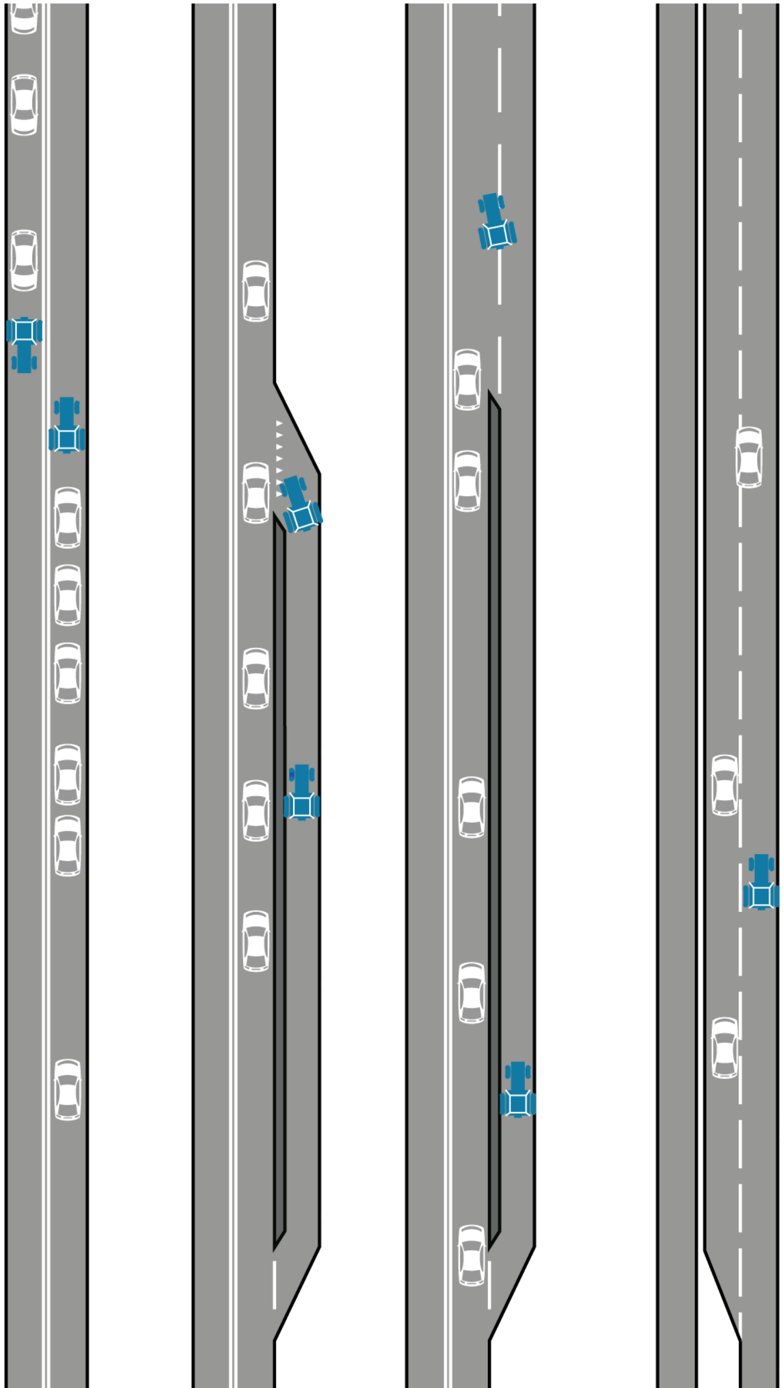
Effectiveness Agricultural Vehicle Interventions on Rural Distributor Roads



Analysis of the impact of infrastructural interventions on rural distributor roads to reduce negative effects of agricultural vehicles on traffic safety, traffic flow and environment.

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Final report
September 2012

Report Master Thesis Project

Effectiveness Agricultural Vehicle Interventions on Rural Distributor Roads

Analysis of the impact of infrastructural interventions on rural distributor roads, to reduce negative effects of agricultural vehicles on traffic safety, traffic flow and environment.

Colophon

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Date: 2012 September 28
Status: final report

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Preface

This is the final report of the master thesis project 'effectiveness agricultural vehicle interventions on rural distributor roads'. It is my final work for the master civil engineering, direction transportation & planning.

The subject of this master thesis project was initiated by dr. ir. Geertje Hegeman, consultant at Royal HaskoningDHV and I had the chance to execute this assignment at the head office of Royal HaskoningDHV in Amersfoort. A research to agricultural vehicles was not the first subject I had in mind when looking for a graduation project. Conversations with Geertje made me curious and the versatility of the research and the opportunity to execute the project at, that time, DHV, convinced me to choose for this subject.

Although I come from a small village and grew up between farmers, I did not expect the subject was that interesting. A lot of information on these vehicles is available, but there are also gaps in the information due to lack of registration. I have found that, despite of the relatively small number of agricultural vehicles, these type of vehicles should not be underestimated. In several provinces attention for agricultural vehicles is increasing in the last years and it is also brought to the attention on national level. Despite of that, regulations in the Netherlands lag still behind in comparison to EU-guidelines, which demands for vehicles registration. Recently, the Dutch government decided to implement a driver license for agricultural vehicle drivers. I believe this is a step forward in relation to traffic safety, but more steps are necessary for further improvement.

The master thesis is conducted under the chair of Traffic Safety under supervision of prof. ir. Fred Wegman. Other member of the committee are dr. ir. Hans van Lint, dr. ir. Ellen Jagtman, ir. Paul Wiggenraad of Delft University of Technology and dr. ir. Geertje Hegeman of Royal HaskoningDHV. Via this way I would like to thank all my committee members for their support, reading of my documents and the comments which helped me further with the research process and finally to this report.

Next to the committee members I would like to thank all my colleagues at Royal HaskoningDHV who had the patience to give answers to my questions, help me learning the basic skills of Aimsun and for the fun. I enjoyed the time working there during my master thesis project and I am honoured that I have the opportunity to work there after my graduation.

Last but not least I would like to thank my family and friends for supporting me during my study and made my study time unforgettable. Special thanks to Luuc who supported me at all time.

I wish you a lot of pleasure while reading the report.

Debbie Ammerlaan
28-09-2012

Summary

Royal HaskoningDHV developed a measuring method in 2010 to measure traffic volume and driving behaviour of agricultural vehicles (AVs) on rural distributor roads. In this way is it possible to measure the number of AVs and determine effects of these vehicles on traffic flow and behaviour. The measuring is starting point for further research for infrastructural interventions that provinces implement for AVs. Problem is that provinces implement different type of interventions, which lead to unpredictable situations and effects. Besides, effects of interventions are unknown. This research shows effects of these interventions on traffic flow, safety and environment analysed for AVs as well as other traffic by making use of a microscopic simulation.

The road type investigated is a rural distributor road type II. This road exists of one roadway with one lane per direction and a speed limit of 80 km/h. AVs in this research consist of all agricultural and forestry tractors and motor vehicles with speed restrictions, which have no license plate. The speed limit for these vehicles on all roads in the Netherlands is 25km/h. However, on rural distributor roads most AVs have restricted speed: up to 40 to 60km/h.

The total yearly average number of fatalities is 16. And every traffic fatality is one too many. Besides, the total number of traffic fatalities is decreasing, which means the number of accidents involving AVs is increasing. Apart from that, the impact of accidents with AVs increases. Also on rural distributor roads the impact is high and the number of fatalities on average is 5 per year. Often speeding, speed differences, driving behaviour, vehicle and road design play an important role causing accidents involving AVs.

An AV can be seen in terms of traffic flow as a so called ‘moving bottleneck’. This means the AV drives with a lower speed compared to other traffic and for that reason is slowing down other traffic. This leads to a row of vehicles behind the AV having the same speed as the AV. From calculations and other measurements it appears that the moving bottleneck has no huge influence on the traffic flow in total. A number of vehicles will have increased travel time, but the effects on the total traffic flow are low. The travel time, and with that the travel time loss, increases when the number of AVs increase.

A sustainable road safety design maximises the traffic safety. Sustainable safe guidelines describe AVs using rural distributor roads as being unsafe and it is therefore undesirable to allow AVs on these roads. AVs differ in speed and mass compared to other traffic (no homogenous situation, no forgivingness), which causes decreasing traffic flow (functionality of the road), which causes unclear situations for other road users (predictability) and it is not always clear what road users can expect of AVs movements .

Although road authorities mainly construct roads following the sustainable safety approach guidelines, many provinces still allow AVs on rural distributor roads. On the one hand to facilitate drivers of AVs and on the other hand because there is no better alternative available for AVs. Together with allowing AVs on those roads, provinces also tolerate overtaking or at least overtaking AVs. This conflicts with the sustainable safety approach. The allowance of overtaking can improve traffic flow, but is unsafe too. Combined with the improvement of traffic flow, provinces implement other interventions as well. These different interventions can lead to less predictability for road users.

Interventions that have been analysed in this research, consist of solutions of spatial planning; policy, pricing and service; traffic management and user behaviour; vehicle interventions; optimization of usage, dynamic traffic management; changes to current infrastructure and new infrastructure. Infrastructural interventions which are further analysed in this research are an overtaking restriction, a passing bay, a passing lane and an overtaking lane. The

choice for these interventions made, because of the difference between sustainable safety and the different infrastructural interventions that are implemented by provinces. Per intervention one design is chosen. Per intervention one length is analysed: a passing bay of 100 metres and a passing and overtaking lane of 200 metres. The four interventions are compared by using three criteria (traffic safety, flow and environment) and applied on a specific situation in Fryslân.

The microscopic simulation model AImsun is used to determine the effects of infrastructural interventions for AVs on traffic flow and safety. Aimsun is a useful tool for this, because it is relatively simple to model Dutch rural distributor roads and infrastructural interventions. Apart from that AVs can be simulated as a separate vehicle type. By making use of output indicators effects are determined on safety, flow and environment determined.

In Aimsun the N358 rural distributor road in Fryslân between Leidijk en Dijkhuisterweg is modelled with eight locations for infrastructural interventions. As input for the model current traffic information has been used, acquired with a method developed by Royal HaskoningDHV. The robustness of the interventions is determined by applying changes to traffic volumes and analysis of different locations of the interventions. The number of simulations is 28 and based on the desired reliability and accuracy of the results. Results of the simulation are related to the 1250m trajectory between Dijkhuisterweg and Oude Vaart. The effects on traffic flow and safety are determined in a quantitative way and on environment on a qualitative way.

Safety effects are measured with surrogate indicators (accidents only occur rarely), involving speed differences, conflict situations and following times. All interventions show that the average speed on the trajectory between Dijkhuisterweg and Oude Vaart of most vehicles lies around 80km/h. Difference between the overtaking restrictions and the other interventions is at lower speeds. The overtaking restrictions show a small peak between 40 to 50km/h. At other interventions this peak is shifted to 60-70km/h. The second indicator which was tested is the number of conflict situations, which consist of the number of stops; the number of hindered vehicles by an AV and the chances to get hindered by an AV; and the number of vehicles that use the intervention and need to merge back to the main traffic lane. Only AVs need to stop on a passing bay and in rare cases on a passing lane. The chance to get hindered by an AV without overtaking and with current traffic volumes is 6%. At higher traffic volumes this chance increases. The chance to get hindered by an AV between Dijkhuisterweg and Oude Vaart and in case of an overtaking restriction is almost twice as high as the other interventions, at a passing bay 2,2% and at a passing and overtaking lane 2,5% . An overtaking lane leads to the largest number of insert and exit movements, because all faster traffic that uses of the lane needs to make a manoeuvre. At a passing bay and passing lane these are only the number of AVs driving on the road an in case of an overtaking prohibition there are no extra manoeuvres. The final indicator for traffic safety is the following time behind an AV. The overtaking restriction leads to longer following times than the other interventions. A passing bay leads to the shortest following times, but the differences with the passing lane and overtaking lane are very small. For traffic safety the user acceptance plays a role for infrastructural interventions too, which is determined on a qualitative way. An overtaking restriction leads to longer rows behind the AV than the other interventions and therefore it leads to an increased urge to overtake the AV and with that a higher risk to offences. The other interventions provide relatively safe overtaking possibilities, which decrease chances of overtaking manoeuvres via the opposite driving directions. At a passing bay an AV will run the risk that it has to wait, especially if traffic volumes increase. This waiting time can discourage drivers of AVs to use the passing bay. The chance that a passing lane and overtaking lane are accepted by users is higher, because AVs almost have no extra hindrance and other traffic has opportunities to overtake the AV.

Effects on traffic flow are measured with the indicators travel time, travel time loss and lengths of the rows behind the AV. Differences in the average travel time per vehicle (cars and trucks) are small for all the infrastructural interventions. The average travel time per vehicle is 55 seconds with an overtaking restriction and 51 seconds with an overtaking lane. The passing lane and overtaking lane lead to an average travel time of 54 seconds on the section. The difference between de overtaking lane and the other intervention can be clarified by the possibility of also overtaking cars and trucks. The travel time loss at an overtaking restriction and at the other interventions 1,5 to 2 seconds. Also these averages are small. Increased differences are in the deviations of the travel time and travel time loss. An overtaking prohibition leads to a larger standard deviation than the other interventions (on average 11 seconds for the overtaking prohibitions and about 6 seconds for the other interventions). These high standard deviations can be clarified by the difference between traffic that follows an AV the whole length of the section and traffic that does not get hindered by an AV at all. So, a number of vehicles have much more travel time due to AVs, while other vehicles have no travel time loss at all. For AVs the effect is on travel time by interventions different than for cars and trucks. For AVs the passing bay is the least favourable, because in many cases the AV has to stop and wait till space is available to insert on the main traffic lane again. On a passing lane the chance to insert without any hinder is larger and in most cases the AV can keep on driving with its desired speed. The AV can drive with its desired speed at an overtaking lane and overtaking prohibition, so this has no influence on travel time. The last used indicator for traffic flow is the length of the row behind an AV. With current traffic volumes the rows consisting of 5 to 8 vehicles are most common for an overtaking prohibition. For the other interventions rows with 1 to 4 vehicles are most common.

The environmental effects of the infrastructural interventions determined on a qualitative way. The overtaking lane and to a lesser extent the passing lane need most space and are therefore the most difficult to embed into the landscape. The overtaking prohibition does not take extra spatial integration and is in this case very favourable. Almost no extra adjustments are necessary. In relation to air and noise pollution a closer look is taken to the acceleration and deceleration movements (number of stops and length of the rows). In this case the passing bay scores poorly, because the AV often needs to slow down on the passing bay and accelerate from a standstill. At an overtaking prohibition often more deceleration movements are necessary to adjust to the speed of an AV. In this case the passing lane and overtaking lane are most favourable.

From the results of the effects of infrastructural interventions on traffic flow, safety an environment is concluded that the differences for traffic flow are in general small. For cars and trucks the passing bay and passing lane are already favourable and the overtaking lane is most favourable. For AVs is the passing bay is least favourable. In relation to traffic safety the speed differences and following times are the highest with an overtaking prohibition. However, traffic does not have to make an extra manoeuvre. The desire to overtaking is higher though and can lead in practice to higher risks. It cannot be predicted by a microscopic simulation model directly how high the risk is. A passing bay leads to higher risks when an AV inserts on the main traffic road from a standstill. The differences between a passing lane and overtaking lane are small, but an overtaking lane has a higher impact on the landscape and construction leads to higher costs.

Summarizing, the results of this study show that there is not one best intervention on rural distributor roads to reduce negative effects of AVs on traffic safety, flow and environment. The overtaking lane and passing lane scores slightly better on traffic safety and flow, but also require the most space and are probably the most expensive. As a result of the outcomes of the simulation and the reason for Fryslân to implement interventions, it is recommended to the province of Fryslân to implement an overtaking restriction for all traffic in combination with a passing lane or overtaking lane. This is for both AVs and other traffic in relation to traffic flow, safety and environment the most favourable intervention on the N358 in Fryslân.

Although different intensities of both other traffic and AVs are simulated, it is recommended to model other existing roads in the Netherlands, to verify the effects of the interventions on other locations. More detailed real life information on traffic flows, intensities of AVs and origin and destinations of all traffic of other location in the Netherlands will improve the validity of the simulations and therefore the outcomes. Supplementary, research in acceptance of the interventions and into driving behaviour on (the end of) the passing lane and overtaking lane is required.

Samenvatting

In 2010 heeft DHV een meetmethode ontwikkeld voor het meten van intensiteiten en rijgedrag van landbouwverkeer op gebiedsontsluitingswegen. Hiermee is het mogelijk om het aantal landbouwvoertuigen en effecten van landbouwvoertuigen op doorstroming en rijgedrag te meten. Deze manier van meten is aanleiding om verder onderzoek te doen naar infrastructurele interventies die provincies ten behoeve van landbouwverkeer nemen. Het probleem is namelijk dat provincies verschillende maatregelen toepassen, maar de effecten hiervan zijn vrijwel onbekend. Dit onderzoek behandelt de effecten van deze interventies op verkeersveiligheid, doorstroming en milieu. Met behulp van microsimulaties zijn deze effecten voor zowel landbouwverkeer als overig verkeer in beeld gebracht.

Het onderzochte wegtype is gebiedsontsluitingsweg type II. Dit is een weg bestaande uit één rijbaan met één rijstrook per richting met een snelheidslimiet van 80km/uur. Landbouwvoertuigen in dit onderzoek zijn alle land- en bosbouwtractors en motorvoertuigen met beperkte snelheid, welke geen kentekenplaat voeren. De limiet voor deze voertuigen op alle wegen is 25 km/uur. Echter op gebiedsontsluitingswegen rijden de meeste landbouwvoertuigen met de snelheid waarop het voertuig is begrensd, tussen de 40 en 60 km/uur.

Bij ongevallen met landbouwverkeer vallen jaarlijks 16 dodelijke slachtoffers. Elke verkeersdode is er een te veel. Daarnaast neemt in Nederland het totale aantal verkeersdoden af, wat betekent dat het aandeel verkeersdoden met landbouwverkeer toeneemt. Daarnaast neemt de ernst van ongevallen met landbouwverkeer toe. Ook op gebiedsontsluitingswegen is de ernst van ongevallen hoog en het aantal dodelijke slachtoffers is gemiddeld 5 per jaar. Vaak spelen snelheidsovertredingen, snelheidsverschillen, rijgedrag, voertuigontwerp en wegontwerp een rol in de oorzaak van ongevallen waarbij landbouwverkeer is betrokken. Vanuit het perspectief van doorstroming wordt een landbouwvoertuig gezien als een 'bewegend knelpunt'. Dit betekent dat het landbouwvoertuig met aan lagere snelheid dan het overige verkeer op de weg rijdt en daardoor het overige verkeer ophoudt. Achter het landbouwvoertuig ontstaat een rij voertuigen die met dezelfde snelheid als het landbouwvoertuig rijdt. Uit berekeningen en uit metingen in de praktijk blijkt echter dat het bewegende knelpunt geen grote invloed heeft op de totale doorstroming. Er zijn een aantal voertuigen met een hogere reistijd, maar het gemiddelde effect is beperkt. De reistijd en daarmee het reistijdverlies nemen wel toe als het aantal landbouwvoertuigen toeneemt.

