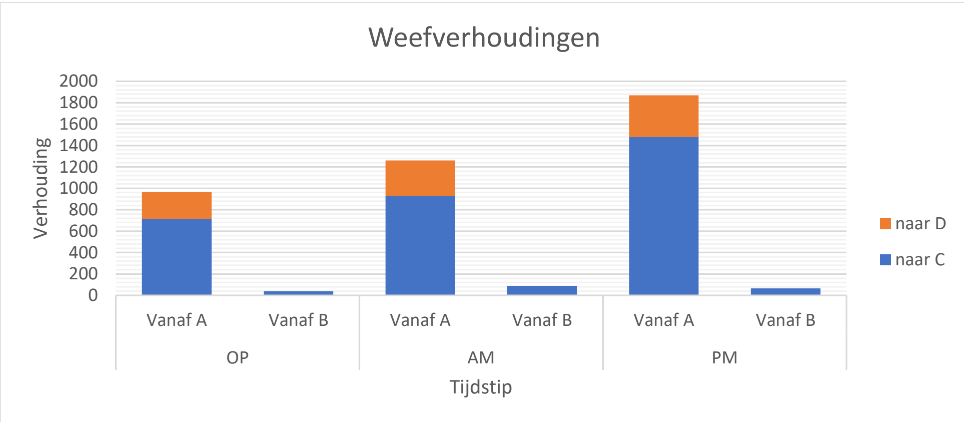
Congestie is weergegeven door tijd-weg-diagrammen. Deze zijn gemaakt met snelheidsdata van een werkweek in september 2016. Onderstaande tabel geeft aan welke kleuren corresponderen met welke snelheid. Ook een traject stroomopwaarts en stroomafwaarts is meegenomen in de figuren. De blauwe pijl geeft ongeveer de locatie van het weefvak aan.

251-255	156-170	111-129	65-75	20-39
200-250	141-155	91-110	50-64	10-19
171-199	130-140	76-90	40-49	0-9

068 – Knooppunt Heerenveen



Gemiddelde werkdagintensiteit: L1 - 20678 L2 - 1783 L3 - 1939 ∑ - 22400

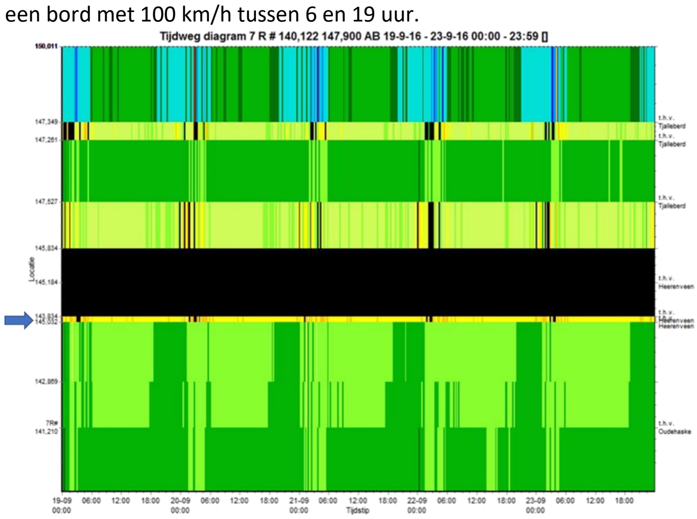


Percentages wevend verkeer: OP - 26% AM - 29% PM - 22%

Lengte: 189 meter, ROA eist 500 meter op basis van verkeersafwikkeling bij 120 km/h.

Snelheidslimiet: 130 km/h op het traject voor en na het weefvak. Bij het convergentiepuntstuk staat een bord met 100 km/h tussen 6 en 19 uur.

Congestie:



A Eerste aankondiging afrit Heerenveen/Zwolle, een verbindingsweg nog voor weefvak. Kort hiervoor staat rechts nog een bord met ‘Knooppunt Heerenveen’ en een snelheidslimiet van 100 km/h tussen 6 en 19 uur.

B Stroomopwaarts van het te beoordelen weefvak ligt een ander weefvak tussen oprit Heerenveen-West en de verbindingsweg naar Heerenveen/Zwolle van het klaverblad. Dezelfde borden worden verderop (zie B2 op de kaart) herhaald.

C Aankondiging uitvoeger naar Leeuwarden (deze uitvoeger is been D van het weefvak).

D Zicht vanaf been B, een klaverblad lus. Slechts kleine bosjes, dus goed zicht op verkeer op de hoofdrijbaan.

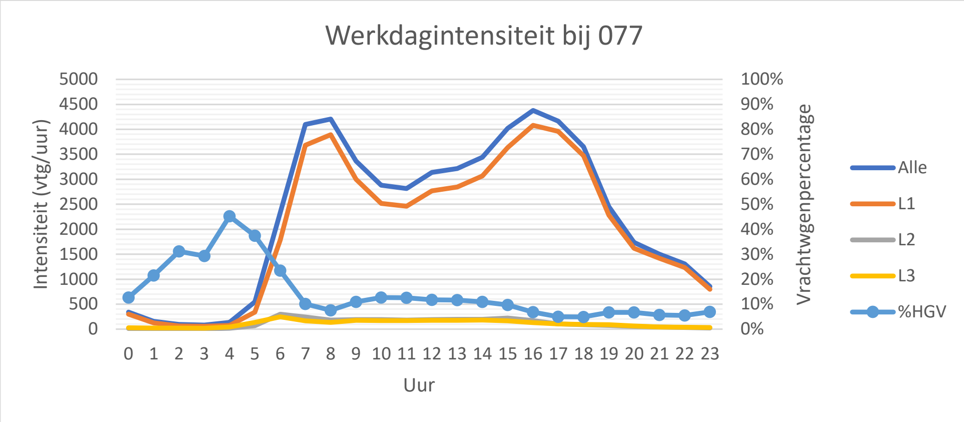
E Begin weefvak. Borden aan het portaal geven aan welke richting hoort bij welke rijbaan. Links en rechts staat sinds 2015 een bord dat aangeeft dat de snelheidslimiet 100 km/h is tussen 6 – 19 uur.

F Halverwege het weefvak.

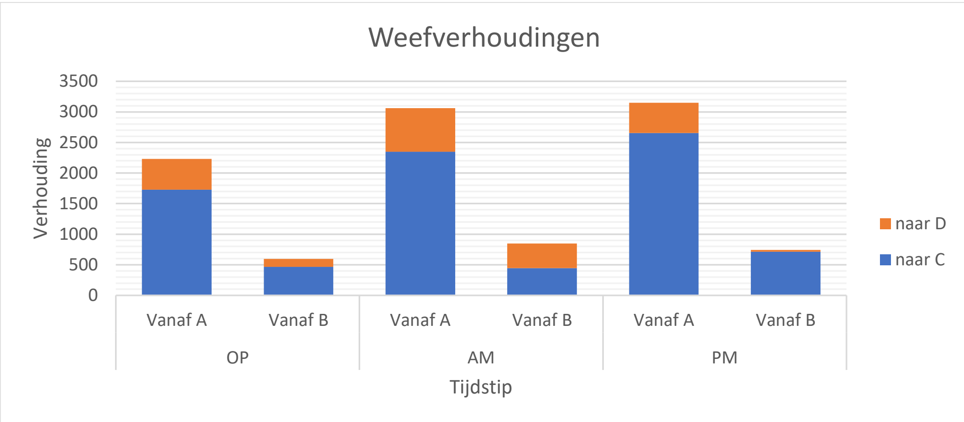
G Been C vervolgt. Na het weefvak is er nog een invoegende verbindingsweg. Hier is een doorgetrokken lijn, dus het is niet toegestaan om te wisselen van de linkerrijstrook naar de rechterrijstrook.

H Bij been D staat een waarschuwingsbord slipgevaar (J20)

077 – De Bilt – Maarssen



Gemiddelde werkdagintensiteit: L1 - 49458 L2 - 2815 L3 - 2627 ∑ - 54900

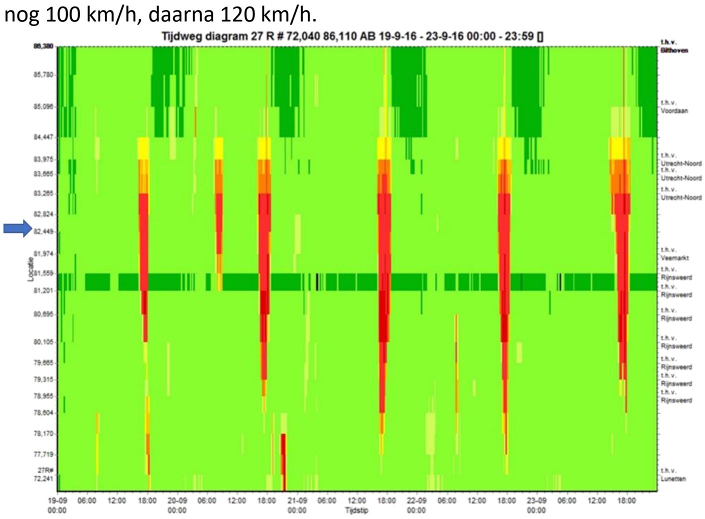


Percentages wevend verkeer: OP - 32% AM - 29% PM - 31%

Lengte: 608 meter, ROA eist 600 meter op basis van verkeersafwikkeling bij 120 km/h.

Snelheidslimiet: 100 km/h op het traject voor en op het weefvak. Na het weefvak gedurende 2 km nog 100 km/h, daarna 120 km/h.

Congestie:



A In knooppunt Rijnsweerd, hoofdrijbaan en rangeerbaan.

B Weefvak op de rangeerbaan (dit is niet het te beoordelen weefvak). Doorgaande weg ligt verhoogd, afrit gaat omlaag. Linkerrijstrook van rangeerbaan voegt in op hoofdrijbaan.

C Snelheidslimiet 100 km/h wordt nog eens herhaald. Borden staan aan beide zijden van de weg.

D Aankondiging afrit Ring Utrecht/Maarssen/N230. Dit afrit is been D van het weefvak.

E Been B komt vanaf lagergelegen punt.

F Begin van het weefvak.

G Einde van het weefvak. Hier staat eenzelfde richtingsbord als bij F. Rechts staat een bord dat een snelheidslimiet van 90 km/h aangeeft en daarboven een bord dat waarschuwt voor slipgevaar (J20).

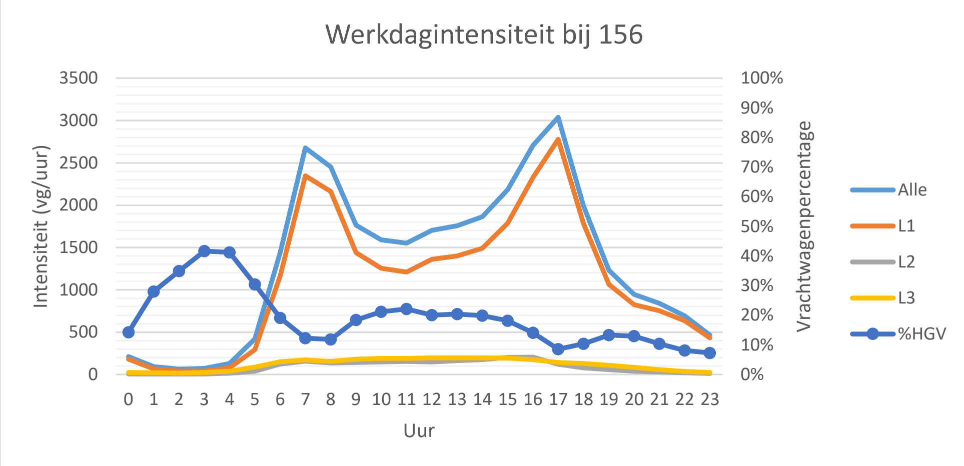
H Links staat een bord met 'ritsen na 300m' (L05-3 + OD728). Kort daarna begint een doorgetrokken lijn, waardoor van rijstrook wisselen niet toegestaan is.

I Been D bestaat eerst uit één rijstrook, maar later worden dit twee rijstroken.

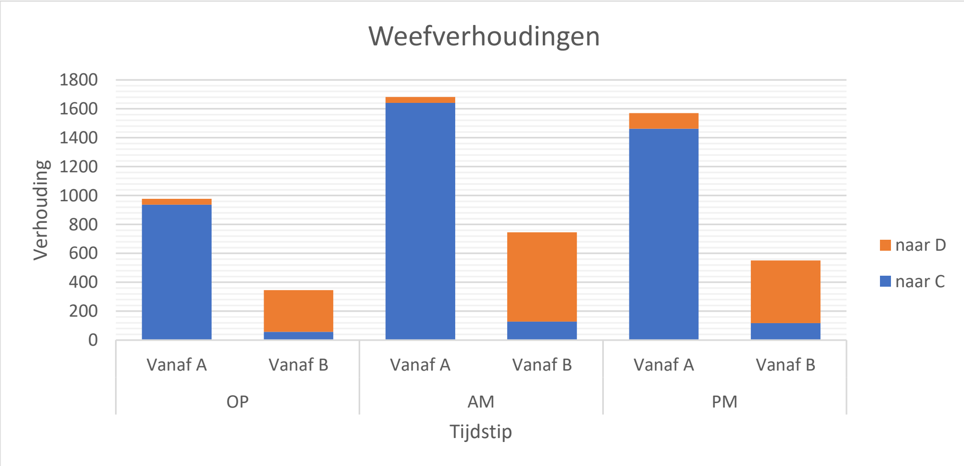
J Einde doorgetrokken streep, nogmaals ritsen bord (L05-3) met daaronder aan de linker kant ‘ritsen vanaf hier’ (OD7226) en aan de rechterkant ‘geef ritser ruimte’ (OB727). Er staat een pijl op de linkerrijstrook.

K Invoeging van verbindingsweg vanaf N230/Maarssen. Deze heeft een toeritdoseerinstallatie (net buiten beeld).

156 – Knooppunt De Baars – Tilburg Noord



Gemiddelde werkdagintensiteit: L1 - 26929 L2 - 2183 L3 - 2788 ∑ - 31900

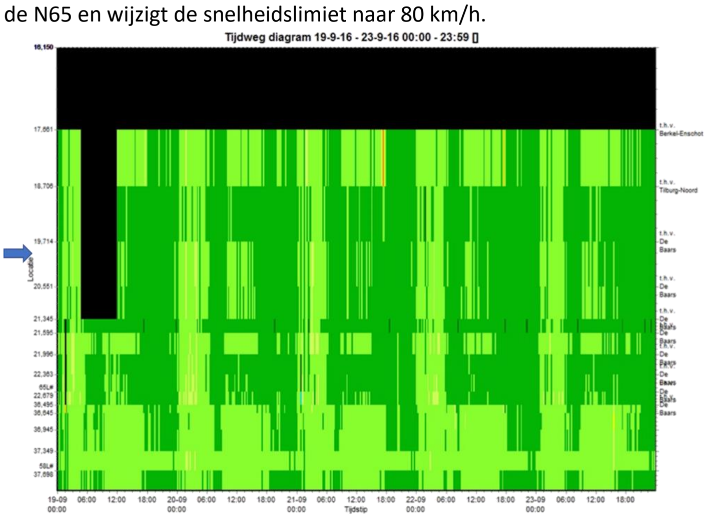


Percentages wevend verkeer: OP - 8% AM - 8% PM - 11%

Lengte: 596 meter, ROA eist 500 meter op basis van verkeersafwikkeling bij 120 km/h.

Snelheidslimiet: Voor, op en na het weefvak 130 km/h. Na afrit Berkel-Enschot gaat de A65 over in de N65 en wijzigt de snelheidslimiet naar 80 km/h.

Congestie:



A Invoeging vanaf Hilvarenbeek op een rangeerbaan.

B Twee rijstoken voegen vanaf rangeerbaan uit richting Eindhoven/A58. Linkerrijstrook voegt in op de hoofdrijbaan (zie C). Hoofdrijbaan gaat door naar weefvak als been A. Zelfde borden worden verderop herhaald (zie B2 op de kaart).

C Invoeging van linkerrijstrook van rangeerbaan op hoofdrijbaan.

D Rangeerbaan voegt in op hoofdrijbaan, en afslag 2 Berkel-Enschot (2700m) en afslag 3 Ring Noord/Tilburg-Noord (1100m) worden aangekondigd.

E Opnieuw afrit 3, nu met de verwijzing Efteling en industrieën Tilburg 0 – 5000.

F Invoeging van been B, dit verkeer komt vanaf de A58.

G Begin van het weefvak, gezien vanaf been A.

H Waarschuwing voor overstekend wild gedurende een kilometer (J27+onderbord) aan beide zijden van de weg aan het begin van het weefvak.

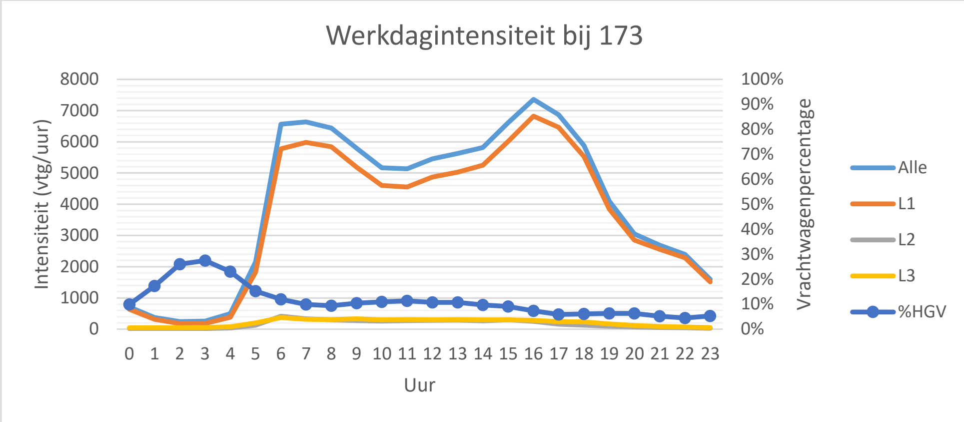
I Bewegwijzering boven het weefvak.

J Bewegwijzering op het weefvak, nu alleen voor de uitvoeger.

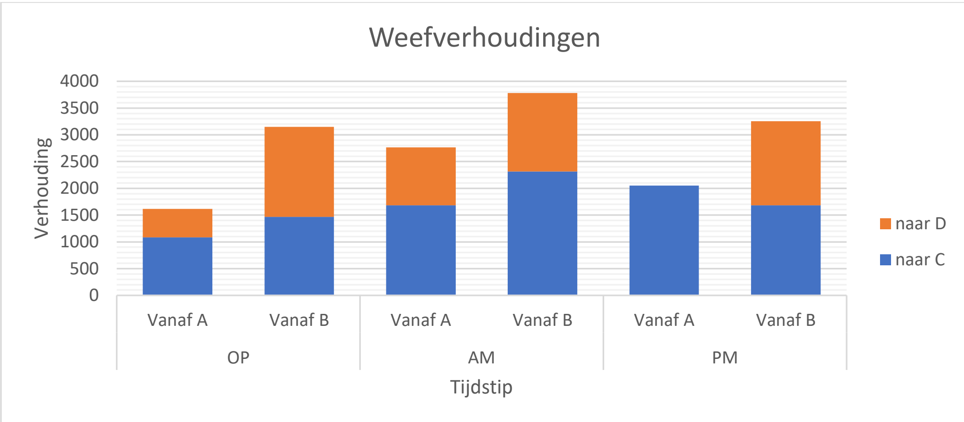
K Einde weefvak. Waarschuwing voor bocht naar rechts d.m.v. bord J03 en bochtschilden en adviessnelheid 50 km/h. Na de eerste bocht wordt been D verbreed naar 2 rijstroken.

L Invoeger vanaf Tilburg-Noord op been C, na het weefvak.

173 – Kralingen – Knooppunt Terbrechseplein



Gemiddelde werkdagintensiteit: L1 - 88479 L2 - 4071 L3 - 4850 ∑ - 97400

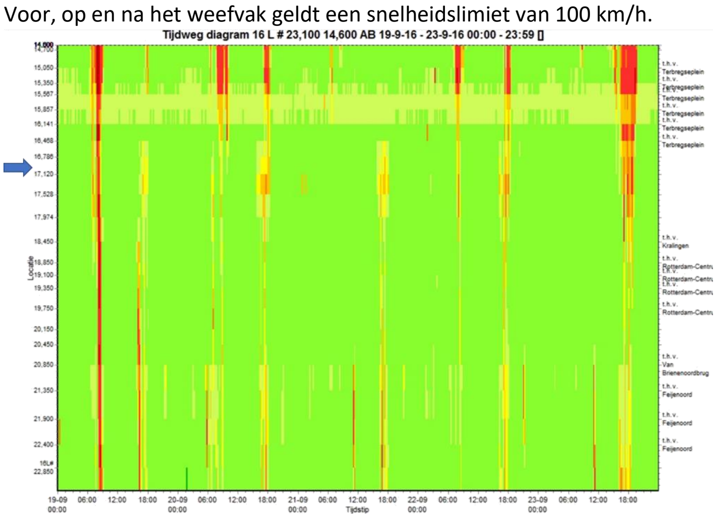


Percentages wevend verkeer: OP - 42% AM - 53% PM - 43%

Lengte: 888 meter, ROA eist 700 meter op basis van verkeersafwikkeling bij 120 km/h.

Snelheidslimiet: Voor, op en na het weefvak geldt een snelheidslimiet van 100 km/h.

Congestie:



A Invoeging vanaf Capelle a/d IJssel op parallelbaan.

B Op de hoofdrijbaan is de rechterrijstrook alleen toegankelijk voor vrachtwagens.
Op de parallelbaan geldt een snelheidslimiet van 100 km/h en is aangegeven dat de rechterrijstrook naar afrit 26 Kralingen gaat, en dat de andere twee rijstroken naar Ring Rotterdam/Den Haag/Utrecht/Havens 200-1000 gaan.

C Dezelfde richtingsborden staan verderop. Hier is ook de snelheidslimiet van 100 km/h op de parallelbaan aangegeven.

D Een DRIP tussen de hoofdrijbaan (been A) en parallelbaan (been B).

E Invoeging vanaf Kralingen op parallelbaan. Links staan geluidsschermen, welke het zicht mogelijk beperken. Het eerste gedeelte van de invoegstrook bestaat uit twee rijstroken, maar de linkerrijstrook wordt nog voor de invoeging afgestreept.

F Kort voor het puntstuk van het te beoordelen weefvak is het einde van de vrachtwagenrijstrook: nu mogen alle voertuigen weer op deze rijstrook rijden.
Ook is afrit 16 P+R Alexander aangegeven.

G Begin weefvak. Links bewegwijzering, rechts bord met maximumsnelheid 100 km/h.

H Bewegwijzering op weefvak.

I Bewegwijzering verderop op het weefvak.

J Bewegwijzering aan het einde van het weefvak. Aangegeven dat de rechterrijstrook van been C voor vrachtauto's is.

K Puntstuk. Rechterrijstrook van been C is alleen toegankelijk voor vrachtauto's. Vanuit been D kun je uitvoegen naar afrit 27 Rotterdam Alexander/Hillegersberg (zie L).

L Voor afrit 27 opent een uitvoeger aan de rechterkant op been D.

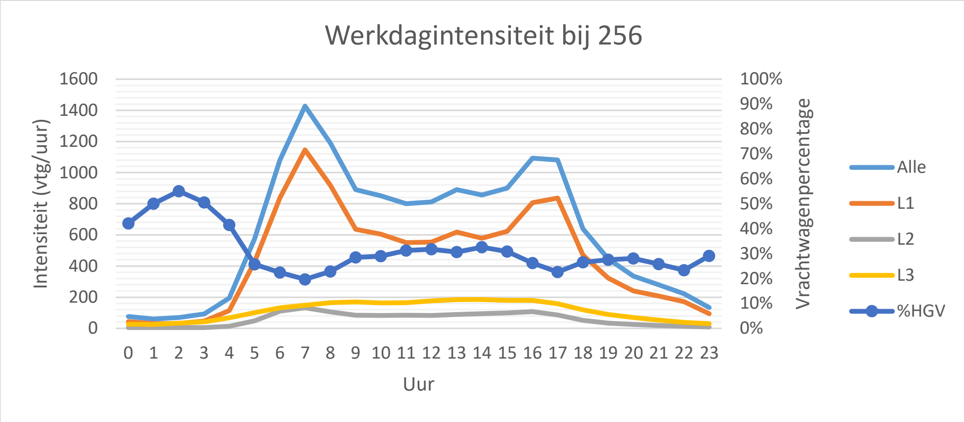
M Afrit 27 voegt uit middels een bocht naar rechts, aangegeven met bord J02 en adviessnelheid van 50 km/h.

N De andere rijstroken van been D vervolgen naar de A20-Oost. Op been C wordt nog eens herhaald dat de rechterrijstrook alleen voor vrachtauto's is.

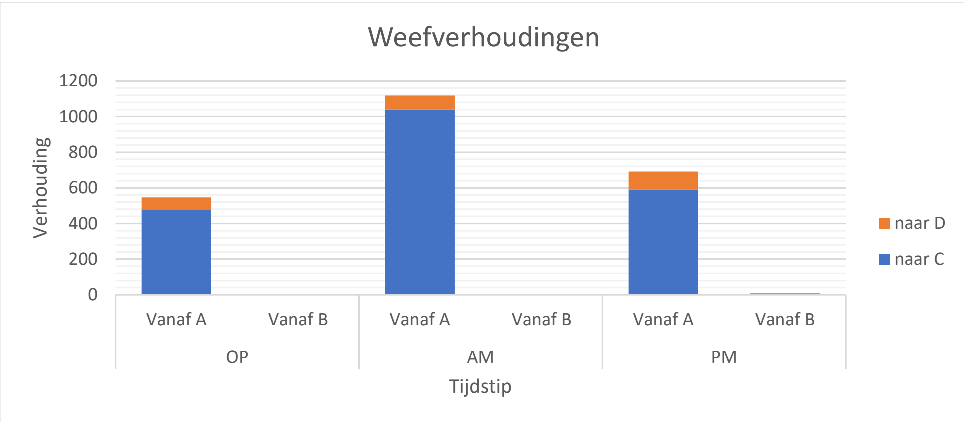
O Been C en D hebben een bocht naar links en rechts respectievelijk, en een adviessnelheid van 80 km/h.

P Nogmaals waarschuwing voor de bocht door borden J02 en J03, en bochtschilden. Op been C wordt na de bocht de vrachtautostrook gesplitst van de rijstroken voor personenauto's.

256 – Knooppunt Hoogeveen



Gemiddelde werkdagintensiteit: L1 - 10910 L2 - 1389 L3 - 2701 ∑ - 15000

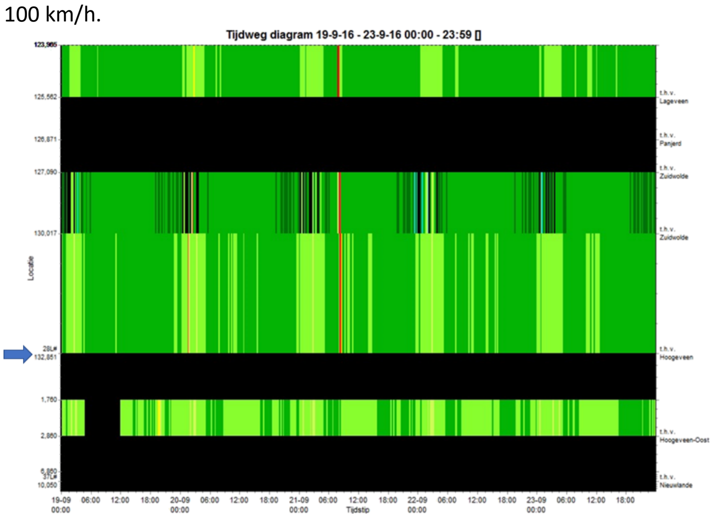


Percentages wevend verkeer: OP - 11% AM - 12% PM - 23%

Lengte: 152 meter, ROA eist 500 meter op basis van verkeersafwikkeling bij 120 km/h.

Snelheidslimiet: Voor, op en na geldt een snelheidslimiet van 130 km/h. De verbindingsweg die vanaf de A28 Noord komt en invoegt na het weefvak heeft een snelheidslimiet van 100 km/h.

Congestie:



A Aankondiging knooppunt Hoogeveen.

B Uitvoegstrook en bebording voor weefvak. Afrit Ommen/N48 (been D van het weefvak) staat op het middelste bord.

C Afslag Ommen/N48 wordt aangegeven. Rechts voegt been B in.

D Zicht vanaf been B. Links staat een boom, rechts een bord dat de snelheidslimiet van 130 km/h aangeeft.

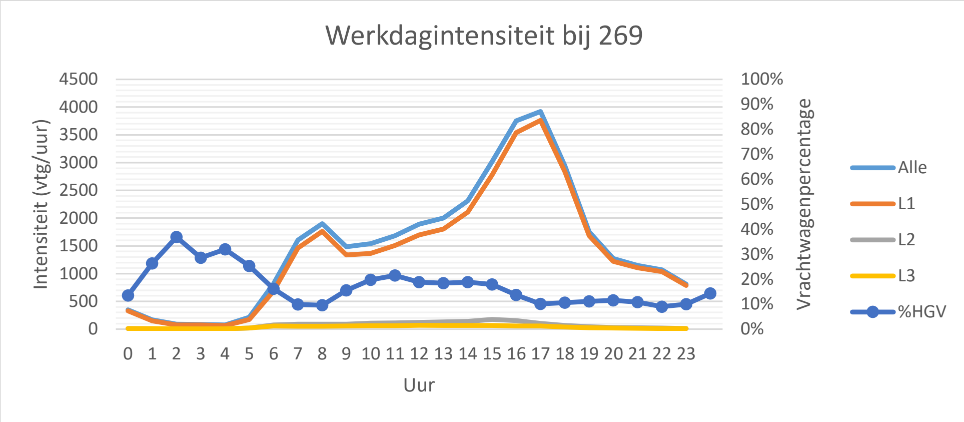
E Begin van het weefvak.

F Bebording op het weefvak.

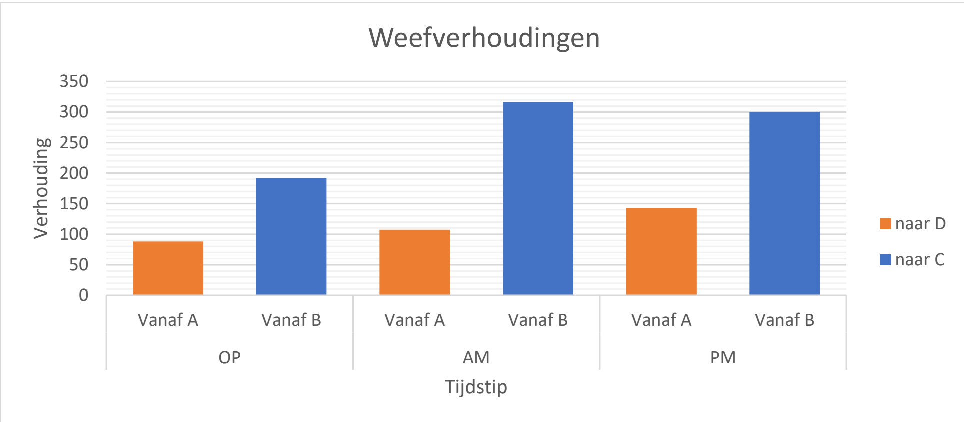
G Einde weefvak.

H Verbindingsweg vanaf A28 komt invoegen vanaf rechts op been C.