Een duurzaam veilige inrichting maximaliseert de verkeersveiligheid. Duurzaam veilige richtlijnen schrijven voor dat landbouwverkeer op een gebiedsontsluitingsweg onwenselijk is. Landbouwverkeer verschilt van snelheid en massa met het overige verkeer (geen homogene situatie, geen vergevingsgezindheid); zorgt voor een verminderde stroming van het verkeer op de wegvakken (functionaliteit van de weg); zorgt voor onduidelijkheid voor overige weggebruikers (voorspelbaarheid) en hiervoor is het niet altijd duidelijk wat ze kunnen verwachten van het rijgedrag van een landbouwvoertuig.

Hoewel veel provincies de wegen zo veel mogelijk duurzaam veilig inrichten, staan veel provincies landbouwverkeer toch toe op gebiedsontsluitingswegen. Enerzijds omdat ze de bestuurders van landbouwverkeer willen faciliteren en anderzijds omdat ze geen betere plek voor landbouwverkeer hebben. Samen met het toestaan van landbouwverkeer staan provincies ook inhalen, of in ieder geval inhalen van landbouwverkeer toe. Dit is ook in strijd met de duurzaam veilig principes. Het toestaan van inhalen kan de doorstroming verbeteren, maar is ook onveilig. Met betrekking tot het verbeteren van de doorstroming passen provincies ook andere interventies toe. Deze verschillende interventies kunnen tot problemen leiden door verminderde voorspelbaarheid bij verkeersdeelnemers.

De interventies, die in dit onderzoek zijn onderzocht, betreffen oplossingen in de richting van: ruimtelijke ordening; beleid, beprijzen en service; verkeersmanagement; voertuigmaatregelen; optimalisatie van gebruik;

veranderingen aan bestaande infrastructuur en het aanleggen van nieuwe infrastructuur.

De infrastructurele maatregelen die nader worden onderzocht zijn een inhaalverbod, een passeerhaven, een passeerstrook en een inhaalstrook. De keuze voor deze maatregelen is gemaakt vanwege het verschil tussen duurzaam veilig en de verschillende infrastructurele maatregelen die worden genomen per provincie. Er is voor elke maatregelen één ontwerp gekozen. Per maatregel is dan ook één lengte onderzocht: een passeerhaven van 100m, een passeerstrook en inhaalstrook van 200m. De vier maatregelen zijn met elkaar vergeleken met elkaar op basis van drie criteria (verkeersveiligheid, doorstroming en milieu) en toegepast op een concrete situatie in Fryslân.

Het microscopische simulatiemodel Aimsun is gebruikt voor het bepalen van de effecten van infrastructurele maatregelen voor landbouwverkeer op veiligheid en doorstroming. Aimsun is hiervoor geschikt omdat het eenvoudig is om Nederlandse gebiedsontsluitingswegen en infrastructurele maatregelen te modelleren. Daarnaast kan in Aimsun landbouwverkeer als apart voertuigtype worden gesimuleerd. Door middel van output indicatoren is bepaald wat de effecten op veiligheid, doorstroming en milieu zijn.

In Aimsun is de gebiedsontsluitingsweg N358 in Fryslân tussen Leidijk en Dijkhuisterweg gemodelleerd met daarin acht locaties voor infrastructurele maatregelen. Voor de analyse is gebruik gemaakt van huidige verkeersgegevens, welke zijn gemeten met de meetmethode van Royal HaskoningDHV. De robuustheid is bepaald door middel van veranderingen in intensiteiten en verschillende locaties van de maatregelen. Het aantal simulaties dat is gedaan is 28 en is gebaseerd op de gewenste betrouwbaarheid en nauwkeurigheid van de resultaten. Resultaten uit de simulatie hebben voornamelijk betrekking op het 1250m lange traject tussen Dijkhuisterweg en Oude Vaart. De effecten op verkeersveiligheid en doorstroming zijn bepaald op een kwantitatieve manier en milieu op een kwalitatieve manier.

Veiligheidseffecten zijn gemeten met surrogaat indicatoren (ongevallen komen te weinig voor), bestaande uit: snelheidsverschillen, conflictsituaties en volgtijd (tijd dat voertuig achter landbouwvoertuig blijft rijden). Bij alle infrastructurele maatregelen laten snelheidsverschillen zien dat het grootste deel van de voertuigen met een snelheid rond de 80 km/uur rijdt. Wel is er een verschil te zien tussen het inhaalverbod en de andere maatregelen in de range van lagere snelheden; bij het inhaalverbod is een piekje rond de 40-50km/uur te zien en bij de andere maatregelen is dit verschoven richting 60-70km/uur. De tweede indicator voor veiligheid is het aantal conflictsituaties. Hierbij wordt onderscheid gemaakt tussen aantal keer dat een voertuig stil moet staan, het aantal gehinderde voertuigen en het aantal voertuigen dat gebruik maakt van de maatregelen en weer in moet voegen op de hoofdrijbaan. Voertuigen die stoppen zijn alleen landbouwvoertuigen die moeten stoppen op de passeerhaven en in een heel enkel geval op de passeerstrook. De kans om gehinderd te worden door een landbouwvoertuig zonder inhalen en met huidige verkeersintensiteiten is bijna 6%. Bij hogere intensiteiten neemt deze kans toe. De kans om door een landbouwvoertuig te worden gehinderd tussen Dijkhuisterweg en Oude Vaart is bij een inhaalverbod bijna twee keer zo hoog als bij de andere maatregelen; bij passeerhaven is de kans 2,2% en bij een passeer - en inhaalstrook is de kans 2,5%. Een inhaalstrook levert de meeste in- en uitvoegbewegingen op, doordat alle snelverkeer dat gebruik maakt van de inhaalstrook een manoeuvre moet maken. Bij een passeerhaven en passeerstrook zijn dit alleen de landbouwvoertuigen en bij een inhaalverbod zijn geen extra manoeuvres. Een laatst gebruikte indicator voor veiligheid is de volgtijd. Het inhaalverbod levert langere volgtijden op dan de andere maatregelen. Een passeerhaven levert de meeste korte volgtijden op, maar de verschillen met de passeer- en inhaalstrook zijn klein. Bij veiligheid speelt ook de acceptatie van gebruikers voor maatregelen mee, dit is bepaald op een kwalitatieve manier door middel van interviews met experts en logische redeneren. Een inhaalverbod leidt tot een hoge inhaalwens van vracht- en autoverkeer en daarmee op een hoger risico dat het verbod wordt overtreden. De andere maatregelen bieden wel inhaalmogelijkheden, waardoor de inhaalwens zal dalen. Bij een passeerhaven kan het zijn dat een landbouwvoertuig lang moet wachten om weer in te voegen en om deze reden de maatregel niet wil gebruiken. De passeer- en inhaalstrook hebben een hogere kans om geaccepteerd te worden, omdat landbouwverkeer vrijwel geen hinder ondervindt en overig verkeer inhaalmogelijkheden heeft. Consequentie voor de verkeersveiligheid is dat een passeerhaven, passeer- en inhaalstrook overtredingen en daarmee risico's op ongevallen kunnen verminderen.

Effecten op doorstroming zijn gemeten met directe indicatoren reistijd, reistijdverlies en lengte van volgrijen. Bij de reistijd is het verschil tussen de maatregelen per gemiddeld voertuig (vracht- en autoverkeer) klein. De gemiddelde reistijd is bij een inhaalverbod 55 seconden en bij een inhaalstrook 51 seconden. De passeer- en inhaalstrook leveren een reistijd op van 54 seconden. Het verschil tussen de inhaalstrook en overige maatregelen is te verklaren doordat op een inhaalstrook ook auto's en vrachtwagens ingehaald kunnen worden. Het reistijdverlies is bij een inhaalverbod gemiddeld 3 seconden en bij de andere maatregelen 1,5 tot 2 seconden. Ook deze gemiddelde verschillen zijn dus klein. Wat wel verschilt, is de variatie in reistijden. Een inhaalverbod zorgt voor een grotere standaard afwijking dan de andere maatregelen (gemiddeld 11 tegen ongeveer 6 seconden). Deze hoge standaard afwijkingen zijn te verklaren door het verschil tussen verkeer dat het gehele traject een landbouwvoertuig volgt en verkeer dat het hele traject geen landbouwverkeer tegenkomt. Een aantal voertuigen zal dus een hoog reistijdverlies hebben, waar de meeste voertuigen weinig tot geen reistijdverlies hebben. Voor landbouwverkeer is het effect op reistijd door de interventies anders. Voor deze voertuigen is een passeerhaven het minst gunstig, omdat hier in veel gevallen moet worden gewacht totdat er weer ruimte is om in te voegen. Op een passeerstrook is de kans om met snelheid in te voegen groter en kan het landbouwvoertuig vrijwel altijd doorrijden met zijn gewenste snelheid. Bij een inhaalstrook en inhaalverbod kan het landbouwvoertuig met gewenste snelheid blijven rijden, dus dat heeft weinig tot geen invloed op de reistijd. Een laatst gebruikte indicator voor doorstroming is de lengte van de volgrij. In de huidige situatie bestaan de meeste volgrijen bij het inhaalverbod uit 5-8 voertuigen en bij alle andere maatregelen uit 1-4 voertuigen.

Naast veiligheid en doorstroming zijn de effecten op het milieu van de infrastructurele maatregelen kwalitatief bepaald. Met betrekking tot luchtvervuiling en geluidsoverlast is gekeken naar versnelling- en afrembewegingen (aantal keer stoppen en lengte van rijen). Hierbij scoort de passeerhaven slecht, omdat het landbouwvoertuig vaak vanuit stilstand weer moet versnellen. Bij een inhaalverbod moet vaker geremd worden naar de snelheid van het landbouwvoertuig. Voor luchtvervuiling en geluidsoverlast zijn daarom een inhaal- en passeerstrook het meest gunstig. De inhaalstrook en in iets mindere mate de passeerstrook nemen de grootste ruimte in beslag en zijn daardoor het lastigst in te passen. Het inhaalverbod kost geen ruimtelijke inpassing en is in dit geval gunstig, omdat er bijna geen aanpassingen nodig zijn.

Samenvattend, is voor de effecten van infrastructurele maatregen op verkeersveiligheid, doorstroming en milieu is geconcludeerd dat met betrekking tot verkeersveiligheid, de snelheidsverschillen en de volgtijden het hoogst bij een inhaalverbod. Echter, verkeer hoeft geen in- en uitvoegbewegingen te maken. De inhaalwens wordt wel vergroot en kan in praktijk tot risico's leiden (negeren verbod). Hoe groot dit risico is, is niet direct uit een microsimulatie te halen. Een passeerhaven levert grotere risico's op als een landbouwvoertuig vanuit stilstand invoegt op de hoofdrijbaan. De verschillen tussen de maatregelen voor doorstroming zijn over het geheel klein. Voor auto- en vrachtverkeer zijn de passeerhaven en –strook al gunstiger en de inhaalstrook het meest gunstig. Voor landbouwverkeer is vooral de passeerhaven ongunstig. Over het algemeen zijn de verschillen tussen de passeer- en inhaalstrook zijn klein, maar een inhaalstrook heeft een grotere aanslag op het landschap en leidt tot hogere kosten.

Samenvattend, de resultaten van dit onderzoek laten zien dat er niet één beste infrastructurele maatregel op gebiedsontsluitingswegen is om negatieve effecten van landbouwvoertuigen op verkeersveiligheid, doorstroming en milieu te verminderen. De inhaalstrook en passeerstrook scoren beter dan op verkeersveiligheid en doorstroming dan de passeerhaven en het inhaalverbod, maar nemen wel het meeste ruimte in beslag en leidt naar verwachting tot een hogere investering. Naar aanleiding van de uitkomsten en de uitgangspunten voor Fryslân om een maatregelen te nemen, is het aan te bevelen aan de provincie om een inhaalverbod te combineren met een passeerstrook of inhaalstrook. Dit is voor zowel landbouwverkeer als ander verkeer met betrekking tot verkeersveiligheid, doorstroming en milieu de meest gunstige oplossing.

Uit de validiteittest komt naar voren dat de microsimulatie een goede methode is om maatregelen op een specifieke locatie met elkaar te vergelijken. Echter, er kunnen geen algemene uitspraken over de maatregelen gedaan worden, omdat er maar één locatie onderzocht is. Aanbevolen wordt om dit onderzoek op meer locaties uit te voeren. Bovendien moet de praktijk uitwijzen of onverwacht rijgedrag optreedt. Daarnaast verdient het de aanbeveling om als de interventies zijn aangelegd, deze te analyseren door middel van camera's.

Content

1 Introduction

In the Netherlands, agricultural vehicles (AVs) use rural distributor roads regularly. From origin these vehicles are allowed on these roads, because the drivers often have an origin or destination along the road, like access to the farmyard or to a lot. However, the presence of these vehicles on rural distributor are point of discussion. Where the speed limit on provincial rural distributor roads is 80km/h, the official speed limit for AVs is 25km/h. This large speed difference can lead to unsafe situations and to a lesser extent to a reduction in traffic flow. Several provinces in the Netherlands, like Zeeland, Fryslân and Gelderland have done research on AVs driving on rural distributor roads and have taken different kind of interventions. These interventions differ from measures to vehicles, changes to laws and regulations and infrastructural interventions. This study concentrates mainly on the impact of infrastructural interventions on rural distributor roads related to AVs.

1.1 Motivation research project

The starting point for this research is a project on the rural distributor road N358 in the Dutch province Fryslân, which is performed by Royal HaskoningDHV. Camera observations are used to find out what the effect of AVs is on the traffic flow characteristics (e.g. intensities, number of followers, travel time) and what kind of driving behaviour is noticeable around AVs (e.g. the number of cars that overtake an AV and in what way). This insight is necessary for the province to determine whether AVs can drive on the N358 in a safe and efficient way, without hindering and causing unsafe situation for other vehicles. Using camera observation is a helpful to decide on taking interventions for AVs to improve safety and decrease disruption (Hegeman & Dijkstra, 2011). The project in Fryslân motivated further investigation of traffic safety, traffic flow characteristics and environment due to AVs on distributor roads, the interventions which are taken and could be taken in different provinces and the effects of those interventions.

1.2 Problem statement

Road authorities are responsible for traffic safety and flow on the roads they manage. Provinces are the main managers of distributor roads in rural areas. These roads should be designed in a sustainable safe way. This means the road should be homogeneous, functional, recognizable and forgiving (SWOV, 2006). Ideally, the attendance of AVs on a rural distributor road does not fit in the vision of a sustainable safe road, because of inhomogeneity in speed. The speed limit for an AV is 25km/h, although in practice these vehicles drive about 40km/h (Hegeman & Dijkstra, 2011), where the speed limit for other vehicles is 80km/h on most rural distributor roads. In practice this lead for instance to the desire of overtaking by other vehicles, which is in many cases allowed, but is a risk taking manoeuvre. Although the number of accidents with AVs seems low, the number of fatal accidents do not follow the trend of the decreasing number of fatal accidents in general, but stays stable. The number of severe accidents involving AVs is even increasing (Jaarsma & de Vries, 2010). This is worrisome, because every traffic victim is one victim too much. To a lesser extent there are problems related to traffic flow and environment: an AV could be seen as a so called ‘moving bottleneck’ which could delay other vehicles. Further on, the size, mass and noise of the vehicle have influence on liveability. This means AVs should be separated from rural distributor roads, but the alternatives are not ideal either. For instance a big tractor driving through an urban area could give a feeling of unsafety; the combination of bicycles on a parallel road leads to large mass differences; there are no alternative roads; there is no space for a (separate) parallel road for AVs and so on. Despite of that AVs still need to have access to the lot or need the road to come to their destination.

For the situation without alternatives for AVs other than using rural distributors roads, provinces should take measures to let AVs use this road on a safe and efficient manner (Baere, 2009). Examples of possible interventions on rural distributor roads are: passing bays (e.g. in Gelderland) and passing lanes (e.g. in Fryslân and Zeeland). However, the effect of AVS on traffic safety, flow and environment and the currently taken infrastructural interventions are not exactly known yet. This means it is not clear which intervention should be recommended to provinces and what the benefits and effects of such interventions are.

Summarizing: allowing AVs on rural distributor roads could lead to negative effects on traffic safety (e.g. accidents) and to a lesser extend to traffic flow and environmental problems. Some provinces take infrastructural interventions to minimize these problems, but exact effects of these interventions on traffic safety, flow and environment are not known yet.

Main problem

The problem statements leads to the following main problem:

For allowing AVS on rural distributor roads interventions are necessary to improve traffic safety and to a lesser extent traffic flow and environmental issues. There is not enough knowledge of the effects of agricultural vehicles and the effects of infrastructural interventions for agricultural vehicles on traffic flow, safety and environment.

This main problem is split up in the following problems:

1. Agricultural vehicles are from origin allowed on rural distributor roads and are still driving on those roads, which could lead to problems.
2. There is little knowledge about the effects of AVs on rural distributor roads on traffic safety and flow and on the environment.
3. If effects are available, interventions could be implemented, but there is no knowledge of the effects of measures for AVs on traffic flow, safety and environment.
4. Road managers do not know which interventions to take when AVs have to make use of rural distributor roads.

1.3 Research objective

From the problem statement, main problem and the derived problems, the main objectives and research questions are determined.

Main objective

The main objective of this research is:

To develop a method for impact analysis of infrastructural interventions on rural distributor roads, which could reduce negative effects of AVS on traffic flow, safety and environment.

The main objective is divided in four goals:

1. Gain knowledge/ insight in the size of the problem in the Netherlands: on how many rural distributor roads AVs are allowed and on which of those roads this leads to problems.

2. Get insight in the effects of AVs on rural distributor roads on traffic safety and traffic flow on in quantitative way and environmental effects on a qualitative way.
3. Make an overview of possible agricultural interventions, which could reduce traffic flow, safety and environmental problem related to AVs driving on rural distributor roads.
4. Determine the effect of possible AVs interventions for AVs on traffic safety, traffic flow characteristics and environmental impact.

Main research question

The objectives lead to the following main and key research questions:

What method can be used to show the effectiveness of infrastructural interventions to minimize possible negative effects of agricultural vehicles on rural distributor roads on flow, safety and environment, given the measured intensities?

Key questions derived from the main research question:

1. On how many rural distributor roads are AVs allowed and to what problems leads the attendance of AVs on these and other type of roads?
2. What indicators/ effects of AVs need to be determined?
3. How could the effects of AVs on traffic safety and flow be determined in a quantitative way?
4. Which AV interventions are available to reduce traffic flow, safety and environmental problems related to AVs driving on rural distributor roads?
5. What are the effects of possible interventions, which could be taken for AVs on rural distributor roads on traffic flow, traffic safety and the environment?
6. How widely applicable are the results of the method used?

1.4 Research approach

The research to the effectiveness of AV interventions on rural distributor roads is split up in seven phases, figure 1-1. This research started with the exploration of the research set-up consisting of a plan of approach (phase I). A first step with a literature review is made and this phase is the starting point for the further phases in the research. The second phase that follows from the approach is the problem analysis, which has a focus on traffic safety, traffic flow and the environment in relation to AVs. The problem with AVs on roads is elaborated with help of a literature review, interviews with several actors and a map inventory of AVs on rural distributor roads. Also traffic accidents involving AVs are analysed and calculations to travel time in relation to AVs are done. From this analysis the main problem is derived. This is the starting point for the research to AV interventions (phase III) and effects of a selection of these interventions: infrastructural interventions (phase IV and V). The research to AV interventions is supported by making use of the Mobility Ladder (further explanation in chapter 3) and extra (literature) research to these interventions. The method used for the determination of the effects of the infrastructural interventions, which consists of a simulation and analysis of simulation data, is described in chapter four and five. After the simulation results are compared with use of an assessment framework. In the evaluation tests for validity, robustness analysis and feasibility are done (phase VI). Finally, there is a discussion about the research to the effects of AV interventions and some recommendations are given.

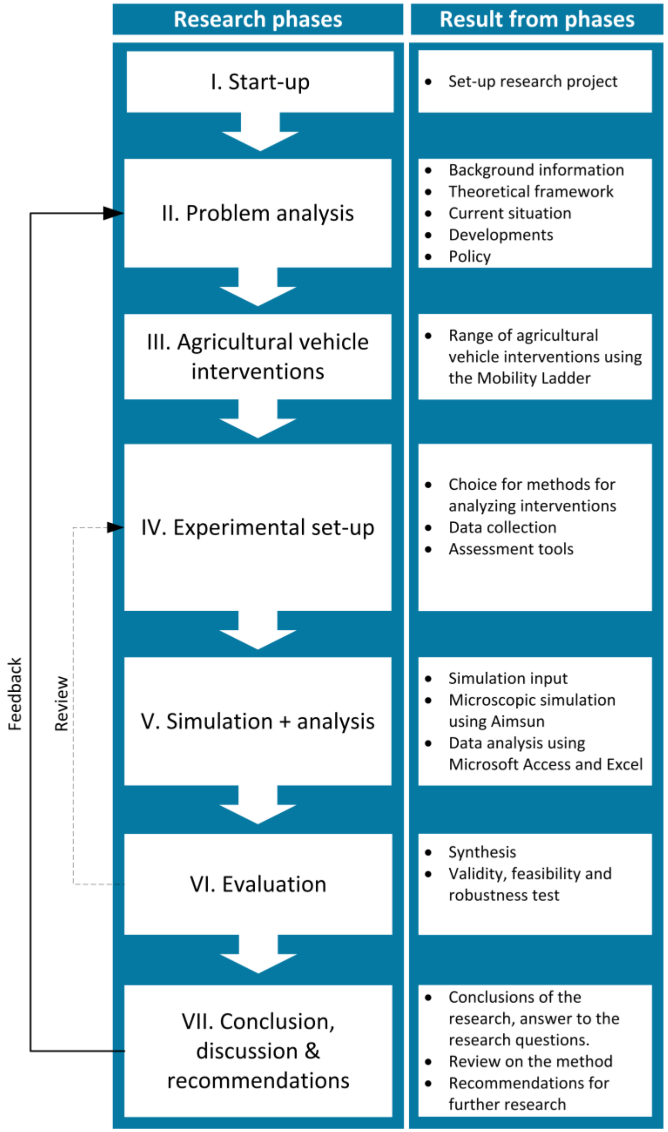


Figure 1-1 Phases research project

1.5 Research scope, relevance and limitations

Research scope

The scope of the project is limited to:

- **Rural distributor roads type II (1x2 lanes)**, where AVs are allowed to drive. Only rural distributor type II are taken into account;. These are roads with a speed limit of 80km/h where AVs are often allowed, despite of the sustainable safety approach (SWOV, 2006) saying this is undesirable. Rural distributor roads type I (2x2 lanes) are not taken into account, because no AVs are allowed onto these roads. Access roads and through roads fall outside the scope of the research, because the problems on access roads are of a different category and on through-roads AVs are also not allowed. More information is given in the next chapter, chapter 2.
- **Vehicles:** the research focusses on agricultural and forestry tractors and motor vehicles with speed restrictions. These are only the vehicles with a speed limit of 25km/h, which have no license plate and are allowed to drive on many roads with a speed limit of 80km/h. These vehicles cause large speed differences on rural distributor roads. More information about agricultural and forestry tractors can be found in the background information in chapter 2.
- **Infrastructural interventions:** there are several possibilities to make improvements on distributor roads. This research goes into depth of infrastructural interventions, such as passing bays and lanes. Besides, a range of other AV interventions are available. These are mentioned, but no further research to the effects of these interventions is done. This choice is made, because several provinces in the Netherlands are implementing several infrastructural measures on this moment, without knowing the exact effect of these measures. More information in chapter 3.

- **Traffic flow, safety and environment:** effects of AVs on rural distributor roads is evaluated for traffic flow, safety and environment. Next to that, there is subjective feeling of delay and an unsafe feeling of road users. The research is not going into depth of the subjective part of traffic safety.
- **Microscopic simulation:** several methods are available for evaluating the effects of infrastructural interventions, chosen is to simulate the effects of infrastructural interventions. The simulation is done on microscopic level, because this gives an indication of the individual effects of the measures. AVs have specific characteristics and do not drive for kilometres on a distributor road. This means the effects for individual drivers are a lot larger than on network level. The support of the choice for the microscopic simulation from the available methods can be found in chapter 4.

Relevance of the research

At the moment, several provinces are taking interventions for AVs. For example: in Zeeland a network for AVs is developed to determine the weak points in the network which are important for AV. In Fryslân measurements to the number and effects of AVs driving on a provincial road are done and in Gelderland passing bays are constructed on provincial roads around municipalities to avoid AVs in the urban area. This are only a few examples of interventions which are taken for AVs. Besides, the number of fatal road accidents in general are decreasing, while the number of fatal accidents involving AVs does not following this trend. The attention for AVs in provinces, the worrisome trend related to traffic accident and also the importance of these vehicles in some provinces makes it necessary to do more research to the effects to several interventions which are taken by provinces.

Limitations of the research

Until the 1980s, information of agriculture and AVs was gathered and kept up to date. In that time there was for instance a model to determine frequencies of rides of AVs. Since the 1980s, the national government quit subsidizing a lot of research for the agricultural sector, because lot exchange became less intensive and gathering information as less useful. Since then less up-to-date data is available, including data for the frequency model. What is known is the kind of agriculture in several areas and estimations of the size of the land. This could be used to get an indication of areas where a lot of AVs are driving and in which season (Jaarsma, 2012). So, at the moment there is little up-to-date knowledge about the effect of AVs and the effects of infrastructural interventions which are taken on provincial roads, such as passing bays. To determine the number and effects of AVs, Royal HaskoningDHV developed a measuring method (Hegeman & Dijkstra, 2011). With this method it is possible to get information of the situation of a certain road on a reliable and accurate way. This information could be used to make a prediction for which interventions could be taken best on that road. Despite of this available method, not many measurements are done at the moment. That is why only limited data of the measurements can be used for this research. For unknown data assumptions should be made.

1.6 Outline

The outline of the report follows mainly the phases of the research methodology, see figure 1-2.

Chapter 1 describes the set-up of the research consisting of the motivation for this research, the problem statement, the research objective including the research questions and the research method including the research phases, scope and relevance of the research.

Chapter 2 is the problem analysis, which digs deeper into the problem related to AVs driving on (rural distributor) roads. This chapter consists of a background information, a theoretical review to the subject and an analysis of the current situation, developments and policies in relation to AVs. Background information is given about AVs, rural distributor roads and reasons for AVs to drive on (rural distributor) roads in the Netherlands. In the theoretical review an overview is given of traffic flow, safety and environment in relation to AVs on rural distributor roads. Next to that, information is given about developments and provincial roads on which AVs are allowed. After that and overview of policies in relation to AVs is given and a comparison between policy and the actual situation is made. Finally, a conclusion with the main problems in relation to AVs on rural distributor roads are given.

In chapter 3, an overview of possible AV interventions are given. These interventions are divided into seven steps, based on the so called *mobility ladder.* The mobility ladder is further explained in this chapter. For all steps a number of possible agricultural interventions are given and a rough estimation of the impact of those interventions are given. This research is focusses on the effects of infrastructural interventions and these interventions are further elaborated at the end of the chapter.

The infrastructural interventions that are further analysed and the method used for the analysis of these are described in chapter 4. This involves the choice for a microscopic simulation model; the data necessary for the simulation, how this can be collected and inserted into Aimsun and the assessment tools and tests for the analysis of out coming data of the simulation.

In chapter 5 the analysis of the simulations are done. This involves the results on effects of the infrastructural interventions on traffic flow, safety and environment. The results are compared with each other, a choice for the intervention that performs best and evaluation tests to robustness and validity are done

In chapter 6 conclusions, discussion and recommendations about the research are given. This includes answers to the research questions, discussion about the method used and recommendations for further research.

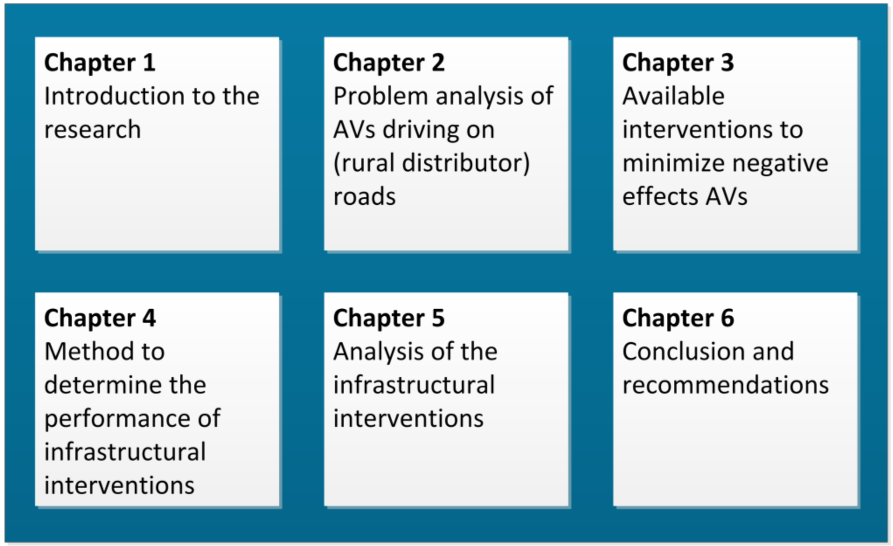


Figure 1-2 Outline of the report

2 Problem analysis

In chapter one, the problem with agricultural vehicles (AVs) driving on rural distributor roads is already explained shortly. This chapter expands on the traffic flow, safety and environmental problems related to AVs.

To make a better understanding of the terms used in the research, some background information on AVs and rural distributor roads is given, followed by a theoretical framework about traffic safety, traffic flow and environment and the current situation related to AVs. Thereafter developments related to AVs and policy in the Netherlands and per province are described. Information gathered in this chapter is used as a basis for the experimental set-up, simulation and analysis of the interventions. This information makes it possible to set up requirements for AV interventions and output indicators and an assessment framework for the analysis of the interventions that are evaluated.

2.1 Background

To make a better understanding of the terms used in the research, background information is given on the analysed aspects, AVs and rural distributor roads.

2.1.1 Traffic flow, safety and environment

The research *Effectiveness Agricultural Vehicle Interventions on Rural Distributor Roads* takes three aspects into account for the evaluation of the effectiveness of AV interventions, namely:

- **Traffic safety:** refers to the chance, number and impact of accidents (objective safety)
- **Traffic flow**: refers to the interaction between vehicles on the road. A closer look is taken to the effectiveness of agricultural vehicle interventions on traffic flow characteristics for the traffic on macroscopic (e.g. average speed, intensity) and microscopic level (e.g. individual delay and speed).
- **Environment:** refers to the impact of AV interventions on the environment.

Paragraph 2.2 describes for all these three aspects theoretical background information and in paragraph 2.3 the current situation is described. First background information on AVs and rural distributor roads is given in paragraph 2.1.2, 2.1.3 and 2.1.4.

2.1.2 Agricultural vehicles

The term AV is often used as a general term for vehicles without a license plate. AVs are not only used for agricultural purposes, but also for land development, construction work and green maintenance.

In this research, the term AV is used for the two following categories (CUMELA, Position Paper, 2009):

- **Agricultural and forestry tractors:** these are tractors with or without equipment and used for moving goods and pulling or supported equipment, see figure 2-1.
- **Motor vehicles with speed restrictions:** mostly machinery, which is designed to work outside roads or for work on or near roads, not being an agricultural tractor or a moped and not for movement of people.

Examples of these vehicles are self-driven AVs, shovels (see figure 2-2) and corn harvesters.

Common characteristics of these AVs in the Netherlands is that a license plate is not necessary to make use of the public roads. The speed limit for these vehicles is 25km/h. and most vehicles are limited at 40-60km/h (Case IH, 2012) no admission test is needed when these vehicles are imported. They do also not need a periodic motor vehicle test. Besides, drivers do not require a driver license. Only people aged 16 or 17 years need a certificate to drive such a vehicle on public roads when they use it for their work. When they drive on public roads without work purpose, no certificate is required (CROW, Kennisplatform Verkeer en Vervoer, 2006). Elaboration on laws and regulations for AVs and characteristics of AVs can be found in appendix A.

2.1.3 Rural Distributor Roads

A distributor road has the function to let traffic flow on road stretches and to exchange the traffic on intersections. The road can be positioned inside or outside a rural area. In this research roads outside rural areas are treated.

Figure 2-1 Agricultural tractor with trailer.

Figure 2-2 Motor vehicle with limited speed: shovel.

The so called rural distributor roads have in the Netherlands a maximum allowed speed of 80km/h, pedestrians, bicycles and mopeds are not allowed. There are two type of rural distributor roads: type I with 2x2 lanes (2 lanes per direction, see figure 2-3) and type II: 1x2 lanes (one lane per direction, see figure 2-4). Following the guidelines of the design of roads in the Netherlands, AVs are not allowed on rural distributor roads type I. For this reason only rural distributor type II are considered in this research. On type II, it is undesirable to allow AVs. In certain situations this is unavoidable, for instance when it is the only possibility for a farmer to access its land or when another route is much longer or more unsafe, like through urban area or in combination with bicycles.

The remainder of this report speaks about rural distributor road of type II, unless indicated otherwise. Through roads are not taken into account, because AVs are prohibited to drive on these roads. Access roads fall outside the scope of the research, because the problems on these roads are of a different category (these can be situations with for example pedestrians or bicycles).

The research is focused on what effect the proposed interventions have on rural distributor roads when AVs are allowed. On these roads there is a discussion to allow AVs or to ban them, because AV's conflict with heavy traffic flows and high speed levels. This could lead to unsafe situations and hindrance for other traffic.

Figure 2-3 Rural distributor road type I

Figure 2-4 Rural distributor road type II with overtaking prohibition.

The general capacity of a type II rural distributor road is 1400 pce/h/lane without any disturbances[4] (CROW, 2002). If AVs are allowed to drive on rural distributor roads type II, overtaking of AVs is often allowed. This does not count for situations where the sight distances is limited, for instance due to tunnels, curves, altitude, trees and so on. More guidelines and requirements for rural distributor roads can be found in appendix B.

2.1.4 Reason for agricultural vehicles to drive on the road

According to the sustainable safety approach (SWOV, 2006) it is undesirable to allow AVs on rural distributor roads. Despite of that, from origin AVs are already allowed on rural distributor roads, because the drivers have often an origin or destination along the road. AVs and other slow moving vehicles make use of the road for several reasons:

- **Transportation of harvest from a parcel to the farm**: if a parcel is not connected to the farm the farmer has to drive with its AV via the road. In case the route is via a rural distributor road, it makes use of this road.
- **Transportation of farm equipment and machinery**: farmers not all have their own machinery for instance to harvest corns, because these vehicles are big and expensive. During the harvesting season contractors are used which have such a machine. This contractor goes to different farms and makes often longer trips via the road to access these companies.
- **The farm is only accessible via the rural distributor road**: there in no alternative route available.
- **Intake points for harvest**: harvest needs to be brought to an intake points. This could be done by a truck, but is also done with tractors. The choice of vehicle totally depends on the structure of the company.
- **Soil and sand transportation**: next to trucks, tractors with dumpers are used for soil transportation. An indication of CUMELA (Eurlings, 2010) is that about 15 per cent of the time transportation with dumpers is done for soil and 40 per cent of those transportations is done via public roads. Usage for building contractors is unknown. Tractors are also used for transportation of sand from extractions to other places, especially when distances between these locations are small.

2.2 Theoretical framework

The attendance of AVs on public roads could lead to unsafe situations, decrease of traffic flow and have influence on the environment. A theoretical framework is given for these three aspects in relation to AVs.

2.2.1 Traffic safety in relation to agricultural vehicles on rural distributor roads

In the Netherlands, road authorities are responsible for traffic safety and flow on the road. This means for road authorities they should take measures and to design the road such, that the road is as safe and reliable as possible. To improve traffic safety, roads are designed following the guidelines of the sustainable safety approach. A sustainable safe infrastructure means it should be designed on such a way that it is clear for users what could be expected of them and in such a way that mistakes are avoided.

The distributor roads subject of this research is one of the three kind of roads distinguished in the sustainable safety approach, see figure 2-5 (SWOV, 2006).

[4] Disturbances which could influence the capacity are for instance bad weather circumstances, a mix of different vehicle types and congestion.