269 – Knooppunt Hattemerbroek



Gemiddelde werkdagintensiteit: L1 - 6410 L2 - 556 L3 - 534 ∑ - 7500

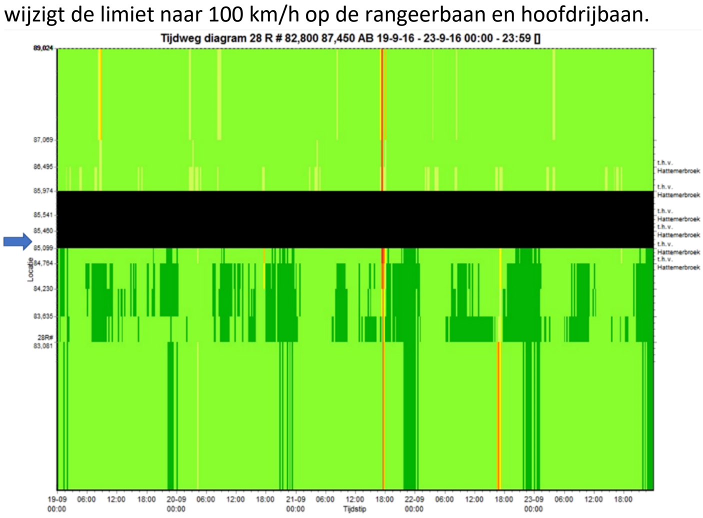


Percentages wevend verkeer: OP - 100% AM - 100% PM - 100%

Lengte: 171 meter, ROA eist 225 meter op basis van bewegwijzering en verkeersafwikkeling bij 90 km/h.

Snelheidslimiet: Voor het weefvak is de snelheidslimiet 130 km/h, voor het begin van het weefvak wijzigt de limiet naar 100 km/h op de rangeerbaan en hoofdrijbaan.

Congestie:



A Aankondiging rangeerbaan (het weefvak ligt op deze rangeerbaan).

B Puntstuk van de rangeerbaan.

C Afrit verbindingsweg voor weefvak.

D Snelheidslimiet verandert naar 100 km/h op hoofdrijbaan en rangeerbaan.

E Afslag Emmeloord-Kampen-N50 (been D) wordt aangekondigd op de rangeerbaan

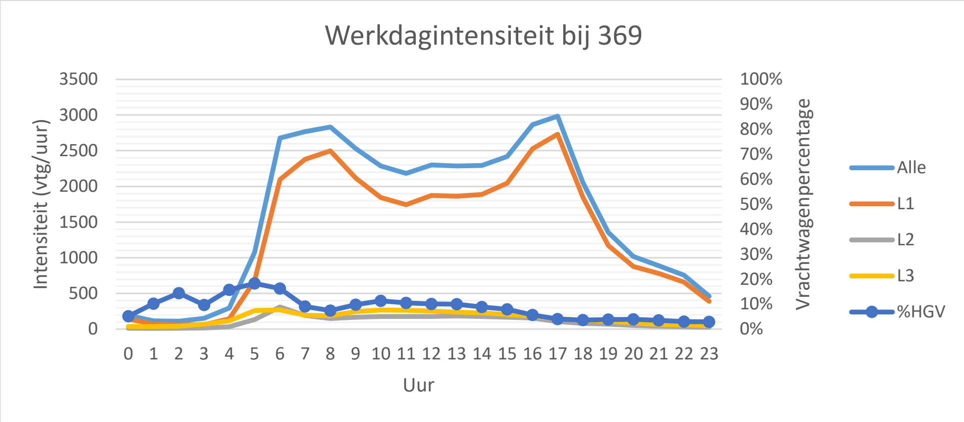
F Zicht vanaf been B. Verder naar links staan wat bomen (zie schaduw).

G Viaduct over het weefvak.

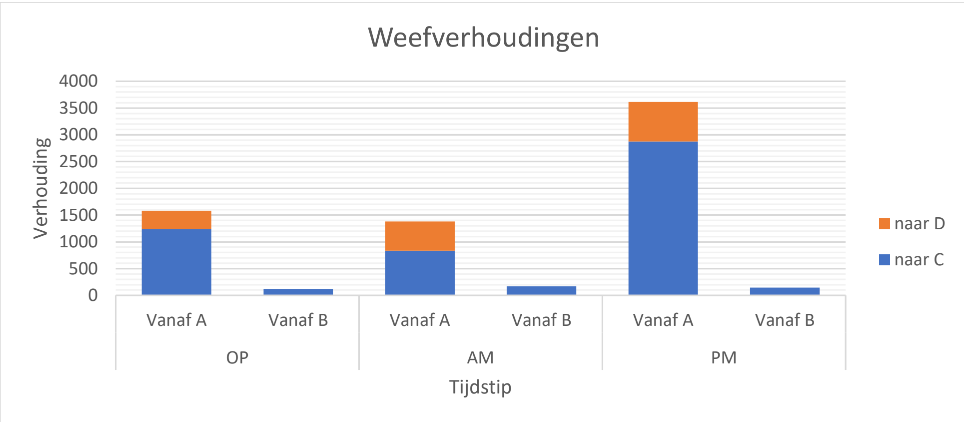
H Einde weefvak. Richting Emmeloord/Kampen/N50 gaat met een bocht naar rechts (been D), en doorgaand verkeer naar Zwolle/A28 (been C) voegt weer in op de hoofdrijbaan.

I Verderop voegt verkeer vanaf A50-zuid vanaf rechts samen met been C.

369 – Knooppunt Zaandam



Gemiddelde werkdagintensiteit: L1 - 33349 L2 - 1642 L3 - 909 ∑ - 35900

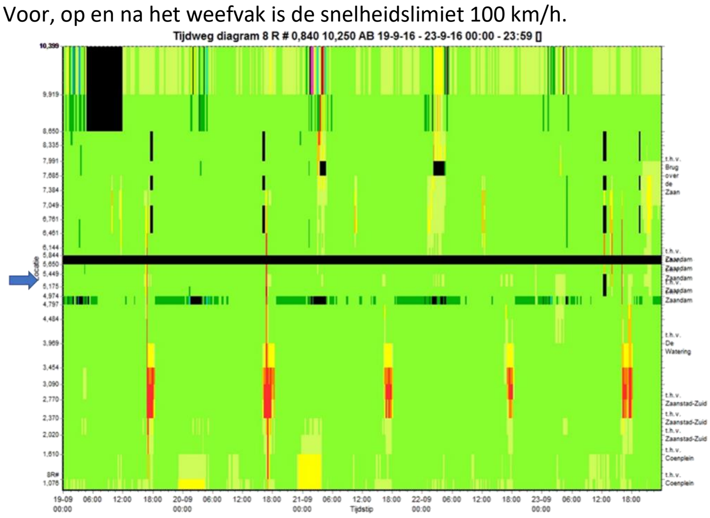


Percentages wevend verkeer: OP - 28% AM - 46% PM - 24%

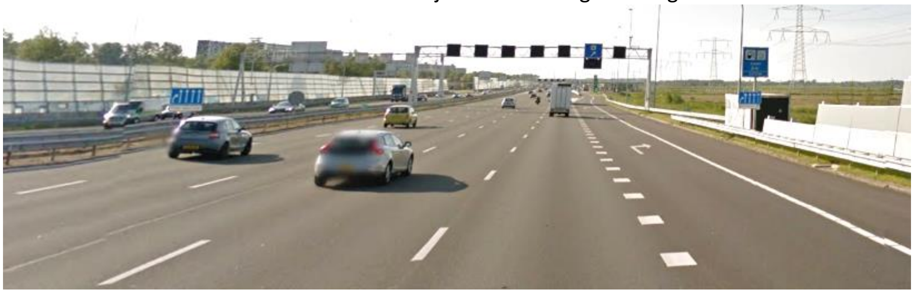
Lengte: 137 meter, ROA eist 500 meter op basis van verkeersafwikkeling bij 120 km/h.

Snelheidslimiet: Voor, op en na het weefvak is de snelheidslimiet 100 km/h.

Congestie:



A Uitvoegstrook naar tankstation/parkeerplaats en ritsen (L05) met links onderbord ‘ritsen vanaf hier’ en rechts ‘geef ritser de ruimte’.
300 meter eerder staat een bord aan beide zijden van de weg dat aangeeft ‘ritsen na 300 m’.



B Invoeging vanaf tankstation. Rechts wordt aangegeven dat knooppunt Zaandam over 900 meter is.

C Bebording afslag Leeuwarden/Den Helder/Purmerend/A7/E22 over 600 meter. Deze uitvoeging is nog voor het te beoordelen weefvak. In een eerdere situatie stonden hier links en rechts L06(AAEE, zie plaatje) borden bij.

D Nogmaals bebording boven de rijbanen. Achter het portaal staat een bord dat de snelheidslimiet van 100 km/h herhaald.

E Na de splitsing staat een bord dat afslag Zaanstad Centrum over 300m aankondigt. Dit afrit is been D vanaf het weefvak.

F Nadering weefvak vanaf been A. Lichte helling.

G Nadering weefvak vanaf been B. Ook hier is een helling.

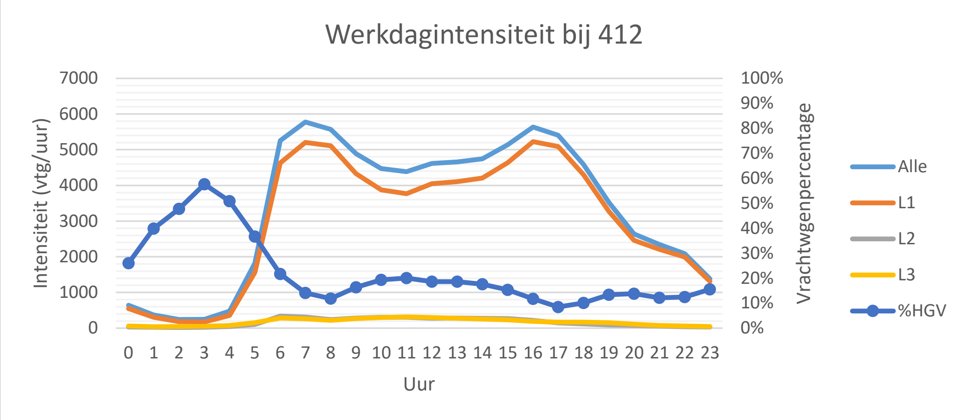
H Nog een nadering vanaf been B. Rechts staat het bord BB05: ‘‘korte invoegstrook’’.

I Op het weefvak.

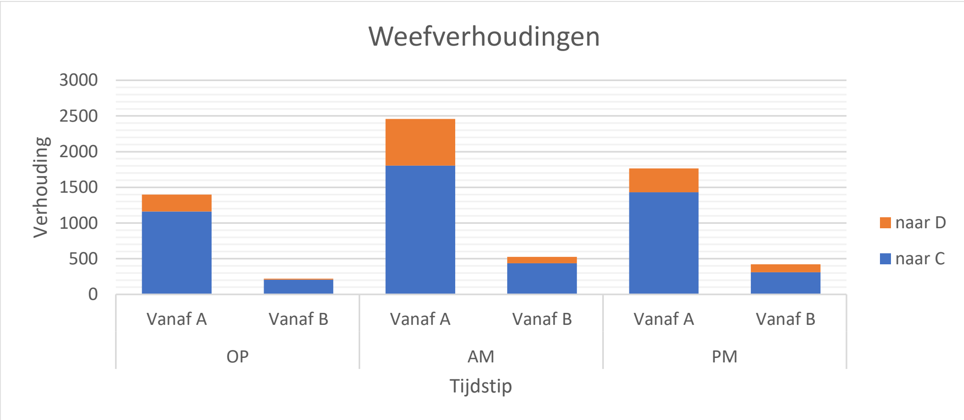
J Puntstuk. Routeborden staan achter het weefvak.

K Rechts de invoeging vanaf verbindingsweg vanaf A7 Noord.

412 – Voorthuizen – Barneveld



Gemiddelde werkdagintensiteit: L1 - 32497 L2 - 2664 L3 - 3739 ∑ - 38900

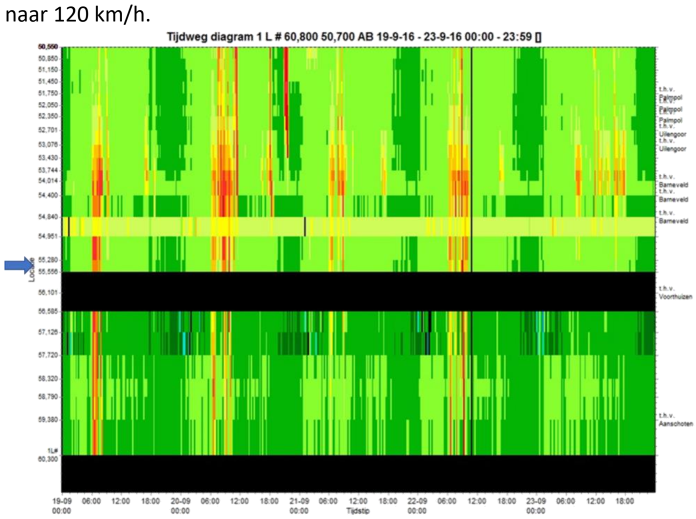


Percentages wevend verkeer: OP - 25% AM - 35% PM - 31%

Lengte: 1306 meter, ROA eist 500 meter op basis van verkeersafwikkeling bij 120 km/h.

Snelheidslimiet: Voor en op het weefvak is de limiet 130 km/h. Vanaf oprit Barneveld is dit gewijzigd naar 120 km/h.

Congestie:



A Aankondiging afrit 16 Voorthuizen over 600m.

B Afstand tot Barneveld, Amersfoort en Amsterdam.

C Herhaling bord afrit 16.

D Afrit naar Voorthuizen.

E Voor het begin van het weefvak: afrit 15 Barneveld/Ede/A30 over 300m. Ben B voegt in vanaf rechts.

F Zicht vanaf been B. Links staat een rijtje bomen.

G Begin weefvak vanaf been A.

H Laag bord afrit 15 op het weefvak.

I Snelheidslimiet 120 km/h. Per febrauri 2016 is de limiet hier 130 km/h, en staat het 120 km/h bord bij oprit Barneveld iets verderop.

J Afstand tot Amersfoort en Amsterdam.

K Herhaling afrit 15.

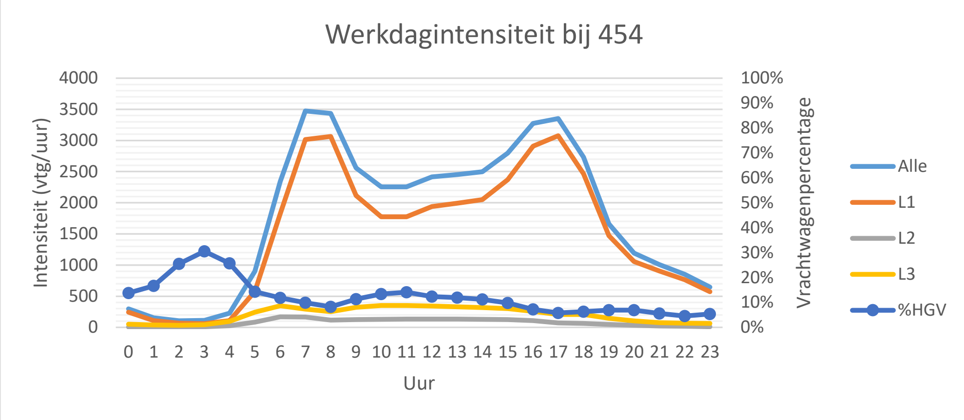
L Puntstuk.

M Been D.

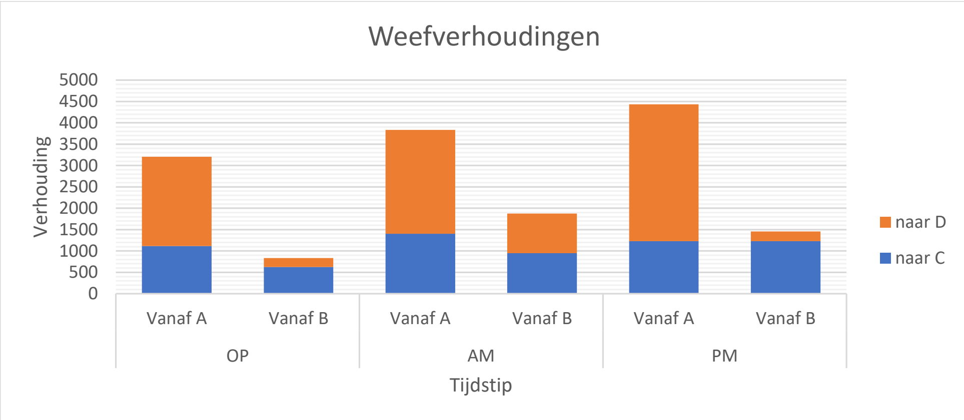
N Invoeging vanaf Barneveld/Ede/A30.

O Lange afstand tot bloklijn vanaf waar ingevoegd mag worden. Invoeging is een weefvak, waarvan been D naar een verzorgingsplaats gaat. Vanaf 2016 geldt vanaf hier de snelheidslimiet van 120 km/h, en mag op het voorgaande traject 130 km/h gereden worden.

454 – Rotterdam Schiebroek – Knooppunt Kleinpolderplein



Gemiddelde werkdagintensiteit: L1 - 72905 L2 - 3882 L3 - 4113 ∑ - 80900

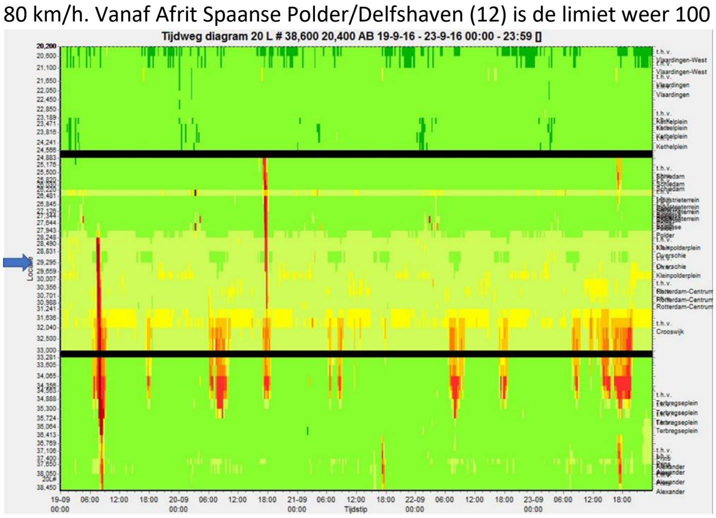


Percentages wevend verkeer: OP - 66% AM - 60% PM - 75%

Lengte: 468 meter, ROA eist 750 meter op basis van bewegwijzering bij 120 km/h.

Snelheidslimiet: Tot afrit Crooswijk (15) is de snelheidslimiet 100 km/h, vanaf dan wijzigt deze naar 80 km/h, dus ruim voor het weefvak, op het weefvak, en na het weefvak is de limiet 80 km/h. Vanaf Afrit Spaanse Polder/Delfshaven (12) is de limiet weer 100 km/h.

Congestie:



A Aankondiging afrit 14 Rotterdam Schiebroek (net voor het weefvak) over 1700m en knooppunt Kleinpolderplein over 2500m.

B Opnieuw bebording. Rechts het oprit vanaf Rotterdam Crooswijk. Bord waarschuwing trajectcontrole direct na het routebord is afgeplakt.

C Einde invoegstrook vanaf Rotterdam Crooswijk. Bord afslag 14.

D DRIP.

E Bebording afrit 14 Rotterdam Schiebroek/Hillegersberg/Centrum.
Geen vluchtstrook onder het viaduct.

F Uitvoeging afrit Rotterdam Schiebroek nog voor het weefvak.
Bebording geeft de richting van linker drie rijstroken die been A van het weefvak vormen aan.

G Afrit 13 Rotterdam Overschie over 1200m.

H Zicht vanaf been A van het weefvak. Nogmaals aankondiging afrit 13. Links komt been B vanaf een hoger punt invoegen. De bloklijn van het weefvak begint al voor de invoeging.

I Zicht vanaf been B.

J Zicht vanaf been B iets verderop.

K Bij het convergentiepuntstuk begint op de linkerrijstrook een doorgetrokken lijn.

L Bebording boven het weefvak. Op het wegdek staan pijlen naar rechts (onder de rode vrachtauto en zwarte auto daarnaast).

M Markering op het wegdek.

N Divergentiepuntstuk. Bebording geeft de verschillende richtingen aan. Doorgetrokken lijn van de linkerrijstrook eindigt.

O Been C (links) vervolgt naar knooppunt Kleinpolderplein. Op been D opent rechts een uitvoegstrook naar Rotterdam Overschie/Blijdorp, de andere rijstroken vervolgen naar Den Haag.

P Been C (links op de foto) gaat omlaag, been D richting Den Haag (midden) gaat omhoog, en uitvoeging Rotterdam Overschie (rechts) gaat omlaag.

H

Building the Simulations

In this appendix, it is described how the weaving sections are simulated in VISSIM. For all weaving sections a general method is used. This method will be described first in section H.1. However, as each weaving section is different, also specific characteristics and simulation strategies are described in section H.2. Thereafter, section H.3 describes how the simulations are calibrated based on the vehicle intensities and section H.4 describes how the required number of runs for analysis is determined.

H.1. General Simulation Strategy

In this section, it is described how in general the microscopic simulation models are created. Paragraph H.1.1 focuses on how the network is created. Time intervals are used to simulate traffic changing over the day. How time intervals are created is described in paragraph H.1.2. Thereafter vehicle compositions are created. For that paragraph H.1.3 describes the vehicle shares. Paragraph H.1.4 focuses on the initial desired speed of the vehicles, which is also part of the vehicle composition settings. Paragraph H.1.5 includes how the corresponding traffic intensities are loaded into the network. Paragraph H.1.6 describes how routes are assigned to vehicles such that the correct weaving shares are included in the model. Finally, paragraph H.1.7 describes how the simulations are performed.

H.1.1. Building the Network

All weaving sections are built with the DTB (Digitaal Topografisch Bestand) as background. The map was put onto the aerial view – which is standard available in VISSIM – by setting the scale and adapting the location.

Thereafter the road network was build. Roads are created using links. If a road section consists of multiple lanes this was applied by changing the number of lanes, which is a characteristic of a link. The standard lane width in VISSIM is 3.50 meters, which corresponds to the Dutch guidelines [50]. Changing the lane width only affects the visual representation of the link and the possibility whether a vehicle can overtake within a lane [65]. In some curves the roads are wider than 3.50 meters, hence here the width is changed for visual representation. However, the lane widths remain too small to overtake within a lane.
In the model the weaving section itself was created, even as a part of the road section upstream and downstream the weaving section and surrounding merging and diverging lanes, as these might influence the traffic behaviour at the weaving section itself. All links were connected by connectors.

The road type of most the links and connectors was set to *type 2: right side rule (motorised)*. A choice was made for this type and not for *type 3: freeway (free lane selection)* as in the Netherlands drivers are expected to drive on the right-most lane and not according to the keep-your-lane system which is used in some other countries. *Type 1: Urban (motorised)* was rejected a this applies the Wiedemann74 car following model, while the Wiedemann99 is recommended for interurban traffic [18] and hence is more suitable for modelling freeway weaving sections. The other two types for footpaths and cycle-tracks are clearly not applicable for freeway weaving sections.
A sixth road type was created, similar to type 2 but with cooperative lane change. On a road section with cooperative lane change vehicle A in figure H.1 switches lanes, if possible, to create the possibility for vehicle B to merge [20, 65]. This type is applied around zipper lane drops, ramp-merges and weaving sections, as here drivers are expected to be more cooperative with respect to lane changes than on other regular road sections.

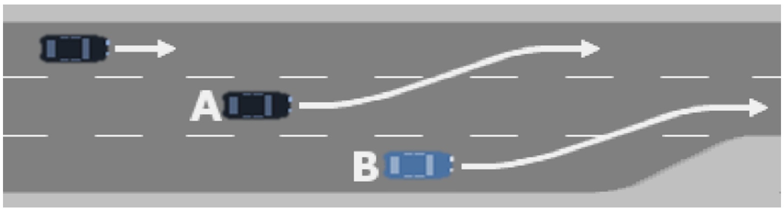


Figure H.1: Effect of cooperative lane changing (adapted from [65])

The lane change attribute of connectors downstream of the weaving section should be set at a length which is larger than the weaving section length according to the VISSIM 9 user manual [65]. This prevents that trough-going vehicles change to the acceleration lane and subsequently change back to the ongoing route. However, in some cases the signage was placed already before the convergence gore. As in reality in those situations the driver already at this earlier location knows which lane should be taken, the lane change attribute was set to the distance between the signage and the divergence gore. In formula:

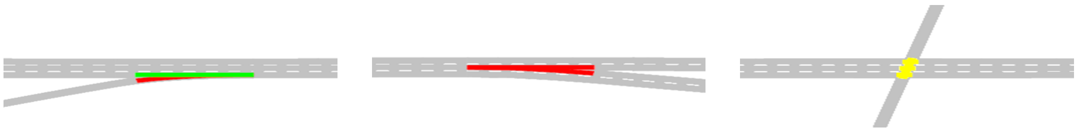
$$\text{lane change attribute} = \max\left(\text{weaving section length}; \text{signage distance}\right)$$

For other connectors the lane change attribute is based on the length of the upstream section.

VISSIM indicates automatically that a conflict area is present. This is amongst others the case when a lane merges onto the main traffic stream or when some lanes split into more lanes such as in case of a taper exit. Examples of such situations are seen in figure H.2. The status of the conflict area is indicated by colours. Green means that the traffic stream has right of way, while the red stream is the minor flow and should give priority to the other stream. For branching conflicts, both should be set to red (i.e. undetermined) according to the VISSIM manual [65] such that vehicles can 'see' each other. In some situations a connector roadway underpasses or overpasses the freeway. In these situations the status of the conflict area is set to yellow (i.e. passive), such that there is no right of way and vehicles are allowed to 'drive on top of each other'.

H.1.2. Time Intervals

Next, time intervals are created for vehicle inputs and vehicle routes, such these can be used to include variations in traffic over the day. An average working day will be simulated. Used traffic intensities are aggregated per hour, so 24 time intervals are required. However, one extra time



(a) Merging conflict (b) Splitting conflict (c) Conflict at overpass

Figure H.2: Examples of conflicts indicated by VISSIM

interval is added for the setup of the simulation, so that the network is filled with vehicles at the start of the simulated day. Each of the 25 time interval consists of 900 simulation seconds, thus in total 22500 seconds are simulated. Hence only a fourth of each hour is simulated. For the setup-interval similar settings as for the first simulated hour are used.

The vehicle routes are based on the OD matrices, which are available for the morning peak (AM), evening peak (PM) and rest of the day (OP). Table H.1 shows which OD patterns is applicable at which hour. A total of five time periods for vehicle routes are required. Such a time period might consist of multiple time intervals. The first time period lasts from 0 till 7200 seconds, the second from 7200 till 9000 seconds, the third from 9000 - 15300 seconds, etc.

Vehicle intensities and vehicle compositions are available per hour. Hence 25 time periods for vehicle inputs will are created, all having a time period of 900 seconds, which equals one time interval.

H.1.3. Vehicle Shares

Before the vehicle inputs can be set, first the vehicle compositions should be included. These vehicle compositions consist of the desired speed distribution of a vehicle type, and the share of the vehicle type relative to other vehicle types, i.e. the HGV share and passenger car share. Paragraph H.1.4 describes how the desired speed distributions are set. This paragraph focuses on the vehicle shares.
There are three main sources for vehicle shares:

- NDW historical data: vehicle intensities for different vehicle types are obtained from the NDW historical database for selected measurement locations. Subsequently the ratio between intensity of vehicles longer than 5.60 meters and overall vehicle intensity can be determined.
- The INWEVA database offers two options for determining the truck share. The first option is to use the truck share for an average working day, which is directly provided in the database. These shares are included in paragraph 4.3.2. The other option is to determine the ratio between the intensity of vehicles longer than 5.60 meters and overall vehicle intensity. These intensities can be obtained from the INWEVA database, which includes intensities per hour for an average working day. In both cases the required location is found by searching on the WVK-ID, which is known for each of the selected weaving sections from the ArcGis analysis;
- Selected link OD matrices: the ratio between HGV intensities and total intensities can be calculated, such as done in paragraph 4.3.2 for the daily average and in appendix D distinguished per time period.

As not every detector location in the NDW distinguishes between passenger cars and heavy good vehicles, this first option cannot be used for all weaving sections. As it its preferred to have a similar method for all ten locations, the first option is rejected. As the OD matrices are

Table H.1: Time periods

Count	Hour	Start	End	OD Matrix	Intensity	Composition
01	Setup	0	900	OP	I_{00}	C_{00}
02	00-01	900	1800	OP	I_{00}	C_{00}
03	01-02	1800	2700	OP	I_{01}	C_{01}
04	02-03	2700	3600	OP	I_{02}	C_{02}
05	03-04	3600	4500	OP	I_{03}	C_{03}
06	04-05	4500	5400	OP	I_{04}	C_{04}
07	05-06	5400	6300	OP	I_{05}	C_{05}
08	06-07	6300	7200	OP	I_{06}	C_{06}
09	07-08	7200	8100	AM	I_{07}	C_{07}
10	08-09	8100	9000	AM	I_{08}	C_{08}
11	09-10	9000	9900	OP	I_{09}	C_{09}
12	10-11	9900	10800	OP	I_{10}	C_{10}
13	11-12	10800	11700	OP	I_{11}	C_{11}
14	12-13	11700	12600	OP	I_{12}	C_{12}
15	13-14	12600	13500	OP	I_{13}	C_{13}
16	14-15	13500	14400	OP	I_{14}	C_{14}
17	15-16	14400	15300	OP	I_{15}	C_{15}
18	16-17	15300	16200	PM	I_{16}	C_{16}
19	17-18	16200	17100	PM	I_{17}	C_{17}
20	18-19	17100	18000	OP	I_{18}	C_{18}
21	19-20	18000	18900	OP	I_{19}	C_{19}
22	20-21	18900	19800	OP	I_{20}	C_{20}
23	21-22	19800	20700	OP	I_{21}	C_{21}
24	22-23	20700	21600	OP	I_{22}	C_{22}
25	23-00	21600	22500	OP	I_{23}	C_{23}

obtained via the selected link analysis on the NRM, which is partially model-based, this option is not preferred. Also, this option results in vehicle shares only for the three time intervals OP, AM and PM, and not for every hour. The second option is based on empirical data and offers the possibility to calculate vehicle shares per hour, hence this option is selected.

The INWEVA data for weekdays per hour for the year 2015 is used. This data distinguishes vehicle intensities per hour into three vehicle categories:

- *L1* passenger cars;
- *L2* light freight traffic;
- *L3* heavy freight traffic

Also, the overall traffic intensity is included, not taking into account passenger car equivalence.

The HGV share in hour i is calculated by dividing the hour-intensity of vehicle categories L2 and L3 by the total number of vehicles in the concerned hour:

$$\text{share}_{\text{HGV},i} = \frac{I_{L2,i} + I_{L3,i}}{I_{all,i}} \cdot 100\%$$

The HGV shares per hour can be found in table H.2. Trivially vehicles different than HGVs are passenger cars, thus

$$\text{share}_{\text{car},i} = 100\% - \text{share}_{\text{HGV},i}$$

The percentage shares of passenger cars and HGVs are included in the *RelFlow* column of the vehicle compositions.