- **Through road**: continue flow of traffic. Through roads are designed for flow of traffic over wide distances. These are for instance freeways with a speed limit of 100 or 120km/h and these roads have a high capacity. On these roads AVs are not allowed, because the very low speed limit of these vehicles can lead to dangerous situations.
- **Distributor road**: flow of traffic on road sections, exchange of traffic at intersections. The speed limit of these roads in urban areas is often 50km/h or 70km/h and in rural areas 80km/h. On 2x2 rural distributor roads AVs are not allowed for safety as well capacity reasons (CROW, 2002). On 1x2 rural distributor roads, AVs are often allowed by provinces to drive on, see paragraph 2.5.3, despite of the sustainable safety approach which says it is undesirable to allow AVs on these roads. Allowing AVs on these roads could lead to unsafe situations, because of the increasing number of overtaking manoeuvres and speed differences.

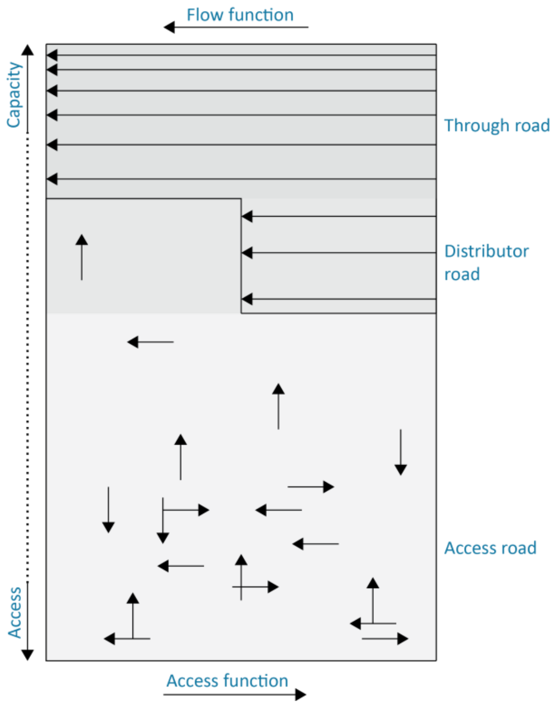


Figure 2-5 Road categorization according to Sustainable Safety (SWOV, 2006)

- **Access road**: exchange of traffic on road sections as well as on intersections. These roads give access to for example houses, offices, farms and lots. In urban areas the speed is often 30km/h, in rural areas 60km/h. On these roads AVs are in most cases allowed, but sometimes prohibited for example in some urban cores. Especially in urban areas the AVs look very big and can give a feeling of unsafety for residents and AVs mixed with bicyclists and pedestrians could lead to unsafe situations. An access road could also be a parallel road, which is often used for AVs as an alternative for provincial roads. Problem on these roads is same as in rural area: bicyclists are, in case of no separate bicycle path, allowed on these roads.

The sustainable safe approach consists of the following five principles (SWOV, 2006):

- **Functionality**: use of roads the way it is designed. Roads should be mono-functional.
- **Homogeneity**: conflicts between road users with a large difference in mass, speed and direction should be avoided. So homogeneity of mass, speed and direction.
- **Recognizable**: design of the road so that traffic situations are consequent, predictable and easy to understand for users.
- **Forgiving**: design of the road on such a way, that serious injuries during an accident are prevented.
- **State awareness**: by the road user. Ability to assess one’s task capability to handle the drive task.

Sometimes it is unavoidable for users of AVs to make use of public roads. In case an AV (with a maximum allowed speed of 25km/h) is driving on a rural distributor road, this is not in line with the sustainable safety approach. In relation to AVs driving on rural distributor roads the following can be said:

- **Functionality**: rural distributor roads are designed for a mono-function, flowing on road sections and interchanging at intersections. With large differences in speed (25km/h vs. 80km/h) this flow function on road sections could decrease.
- **Homogeneity**: the large difference in speed and mass between cars and AVs and the difference in speed between trucks and AVs (mass is about the same) makes it a heterogeneous situation. These large differences in speed can cause unsafe situations, for example when cars behind AVs are overtaking on a road with 1x2 lanes and oncoming vehicles are coming.
- **Recognizable**: in case of AVs using public roads, it should be clear for road users that AVs make use of the road. At the moment, traffic signs are used to show AVs are allowed on the road or not. Next to that, there are situations where overtaking of AV's is allowed and situations where not. Different kind of markings is used to make it recognizable if overtaking is allowed or not. So it should be clear for road users to see that there could be AVs driving on the road due to this signs and markings. If the situation is not clear for road users, this could lead to unexpected situations, which could lead to unsafe situations.
- **Forgiving**: AVs are big, heavy obstacles, which leads to large differences in mass and size. This can create an unforgiving situation.
- **State awareness**: to drive an AV in the Netherlands, no driver license is permitted. A certificate for people of 16 and 17 years old is necessary, but only when they use the AV for their work on public roads. Besides car drivers often do not know how an AV is driving and do not know what to expect from the AV. This means it is hard for other road users to assess the task capability of a driver of an AV (state awareness).

2.2.2 Traffic flow in relation to agricultural vehicles on rural distributor roads

The speed limit for AVs is 25km/h, but vehicles are bounded to 40 or even 60km/h. On rural distributor roads the speed limit is 80km/h, so when AVs are driving on these roads speed differences of 20-55km/h occur. For this reason AVs could delay other vehicles. The slow moving AV can be seen as a so called *moving bottleneck* (Hoogendoorn, 2000). This means the vehicle slows up other vehicles, because it drives with a slower speed than the main traffic flow. The following vehicles have to move with the same speed as the AV, unless the following vehicle is overtaking the slow moving vehicle. The number of overtaking opportunities depends on the opposing traffic flow and overtaking sight distance. Capacity of the road in case of a moving bottleneck is determined by the speed of the AV and the overtaking possibilities. The theoretical framework of traffic flow describes the effects of AVs on two lane roads by a macroscopic model, by means of intensities, densities and average speed. The effects differ between situation where overtaking is allowed and where it is prohibited.

Quantitative model without overtaking

Let us assume an AV driving on a road section of a 1x2 rural distributor road. In this assumed situation overtaking is not allowed, because of the limited sight distance or other unsafe situations. In this situation other traffic cannot do something else than following the AV with the same speed until it leaves the road or leaving the road itself. This could cause a row with a growing length, until the AV leaves the road again. The consequences of an AV when other traffic cannot take over the AV are described by a quantitative model (Botma, 1981). Via this model it is possible to determine the traffic flow characteristics, like travel time delay and length of the row behind the AV.

Hein Botma has set up the ELOVO project (Effect of agricultural traffic on traffic flow of other traffic on rural two lane roads) (Botma, 1981). This is done by developing a macroscopic model to determine the effects of slow moving vehicles (10-40km/h) on rural two lane roads. For the ELOVO project a macroscopic traffic model is treated to determine the effect of the disruption in time and space, the number of hindered vehicles and the extra travel time of other traffic. This depends on the length of the ride and the speed of the slow moving vehicle, the intensity of the other traffic and if applicable, overtaking possibilities. Starting point of the model is the kinematic wave theory of Lighthill & Witham. This is a macroscopic theory in which the traffic stream can be seen as a flowing medium and not per individual vehicle. The flow of traffic can be characterised by intensity, density and average speed. Changes in the flow can take place in time and space.

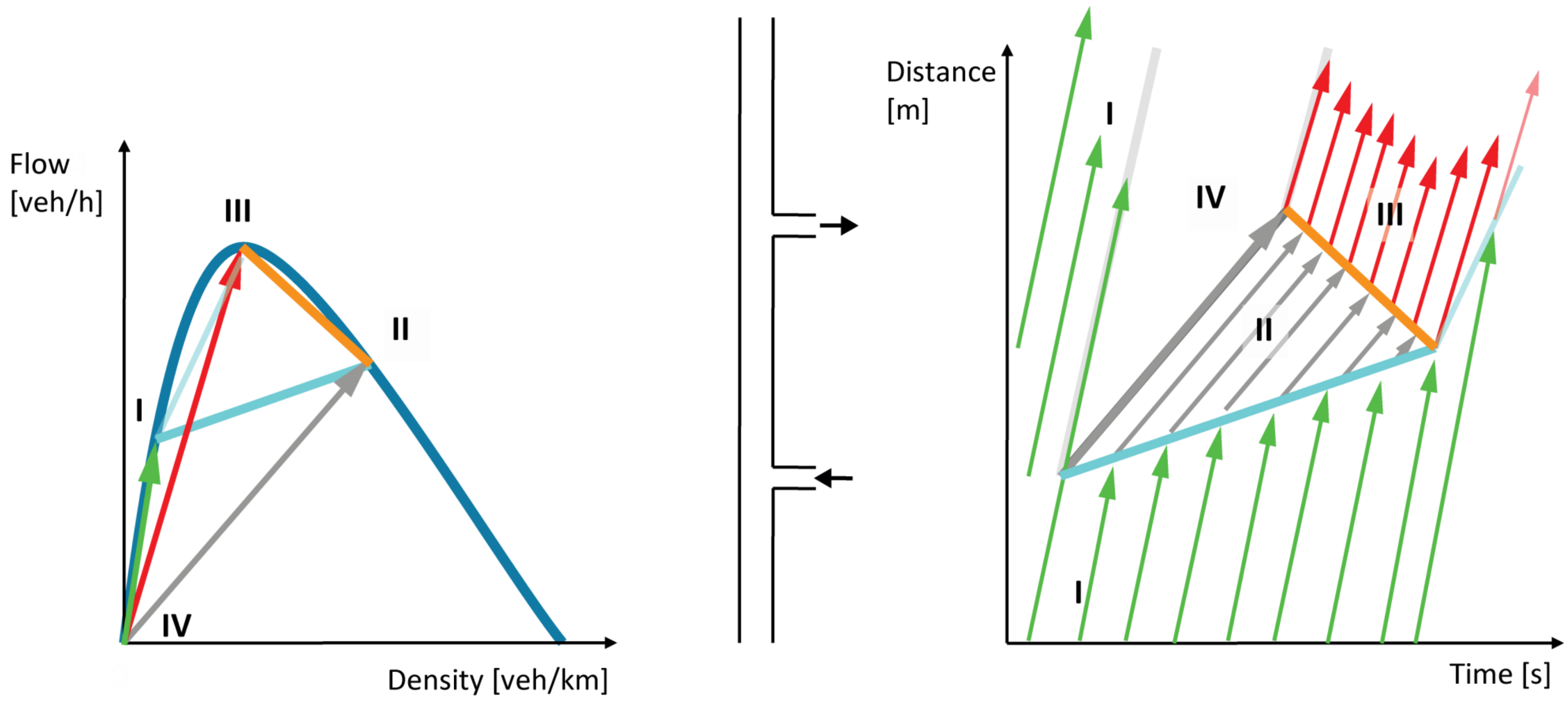
The theory of the moving bottleneck is described with help of a fundamental diagram and a time-space diagram, as shown in figure 2-6. It shows a situation where there are only cars driving, at a certain moment an AV enters the road, drives here for a while and then leaves the road again. Before the AV enters the road, traffic drives with free flow speed (I). When the AV enters the road, traffic downstream of the AV joins the row and follows the slow moving vehicle with the same speed (II). In this case no overtaking is allowed, so the traffic has to follow the AV until it leaves the road. When the AV leaves the road, a transition from a row behind the AV (II) to the capacity conditions of the traffic (III) takes place. A transition between two phases is called a shockwave. During capacity conditions it is possible that some vehicles drive from free flow to the capacity state, so these vehicles join in the row at the back. The destruction of the row downstream grows faster than grow upstream (except when intensity upstream is higher than the capacity), so the row dissolves at a certain moment. From the capacity state there is a gradual transition to free flow conditions. After this, the disruption is totally dissolved and traffic can drive with free flow speed again. The elaboration of the model without overtaking can be found in appendix C.

Quantitative model with overtaking

In case of overtaking, an extra manoeuvre has to be made by the cars which have the desire to pass the AV. The overtaking manoeuvre can be defined as a movement of a vehicle to another lane to pass at least one (slower) preceding vehicle and then moving back to its original lane (Hegeman G. , 2008). During measurements in the province Fryslân (Hegeman & Dijkstra, 2011), the overtaking manoeuvre was measured on the moment the left front wheel of the overtaker passes the centre line until the right back wheel passes the centre line again, see figure 2-7.

In case of overtaking, various overtaking strategies could be used (Hegeman G. , 2008):

- **Accelerating overtaking**: the vehicle that has the desire to overtake the AV first approaches the AV and drives for a certain time behind the AV. If the gap and sight for overtaking is large enough, the vehicle overtakes the AV.
- **Flying**: directly overtaking the preceding vehicle without waiting behind the AV and without losing much speed.
- **Piggy backing**: a vehicle that follows another vehicle that is overtaking.
- **2+**: overtaking more than one vehicle at once. For example a following vehicle and an AV.



Legenda

Phases:
I: Free flow
II: Moving bottleneck + row
III: Capacity
IV: Empty road downstream of slow moving vehicle

Fundamental diagram
Traffic in free flow (I)
Slow moving vehicle and vehicles following (II)
Tail of the queue
Transition from following row (II) to capacity (III)
Traffic during capacity (III)

Figure 2-6 Moving bottleneck shown in the fundamental diagram en in the time-space diagram for a slow moving vehicle driving over a short distance on a road section. Other vehicles on the road do not overtake the vehicle in this situation.

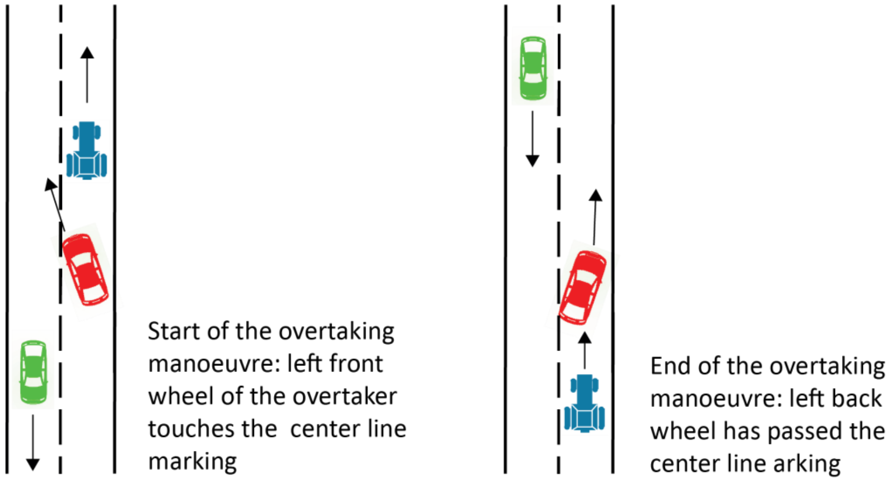


Figure 2-7 Start and ending of an overtaking manoeuvre

Which overtaking strategy is done by the overtaker depends on the circumstances and the driver. In general accelerating overtaking is the most used overtaking strategy.

The number of actually performed overtaking manoeuvres depends on:

- **Intensity of the traffic in *both* directions**: the number of overtaking manoeuvres depends on the intensity and distribution of the traffic in both directions. The more vehicles in the same direction as the AV, the more vehicles have the desire to overtake this vehicle. The higher the intensity in the opposite direction of the AV, the less availability of gaps. This means less possibilities and chance to overtake the AV.
- **Sight distance**: the better the sight distance, the better the overview whether overtaking is possible or not. This sight distance could depend on the design of the road (for example curves, tunnels and altitude)
- **Composition of the traffic flow**: for trucks it is more difficult to overtake an AV or when a truck is following an AV it is also harder for a other vehicle to overtake the AV and the truck. So the percentage of trucks on the road could influence the number of overtaking possibilities and the travel time.

Let us assume a provincial road, where overtaking of AVs is allowed. Again an AV is driving on a road section of a two lane road for a short while; it enters the road at a certain point A and leaves the road at a certain point B. In this situation it is possible for other traffic to overtake the AV by making an overtaking manoeuvre. The more vehicles overtake the AV, the less delay for the vehicles could be; vehicles follow the AV for a shorter period and the row behind the AV is also shorter. This last means that the row dissolves faster if the AV has left the road.

As basis, the same quantitative model as in the situation without overtaking can be used. Difference is that vehicles can overtake. In the time-space diagram, Figure 2-8, this overtaking manoeuvre is shown. In this figure a car is following an AV. The car decides to overtake the AV, accelerates and passes the AV (accelerating overtaking manoeuvre). At the same time, a car in the opposite directing is approaching. The gap between the approaching car and the overtaker is big enough to overtake the AV without collision. In C the theoretical model for a moving bottleneck with overtaking is more elaborated.

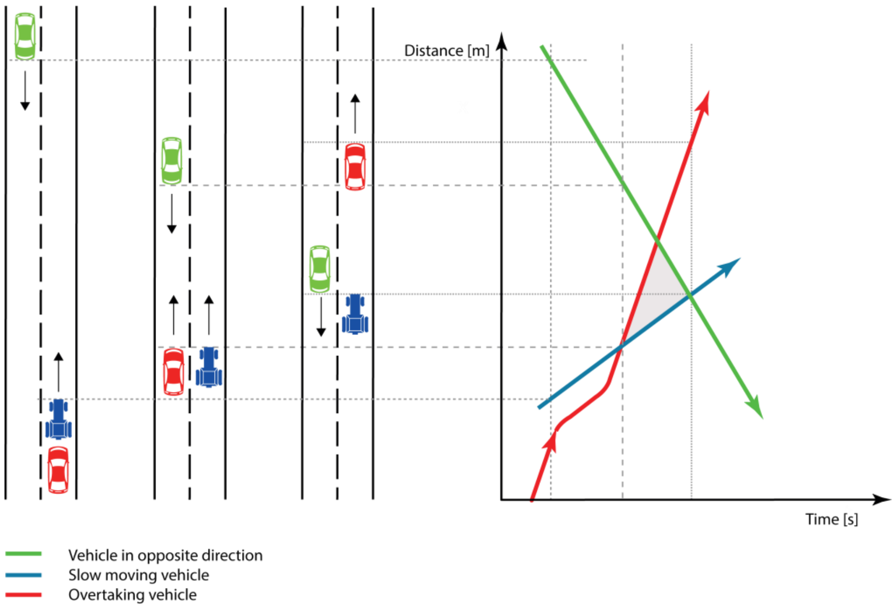


Figure 2-8 Overtaking of the AV in the time-space diagram

Calculations for the province of Fryslân

In Fryslân, measurements are done to determine the number of AVs, the speed of the vehicles, but also characteristics of other traffic (Hegeman & Dijkstra, 2011). With the available data, it is possible to determine the travel time delay and the number of hindered vehicles by using the method of Botma as described above and in the appendix. Calculations of the travel time delay and number of hindered vehicles can be found in appendix D.