Table H.2: Share of HGVs per weaving section per hour

Hour	ID								
	068	077	156	173	256	269	369	412	454
00	16%	13%	14%	10%	42%	14%	5%	26%	14%
01	28%	22%	28%	17%	50%	26%	10%	40%	17%
02	45%	31%	35%	26%	55%	37%	14%	48%	26%
03	46%	29%	42%	27%	51%	29%	10%	58%	31%
04	44%	45%	41%	23%	42%	32%	16%	51%	26%
05	32%	37%	30%	15%	26%	25%	18%	37%	14%
06	21%	23%	19%	12%	22%	16%	16%	22%	12%
07	13%	10%	12%	10%	20%	10%	9%	14%	10%
08	13%	7%	12%	9%	23%	10%	7%	12%	8%
09	17%	11%	18%	10%	28%	15%	10%	16%	11%
10	19%	13%	21%	11%	29%	20%	11%	19%	13%
11	20%	13%	22%	11%	31%	22%	11%	20%	14%
12	18%	12%	20%	11%	32%	19%	10%	19%	12%
13	19%	12%	20%	11%	31%	18%	10%	19%	12%
14	18%	11%	20%	10%	33%	19%	9%	18%	11%
15	17%	10%	18%	9%	31%	18%	8%	15%	10%
16	12%	7%	14%	7%	26%	14%	6%	12%	7%
17	9%	5%	9%	6%	23%	10%	4%	8%	6%
18	10%	5%	10%	6%	27%	11%	4%	10%	6%
19	11%	7%	13%	6%	28%	11%	4%	13%	7%
20	12%	7%	13%	6%	28%	12%	4%	14%	7%
21	11%	6%	10%	5%	26%	11%	4%	12%	6%
22	10%	5%	8%	4%	23%	9%	3%	12%	5%
23	12%	7%	7%	5%	29%	10%	3%	16%	5%

H.1.4. Desired Speed

Another part of the vehicle composition is the initial desired speed of the vehicles. VISSIM includes some initial desired speed distributions, mostly for tenfolds, such as for 10 km/h, 80 km/h and 100 km/h. Table H.3 shows the distribution called 100 km/h. Note that in this distribution many vehicles drive faster than 100 km/h, which is not corresponding well to a maximum speed limit of 100 km/h.

A possibility within VISSIM is to create new desired speed distributions. For creating such a distribution, the probability distribution of the desired speed distribution is required.

Several options are available that can be used as desired speed:

- The maximum speed limit on the road section;

Table H.3: Standard desired speed distribution, example 100 km/h

X	$F(X)$
88.00	0.00
95.00	0.03
100.00	0.10
110.00	0.70
120.00	0.91
130.00	1.00

- The free-flow speed that is given by the ROVM viewer. The ROVM (Regionaal Operationeel VerkeersManagement, which is Dutch for regional operational traffic management) viewer displays amongst others real-time speeds and intensities measured by loop detectors. It also includes the free flow speed, which is the speed at calm traffic conditions. It is measured over a longer term and extreme low speeds due to traffic jams or accidents are filtered out;
- Empirical speed data from the NDW database: these speeds are measured using loop detectors. Some of them also the length of the vehicle, such that a distinction can be made between passenger cars and heavy good vehicles.

As desired speed distributions are not corresponding directly to the maximum speed limit, and the second and third option are based on empirical data, they are preferred above the first option. The third option makes a distinction into vehicle type, and the calculation is more clear than the black box of determining the free flow speeds of the second option. Hence a choice is made for this third option. As resulting desired speeds are not likely to correspond with the standard desired speed distributions in VISSIM new distributions will be created. Extra benefit of the third option is that the raw speed data can be used to calculate percentiles and apply that as probability distribution into VISSIM. For the second option only one value is available, which is not a tenfold and hence not a standard distribution in VISSIM, so it is not possible to come up with a corresponding probability distribution.

The probabilities needed for the speed distributions are calculated using box plots. Due to the characteristics of a box plot this is a straightforward method to calculate the share that belongs to a value. 50% of the values are within the coloured box in figure H.3. 25% of the values is less than the lower quartile, 50% is less than the median and 75% of the values are less than the upper quartile value. Values that are less than the lower limit or more than the upper limit are seen as outliers, and are removed.
Speed data for creating the box plots are obtained from the NDW historical database. Daily average speeds, measured in the month September 2015 on workdays are used. In some cases the loop detector did not work properly, resulting in a speed value of -1 km/h. These incorrect values are removed from the data. The exclusive quartile values are calculated, which exclude the mean from the calculations. Exclusive values are supposed to give a better estimate of the population and a more accurate view of what values should be considered as outliers than inclusive quartiles [10, 53].

For the speeds obtained from the NDW for a loop on weaving section 068 the box plots as shown in figure H.4 are created. As seen, in this data set there are no outliers. From this box plot a desired speed distribution as in table H.4 can be created, which results in a desired speed distribution graph in VISSIM as shown in figure H.5.

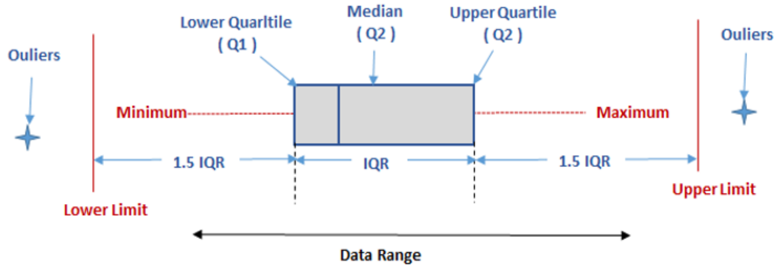


Figure H.3: Principle of a box plot [57]

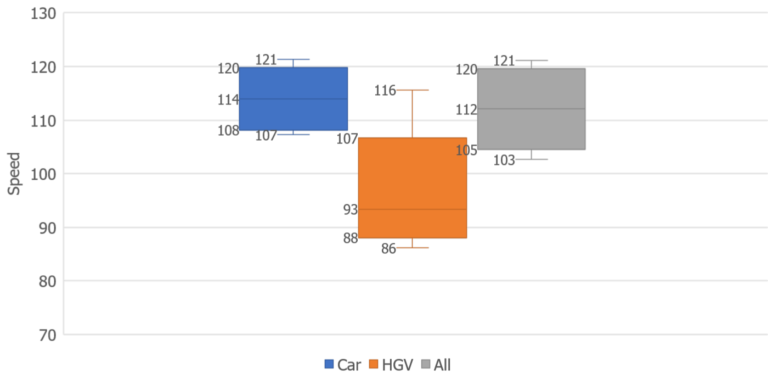


Figure H.4: Box plot of speeds at weaving section 068

Table H.4: Desired speed distribution for ID068

X_{Car}	X_{HGV}	X_{Any}	$F(X)$
107.3	86.2	102.7	0.00
108.2	88.1	104.5	0.25
114.0	93.4	112.1	0.50
119.7	106.7	119.5	0.75
121.4	115.6	121.2	1.00

The desired speed distributions for cars and HGVs are included in the VISSIM simulation model. However, not each loop detector distinguishes between vehicle lengths. Hence for some weaving sections only the distribution for 'any vehicle' is available. To be able to get a distribution for cars and HGVs at those weaving sections scaling factors are calculated. These scaling factor are calculated from average speeds measured by loop detectors at weaving sections that distinguish between vehicle type. The scaling factor for cars is found by dividing the average car speed by the average AnyVehicle speed for each weaving section, and taking the average of all obtained values. This idea is illustrated in table H.5. It is found that on average cars drive 1.037 times faster than the average of all vehicles. Similarly, a scaling factor for HGVs is found. Trucks drive slower than the average of all vehicles, the AnyVehicle speed should be multiplied by 0.838 to obtain the HGV speed. It should be noted that this method results in an estimation, and that hence the values might not be exactly representing reality.

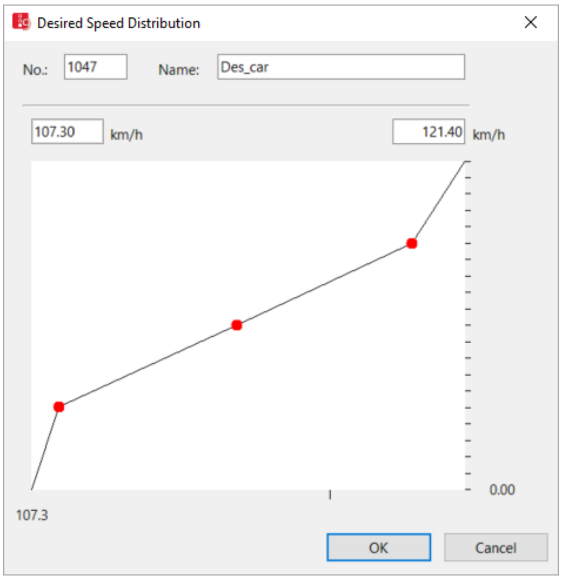


Figure H.5: Desired speed distribution graph for ID068

Table H.5: Calculation of scaling factor for AnyVehicle to cars

ID	$\text{Speed}_{\text{cars}}$	$\text{Speed}_{\text{any}}$	Factor
068	114.1	112.1	1.017
156	119.2	115.5	1.032
256	118.3	111.2	1.063
269	97.0	93.7	1.035
412	87.0	83.9	1.036
	Average		1.037

This method results in the desired speed distributions that can be found in tables H.6 till H.8. The tables also include whether empirical speeds or speed estimated using scaling factors are used, and whether outliers are removed.

These desired speed distributions are used in the VISSIM models as initial desired speed of the vehicles. However, at some locations vehicles are expected to change their desired speed. Examples of such locations are on connector carriageways, in cloverleaf loops and when passing signage setting a different maximum speed limit. Also, drivers mostly arrive at the convergence gore with a speed lower than the speed on the main roadway. In contract to vehicles in the field, simulated vehicles do not automatically adapt their speed to circumstances such as curves. Therefore this temporary decreased desired speed is implemented in the simulation models using reduced speed areas.
Not for all these locations speed data is available. Hence the desired speed on such reduced speed areas is estimated. For example in cloverleaf loops several reduced speed areas are applied, reducing the speed smoothly from 90 km/h at the divergence gore to 50 km/h in the middle of the loop with a step of 70 km/h in between, and increasing again in similar way till 90 km/h. For this the standard included distributions are used. In case of a lower initial desired

speed, the desired speeds in the curves are also set at lower values.

Table H.6: Desired speed distributions for weaving sections ID068 (left), ID077 (middle) and ID156 (right)

ID068	Empirical	
X_{Car}	X_{HGV}	$F(X)$
107.3	86.2	0.00
108.2	88.1	0.25
114.0	93.4	0.50
119.7	106.7	0.75
121.4	115.6	1.00
No outliers	No outliers	

ID077	Estimated	
X_{Car}	X_{HGV}	$F(X)$
35.5	28.8	0.00
66.1	53.6	0.25
80.8	65.6	0.50
90.7	73.6	0.75
120.4	97.8	1.00
No outliers	No outliers	

ID156	Empirical	
X_{Car}	X_{HGV}	$F(X)$
109.9	84.5	0.00
113.6	87.7	0.25
120.1	93.1	0.50
124.0	104.0	0.75
126.4	121.0	1.00
No outliers	No outliers	

Table H.7: Desired speed distributions for weaving sections ID173 (left), ID256 (middle) and ID269 (right)

ID173	Estimated	
X_{Car}	X_{HGV}	$F(X)$
60.4	48.8	0.00
75.7	61.2	0.25
81.6	66.0	0.50
88.7	71.7	0.75
106.4	86.0	1.00
Six outliers	Six outliers	

ID256	Empirical	
X_{Car}	X_{HGV}	$F(X)$
108.0	71.3	0.00
113.4	75.5	0.25
116.3	81.6	0.50
122.3	92.0	0.75
131.3	106.2	1.00
No outliers	No outliers	

ID269	Empirical	
X_{Car}	X_{HGV}	$F(X)$
77.1	57.2	0.00
96.7	78.2	0.25
98.5	79.4	0.50
98.8	87.5	0.75
99.9	89.6	1.00
Two outliers	One outlier	

Table H.8: Desired speed distributions for weaving sections ID369 (left), ID412 (middle) and ID454 (right)

ID369	Estimated	
X_{Car}	X_{HGV}	$F(X)$
81.5	65.9	0.00
91.3	73.9	0.25
96.8	78.2	0.50
105.0	84.9	0.75
114.4	92.5	1.00
No outliers	No outliers	

ID412	Empirical	
X_{Car}	X_{HGV}	$F(X)$
56.4	45.4	0.00
75.2	61.2	0.25
92.3	76.4	0.50
100.3	81.7	0.75
105.4	90.2	1.00
No outliers	No outliers	

ID454	Estimated	
X_{Car}	X_{HGV}	$F(X)$
51.6	41.7	0.00
73.8	59.6	0.25
76.6	62.0	0.50
79.3	64.1	0.75
87.1	70.4	1.00
Six outliers	Six outliers	

H.1.5. Vehicle Inputs

On the incoming links vehicle inputs are located. In most cases this is on leg A and leg B, however in some cases some more incoming and exiting links are simulated, which requires other settings for vehicle inputs. Possible sources for the applicable vehicle intensities are:

- NDW historical database;
- INWEVA database;
- Selected link OD matrices.

As the selected link OD matrices are only available per time period and not per hour, and are partially model-based and in a lesser extend based on empirical data this option is rejected. The INWEVA intensities are only known for the main weaving section, and not for each single incoming link. Hence a choice is made to obtain vehicle intensities from the NDW historical database.

For the month September 2015 vehicle intensities per hour are obtained from the NDW database. A choice is made for the year 2015 as for this year more data is available than for earlier years. The month September is selected as this is a representative month without holidays and vacation. Only the working days are selected. For each hour the average intensity is calculated, such that all I_i's in table H.1 are known for each selected measurement location.
For each input link a corresponding measurement location is selected. However, not for each incoming link data on vehicle intensities is available. In most cases it was possible to estimate the number of vehicles by adding and subtracting intensities at other locations, assuming the law of conservation of vehicles. This results in the vehicle intensities included in table H.9 till H.11. The links called 'input' include the vehicles reaching the weaving section via leg A and some more vehicles taking the off-ramp upstream of the weaving section. The links called 'ramp' include traffic entering the freeway right after the weaving section. These ramps might influence the behaviour at the weaving section and are hence included in the model.

Table H.9: Vehicle intensities at weaving section ID068 (left), ID077 (middle) and ID156 (right)

Hour	Input	LegB	Ramp
00	293	5	43
01	183	3	20
02	162	5	13
03	163	8	13
04	196	14	24
05	488	77	83
06	1 420	101	392
07	2 406	141	714
08	2 453	131	712
09	1 786	91	474
10	1 600	90	445
11	1 637	92	431
12	1 755	95	485
13	1 878	103	499
14	2 084	100	562
15	2 153	96	653
16	3 055	103	962
17	3 086	106	1 025
18	2 091	85	523
19	1 374	78	331
20	1 010	73	264
21	858	79	233
22	706	66	200
23	474	45	113

Hour	LegA	LegB	Ramp
00	295	27	54
01	154	12	31
02	96	9	23
03	87	7	18
04	144	9	27
05	576	35	61
06	2 324	137	257
07	3 880	432	668
08	3 838	558	846
09	3 032	371	522
10	2 632	274	375
11	2 553	287	271
12	2 837	334	297
13	2 896	339	342
14	3 129	283	376
15	3 645	354	409
16	3 820	513	459
17	3 269	703	466
18	3 365	560	385
19	2 363	273	367
20	1 672	169	266
21	1 342	162	234
22	1 103	152	244
23	715	81	146

Hour	LegA	LegB	Ramp
00	142	50	29
01	67	21	18
02	47	13	11
03	54	17	12
04	98	35	27
05	310	109	78
06	1 072	384	244
07	1 944	756	422
08	1 825	625	466
09	1 207	541	268
10	1 062	451	253
11	1 122	365	252
12	1 279	417	291
13	1 283	441	292
14	1 395	454	328
15	1 671	514	391
16	2 056	689	532
17	2 387	735	605
18	1 493	556	335
19	938	306	196
20	749	205	145
21	629	175	113
22	490	153	96
23	345	106	72

Table H.10: Vehicle intensities at weaving section ID173 (left), ID256 (middle) and ID269 (right)

Hour	LegA	LegB Par	LegB Ramp
00	365	282	32
01	219	148	19
02	169	96	13
03	183	108	9
04	291	221	25
05	1 298	879	72
06	3 758	2 758	180
07	3 593	2 698	316
08	3 687	2 299	417
09	3 425	2 141	323
10	2 902	1 945	306
11	2 760	2 091	322
12	2 914	2 292	373
13	3 042	2 344	368
14	3 169	2 457	398
15	3 618	2 802	439
16	4 228	2 897	598
17	3 635	2 345	659
18	3 319	2 212	549
19	2 332	1 681	324
20	1 697	1 253	243
21	1 360	1 121	167
22	1 195	1 046	154
23	820	745	95

Hour	Input	LegB*	Ramp
00	75	11	49
01	59	1	28
02	68	5	29
03	87	3	45
04	208	10	130
05	686	88	362
06	1 470	325	827
07	2 038	300	1 327
08	1 683	184	1 193
09	1 141	157	914
10	1 043	149	858
11	1 006	135	856
12	1 041	135	879
13	1 176	155	914
14	1 103	139	900
15	1 172	143	974
16	1 485	216	1 267
17	1 473	187	1 267
18	845	45	733
19	594	1	434
20	426	11	344
21	359	8	297
22	289	17	223
23	155	21	128

Hour	Input*	leg B	Main
00	19	21	247
01	4	9	133
02	4	12	103
03	6	13	103
04	5	17	134
05	35	68	361
06	97	271	1 026
07	105	632	2 036
08	47	753	2 414
09	59	420	1 644
10	40	316	1 518
11	63	311	1 489
12	75	361	1 733
13	71	389	1 901
14	78	432	1 998
15	108	482	2 166
16	162	628	2 805
17	223	619	2 820
18	87	377	2 293
19	55	299	1 561
20	44	132	1 004
21	28	106	832
22	39	94	673
23	23	54	464

* No loop detectors were available for these legs, and calculating intensities from other locations resulted in some negative values, indicating a deviation in the measurements of one of those detectors. Hence estimated values are used.

Table H.11: Vehicle intensities at weaving section ID369 (left), ID412 (middle) and ID454 (right)

Hour	Input	LegB	Ramp
00	525	34	2
01	302	16	1
02	188	10	1
03	182	7	1
04	202	7	11
05	455	38	63
06	1 524	117	133
07	2 550	261	165
08	2 740	298	170
09	2 284	216	155
10	2 391	229	156
11	2 517	272	163
12	2 860	294	182
13	3 036	282	190
14	3 540	344	188
15	5 086	394	213
16	6 047	473	272
17	6 087	468	324
18	4 672	320	209
19	2 665	284	136
20	1 957	255	52
21	1 779	225	0
22	1 491	206	0
23	1 164	130	0

Hour	LegA	LegB	Ramp
00	258	74	100
01	189	58	54
02	196	75	37
03	247	74	36
04	355	103	78
05	1 136	263	403
06	2 506	598	1 133
07	2 513	652	1 304
08	2 691	569	1 231
09	2 376	461	1 097
10	2 090	468	1 012
11	2 016	470	1 001
12	2 139	505	1 128
13	2 092	513	1 164
14	2 085	521	1 146
15	2 251	521	1 181
16	2 662	659	1 352
17	2 685	704	1 411
18	1 927	391	1 145
19	1 282	308	784
20	984	239	548
21	851	203	491
22	750	190	437
23	486	121	267

Hour	Input	LegB
00	684	182
01	391	88
02	274	50
03	266	47
04	515	78
05	1 876	167
06	5 389	637
07	5 789	980
08	5 558	932
09	5 236	819
10	4 844	669
11	4 662	812
12	4 947	867
13	5 069	872
14	5 146	931
15	5 425	994
16	5 939	1 062
17	5 519	1 076
18	5 317	785
19	4 168	705
20	2 998	582
21	2 483	521
22	2 221	499
23	1 421	354

H.1.6. Vehicle Routes

Next, vehicle routes are included. First, two static vehicle routes are added with the routing decision located on leg A and having destinations on leg C and leg D. One of these routes is for cars and the other is for HGVs. For each of the five time intervals for vehicle routes (OP, AM, OP, PM, OP) created in paragraph H.1.2 the relative flow is filled in based on the route shares in appendix D. Similarly, routing decisions are created for both cars and HGVs entering the network on leg B.

A partial vehicle route is added on the weaving section itself, serving local distribution of vehicles on the weaving section. After leaving the partial vehicle route vehicles continue with their original static vehicle route [65].

H.1.7. Simulation

Lastly, simulation settings are adapted. The number of simulated seconds is set to 22500 and the number of simulations to 10. To analyse the trajectories in SSAM it is asked to write vehicle trajectories to a .trj file. Also, vehicle travel times and data collection measurements are asked for, such that they can be used for comparison to real data and hence for calibration. To obtain that information, data collection points and vehicle travel time measurements are added to the model. Each 900 simulation seconds data is written.

H.2. Individual Weaving Sections

Not all weaving sections are equal. For each weaving section specific characteristics are included in the model which are listed in this section.

Weaving Section 068

This weaving section is located within a cloverleaf interchange. Hence within short distance upstream and downstream of the weaving sections connector roads are situated. As traffic behaviour on the weaving section might be influenced by these connector roads they are also included in the simulation model. Traffic on this upstream off-ramp leaving the road section is included in the vehicle input. Using a vehicle route the share of diverging traffic is implemented such that the correct number of vehicles reaches the weaving section. On the off-ramp a reduced speed area (90km/h) is situated to simulate that drivers decrease speed when leaving the freeway. After the off-ramp a new static routing decision is located for vehicles that continue towards the weaving section. Reduced speed areas are applied on both clover leaf loops, which set the desired speed of the cars to 90 km/h in the 50 meters closest to the gores, 70km/h for all vehicles in the 100 meters before/after that and 50 km/h on the rest of the loop. After the weaving section a connector road merges onto the roadway. Here traffic on the main road has right of way. At the onramp it is not allowed for vehicles on the left lane to change lanes to the right lane. On the connector road a reduced speed area of 90 km/h for cars is applied.

Weaving Section 077

The weaving section is located between an onramp and a trumpet interchange. Upstream of the weaving section another onramp is located, so the merging behaviour is also included in the simulation. Downstream the weaving section vehicles from the N230 merge onto the main roadway. This is also included in the simulation model. Between the weaving section and the merge from the N230 the left lane is dropped after a section with a lane change prohibit.

Weaving Section 156

This weaving section is located between an intersection and a junction. Leg B is a connector road, of which the desired speed limit is set to 90 km/h. The off-ramp is via a cloverleaf loop, where the speed limit is reduced stepwise to 90, 70 and 50 km/h. Downstream the weaving section an onramp is situated, which is also included in the model as this might influence behaviour at the weaving section. Here traffic on the main stream has priority.

Weaving Section 173

Leg A and leg C of this weaving section have dedicated lanes for heavy good vehicles, which are not accessible for passenger cars. This is implemented in the simulation by setting a blocked vehicle class on the concerned link. Traffic on leg B consists of traffic that was already on the parallel road and vehicles that are merging onto the parallel road shortly before the weaving section. Leg C splits into a road for passenger cars and a lane for heavy good vehicles. The static vehicle route destination on this leg is located upstream this splitting. As the HGV lane is not accessible for passenger cars the vehicles take the correct lane. However, the regular lanes are accessible for HGVs, and some HGVs take these lanes if they do not find a sufficient gap on the dedicated HGV lane. To encourage HGVs to use the dedicated lane instead of the other lanes HGVs are blocked on the regular lanes of leg C, such that the HGVs try to merge onto the HGV lane as soon as possible. This results in the simulation better matching the real situation. Leg D splits into a cloverleaf off-ramp and two lanes towards the A20-east via a taper. At the taper the priority is set as undetermined such that vehicles can 'see' each other.

Weaving Section 256

This weaving section is located within a cloverleaf intersection. Hence shortly before the weaving section an off-ramp is situated for the connector road, and after the weaving section an onramp for another connector road. These are included in the simulation model.
No other specific settings are applied at this weaving section.

Weaving Section 269

This weaving section is located on a parallel road through a cloverleaf interchange. Both the main roadway and parallel roadway are included in the model, such that their merging downstream the weaving section can also be included in the simulation. The parallel roadway first includes an off-ramp for the connector road towards the A50. The vehicles that take this off-ramp are also included in the vehicle input, so another static vehicle route is created to have a correct diffusion of traffic towards this connector road and towards the weaving section. This share is based on intensities from the NDW.
At the divergence gore the speed limit changes to 100 km/h on both the C/D lane and the main roadway. This is implemented by adding a new desired speed decision on each lane. Such desired speed decision changes the initial desired speed of the vehicle from that point on, and thus not only for a short period such as a reduced speed area does.

Weaving Section 369

Weaving section 369 is also located between two cloverleaf loops and has ramps upstream and downstream. Hence these are also included in the model. Similar to previous weaving sections with upstream off-ramps, an extra vehicle route is implemented to simulate the share of trough going vehicles.

Weaving Section 412

This weaving section is located between two partial cloverleaf junctions. Also, the other onramp and off-ramp are included in the model as they are close to the weaving section. Again, vehicles going to the first off-ramp are included as input in the model, so an extra route was created to make sure the correct number of vehicles takes the off-ramp and goes through respectively. To simulate that vehicles have to brake for the traffic lights and turn left or right at the end of this off-ramp a reduced speed area with a speed of 15 km/h is applied. For similar reasons extra vehicle inputs are applied on the second onramp.

Weaving Section 454

Also at this weaving section influence of the upstream off-ramp is included in the simulation by including the off-ramp in the model.
At the weaving section and a short distance before it is not allowed for vehicles on the leftmost lane to change lanes. However, when this was applied in the simulation many vehicles that had a destination on leg D did not change lanes in time, leading to congestion on the leftmost lane and errors in the simulation. Hence it was decided not to include this lane change prohibit in the simulation.
At the weaving section the maximum speed limit is 80 km/h. Hence the desired speed for ramps at the gores is set to 70 km/h instead of 90 km/h using reduced speed areas.

H.3. Calibration

For obtaining reliable results from SSAM it is required that the input for SSAM is also reliable. Hence it is important that the VISSIM models are well representing the real traffic state. According to the Oregon Protocol for VISSIM Simulation [40] at first an error correction should be done. This error correction consists of three stages:

1. *Verifying VISSIM Inputs:* At first the VISSIM simulation model should be checked. This includes checking the geometry and speeds, vehicle demands and vehicle types and behaviour. Multiple questions are listed, such as: is the number of lanes correct? are no connectors missing? are the desired speed distributions correct? are conflict area settings ok? are vehicle compositions correct? are the vehicle types and classes correct? Are the OD matrices correct? Etc.

2. *Animation Checking:* The animation should be checked in close detail for full seeding and simulation time. Potential causes of unrealistic animations are errors in expectations, errors in data coding and errors in route assignment. Common issues are irregular vehicle operations, average travel speeds that exceed speed limits, stopped vehicles in flowing traffic, frequent lane changes or lane changes at unrealistic locations, etc.

3. *Correction of Error Files:* At the end of the simulation an error file is given. Three error messages indicate potential issues in the model: (i) an entry link did not generate all vehicles (congestion spillback off the network), (ii) a vehicle left its route because it did not find the next link, or (iii) a vehicle was removed because it reached the maximum lane change waiting time.

These errors are checked, and if required changes are made to the model. However, at some extreme congested locations still some vehicles are removed because of a too long waiting time. This is prevented by making vehicles more cooperative, but this did not solve the problem completely. An option is to extend this diffusion time, but waiting for longer than one minute is not realistic so the removal of a few vehicles is accepted.

The next stage is the calibration. Many output values could be compared, varying from traffic volumes/densities and travel times to queue lengths and lane utilisation, etc. Also, attention should be paid to weaving behaviour according to the Oregon Protocol for VISSIM Simulation [40]. This should be done by comparing whether traffic volume data matches with OD data, in similar way as the volume/density should be calibrated.

Many of the input variables for VISSIM are based on empirical data and are hence expected to represent reality well. However, VISSIM contains many other settings such as driving behaviour characteristics. As it would be too time consuming to determine values for all driving behaviour parameters, most are left at their initial value, and hence only the volume/density calibration is performed as this is required for calibrating weaving behaviour.
This is done by comparing the number of vehicles passing a location in the modelled network to the intensities measured by loop detectors obtained from the NDW. For that data collection points are created in the models at similar location as they are visualised on the map in the NDW.

Three runs per model are executed with random number seed number 42, 43 and 44 respectively. Average values of the three runs are compared to intensities from the NDW. As in the models a time interval of 900 simulation seconds is used for one hour, only 25% of the number of vehicles stated as vehicle input is put onto the network. Hence vehicle intensities from the model should be multiplied by four to obtain the number of vehicles per hour.

Simply comparing the percentage difference is not a fair comparison. For example when taking a tolerance of 10% a main freeway link with 4000 vehicles per hour might deviate 400 vph, but a ramp with only 80 vph might only vary 8 vph to meet the criteria. Hence, vehicle intensities are compared using the GEH formula, which is the best universal measure to compare simulation inputs and outputs according to the Oregon Protocol for VISSIM Simulation [40, p. 49]. The formula is named after Geoffrey E. Havers, who invented the formula in the 1970s [19]. Although the formula has similarities to the Chi-squared formula, it is not a true statistical test. Despite the test is more empirical it is proven useful for many traffic analyses. The test is also used in the Traffic Modelling Guidelines of Transport for London [58].

For hourly flows the GEH value is calculated as

$$GEH = \sqrt{\frac{2\,(m-c)^2}{m+c}}$$

where m is the output traffic volume from the simulation model in vehicles per hour at a measurement location, and c is the observed traffic volume in vehicles per hour on the same location, which in this case is the vehicle intensity according to the NDW database. Table H.12 describes how the calculated GEH value should be interpret. The target is that 85% of the freeway links within the calibration area have a GEH value below five.

Table H.12: Interpretation of the GEH statistic [40]

GEH value	Interpretation
GEH $<$ 5.0	Acceptable fit
5.0 $\leq$ GEH $\leq$ 10.0	Caution: possible model error or bad data
GEH $>$ 10.0	Unacceptable

In principle, the GEH statistics should be calculated for all mainline links and ramps within the study area. However not for all these locations historical traffic intensities are available. Hence it is decided to test intensities on the weaving section if possible, and if not, to compare intensities on other available links. Furthermore, it is not clear from the documentation if intensities for only one hour should be compared, or a daily average or intensities for multiple time periods. To get an idea of the quality of the simulation over the entire simulated day it is decided to compare all 24 hours and postulate that 85% of these hours have a GEH value below 5.0 and 98% a GEH value below 10.0.

Weaving Section 068

For weaving section 068 vehicles are count on leg A, leg C and leg D. The intensities in the model on leg A are matching well to the data. On leg C no GEH value larger than 10.0 is measured, but in too many hours the GEH value was exceeding 5.0. On leg D in some hours the GEH value was exceeding 5.0, and in too many hours the value was exceeding 10.0. On both leg C and D the average number of vehicles per hour was higher in the VISSIM simulation than in the NDW data. These too high intensities might be due a too high number of vehicles coming from leg A or B, and in peak hours due to an incorrect route choice. However, these settings are based on empirical data and changing them might lead to larger differences here. When zooming in on the identical lanes of leg C it is seen that intensities per lane are matching empirical data well. And as there are multiple sources for the deviation per link and changing them might lead to deviations at other locations, no changes are made for now.