2.2.3 Environment in relation to AVs

Effects of AVs in relation to environment can be are analysed via the planet part of the People, Planet Profit principle (Triple P), see figure 2-9 (MVO, 2012). This term finds its origin in sustainable development and represents not only environment, but also people and benefits. Explanation of the triple P:

- **People**: consequences for people in the surroundings, e.g. on safety and liveability.
- **Planet**: consequences for the environment
- **Profit**: the production and economic impact

The people part can be partly found back in the safety part of this research and the profit part in the traffic flow part and costs of possible interventions..

In this research these environmental issues are taken into account on a qualitative way. This means the effects of AVs on the planet are not explained by indicators, but give an inside in the possible effects.

In relation to the planet part are environmental issues related to AVs driving on roads are related to the quality of the air and noise hinder which could be created by AVs. Also the impact on the landscape is taken into account. This consists of the space necessary to implement an intervention.

Figure 2-9 Environmental issues related to AVs will be analyzed by the three Ps

2.3 Current situation in relation to AVs on rural distributor roads

At the moment AVs make use of (rural distributor) roads. The effects of AVs has impact of traffic flow, safety and environment. The current situation in relation to AVs is mostly described for AVs driving on rural distributor roads, but for traffic safety also a comparison with other roads is made.

2.3.1 Current situation in relation to traffic safety

Accidents with agricultural vehicles (objective safety)

Accidents in relation to AVs driving on public roads are hard to judge relatively, because no exact number of AVs and kilometres driven by AV are known It is expected that the number of kilometres has increased by developments in the agricultural sector, but the exact number is not known (Onderzoeksraad voor Veiligheid (OvV), 2010). Therefore, it is hard to draw a conclusion about the developments in the number of accidents. Nonetheless, in figures something can be say about the number of accidents, see table 2-1. This information is based on the research to accidents of AVs between 1987 and 2008 is used (Jaarsma & de Vries, 2010). This research provides an indication of AVs involved in road accidents. Important to note is that this research is done for agricultural and forestry tractors and not for motor vehicles with speed restrictions.. This means involving the motor vehicles with speed restrictions could lead to even a higher accident rate. The most important source used by Jaarsma & de Vries is a spread sheet made by the Data-ICT-Service of Rijkswaterstaat consisting of police registrations

The number of fatalities involving AVs has been stable around 16 per year in the past years. This seems low, but one can say that every traffic fatality is one too many. Moreover, a worrisome trend is that the number of fatalities involving AVs stays constant where the total number of traffic fatalities decreases. And, the impact, i.e. the severe accidents involving AVs is increasing. Also on rural distributor roads is the impact high and the average number of fatalities is 5 per year.

Table 2-1 Overview of accidents with AVs between 1987 and 2008

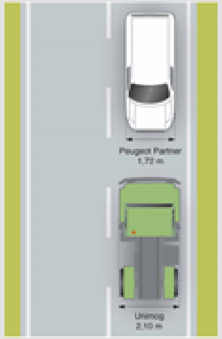
	Fatalities	**Hospitalizations**	**Injuries**
Number of accidents involving AVs	15-16 per year	About 97 per year	About 144 per year, but decreasing
% of total number of accidents	Grown from 1 to 2% of total road accidents	About 1%, but increasing	Constant (same development as total number of injuries)
	Rural access roads	**Rural distributor roads**	**Urban areas**
Number of fatalities	8	5	3
	Flank collision	**Frontal accident**	**Head-tail**
Classification	45%	19%	16%
	No priority	**No throughput**	
Cause accidents	19%	17%	
	1st involved vehicle	**2nd involved vehicle**	
Involved road users	59% AV	Cars: 36% Bicycles: 17% (for fatalities 20% bicycles) Moped: 16%	

Severity rate

The severity rate can, in contrast to the number of accidents, provide more information about the risks of accidents with AVs. A rate for severity is the accident severity. This rate is a scale for the degree of unsafety which can be used to compare different locations or different circumstances, for instance in or outside urban areas or on distributor roads and access roads. The accident severity is the number of fatalities per hundred victims of accidents with injuries or fatalities. The higher this rate, the higher the risk of a road accident on that specific location of circumstances. When In rural areas the severity rate is higher than in urban areas, but there a differences between the type of roads. In rural areas the differences between the access roads (severity rate 6.8) and rural distributor roads (severity rate 6.9) are small. Nonetheless, the accident with pedestrians, bicycles , motor or scooter have a lot higher severity rate with AVs , than for instance cars or trucks, especially when AVs are the cause of the accident (Jaarsma & de Vries, 2010).

Swifterband

Description: an Unimog (multipurpose car) was driving on a rural two lane road with speed limit 80km/h. On the the opposing lane three vehicles approached the Unimog. While the passenger car and the van overtook the truck, the van was too late for turning back and hit the Unimog. The driver of the van died, the driver of the Unimog stayed unharmed.



Accident factors: conflict aggressiveness, risk perception and choice of vehicle, speed and road design and separation of AVs.

Accident could have been prevented by: e.g. implementation of an overtaking prohibition and separation direction, separation of AVs, enforcement of the speed limit.

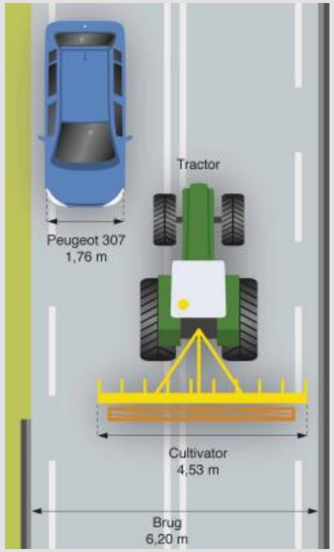
Figure 2-10 Description of an accident involving an AV on a rural access road (source: Onderzoeksraad voor Veiligheid (OvV), 2010).

Analysis of a number of accidents involving AVs

Three accidents with AVs are analysed, including one accident on a rural access road, one on a rural distributor road and one on a small access road (Onderzoeksraad voor Veiligheid (OvV), 2010), see figure 2-10, figure 2-11 and figure 2-12.

Wieringerwerf

Description: A tractor with a 4,5m wide field cultivator behind its vehicle on a rural distributor road in the municipality Wieringerwerf. At the height of a bridge (width 6,2m) a passenger car meets the tractor and is hit by its cultivator. The driver of the passenger car is seriously injured.



Accident factors: width of the vehicle, conflict aggressiveness, risk perception and choice of equipment and separation of AVs.

Accident could have been prevented by: e.g. separation of AVs, abide by the rules of the tractor driver, enforcement (movement of the AV from road, because of the large width of the AV or remove the cultivator from the AV when using the road), swerve opportunities for the passenger car.

Figure 2-11 Description of an accident involving an AV on a rural distributor road in Wieringerwerf (sourc: Onderzoeksraad voor Veiligheid (OvV), 2010).

Woldendorp

Description: an agricultural tractor was driving with a dumper on a small rural access road where the speed limit is 60km/h. No centre line and side marking were present. While the tractor took over bicyclists, the back cyclist fell was run over by the tractor and died.

Accident factors: width of the road (only 3,15m) and tractor (2,95m), no path for bicyclists, conflict aggressiveness (no side protection on tractor).

Accident could have been prevented by: e.g. side protection (could have decreased the impact), separation of bicyclists.

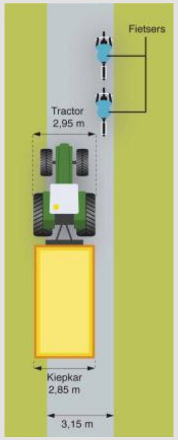


Figure 2-12 Description of an accident involving an AV on a small access road in Woldendorp (source: Onderzoeksraad voor Veiligheid (OvV), 2010).

From these three (and other) accidents one can conclude that the cause of accidents vary a lot. Accidents could be caused (or reinforced) for instance by speeding, differences in speed, behaviour and design of the AV. The accidents could have be prevented by several possible interventions. These interventions are discussed in chapter 3.

User acceptance

Different actors could have problems with AVs (not) driving on rural distributor roads and therefor influences the acceptance of AVs driving on rural distributor roads.

Road authorizations are responsible for traffic flow and safety on the road. In relation to traffic safety problems can occur because of large differences in speed, size and mass. Furthermore, unsafe or forbidden overtaking manoeuvres and unpredictable turning movements from and to lots could occur. In relation to traffic flow AVs could lead to traffic flow problems, because of low speed limits for AVs. Road authorities are responsible for solving these safety and traffic flow problems. They are also responsible for the road construction and following the existing guidelines, like the sustainable safety approach. This means it is undesirable to allow AVs on rural distributor roads, but sometimes there is no alternative for these vehicles. Other issues for road authorities are damage at the side of the road, because of the large size, width and mass of AVs (Provincie Noord-Brabant, 2005). In a number of urban areas are problem contacted with the liveability by AVs driving through urban areas. For this reason some road authorities (like the province Gelderland) allow AVs on provincial roads around the municipality. The roads through the centre of the municipalities are closed for AVs and on the provincial roads some interventions are taken to avoid negative effects on traffic flow and safety. In Gelderland are for this reason some passing bays constructed. What the exact of these passing bays are, is not known yet.

Farmers have to transport for instance harvest, cattle or grass between their lots, farm or depot. Driving on roads could give problems to drivers of tractors with the visibility of other traffic, other traffic that overtakes their vehicle and cut them off. Tractors also can make turning movements on unexpected places for other road users, because of entrances to their land (no common entrance for other traffic). Another issue is that AVs do not always have another possibility than driving to their destination than making use of rural distributor roads for transportation. If AVs have to make a detour this can lead to extra time and costs for the farmer.

Agricultural service supply agencies drive their AVs over larger distance. Drivers for agricultural service supply agencies have often a larger working area than farmers have. A working area with a radius of 30 kilometre is not uncommon (Dijkema, 2012). This means these vehicles drive over a longer distance and this could lead to a lot of following vehicles on rural distributor roads, because of the difference in speed. Another problem of these vehicles is that it are large machines, which have a large width, such as a harvester. The maximum width of these vehicles on the road is 3,5 meters and vehicles with this wide width could lead to unsafe situations.

Road users other road users on roads. On rural distributor roads this are for instance drivers of passenger cars and trucks. On rural distributor roads other road users could get the feeling that they lose a lot of time when they are driving behind AVs. This could lead to irritation and (unsafe) overtaking manoeuvres. Next to that those big AVs could give a feeling of unsafety as well as overtaking manoeuvres. AVs could also make turning movements on locations where other road user this do not expect and mud on the road caused by AVs could lead to slippery roads for other road users. On parallel roads the combination of AVs and bicyclists could lead to unsafe situation and a feeling of unsafety by bicyclists. This also counts for AVs driving through cores of municipalities in combination with bicyclists and pedestrians.

Residents in the surrounding area of roads where AVs are driving. These people could have noise and air pollution hinder of AVs. Also AVs driving on in front of their house could give a feeling of unsafety. It is often undesirable for residents to see AVs driving through urban areas or on parallel road in combination with bicyclists and pedestrians. On the other hand, AVs could lower the speed of other traffic on rural distributor roads (Province Fryslan, July 2012)

Summary of traffic safety in relation to AVs

Problem with accident statistics with AVs is that the exposure of AVs on public roads is not known. For this reason only in figures something can be said about the number of accidents.

The number of fatalities involving AVs has been stable around 16 per year in the past years. This seems low, but one can say that every traffic fatality is one too many. Moreover, a worrisome trend is that the number of fatalities involving AVs stays constant where the total number of traffic fatalities decreases. And, the impact, i.e. the severe accidents involving AVs is increasing. Also on rural distributor roads is the impact high and the average number of fatalities is 5 per year. On these roads speeding, speed differences, driving behaviour, design of the AV and roads design are the main cause of accidents.

2.3.2 Current situation in relation to traffic flow

Number of agricultural vehicles on the road

Table 2-2 shows an estimation that AVs are between 1,0 and 2,4% of the total fleet of motor vehicles in the Netherlands. This is an estimation by Off-Highway Research (Off-Highway Research, 2009) and another estimation by *Dienst Wegverkeer* (RDW) and suppliers is 200.000 tractors and 20.000 pieces of self-driven equipment (CUMELA, Position Paper, 2009). This difference in estimation is caused by the lack or registration of AVs since 2006 (CROW, Kennisplatform Verkeer en Vervoer, 2006), so the exact number of AVs in the Netherlands is not exactly known.

An estimation of CUMELA[5] is that 70.000 – 80.000 of these vehicles make frequently use of the road. About 50-60% of these vehicles are coming from agricultural service supply agencies. The number of bought tractors with dumpers increased with about 7 per cent between 2006 and 2010 (Dijkema, 2012).

Number of trips of AVs

There is little known about the number of trips driven by AVs. An indication of this number can be made if a lot of knowledge of the area is available. It is also possible the measure the number of trips of AVs with use of cameras ((Hegeman & Dijkstra, 2011), see also 4.3.3.

[5] Branch organization for agricultural service supply agencies, active in land development and earth moving, fertilizer distribution and agricultural contract work

Table 2-2 Size of the fleet of motor vehicles in the Netherlands (Onderzoeksraad voor Veiligheid (OvV), 2010)

Category	Numbers	Percentage [%], off-highway	Percentage [%], RDW
Passenger cars	7 391 903	80.7%	79.7%
Delivery vans	862 303	9.4%	9.3%
Motorbikes	585 204	6.4%	6.3%
Lorries	220 220	2.4%	2.4%
Agricultural and forestry tractors	85 000[6] / 200 000[7]	0.9%	2.2%
Self-driven equipment	12 175[6]/ 20 000[7]	0.1%	0.2%
In total	**9 156 805[6]/ 9 179 630[7]**	**100.0%**	**100.0%**

Per type of agriculture, the season and for soil activities, the number of trips can differ a lot. In general, most AVs are used from April to October (main season), but also in February and March activities could be noticed (Jaarsma, 2012):

- **Half of February and March**: fertilization season. Farmers and contractor companies could drive with large machinery and tanks on the road.
- **From April**: making the land ready for seeding and seed it: a lot of farmers drive with their own tractor on the road.
- **May and June**: in general a bit quieter period. Possible to cutting grass and transport it to store it. This is done about 4-5 times a year. The transport depends on the weather: grass has to be removed from the field when it is dry.
- **Summer months**: several activities, like mowing and haying.
- **Autumn**: harvesting of several crops, like beets. Large machinery of agricultural service supply agencies are used.

Vehicles for earth moving and construction are used the whole year and when used for a certain location only for a while a peek in the number of AV's are noticeable.

Length of trips of agricultural vehicles

There is little knowledge about the number of trips of AVs, but there is even less knowledge about the length of these trips. This could also be determined via gathering a lot of information of a certain area, but this is intensive.

Length of trips could be determined by the number and distance between parcels of one agricultural company; the larger the distance between the parcels which are not connected, the longer trips the farmer has to make via public roads. Another point that influences the trip length is the distance to intake points of harvest. Some farmers, harvest has to be brought to intake points. This could be done by tractors. For certain crops, the number of intake points are decreased. This means the length of the trips with the tractor are longer (Jaarsma, 2012). Next to that, the use of machines of a contractor is also of influence for the trip length. For instance for corn or beet harvesting, for which really large and expensive machines are needed, contractors are used. To give an example: for machine-lifting beets 90% of the vehicles are coming from agricultural service supply agencies and 70% of earth moving activities is done by these companies (CUMELA, Position Paper, 2009). These contractors go to several farmers in the region for cropping the harvest. The area could have a radius of about 30 kilometre (Jaarsma, 2012). The transport of this machinery goes all via the road, so this could lead to long trips of AVs on road. These machines are only used during certain seasons.

[6] Estimation by off-highway research
[7] Estimation by RDW and suppliers

The total number of kilometres driven by AVs and the length of their rides is not known. From a small survey by Rijkswaterstaat an indication of the length of the rides is that more than 60% of the rides are 10 kilometre or longer on public roads. (De Onderzoeksraad voor Veiligheid, 2010). Note should be made for this number, because this could differ per area, type of agriculture, per season, the size of the company and so on. To exactly known driven kilometres in an area, extra research needs to be done.

Summary of traffic flow in relation to AVs

The number of vehicles and the length of trips of AVs is not known in the Netherlands. This information is dependent of a lot of factors. For instance on the season, the type of agriculture and the distance between the lots of one farmer. For this reason should per location be analysed how many AVs are driving on the road and how long their trip is. This could give a better insight in the effects of AVs on traffic flow on that specific location.

2.3.3 Current situation in relation to environment

AVs driving on (rural distributor) roads could have effects on the environment. In the Netherlands, traffic and transport is partly responsible for emissions of greenhouse gas (18% in 2009), acidifying emissions (27%) and emissions of particulates (32%). The emissions have influence on the living environment, because traffic and transport takes mostly place on ground level.

The emissions of road traffic are coupled to the category traffic and transport, while emissions of AVs are coupled to the sector in which these vehicles are used (Compendium voor de leefomgeving, 2010). Effect of the presence of AVs on rural distributor roads could have influence on these environmental issues.

Next to the emissions, traffic is also responsible for a part of the noise hinder and vibrations. This can be caused by AVs driving on rural distributor which hinder other traffic. This traffic has to make extra acceleration and deceleration movements because of the AV driving on the road. This could also have influence on the quality of the air.

If AVs are not allowed to drive on rural distributor roads, it can be possible that these vehicles have to make large detours, which causes extra noise and pollution hinder.

During harvesting season it can be possible that there is more mud on the road because of the AVs driving in the road with their crops. This could lead to a slippery surface of the road.

2.4 Developments in the agricultural sector

In the agricultural sector there are some developments going on which could influence the number of AVs driving on roads and the speed of AVs. These are developments in the number and size of the agricultural companies in the Netherlands and the developments of the AVs itself. Both have consequences for the attendance of AVs on rural distributor roads.

2.4.1 Number and size of companies

The number of agricultural and horticultural companies is decreasing since 1960's. In that period there were 300 000 companies in the Netherlands, in 2010 there were only 72 000 left. In the last ten years the number of companies is decreased with 28 per cent. From the remaining 72 000 companies, 38 000 companies (53%) are livestock companies. Figure 2-13 shows that although the number of companies decreases, the total surface of agricultural land stays about the same. In other words, the size of the companies grow, which leads to increase of scale. Besides, the size of the lots stays the same, see figure 2-14.

This means that per company more surface of agricultural ground is available; this is called increase of scale (CBS, 2012). This means companies have more lots, which are often not connected to each other. This means that company owners have to make more and longer rides with their AVs on public roads. Because, farmers have to transport machinery, harvest, cattle and so on, from one lot to another or to the company itself.

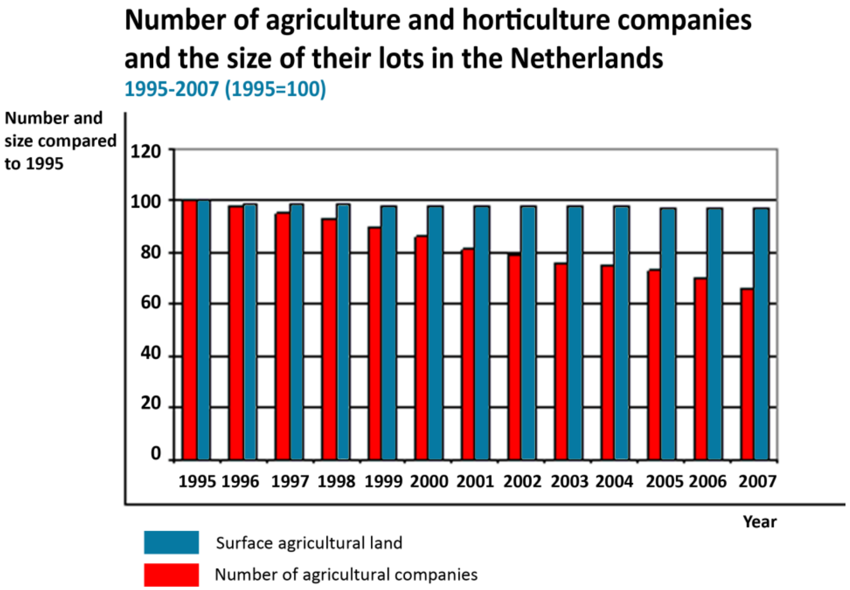


Figure 2-13 Number of agricultural and horticultural companies and the size of agricultural land between 1995 and 2007 in the Netherlands (CBS, 2008).

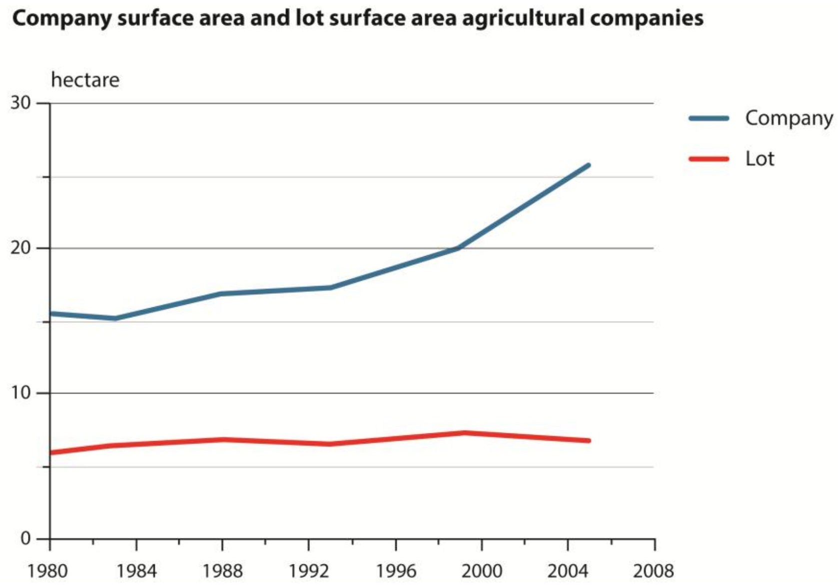


Figure 2-14 Surface of agricultural companies and size of the surface of the parcels of these companies (Compendium voor de leefomgeving, 2011)

2.4.2 Developments agricultural vehicles

Next to the increase of scale in the agricultural sector, developments in AVs take place. Technological developments have increased the possibilities with AVs and the vehicles are stronger, faster and bigger.

The maximum power of tractors is increased from 60-70pk (45-55kW) in the 1960's to more than 300pk (215kW) at this moment. Corn harvesters can have a power of even more than 800pk (600kW) (CUMELA, Position Paper, 2009). Nowadays, most agricultural tractors have a power of 75-150kW (medium class). Vehicles in the heavier class are used for harvesting, pick-ups and transport. These vehicles are also used for earth moving activities by contracting firms (Jaarsma & de Vries, 2010). With the increasing power of the AVs, the speed of the vehicles is also increases. While the speed limit for AVs is 25km/h, about a third of all tractors drive more than 40km/h. About 75-80% of the new sold vehicles can drive faster than 40km/h. The medium class tractors are limited between 40-60km/h. There are already high class AVs that can drive 80km/h (Rijkswaterstaat, 2006).

2.4.3 Effects of developments

The decreasing number of agricultural companies and similar surface of lots leads to longer trips of AVs. Next to that more companies make use of contracting firms. The work radius of one contacting firm is often higher than 30 kilometres. This leads to longer rides via public Developments in AVs lead also to higher driving speeds by AVs. This could on the one hand lead to problems with traffic safety, because regulations and road design for AVs do not take into account this high speed and the speed limit in the Netherlands is still 25km/h. At the other hand, on rural distributor roads this leads to smaller differences in speed with other traffic and therefore it is expected that the number overtaking manoeuvres decreases. But, important to take into account is that a driver license is at this moment not required and higher speeds could lead to more dangerous situations. In 2014 the driver license for AVs will be implemented.

2.5 Policy framework

National policies are available to develop guidelines for road authorities. Road authorizations, such as provinces, are free to stick to the guidelines. Regarding AVs, national guidelines are available, but many provinces have their own way to deal with those vehicles in relation to rural distributor. This is reflected in the difference between the policies and what happens in practice.

2.5.1 National policy for AVs driving on rural distributor roads.

In the Netherlands, there are AV regulations which are part of the law for road regulations (Wegenverkeerswet 1994). In these regulations, permanent (user) demands are described, such as maximum dimensions, mass, speed and lightning. This regulations should followed by AVs when driving on public roads. Regulations in relation to vehicle characteristics can be found in appendix A. In this appendix also a comparison between the AV regulations in the Netherlands and in surrounding countries is made. From this comparison can be concluded that Dutch regulation on AVs stay different than surrounding counties. Besides, Dutch regulations stay behind EU-approval which demands for national registration of AV, which is still not the case in the Netherlands.

As mentioned before, the sustainable safety approach gives guidelines to maximise traffic safety. A sustainable safe infrastructure means it should be designed on such a way that it is clear for users what could be expected of them and in such a way that mistakes are avoided. Following this approach it is undesirable to allow AVs and overtaking of AVs on rural distributor roads.

Besides, the guideline 'essential recognisability characteristics' helps road authorizations to construct a road on a sustainable safe way. Via this way it should be clear to road users what is expected from them when driving on the road.

Often, it is traditionally allowed for to AVs to drive on rural distributor roads. To meet the guidelines, changes to the road should be made. The province of Gelderland has developed an assessment framework. This assessment framework can be used by all provinces and is included in the national guidance for AVs (CROW, Kennisplatform Verkeer en Vervoer, 2006), see figure 2-15. This schedule can help provinces and municipalities to find a new route for AVs instead of driving on rural distributor roads. More elaboration on this assessment framework and other available assessment frameworks can be found in appendix F. The frameworks can be a first guideline to decide on possible alternatives for AVs driving on rural distributor roads. The schedules are too general to make a

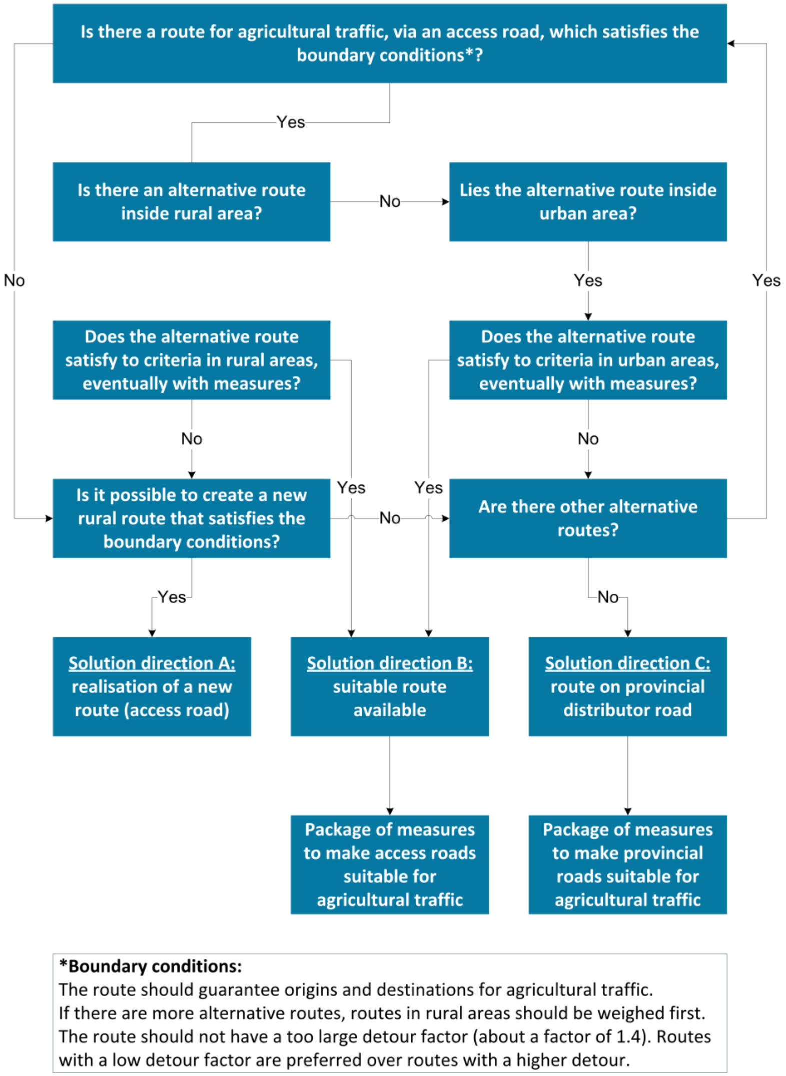


Figure 2-15 Assessment framework agricultural vehicles on rural distributor roads, province of Gelderland (CROW, Kennisplatform Verkeer en Vervoer, 2006)

grounded choice for an intervention on specific location, because only a few factors are taken into account and not all effects are known at the moment. More research is necessary for a grounded decision.

2.5.2 Provincial policies

National guidelines for rural distributor roads about AVs say it is undesirable to allow AVs on rural distributor roads. Road authorizations, such as provinces are free to stick to the guidelines. In general provinces use these guidelines as a starting point for their own policy. Conflicts between policy and practice can occur, because the guidelines cannot be implemented overnight and policy can conflict with surroundings. For example the policy recommends a parallel road, but in practice there is no space for this road. For this reason many provinces have their own way to deal with AVs in relation to rural distributor roads. This is reflected in the difference between the policies and what happens in practice and the difference in interventions which are taken by provinces. An overview of the policy per province is shown in table 2.4. From the table there can be determined some clusters with the same kind of policy:

- Provinces that facilitate AVs as much as possible on rural distributor roads if necessary: Fryslân, Groningen, Drenthe.
- As much as possible separation of AVs and other motorized traffic, only allow AVs when there is no alternative available: Overijssel, Gelderland, Utrecht, Noord-Holland, Zuid-Holland, Noord-Brabant, Limburg.
- Dependent on the situation: Flevoland (depends on intensities) , Zeeland (depends if it is a part of the quality network for AVs).

According to the sustainable safety design (SWOV, 2006) it is undesirable to allow overtaking on rural distributor roads. In the cases where AVs are allowed on rural distributor roads, overtaking of AV is often also allowed, see Table 2-4. Overtaking of vehicles is regulated by road marking; if overtaking is not allowed double axis marking is used (two extended lines between the traffic lanes as direction separation) or a physical separation direction and an interrupted, double axis marking if AVs are allowed.

2.5.3 AVs allowed on many rural distributor roads

From the last paragraph (2.5.2) it is clear that the policy differs per province. For some provinces are AVs important and they try to give room to these vehicles on as many ways as possible, while in other provinces avoid AVs as much as possible on these roads. In practice there could be differences inside a province between the policy and the actual allowance of AVs on rural distributor roads. In figure 2-16 an overview of provincial roads where AVs are allowed and where not. This information in this map is composed by getting information from interviews with provinces, use of available maps of provinces, ViaStat and use of Google maps. In general can be concluded from this figure that in all provinces on more than half of the roads AVs are allowed, even in the provinces that do not want to allow AVs on rural distributor roads, such as Zuid-Holland. An overview of an estimation of the length of the rural distributor roads is given in table 2-3.

From the map and table can be made the following division:

- On more than 80% of the rural distributor roads AV allowed: Drenthe, Overijssel, Flevoland, Gelderland and Limburg.
- Between 70-80% AVs allowed on rural distributor roads: Groningen, Noord-Holland and Zeeland
- On less than 70% (but not lower than 53%) of the rural distributor roads AVs allowed: Fryslân, Utrecht, Zuid-Holland and Noord-Brabant.

Provinces that deviate strongly from their policy in comparison with the actual situation are:

- **Fryslân**: policy Fryslân is that AVs are allowed as much as possible on rural distributor roads if necessary. However, in practice AVs are often not allowed on rural distributor roads. Reason for this could be that there are enough alternative routes, like access roads or parallel roads.
- **Gelderland**: despite of the policy not allowing AVs on rural distributor roads, on a lot of these roads AVs are still allowed. Reasons for this could be that Gelderland has chosen to allow AVs on provincial roads around municipalities and avoid AVs through cores of municipalities and that there are no proper alternative routes

The difference in policy and the actual situation suggests that there are no other options for AVs than using these rural distributor roads and that these vehicles drive here from origin (Gelderland) and for Fryslân that there are enough alternatives so that AVs do not necessarily have to use the rural distributor road.

Table 2-3 Overview of the estimation of the length of rural distributor roads where AVs are allowed and where prohibited

Province	Total length provincial roads (CBS, 2011) [8]	Estimation rural distributor roads type II	Estimation AVs allowed on rural distributor roads		Estimation AVs prohibited on rural distributor roads	
Friesland	671	498	266	53%	232	47%
Groningen	606	403	320	79%	83	21%
Drenthe	518	381	320	84%	60	16%
Overijssel	845	667	537	80%	131	20%
Flevoland	515	312	304	97%	8	3%
Gelderland	1387	1197	1000	84%	197	16%
Utrecht	381	284	172	61%	112	39%
Noord-Holland	640	581	449	77%	132	23%
Zuid-Holland	705	506	269	53%	237	47%
Zeeland	493	302	229	76%	72	24%
Noord-Brabant	611	608	407	67%	201	34%
Limburg	491	452	371	82%	81	18%
Total	7863	6190	4644	75%	1546	25%

[8] Consisting of the length of the main carriage way, connecting lanes (e.g. intersections, on and off ramps) and some other tracks.

Table 2-4 Policy for agricultural traffic on rural distributor roads per province

Province	Policy agricultural traffic on rural distributor roads	Overtaking
Fryslân (Dijkstra H. , 2012) (Fryslân Province, 2011)	Separate bicycles and slow motorized traffic as much as possible. Allow AVs on rural distributor roads if necessary.	In most cases allowed, only not in unsafe situations.
Groningen (Provincie Groningen, 2009) (Oude Egberink, 2012)	Create space for agricultural traffic. Allow AVs as much as possible on rural distributor roads. Avoid AVs on school routes.	In most cases allowed, only not in unsafe situations.
Drenthe (Provincie Drenthe, 2011) (Hiddema, 2012)	Allow AVs as much as possible on rural distributor roads, to avoid as much situations with combination of bicycles and agricultural traffic as possible. If the speed is too high (100km/h) or with certain characteristics, AVs are not allowed.	In most cases allowed, only not in unsafe situations
Overijssel (Goudappel Confeng, 2010) (Beek, 2012)	Striving for separation of fast and slow traffic, following the sustainable safety guidelines and road categorization. Minimize agricultural traffic on rural distributor roads.	Limited overtaking possibilities
Flevoland (Provincie Flevoland, 2006)	Dependent on the traffic intensities, slow moving traffic is permitted or not. With an intensity of more than 12.000 motor vehicles there should be parallel roads for slow moving traffic.	In most cases allowed, only not in unsafe situations.
Gelderland (Royal Haskoning, 2004) (Pit, 2012)	In principal no agricultural traffic on rural distributor roads, only when no other alternative available. In practice this leads to a lot of roads with agricultural traffic	In most cases allowed, only not in unsafe situations.
Utrecht (Provincie Utrecht, 2011)	Agricultural traffic and other motorized traffic preferably separated.	Overtaking in most cases allowed.
Noord-Holland (Winters, 2012)	Avoid agricultural traffic as much as possible on rural distributor roads, dependent on alternative routes or to avoid AV through centres.	If AV allowed always overtaking of AV allowed.
Zuid-Holland (Dijk, J.W.A. van, 2010)	Most roads are closed for agricultural traffic. Licenses are given to AVs that have no other alternative route or parallel road.	Overtaking allowed when AV are allowed, unless unsatisfactory sight distance (tunnels, turns).
Zeeland (Provinciale Staten van Zeeland, 2011)	As less as possible on rural distributor roads. As much as possible via the quality network for agricultural traffic.	In most cases allowed, only not in unsafe situations.
Noord-Brabant (Provincie Noord-Brabant, 2005)	No agricultural traffic on rural distributor roads is allowed, except when there is no other alternative available.	Overtaking prohibition, eventually on certain times
Limburg (Baere, 2009) (Roukens, 2012)	Separate agricultural traffic and other motorized traffic on rural distributor roads as much as possible.	In most cases allowed.

2.6 Conclusion: AVs in relation to traffic flow, safety and environment

In this research an analysis is done to effects on traffic flow, safety an environment of AV interventions. The investigated road type is a rural distributor road type II, consisting of one roadway with one lane per direction and a speed limit of 80km/h. With AVs are meant all agricultural and forestry tractors and motor vehicles with speed restrictions. These have a speed limit of 25km/h and no license plate.

Accidents with AVs leads every year, on average, to 16 fatalities in total. Every traffic fatality is one too many. Besides, the total number of traffic fatalities is decreasing, what means the share of accidents involving AVs is increasing. Next to that, the seriousness of accidents with AVs increases. Also on rural distributor roads the seriousness is high and the number of fatalities is on average 5 per year. Often, speeding, speed differences, driving behaviour, vehicle and road design play a role in the cause of accidents involving AVs.