Weaving Section 077

On weaving section 077 the intensities on the weaving section are satisfying the criteria of being below 5.0 in 85% of the measurements. However, when zooming in onto the identical lanes within the weaving section it is seen that in the simulation more vehicles use the leftmost lane and less vehicles use the rightmost lane than in reality.

Weaving Section 156

On weaving section 156 the GEH statistic is above 10.0 in the morning peak hour on leg D: here intensities in VISSIM are clearly lower than measured by the NDW. At similar time intensities on leg C after the merge of the connector road are higher in VISSIM than according to the NDW, resulting in a GEH value above 5.0 for the second hour of the morning peak. Therefore, it is decided to change the route choice share for the morning peak hour as shown in table H.13. Here the share of vehicles towards leg D is multiplied by 150% and the share towards leg C with 90% as these percentages are the differences between modelled and measured intensities. These changes result in lower GEH values. Although some GEH values still are between 5.0 and 10.0, a sufficient share is below 5.0.

Table H.13: Adapted morning peak hour route shares for ID156

AM route	Cars		HGV	
	Old	New	Old	New
A >C	1641	1477	140	126
A >D	41	61	24	35
B >C	127	115	15	13
B >D	618	928	115	173

Weaving Section 173

At weaving section 173 it is seen that the intensities at the beginning of the day are corresponding well. However, from 15:00 hours on the intensities in the model are lower than in the NDW and later on intensities are higher, but all around similar number of vehicles. This suggests that the road capacity in the simulation is lower than the real capacity, such that vehicles are collected outside the network until capacity is available. Hence capacity of the model should be increased. However, adding lanes will result in a very different traffic situation which is not representative. Another option is to adapt some driver characteristics. Settings are left at their initial value and deviations are accepted for the initial simulation models. In the speed calibration phase of the sensitivity analysis, vehicle inputs are somewhat decreased.

Weaving Section 256

At weaving section 256 no intensities are available on the weaving section itself. However, intensities on the input link are corresponding well. For leg A itself and leg B no direct data is available (vehicle inputs are calculated from other links using the law of conservation of vehicles). On leg C intensities in the model are higher than in the NDW on the entire day. One hour before the morning peak, during the morning peak and one hour after the morning peak a GEH value of above 10.0 is found. During the rest of the day the GEH remains above 5.0. On leg D intensities in the model are slightly higher than according to the NDW. However, as the GEH value is below 5.0 they are within the acceptable range, except for the evening peak hour in which the GEH value is above 10.0. Here intensities in the model are clearly higher than in the NDW. Hence it is seen that all intensities downstream the weaving section are higher in the model, indicating that it is caused by the input intensities and not by the route shares. However, only a few vehicles enter the network via leg B, so changing that will have no or only a slight effect. Changing the network input towards leg A and the ramp upstream the weaving section will in turn create larger differences here, which is also not desired. Hence the share towards the connector road upstream the weaving section is increased with 50%, such that less vehicles from the input link reach leg A and hence less vehicles reach leg C or D.

Weaving Section 269

This weaving section is located on a C/D lane. On leg A in most hours the GEH is below 5.0, except for some hours in which the intensities in VISSIM are lower than in the NDW. Hence the number of vehicles towards the weaving section is increased by changing the route share between the weaving section and the off-ramp upstream such that twice as much vehicles go towards the weaving section than head towards the off-ramp, as initially estimated. Also, the number of vehicles entering the network via the input link towards leg A is doubled. These changes resulted in GEH values within the acceptable range. The main roadway at weaving section 269, which is also included in the model has for each hour a GEH value below 5.0.

Weaving Section 369

At weaving section 369 no intensities are measured on the weaving section itself. Hence intensities on the incoming and outgoing legs A, C and D are investigated. On leg C too few vehicles are modelled during the morning peak as the GEH value is between 5.0 and 10.0. As this is for only two hours at one location, this is within the 85% range. Hence no changes are required for this weaving section according to the GEH values.

Weaving Section 412

At weaving section 412 many detectors do not have data in the NDW database. Intensities on leg B are corresponding well. On leg C less vehicles are measured in VISSIM than by the NDW. For other locations no complete data is available, making it difficult to determine what interventions could be taken to improve the model.

Weaving Section 454

At weaving section 454 the intensities are corresponding well at the beginning and end of the weaving section and on leg C and D, except for during the peak hours. At the beginning and end of the weaving section too few vehicles are simulated between 6:00 and 7:59, and too many during the evening peak hour. On leg C in both the morning and evening peak the GEH value exceeds 10.0 due to too few vehicles in the model compared to the NDW. On leg D the situation is the other way around, here too many vehicles are count in the model. However, during the morning peak here the GEH value is below 10.0, but also in the two hours after the evening peak hour too many vehicles are observed in the model. To improve the correspondence during the peak hours the shares towards leg C and leg D for the AM and PM peak could be adapted. Based on the shares between simulated intensities and NDW intensities the number of vehicles towards leg C is increased with 30% and towards leg D is decreased with 15% during both the AM and PM peak period. This results in the OD matrices as show in table H.14.

Table H.14: Adapted morning and evening peak hour route shares for ID454

AM route	Cars		HGV		PM route	Cars		HGV	
	Old	New	Old	New		Old	New	Old	New
A > C	1401	1821	251	326	A > C	1232	1602	167	217
A > D	2434	2069	441	375	A > D	3202	2722	477	405
B > C	946	1230	46	60	B > C	1229	1598	22	29
B > D	928	789	38	3	B > D	229	195	15	13

Weaving Section 499

For weaving section 499 it was found after analysing driving behaviour that leg D was very congested, which was not in line with the expectations. Although conflicting to the real situation the lane drop on this link was removed to facilitate a better flow. This reduced the congestion problems, but resulted in almost all GEH values being above 5.0. After re-consulting the OD-matrices it was found that these were developed for the downstream weaving section and hence the route shares are not representative for the concerned weaving section. Hence no further calibration and analysis will be done for this weaving section and the weaving section will be removed from the selected weaving sections.

Overall it can be concluded that the intensities in simulations are corresponding reasonable well to the observed intensities after making the described changes. On some (busy and congested) weaving sections deviations in intensities are larger, however changing traffic intensities will not always solve these differences as then at other locations the differences increase. Also at some weaving sections differences are larger during some time periods. If this occurred during the peak hours and it was clear that the route choice settings were causing these differences, these were changed in the model to obtain a better fit. In some other situations in which an off-ramp was situated prior to the weaving section the share between vehicles taking this off-ramp and continuing towards leg A was changed.

In guidelines recommending the applications of the GEH only one GEH value per link is calculated. In case multiple time periods are modelled an average flow per hour is calculated and compared. At most of the investigated locations this leads to a GEH value being below 5.0. However, this way differences are averaged out and no clear view of the simulation model quality over the day is obtained. This comparison method is useful when only simulating the critical peak hours, but not when modelling an entire day. Hence no conclusions are drawn from this average GEH, and hourly GEH values are used for calibration, as described.

Another measure that can be used for calibration according the Oregon Protocol for VISSIM Simulation [40] are speeds. This calibration on speeds was not included in the initial analysis, however the sensitivity of performing more extensive calibration using speeds is described in paragraph 5.6.7.

H.4. Number of Simulation Runs

After the model is calibrated, the data set for the SSAM analysis can be created. According to the Oregon Protocol for VISSIM Simulation [40] the reported results shall be an average of a minimum of ten simulation runs with different random number seeds. However, to ensure that the reported value is indeed a statistical representation of the average the number of simulation runs should also satisfy the following formula:

$$\tilde{N} = \left(2 \cdot t_{\alpha/2,N-1} \cdot \frac{s}{R}\right)^2 \tag{H.1}$$

In this formula $\tilde{N}$ is the required number of simulation runs, $t_{\alpha/2,N-1}$ is the Student's t-statistic for a two-sided error with $N-1$ degrees of freedom and significance level α, s the standard deviation of about the mean for the selected measure and R the 95%-confidence interval for the true mean. [40]. It is recommended that $\tilde{N}$ is rounded up to the next integer. Hence the minimum number of required simulations N is:

$$N = \max\left(10, \lceil\tilde{N}\rceil\right) \tag{H.2}$$

The Oregon Protocol for VISSIM Simulation [40] sets a confidence interval of 95%, hence similar interval is used. Multiple measurements are available to use for determining the required number of runs. Suggestions are the average vehicle delay at an intersection, the average travel time through a corridor or the average vehicle speed. A choice is made to determine the required number of runs from the average travel time between the convergence and divergence gores. This option is preferred as it is based on the major area of the simulation model, and includes a larger area and not a single point such as would be the case when using a measure such as average speed.

For the calculation 10 initial runs are performed with random number seeds 50 – 59. These resulted in the average travel times on the weaving sections as shown in table H.15. From these averages the minimum number of runs is calculated according to equation H.1. For that α is set at 5%, such that $t_{\alpha/2,N-1} = 2.262$. After application of equation H.2 it is found that for most weaving sections 10 runs are sufficient, and that for weaving section 369 at least 12 runs should be performed to obtain a statistical significant result.

Table H.15: Calculation of minimum number of simulation runs

ID	Average Travel Time										$\lceil\tilde{N}\rceil$	N
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10		
068	6.38	6.43	6.36	6.43	6.43	6.42	6.39	6.38	6.43	6.44	1	10
077	34.98	35.22	35.20	35.33	35.31	35.41	34.97	35.14	34.99	35.54	1	10
156	19.59	19.62	19.56	19.68	19.69	19.70	19.60	19.55	19.42	19.41	1	10
173	157.08	149.82	144.69	156.45	153.22	156.57	157.16	156.19	151.91	161.46	8	10
256	5.59	5.56	5.64	5.68	5.66	5.64	5.61	5.62	5.59	5.56	1	10
269	7.10	7.13	7.11	7.05	7.08	7.07	7.08	7.11	7.17	7.11	1	10
369	6.60	6.61	6.06	6.38	6.35	5.95	6.24	6.08	6.04	6.36	12	12
412	67.29	67.13	67.03	67.43	67.04	66.90	67.34	67.54	67.42	67.58	1	10
454	29.61	29.43	28.93	29.76	29.63	29.33	29.89	29.59	29.31	31.18	4	10

I

SSAM Conflict Identification Algorithm and User Interface

In the final SSAM validation report by Gettman et al. [22, p. 14 – 20] it is described how SSAM identifies the conflicts that occurred in the simulations using an algorithm. For this the vehicle trajectory files (.trj files) obtained from the simulations are processed by SSAM. Hence first these files should be imported into SSAM, such that SSAM can process the vehicle trajectory files into usable data, as illustrated in figure I.1. To do so, the .trj files can be imported from the computer by clicking the 'Add' button in the *configuration tab*, as shown in figure I.2 and selecting the required files. Subsequently the desired analysis threshold values for the conflicts and conflict angles (see table 4.8) can be set. Thereafter the analysis is started by clicking the 'Apply' and 'Analyze' buttons.
The size of a trajectory file grows with the number of vehicles in the network and the simulation time, and may result in large data files. Hence the analysis might require some hours of processing time. The analysis procedure is summarised in four steps.

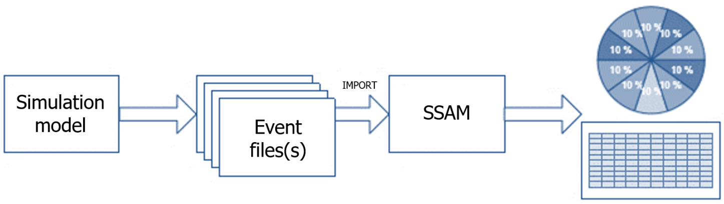


Figure I.1: The operational concept of uploading .trj files to SSAM (adapted from [22])

Step 1

At first the size of the analysis area is determined from the .trj file. From this SSAM determines whether English of metric units are used. The simulation region is divided into zones as indicated in figure I.3 such that the required number of vehicle-to-vehicle is reduced considerably. These square zones cover 15.25 by 15.25 meters (or 50 by 50 ft.).

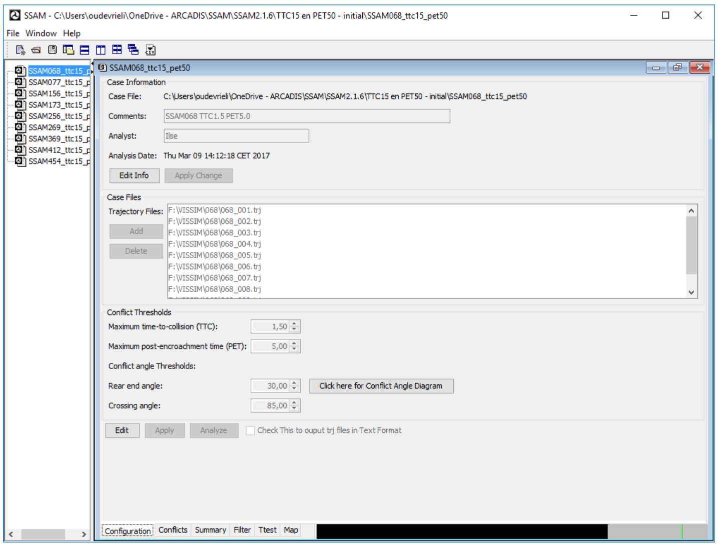


Figure I.2: In the SSAM configuration tab the desired .trj files and threshold values are selected

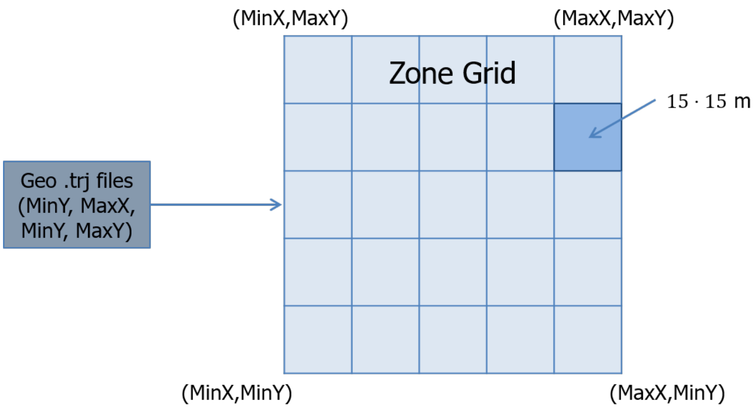


Figure I.3: Simulation area divided into zones (adapted from [22])

Step 2

In the second step a single time step of a trajectory file is analysed. For each vehicle in the network, SSAM calculates the projection location. This location is the expected location of the vehicle as function of the vehicles current speed, if it continues to travel along its (future) path for up to the maximum TTC threshold value $maxTTC$, and is based on the next ten seconds of trajectory data. This $maxTTC$ threshold value is configured by the user before starting the analysis, and is set to $1,50$ seconds in figure I.2.