In terms of traffic flow, an AV can be seen as a so called 'moving bottleneck'. This means the AV drives with a lower speed than other traffic on the road and for that reason keep up other traffic. This leads to a row of vehicles behind the AV that drive with the same speed as the AV. From calculations and other measurements in practice appears that the moving bottleneck has no huge influence on the total traffic flow. A number of vehicles will have a higher travel time, but the effects on the total traffic flow are low The travel time and with that the travel time loss increases when the number of AVs increases.

A sustainable safe road design maximises the traffic safety. Sustainable safe guidelines describe AVs driving on rural distributor roads as unsafe and it is therefore undesirable to allow AVs on these roads. AVs differ in speed and mass with other traffic (no homogenous situation, no forgivingness), can cause decreasing traffic flow for traffic on road sections (functionality of the road), causes unclear situations for other road users (predictability) and it is not always clear what road users can expect from the driving behaviour of AVs.

Although road authorities construct the roads as much as possible following the guidelines of the sustainable safety approach, many provinces still allow AVs on rural distributor roads. At one side to facilitate drivers of AVs and at the other side because there is no better place available for AVs. Together with allowing AVs, provinces also allow often overtaking or at least overtaking of AVs. This conflicts with the sustainable safety principles. The allowance of overtaking can improve traffic flow, but is also unsafe. In relation to the improvement of traffic flow, provinces implement also other interventions (see chapter 4).

The difference between policy and practice and the interventions that are taken by provinces are reason for further research.

Figure 2-16 Provincial roads on which agricultural vehicles are allowed and on which not.[9]

[9] The content of this map is composed by several sources:
- Available maps at Provinces
- Viastat
- Google maps, street view

3 Available interventions to minimize negative effects agricultural vehicles

Different interventions are available to reduce negative effects of agricultural vehicles (AVs) on traffic flow, safety and environment. These available interventions are categorised in seven steps, inspired by the Mobility Ladder[10] (C. Verdaas, 2005). This Ladder is an accepted method to systematically pass through possible interventions in a mobility question. The methodology is aimed at weighing solutions and to avoid constructing new or extending existing infrastructure as much as possible by applying alternative solutions. In this research the steps are used to give an overview of all –ready developed- interventions. An overview of the seven steps shown in figure 3.1. The discussed interventions are based on proposed interventions by the workgroup agricultural traffic[11] and other existing interventions. This can be alternatives for rural distributor roads or interventions that improves the situation with AVs on (rural distributor) roads. Within the scope of this research the infrastructural interventions of step 6 are chosen to be analysed in more detail.

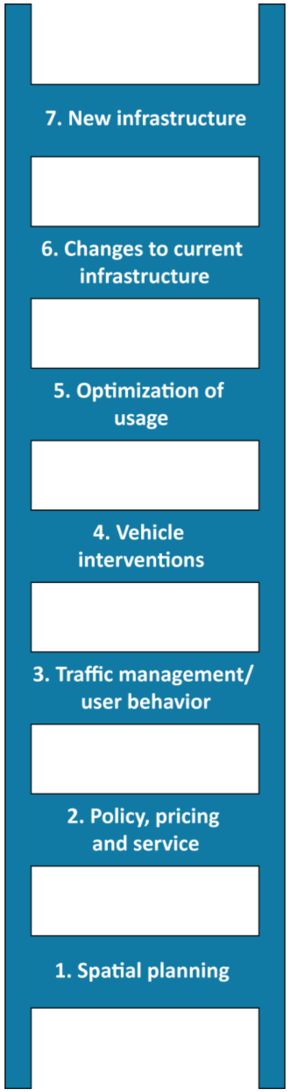


Figure 3-1 Steps inspired on the Mobility Ladder to categorize possible AV interventions

[10] From origin this was called the Ladder of Verdaas and there are different versions of the Mobility Ladder available in which the seven aspects also can vary. As basis the Mobility Ladder as used in the toolbox of sustainable mobility from the unit Mobility at DHV is used for inspiration.

[11] The Workgroup Agricultural Traffic was a group taking initiative to improve traffic safety of agricultural and forestry tractors. The workgroup consisted at the time of CUMELA Nederland, Land- en tuinbouw organisatie LTO Nederland, Regionaal Orgaan Verkeersveiligheid Zeeland ROVZ, Vereniging Veilig Verkeer Nederland, Bureau Verkeershandhaving Openbaar Ministerie BVOM, Ministerie van Verkeer en Waterstaat and Dienst Wegverkeer RDW. Point of interests of the group were: education, information, sustainable safety and (road) infrastructure, vehicle safety, categorization/ labelling, driver license, speeds and enforcement (Initiatiefgroep Landbouwverkeer, 2008).

3.1 Step 1: spatial planning: allotment, quality network and alternative routes

Allotment seems the eldest applied way of spatial planning as a solution to reduce the number of kilometres driven by AVs. Other interventions related to spatial planning are a quality network and alternative routes. An overview and possible advantages and disadvantages is given in table 3-1. Although spatial planning should always be the first step to solution to reduce AV kilometres, the potential of the available interventions allotment, quality network and alternative routes is getting smaller. A lot of changes in spatial planning have already taken place and the limited space in the Netherlands makes it difficult to create some space for alternative routes. An opportunity for spatial planning is the development that companies grow and there is a higher chance for combining companies.

3.2 Step 2: policy, pricing and service

Policy, pricing and service can influence the choice of road users. In the law almost no regulations for drivers and AVs are set-up. Since the 1950s almost nothing changed to the Dutch law and regulations on AVs. Some changes in this could have a positive influence for the position of AVs on (rural distributor) roads, see table 3-2 for possible changes. These changes can have a large influence on the safety of the AVs.

3.3 Step 3: traffic management and user behaviour

Interventions in traffic management and user behaviour could steer the behaviour or give information to road users to improve the situation, like education on schools and for drivers and information to other road users to warn about the risks, see table 3-3. This could be a very effective method, but problem with this kind of interventions is that it is a temporary solution.

Table 3-1 Overview of AV interventions related to spatial planning

Spatial planning intervention	Description	Possible advantages	Possible disadvantages
Allotment	Exchanging of lots between farmers with the aim to concentrate lots to reduce agricultural kilometres	More concentration of lots of one company, so that less rides via public roads need to be made. This has a positive influence on traffic flow, safety and environment.	Already a lot of allotment has taken place in the seventies and eighties (Jaarsma, 2012). Although it still takes place, the gain in reduction of agricultural kilometres is marginal.
Quality network (Provinciale Staten van Zeeland, 2011)	A quality network for agricultural traffic treats agricultural traffic as a full traffic participant and is an overview of roads used by AVs	It points out which roads should be closed or opened for AVs, so that agricultural traffic can drive fluently and safe on the road.	It gives an overview of problems, but do not all solve these problems.
Alternative routes	Routes on other roads than rural distributor roads for farmers to drive between their lots and farm.	AVs do not have to make use of rural distributor roads. Speed differences between AVs and other vehicles are smaller.	This could lead to detours for AVs. On these alternative roads also problems with AVs could occur.

Table 3-2 Possible changes in relation to policy, pricing and service

Changes in laws and regulations	Description	Possible advantages	Possible disadvantages
Registration/ license plate	Vehicles need to be registered and get a license plate to make use of public roads.	Registration of AVs makes several things possible: Categorization of AVs: there can be made a distinction between slow (<25km/h) and fast AVs (>25km/h). This makes it possible to allow for instance only fast AVs on rural distributor roads. Knowledge about the number of AVs in the Netherlands, because all vehicles are registered. It would be easier to recognize and register (e.g. via license plate cameras) AVs on roads, because of a license plate. AVs are registered under an owner/ keeper of the AV.	Extra costs for owners of AVs Chance for a lot of farmers is high that they cannot use their AV anymore and need to buy new AVs.
Admission test	An admission test for AVs should be implemented in the Netherlands. Like all vehicles in the Netherlands, AVs should have an admission test by *Dienst Wegverkeer* (RDW) when imported or bought (RDW, 2012).	Vehicles are tested to and controlled on requirements for safety and environment. So there is more control over the vehicles imported and bought.	Extra costs for owners of AVs Chance for a lot of farmers is high that they cannot use their AV anymore and need to buy new AVs.
Periodic motor vehicle test	If a periodic motor vehicle test is needed. This means AVs are not tested to the requirements.	Higher quality of AVs, because AVs driving on public roads should meet the requirements.	Extra costs for owners of AVs
Speed limit	Increase the speed limit for AVs on rural (distributor) roads to 40km/h. At the moment AVs are only allowed to drive with a maximum speed of 25km/h. All modern AVs can drive with a speed of at least 40km/h and this is also the actual speed these	Less speed differences on rural distributor roads (40km/h instead of 55km/h in speed difference) The low speed limit and the higher actual driving speed, makes it difficult for road authorizations to allow AVs on rural distributor roads, because of the high speed differences. When these vehicles are allowed to drive faster, it is easier for road	Negative effect on seriousness of accidents involving AVs (Onderzoeksraad voor Veiligheid (OvV), 2010) (no combination of bicycles and AVs anymore) Not all AVs are constructed for speeds higher than 25km/h. This counts even more for vehicles with dumpers, which do not have high technical

Changes in laws and regulations	Description	Possible advantages	Possible disadvantages
	vehicles driving with.	authorizations to allow AVs on rural distributor roads. (and make the road part of a regional, logistic agriculture route)	requirements. This could lead for instance to problems with brakes and stability of the vehicle. This will mainly count for older vehicles and not for the modern ones (these are mostly also constructed for countries where speed limit for AVs is 40km/h or even higher). (Onderzoeksraad voor Veiligheid (OvV), 2010). This could be solved by making a distinction between slow and fast AVs, see *registration/ license plate*. More noise and air pollution
Driver license/ requirements of abilities	In 2014 a driver license will be introduced to make use of AVs on public roads.	Improvement of the driver capabilities of drivers of an AV. Easier to register violations of drivers of AVs It is possible to make give restrictions to younger drivers, for instance less load, number of dumpers and size of the vehicle in what the drivers are allowed to drive in.	Extra investments for drivers of AVs are needed

Table 3-3 Agricultural vehicle interventions related to traffic management and user behaviour

Traffic management and user behaviour interventions	Description	Possible advantages	Possible disadvantages
Education on primary schools (Verkeerseducatie loket, 2012)	Give education about agricultural traffic on schools to inform children about the risks of agricultural traffic. There is already a teaching package available for primary schools (group 7 and 8), called 'Dealing on a safe way with noticeable agricultural traffic.' This package is already in use by the provinces Gelderland and Overijssel.	Learn children how to deal on a safe way with AVs on the road. Provinces who want to give attentions to AVs can make use of this package.	Only a small group of road users will be informed and the information will only be temporary. The children should stay informed and not only once.
Education to young and novice drivers of AVs	Another possibility is to give education to young and novice drivers of AVs. On this moment they do not need a driver license to make use of the road, while they drive in a larger and heavier vehicle which will have more impact during a possible intervention. In 2014 a driver license for AVs will be introduced in the Netherlands, so until this time an alternative education method could be used. In the province of Drenthe such trainings are already given to drivers of AVs.	Young and novice drivers get extra education and will learn about the risks of driving with a large vehicle on the road.	It is only education and no driver license, so skills with the AV itself will not be learned. A driver license will therefore be a good alternative.
Information	During harvesting season, several provinces make campaigns to inform road users about the risks of more agricultural traffic on the roads. Movies are made to warn for slippery roads, turning AVs on places where it is not expected and the lower speed of these vehicles. Provinces where these campaigns are already executed are Flevoland and Gelderland (Initiatiefgroep Landbouwverkeer, 2008).	It is good to warn people about the risks and number of AVs on the road during harvesting season.	Outside the harvesting season less attention is given to AVs, while there are still risks.
Enforcement (Initiatiefgroep Landbouwverkeer, 2008)	Increase the enforcement on AVs, this could lead to: When a driver license and administration for AVs will be implemented, enforcement for AVs will be easier and more effective; violations can be more easily administrated. For serious violations it will be possible to void a driver license or a license plate. Improvement of traffic safety (more safe vehicles, lower speeds of AVs).	Enforcement will make drivers of AVs more aware of the requirements for AVs and improves the chance that these drivers improve the quality of their vehicles.	Only a small group of violators will get caught or a lot of extra people are needed to control.

3.4 Step 4: vehicle interventions

Despite of the bigger AVs, technical developments, requirements for traffic safety and other developments in the agricultural sector, no big changes to the Dutch laws are made. Only brand new agricultural and forestry tractors have to follow the EU-guidelines. Vehicle safety interventions which could be implemented are shown in table 3-4 (Initiatiefgroep Landbouwverkeer, 2008). These interventions could be combined with a periodic vehicle test/ admission test. By implementing these rules, the quality of AVs driving on the roads could be improved and could improve safety.

3.5 Step 5: optimization of usage, dynamic traffic management:

To improve efficiency on rural distributor roads when AVs are allowed, a time window could be introduced. This is a time bounded running-in prohibition for AVs. This could be a time window during peak hour, what is already implemented in some provinces. A time window on rural distributor roads during peak hours means AVs are not allowed to drive on the road during peak hours. This could decrease the pressure on traffic flow, safety an environment during peak hours. Disadvantage of the time window is that AVs have to use (longer) alternative routes or might not be able to come to their destination during peak hours.

Table 3-4 Overview vehicle safety interventions

Vehicle safety intervention	Description	Possible advantages	Possible disadvantages
Visibility	Mirrors, reflection (TNO)	Higher visibility and recognisability of AVs	
Protection material on vehicle	For instance screens at both sides of vehicle, protection beam at the front and coverage of sharp parts.[12]	Chance for getting underneath an AV during an accident will be smaller for other road users. Decrease the impact of an AV on other road users in case of a collision. No dangerous, out pulling parts.	Drivers need time to add protection when driving on public road (also when only use it for a very short ride, for instance cross a road)
Brakes	Set requirements for brakes of dumpers, now only requirements for vehicles.	Better braking capabilities of AVs with dumpers	
Decrease number of AVs on public roads	Decrease the number of AV by for instance using other transportations vehicles, like trucks.	These trucks are almost always allowed on rural distributor roads and can drive with about the same speed as passenger cars.	Not possible for all sorts of agriculture. Higher costs for transportation. Not reliable for short rides.

[12] Comparison with regulations abroad, for example Germany where is compulsory when agricultural vehicles are making use of the public road.

3.6 Step 6: changes to current infrastructure

The sixth step is changes in existing infrastructure. With regard to AVs focus is on changes to rural distributor roads. Possible changes to rural distributor roads are: an overtaking prohibition, a passing bay, a passing lane, an overtaking lane, interventions at intersections or downgrade of a rural distributor road to an access road. Each intervention has possible advantages and disadvantages, see table 3-5.

Table 3-5 Infrastructural interventions when agricultural vehicles are allowed to drive on rural distributor roads; changes to current infrastructure.

Combination traffic and agricultural traffic on rural distributor lanes			
Infrastructural intervention	Description	Possible advantages	Possible disadvantages
Overtaking prohibition for all vehicles 	Prohibition of overtaking of other vehicles via lanes in the opposite direction, also AVs. This is starting point of the sustainable safety approach. This could for instance be done by a implementing double axis marking or a physical separation.	No overtaking manoeuvres are allowed and in case of physical separation it is also not possible anymore. This will improve traffic safety.	In case of no physical seperation enformcement is necessary. Next to that people can feel irritated while following an AV and there is no traffic in the opposite direction and they will extra travel time.
Allow overtaking 	At the moment, overtaking of AVs is often allowed. This is shown by a sign combined with an interrupted double axis marking.	Traffic gets the opportunity to overtake AVs and therefore could lose less travel time.	Overtaking via the opposite driving direction could lead to unsafe situation and in forst case to frontal collisions. Impact of these accidents is high.
Passing bay 	Bay at the right sight of the road with a length of about 50 to 100 meters. This bay can be used by AVs to wait on and let other vehicles pass the AVs. In some provinces is usage of passing bays by AVs compulsory in other provinces voluntary.	Other traffic can overtake the AV while making no overtaking manoeuvre via the lane in the opposite direction. This could lead to safer situations and less travel time Queues behind an AV could become shorter.	The AV has to make an extra manoeuvre and have to wait on the passing bay till there is a gap big enough to merge on the main road again. This could lead to extra delay for the AV.

Combination traffic and agricultural traffic on rural distributor lanes			
Infrastructural intervention	Description	Possible advantages	Possible disadvantages
Passing lane 	A lane on the right sight of the road with a longer length than a passing bay, on which an AV can drive while other vehicles pass the AVs on the main road.	The same advantages as a passing bay. Extra advantage is that the passing lane is longer and the vehicle can drive further with its desired speed. At the end of the lane the AV has more space to insert to the main road than on a passing bay.	The AV has to make an extra manoeuvre. If it is busy, the AV has to wait at the end of the passing lane for a big enough gap to merge again.
Overtaking lane (2+1) 	A lane which is constructed at the left side of the main traffic lane, over a limited length of the road. Via this way it is possible to let faster traffic overtake slower vehicles without driving in the opposite direction.	Traffic that wants to overtake the AV can steer to the overtaking lane and the AV do not have to make an extra manoeuvre.	At the end of the lane faster traffic needs to merge to the main traffic lane again. It could be that there still drives an AV and the overtaker wants to overtake the vehicle and accelerates, which could lead to unsafe situations at the end of the overtaking lane.
Interventions at intersections	Interventions at intersections could be taken, for instance an extra streaming lane before and after the intersection or a turbo round about This could give extra opportunities to overtake AVs	If an AV will not turn off at an intersection, cars have the opportunity to overtake the AV.	The overtaking manoeuvre at an intersection can distract from the other interchanging activities at an intersection.
Downgrade distributor road to access road (Fietsberaad, 2008)	Downgrade of a rural distributor road to a rural access road with a speed limit of 60km/h instead of 80km/h	The speed differences between AVs and other traffic will become smaller.	The streaming function on road sections will disappear and other traffic than AVs need longer travel time. Overtaking manoeuvres can still occur.

3.7 Step 7: new infrastructure

The seventh and last step is construction of new infrastructure. This can be create a separate lane or road for AVs or a new alternative route.. In table 3-6 an overview of these interventions.