Figure I.4 shows that the path is a set of straight line segments $(S_1, S_2, S_3, \dots)$ connecting the future vehicle locations $(X(t), X(t+1), X(t+2), \dots)$. These projected vehicle positions are calculated, assuming that SSAM is going to analyse the conflicts for vehicle A at time t_1. First all data related to vehicle A is obtained from the trajectory file, such as the location, speed, acceleration, etc. at time t_1 and several time steps later. The location of the vehicle is denoted using coordinates $(x_1, y_1), (x_2, y_2), \dots$. Then the distance of vehicle A along the trajectory is defined by

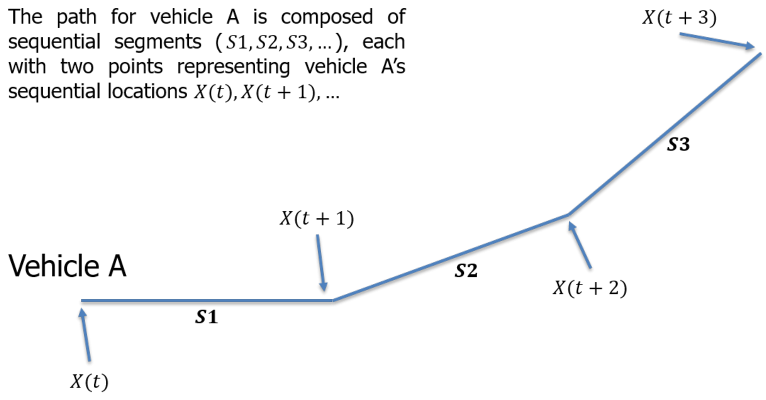


Figure I.4: Projected vehicle path (adapted from [22])

those locations:

1. Each vehicle is represented as a rectangle with four corner points (shown in figure I.5)
2. The distance that the vehicle will travel in the next $maxTTC$ seconds will be calculated using (see figure I.5)
$$DIS_1 = V_1 \cdot maxTTC$$
3. The location of the vehicle in the next time step (x_2, y_2) is calculated from the distance at current location to that location, denoted as (see figure I.5)
$$DIS_2 = \left|X(t+1) - X(t)\right|$$

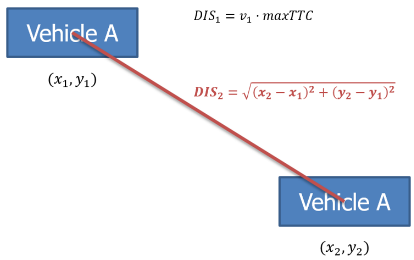


Figure I.5: DIS_1 and DIS_2 (adapted from [22])

4. If DIS_2 is less than DIS_1, then DIS_2 is subtracted from DIS_1. The previous two calculations are repeated, and DIS_1 and DIS_2 are updated:
$$DIS_1 = DIS_1 - DIS_2$$
$$DIS_2 = \left|X(t+2) - X(t+1)\right|$$
and the new $DIS_1$1 and DIS_2 are compared again (see figure I.6)
5. If DIS_2 is more than DIS_1, then the location is calculated to locate the projection point within the segment of DIS_2 (see figure I.7)

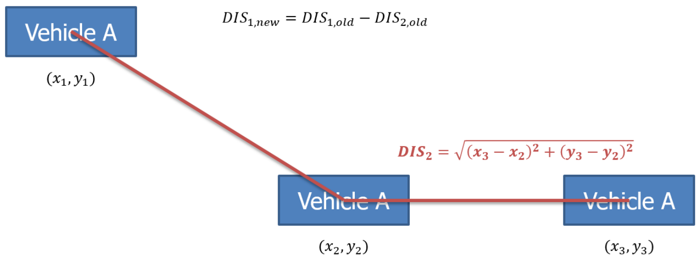


Figure I.6: Updated DIS_1 and DIS_2, when old $DIS_1 > DIS_2$ (adapted from [22])

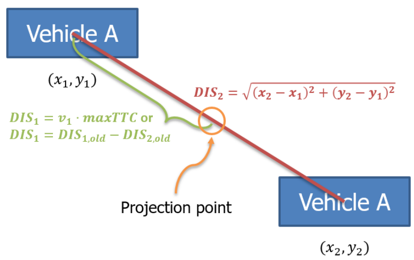


Figure I.7: Projection point when old $DIS_1 < DIS_2$ (adapted from [22])

Step 3

In the next step for each vehicle the rectangular that represents the location and orientation at its projected future position is calculated. The rectangle is put on the zone grid, and it is calculated which grid zones contain at least some part of the rectangular vehicle. If the vehicle is projected within a zone, the vehicle is added to the occupants list of that zone. Any time a vehicle is added to a zone occupancy list that already contains one or more vehicles, a check for overlap of the new vehicle with each of the vehicles in that zone is performed. It may occur that two vehicles are assigned to the same zone without overlapping. If two vehicles are overlapping, this indicates that a future collision is projected for this vehicle pair, hence a potential conflict is identified (see figure I.8).

SSAM lists all conflicting vehicle pairs (and conflict events) for the current time-step. In each time step, the list is already filled with conflicting vehicle-pairs from the previous time-step. If the vehicle that has been added to the zone grid overlaps with another vehicle, that vehicle-pair is added to the list for the current time step (if it was not already in the list).

Step 4

In the last step, more a more detailed processing of each conflicting vehicle-pair in the list for the current time-step is performed:

1. Update the TTC of the vehicle-pair. The TTC is found by iteratively shortening the future projection time line by a tenth of a second, and re-projecting both vehicles similarly as done before over successively short distances until the projection locations of the vehicles are not overlapping anymore. This way a more accurate TTC value is retrieved for this

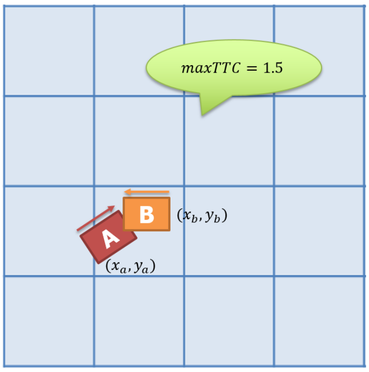


Figure I.8: Conflict between two vehicles at $maxTTC$ (adapted from [22])

time-step. Figure I.9 shows that the TTC value is reduced from the $maxTTC$ value of 1.5 seconds to a TTC of 1.3 seconds. The vehicles are not having a large overlap, but have just barely come into contact. If the projection time-line is reduced to 0 seconds and the vehicles are still overlapping, this is a crash.

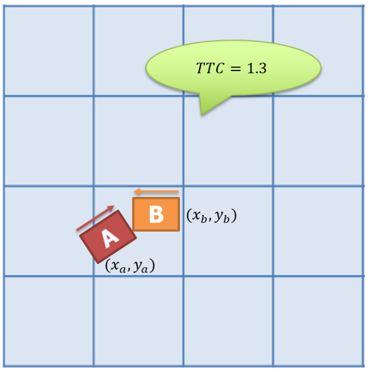


Figure I.9: Conflict between two vehicles at $TTC = 1.3$, vehicles no longer in conflict (adapted from [22])

2. Various surrogate safety measures, such as the minTTC (i.e. minimum of the current TTC value and that of the prior time-step, if applicable, for a vehicle pair) are calculated and updated. Also the current positions of both vehicles are recorded for post-encroachment analysis.

3. If the vehicle-pair does not overlap over the projection time between 0 and $maxTTC$, then vehicle pair is in the list because it was in the list in the previous time step. The event remains in the list, such that it can be investigated if the following vehicle eventually occupies (or encroaches on) a position which was occupied before by the other leading vehicle. The time difference between the leading vehicle occupied the location and the trailing vehicle arrived is the post-encroachment time (PET). If such a PET was observed, the minimum PET is updated for the vehicle pair. The event remains in the list as a new minimum PET can be found as vehicles continue their trajectory.

4. If the vehicle-pair in the conflict event list is no longer on collision course, and the PET to any prior position clearly could not further reduce the minimum PET, or the maximum PET

set by the user has elapsed, then the vehicle-pair could be removed from the conflict event list. However, before removing first all final surrogate measures are computed. These include amongst others the conflict start and end points, the conflict angles and DeltaV. Also, the classification into crossing conflict, rear-end conflict or lane-change conflict is made. If the conflict event is ended, the conflict and corresponding surrogate measures are added to the conflict table and the event is removed from the tracking list.

Analysing conflicts

After SSAM has calculated all conflicts according to the described algorithm, these conflicts can be analysed. In the *Filter tab* as shown in I.10 a filter can be applied on the surrogate thresholds, on the conflict type, the link number, the trajectory file and the area if desired (see table 4.9). It should be noted that these TTC and PET filter values differ from the threshold values set in the configuration screen (figure I.2) as the filter thresholds are for filtering on the calculated conflicts shown in the conflicts tab, and the threshold values in the configuration screen are for projecting the vehicle location and calculating the conflicts.

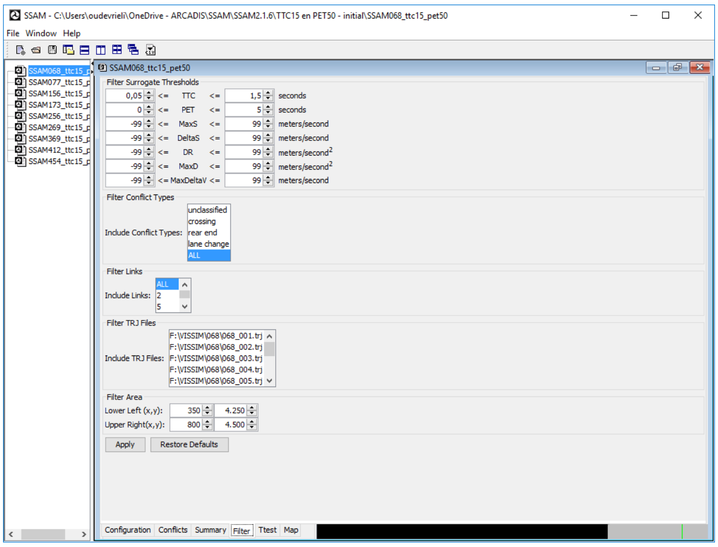


Figure I.10: In the SSAM filter tab a filter on the conflicts can be applied

SSAM provides information on the individual conflicts in the *Conflicts tab*, such as the time at which the TTC was minimum, the values of the surrogate safety measures, the angle between the conflicting vehicles, the vehicle IDs, the length of the vehicles, on which link the vehicles were located, the coordinates at this the minimum PET was observed, et cetera. Figure I.11 shows a part of the screen showing the conflict information.

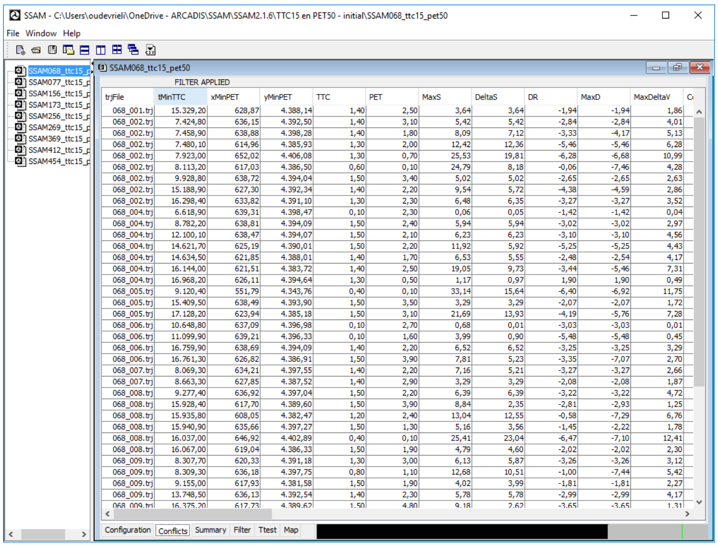


Figure I.11: In the SSAM conflicts tab characteristics of all conflicts are given

The *Summary tab* as shown in figure I.12 gives an overview of the calculated conflicts, and can be seen as a summary of the conflicts tab. Both information on conflicts before and after filtering is given, even as a distinction into the different .trj files. The tab includes in the upper half information on the surrogate values corresponding to the conflicts, such as the minimum, maximum, mean and variance in TTC, PET, MaxS, etc. In the lower half information on the total number of conflicts is given, even as the frequency of the different conflict types.

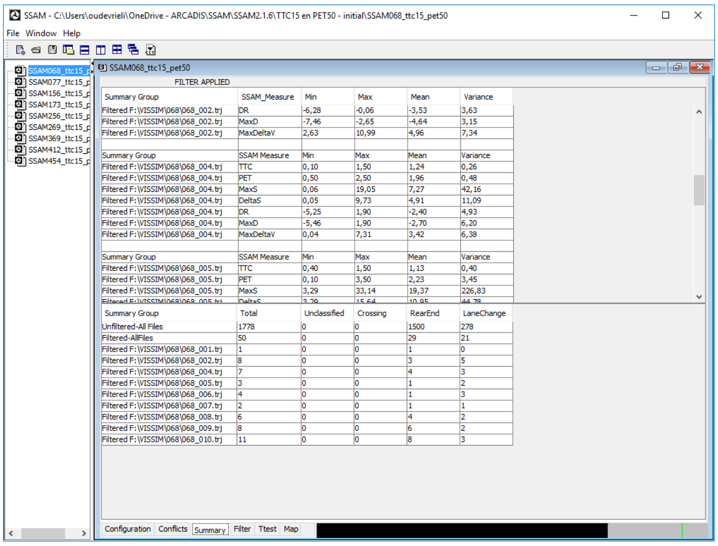


Figure I.12: In the SSAM summary tab a summary of the conflicts per trajectory file is given

The *Ttest tab* can be used for a T-test on two SSAM files. Figure I.13 shows the T-test between the initial ID068 file and the ID068 file with the Wiedemann 74 car-following model for a T-test significance level of 0.0005, an F-test significance level of 0.01 and for analysing the filtered data.

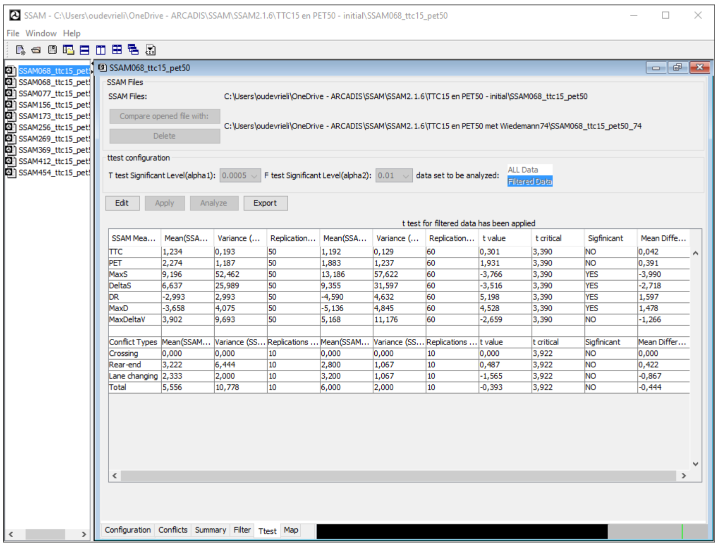


Figure I.13: In the SSAM T-test tab a T-test can be performed between two SSAM files

Lastly, in the *Map tab* in figure I.14 the conflicts can be displayed on a map. It is possible to select a background image on which the conflicts should be displayed. It is also possible to assign different colours to different TTC values or conflict types. The green rectangle indicates the conflict filter area.

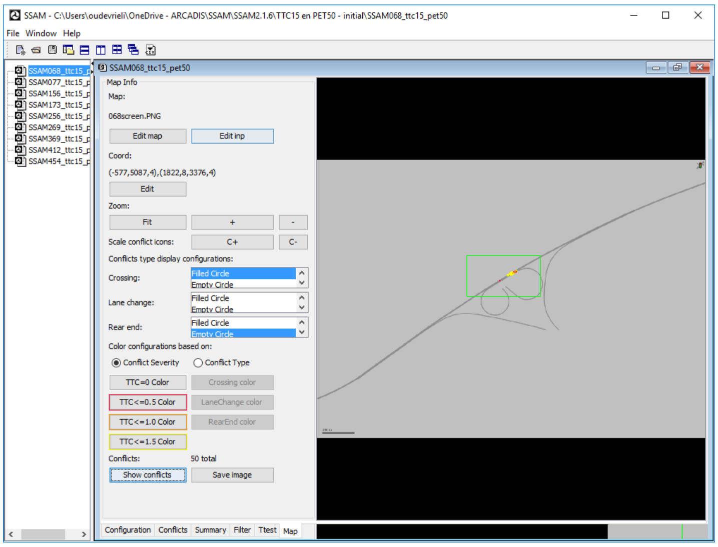


Figure I.14: In the SSAM map tab graphically displays the conflicts

The screenshots are made from SSAM version 2.1.6. However, the SSAM 3.0 version has a somewhat different layout. Furthermore, more mapping options are available in the map tab.