Table 3-6 New infrastructure agricultural vehicle interventions

Agricultural vehicles separated from other traffic			
Infrastructural intervention	Description	Possible advantages	Possible disadvantages
Parallel road (with/ without bicycles) with separate bicycle path or combined			
	A road next to the distributor road, to separate agricultural traffic from other traffic. In some cases AVs have to share this road with bicycles (Baere, 2009).	AVs do not drive on the main road anymore. This could lead to less delay for other traffic. Also no risky overtaking manoeuvres will be made anymore.	Vulnerable road users are combined with a large and heavy AV. The road should be wide enough so that AVs can safely pass bicycles. A parallel road with a separate bicycle path will be better, a lot of extra space (and money) is required.
Agricultural path			
	A path between a rural distributor road and bicycle path, especially constructed for AVs (Verkeerskunde, 2011)	The AV will have a separate path which improves traffic safety and flow on the main road. Sustainable safety subscribe a shoulder. The path could fit in this shoulder.	The vehicles need at a certain moment enter their lot or another destination. Therefore a agricultural path at both side of a rural distributor road is desirable, what will take even more space.
New alternative routes	This could be a new road for all traffic, e.g. a rural access road or a separate route for AVs	AVs can be replaced from rural distributor roads to the alternative route.	In practice there is often not enough space/ money to create a totally new route.

3.8 Current interventions taken by Provinces

Provinces do not all have the same policy on AVs; this can also be seen in the interventions which are taken by provinces, see table 3-7. Some provinces use mainly education and campaign (e.g. Overijssel, Drenthe), where other Provinces focus more on infrastructural interventions (e.g. Fryslân).

Interventions in the province Fryslân

At the moment the province of Fryslân is still working on the elaboration of passing lanes on the N358. The plan is to construct a total number of eight agricultural passing lanes, four per direction divided over the 13km long part of the road. Reason for constructing these lanes is to let passengers cars and trucks pass the AV on a safe way.

Choice was made to apply interventions on the rural distributor road itself instead of parallel roads, agricultural paths and so on, because of the available space, the traffic safety of road users, inhabitants and the costs is chosen for the passing lanes. Goals is reduce the number of unsafe overtaking manoeuvres around AVs.

Chosen is for passing lanes instead of passing bays, so that AVs do not always have to stop. AVs are allowed to always make use of the provincial road, that is why the province wants to make the passing lane initially not required. Overtaking will be not allowed between the A7 and the exit Augustinusga, except for overtaking of AVs. This choice is made to improve safety of local communities along the N358.

Table 3-7 Current interventions taken by Provinces

Province	Actual use of interventions
Fryslân	Agricultural path Parallel road Restructure agrarian exits Passing lanes
Groningen	Protocol for problems with mud during harvesting season. Time window Parallel roads (bicycles and AVs combined and AVs only)
Drenthe (Provincie Drenthe, 2011)	Campaign about AVs during harvesting season Trainings for drivers of AVs Education on schools
Overijssel	Education on schools
Flevoland (Provincie Flevoland, 2011)	Parallel roads Extending width of the road Target lane AVs Campaign for drivers and other roads users
Gelderland	Passing bays
Utrecht (Provincie Utrecht, 2011)	Regional approach Allotment
Noord-Holland	No use of passing bays
Zuid-Holland	Avoid AVs as much as possible on rural distributor roads
Zeeland	Passing lanes Alternative routes Parallel roads
Noord-Brabant	Time window Separate roadway Parallel roads Passing bays
Limburg	Package of interventions

3.9 Conclusion on AV interventions and choice for further analysis of infrastructural interventions

There are several types of AV interventions available. In this research, available interventions are divided into seven categories, namely: spatial planning; policy, pricing and service; traffic management and user behaviour; vehicle interventions; optimization of usage, dynamic traffic management; changes to current infrastructure and new infrastructure. A distinction can be made between interventions which could be used before allowing AVs on rural distributor roads (spatial planning, new infrastructure) interventions for allowing AVs on rural distributor roads (optimization of usage, changes to current infrastructure) and interventions applicable for every situation (policy, traffic management, vehicle). Although step 1 to 5 are implemented and contribute to the reduction of the number of AVs on rural distributor roads, there will remain rural distributor roads with AVs. And, as long as the sustainable safety design is recommended and not compulsory, provinces are free to implement interventions of step 6: changes to current infrastructure.

Within the scope of this research the infrastructural interventions are studied in more detail. Reason for this is that many Dutch provinces allow AVs on rural distributor roads and overtaking of AVs, also when their policy is to ban AVs as much as possible on rural distributor roads. Several provinces apply infrastructural interventions for AVs driving on rural distributor roads, such as passing bays and passing lanes. Problem is that these interventions are different per province and that the exact impact of those interventions is not exactly known yet. Besides, the different solutions per province can have influence on the predictability on a negative way and can lead to unclear situations for road users on rural distributor roads. The analysis focusses on the performance of infrastructural interventions; what the effects of these interventions are on traffic safety, traffic flow and environment and whether the interventions have (both positive and negative) consequences for all traffic using rural distributor roads and its' local residents. How this is analysed, is described in chapter four.

Not focussing on the other interventions does not mean the other available interventions should be excluded. Instead, it is important to take all possible solutions into account when before allowing AVs to drive on rural distributor roads.

Interventions that are further analysed in this research are an overtaking prohibition, a passing bay, a passing lane and an overtaking lane. An overtaking prohibition is the starting point of the sustainable safety approach; this is the ideal situation following the approach. This is compared to the other three chosen interventions. The allowance of overtaking is not taken into account, because this on forehand an undesirable and risky intervention. The further analysed interventions are interventions that could replace the allowance of overtaking. The downgrade of a distributor road to an access road is be further analysed. This change does mean it is no rural distributor road anymore and other extra factors play a role, such as bicycles and mopeds. This falls outside the scope of the research. Interventions at intersections are not taken into account for the same reason. These interventions take place at intersection level and can be seen as an extension of a roundabout or intersection with extra streaming lanes.

4 Determining performance of infrastructural interventions

Several methods are available for determining effects of agricultural vehicles (AVs). After a thorough comparison of the possible methods, a microscopic simulation is chosen for analysing the infrastructural interventions (no overtaking, passing bay, passing lane and overtaking lane) for AVs. The chosen microscopic simulation model Aimsun is able to determine the performance of infrastructural interventions. The input data for the simulation was collected by Royal HaskoningDHV on the N358 in Fryslân. The location of the measurements is used to apply the infrastructural interventions and analyse the effects of the interventions on that specific location

4.1 Microscopic simulation model best applicable method to analyse infrastructural interventions

The effect of infrastructural interventions on traffic safety, traffic flow and environment needs to be analysed. To analyse this, several methods are available, like simulation, driver simulator, manual calculations and practical tests. A microscopic simulation is preferred in this case, because of the need to see the effects of an AV on the remaining traffic. In a driver simulator focus is on only one vehicle and real traffic measurements take too long, because of the limited number of AVs on the road. No manual calculations are made for all interventions, because of the calculation time with all possible scenarios. Consideration of using a microscopic simulation instead or a macroscopic simulation is that the effects of individual vehicles need to be analysed; on macroscopic level the effects per vehicle cannot be determined.

4.2 Aimsun best applicable microscopic simulation model to analyse infrastructural interventions

The microscopic simulation model Aimsun is chosen to be the best applicable model to analyse the impact of infrastructural interventions on traffic flow, safety and environment.

There are several microscopic simulation models available. To choose which microscopic simulation model to use in this case, the following requirements for the model are compared to the characteristics of the models:

- Possible to use it for the Dutch road situation;
- Possibility of overtaking is a pre;
- Program should be available for this research: if the program is not available to use for this research (it is for instance for intern use only), it will be difficult to use it;
- The possibility to model rural roads;
- The program should be kept up-to-date: it should be possible to use it in future as well.

The microscopic simulation models Paramics, RutSim, Omnitrans, Fosim, Dracula and Aimsun are considered with respect to the above requirements. The microscopic model Aimsun is chosen based on the fact that it fulfils most of the requirements: it is applicable for the Dutch situation, it is applicable for rural distributor roads, the program is available for this research and the program is still keeping up-to-date.

A more elaborate explanation for the choice of a microscopic simulation and for the microscopic simulation model Aimsun is given in appendix H.

4.3 General description microscopic simulation model Aimsun

The microscopic simulation model Aimsun, which is used for the simulation of the infrastructural interventions, is a tool for traffic analysis to help in the design and assessment of traffic systems. The microscopic simulation model follows a microscopic simulation approach, which means that the behavior of each vehicle in the network is continuously modelled during the simulation time period, while it travels through the network, according to several vehicle behavior models, like car following and lane changing models.

Aimsun is a dynamic model, which is characterized by a dynamic traffic assignment algorithm. This means the model is time-dependent and the system is modelled at a high level of detail. Time dependency enables Aimsun describe dynamics of congestion formation and other disruptions, for instance effects of a moving bottleneck. Besides that, vehicles are assigned individually to the network by linking each vehicle with multiple dimensions (e.g. time and space) and user classes. For this reason a dynamic traffic model gives, in contrast to a static assignment model, a more realistic representation of traveller behaviour decisions, a more explicit description of traffic processes and their time-varying properties and a more complete representation of the network elements. Static assignment models only simulate an average situation for a certain period (e.g. peak hour or day) with a homogeneous travel demand (considering one type of vehicle and assuming homogeneous departure rates). Given the dynamic nature of traffic, dynamic assignment models are superior to static models (Bliemer, 2001). However, a dynamic traffic assignment requires, in comparison to static assignment models, higher quality input data for the model design and calibration and validation procedures. Next to that more calculation time is needed and output results are more difficult to interpret.

4.3.1 In- and output in Aimsun

To start the simulation and get output from the microscopic simulation method Aimsun, input is necessary, see figure 4-1. The quality of the Aimsun model strongly depends on the availability and accuracy of the input data. The input required for the model is a simulation scenario and a set of simulation parameters that define the experiment.

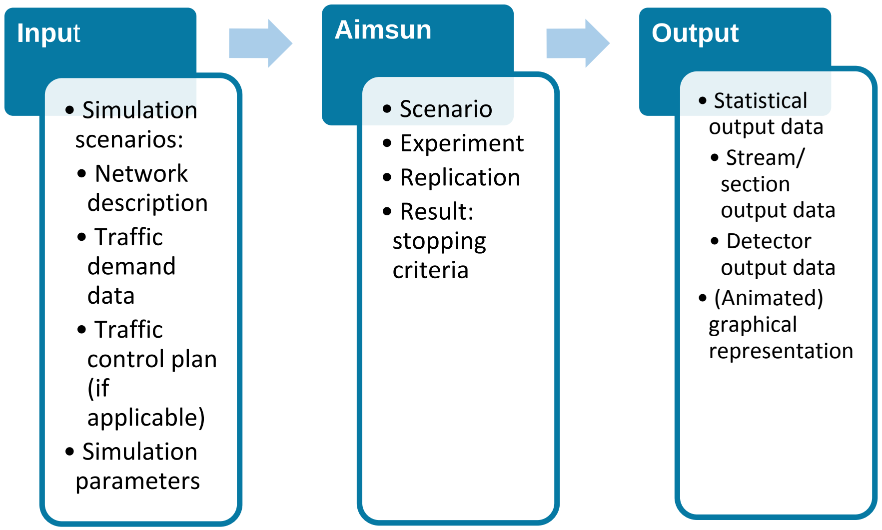


Figure 4-1 Overview of the in- and output in the Aimsun microscopic simulation model

A scenario consists of a network description, traffic control plans and traffic demand data. Simulation parameters are vehicle characteristics and local parameters. A replication describes the random seed and the number of threads to use during the simulation, a stopping criteria can be for instance the number of interations. Output of the Aimsun microscopic simulation model is provided via an animated graphical representation, statistical output data (e.g. flow, speed, delays) and data gathered by simulated detectors (e.g. counts, occupancy).

4.3.2 Necessary input data for Aimsun

Data that is necessary as input for the simulation model on traffic flow, safety and environment:

Traffic flow

- **Traffic volume passenger cars and trucks**: number of passenger cars and trucks on the road per hour and per day. The higher the intensity of the traffic, the more vehicles are hindered by an AV. Intensity in relation to capacity of the road.
- **Traffic volume of AVs**: number of AVs driving on the road (per hour, during the day, during the week, month and per year).
- **Speed driven by passenger cars and trucks**: the speed driven by passenger cars and trucks on the road says something about the actual driven speed on the road.
- **Speed of the AVs**: the speed of the AVs have large influence on the travel time delay of other traffic.
- **Trip length of an AV**: Length of a trip over a rural distributor road by an AV. The longer the trip of an AV on a rural distributor road is, the larger the hinder for other traffic could be.

Extra data needed in case of overtaking:

- **Intensity of the traffic in *both* directions**: de number of overtaking possibilities depends on the intensity of the traffic in both directions. The higher the intensity in the opposite driving direction of the AV, the less possibilities following traffic has to overtake the AV (less available gaps).
- **Traffic generation:** the distribution of traffic over a road section influences the size of the gaps. The larger the gaps between vehicles in the opposite driving direction of the AVs, the more time a follower has to overtake an AV, so more chance that a follower is doing that.
- **Number of overtaking manoeuvres**: this number says something about the possibility to overtake other vehicles on the road (enough sight distance, large enough gaps).

Traffic safety

- **Speed**: actual driven speed of the AVs and other traffic.
- **Distance headway**: The distance between the AV and the following vehicle.
- **Inserting distance**: The distance between the AV and the vehicle inserting in front of the AV.
- **Gaps:** The time between the vehicle that just has past the AV and the first vehicle in the opposite direction.
- **Number of overtaking manoeuvres** (see traffic flow): the more overtaking manoeuvres, the more risks on an accident occur.
- **Overtaking time:** the time it takes to overtake the vehicle.

Environment

Effects for the environment are determined on a quantitative way, which means no direct indicators are used. An estimation of the effect are made by making use of traffic flow and safety output. An estimation on noise hinder and emissions can be derived from the number of acceleration and deceleration movements.

These are based on the differences in speed, the number of stops and the number of hindered vehicles by an AV. The more acceleration and deceleration movements have to be made, the larger the impact on the environment are. Next to that, the impact on the landscape is taken into account.

4.3.3 Measuring method for agricultural vehicles

Royal HaskoningDHV has developed a method to measure effects of AVs. During this research information was gathered in two ways (Hegeman & Dijkstra, 2011):

1. Cameras at the side of the road: observing traffic on a trajectory. On about one location per two kilometre cameras were placed. Position of the cameras dependent on the attendance intersections, indications of the number of AVs and plans for possible measures. One camera can recognize license numbers, with which can determined intensities, travel times and travel speed of all traffic with a license plate. AVs do not have a license plate. For this reason other overview cameras ('normal' cameras) were placed to make observations of AV. With these cameras intensities, travel times and driving speed of AVs can be determined. Information of the cameras was combined to get an indication of the influence of AVs on travel time of other traffic. A disadvantage of the method on this moment is that AVs had to select manually from movies. The cameras can be used for different periods of time.
2. Cameras on an AV (participation observation): this method is used to observe driving behaviour of other traffic, which is driving around an AV. With these cameras the following characteristic can be determined: time and distance headways, the number of overtaking manoeuvres, strategies for overtaking, accepted gaps for overtaking and inserting distance in front of the tractor).

An overview of the data that can be collected via the method is shown in table 4-1.

Table 4-1 Data that can be measured with the method of DHV

Traffic flow characteristics	Driver behavior
Intensity AVs	Following time behind AV
Intensity other traffic	Overtaking strategies
Travel times of AVs	Overtaking time
Travel times other traffic	Position of the overtaking manoeuvre
Influence AVs on travel time of other traffic	Distance to the vehicle after overtaking
Average speed	Time till first oncoming vehicle
Length of the row behind the AV	

Advantages of the measuring method:

- The participating observations give an indication about the number of overtaking manoeuvres and overtaking behaviour in relation to AVs.
- The method gives an insight in the number of AVs, traffic flow characteristics of this vehicle and traffic flow characteristics of other traffic.
- The reliability of the use of cameras to determine the number of vehicles, travel times and speeds is high: about a 95% reliability of the data.
- The cameras on the tractor are not visible for other road users. This means the chance that the driver behaviour is influenced is small.

Disadvantages of the measuring method:

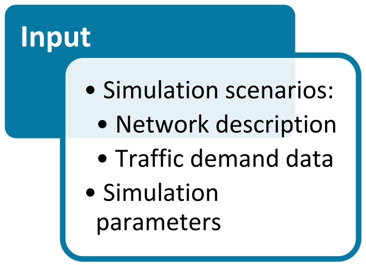
- The cameras are placed on such a distance (minimal one kilometre from each other), so that it could not be measured how long most AVs and other traffic are exactly on the road. So the exact trip distance and route of the AV is not measured. What could be measured are vehicles that pass more than one camera. To determine trip distances and the routes of AVs more cameras could be placed, which leads to higher costs. A consideration should be made between the number of cameras and the accuracy.

- The method is intensive: the intensities of AVs were determined by hand by watching the movies. In August 2012 this problem is solved by using a method where AVs are filtered almost fully-automatic.
- Validity of the measurements from the tractor could be more realistic by making shorter rides with the AV instead of riding the whole length of the road at once. A side-note should be made: AVs with a dumper cannot turn very easily.

The method is already a good method to measure the number of AV, the effects of AVs on travel time and behaviour of traffic in relation to an AV. With some improvements the method could be less intensive and more valid. Results of the measurements done with this method can be used as input for the prediction of effects of infrastructural interventions. A short overview of results from the measurements in Fryslân can be found in appendix E

4.4 Input in the Aimsun microscopic simulation model

The measured data are used as input for the Aimsun model. This is mainly traffic demand data. Next to that, the network and simulation parameters needs to be inserted.



4.4.1 Network description

The infrastructural interventions are tested on the N358 between Leidijk and Dijkhuisterweg in the Province Fryslân, see figure 4-2. On this 13km long part of the N358, measurements on AVs are already done and plans are made to construct about eight passing lanes. The available data of this location (see the location of cameras in figure 4-2 where most data is gathered) and the desire to create infrastructural interventions for AVs makes this location usable for this research. The location of the infrastructural interventions are already chosen by the Province of Fryslân. The same locations are used for this research. To determine the effects of the interventions, focus is mostly done at one part of the road, namely between Dijkhuisterweg and Oude Vaart, see figure 4-3. This section has a length of about 1250 meters and the interventions start at 350, from the origin of the section.This section is chosen, because is a section with a high traffic and AV volume and one of the locations where one of the interventions is going to be constructed.

The network of the N358 is in Aimsun built up with three geometric elements: nodes (transfer from one section to another), sections (connections between nodes) and centroids (source of vehicles). The network is built in Aimsun as realistic as possible. Assumptions which are made:

- Towards production and attraction points, a simplification is done: only at the ends of the simulated roads traffic enters or leaves the network. All private entrances and exits are not modelled. Consequence of this this is that there are fewer locations where the traffic enters or leaves the traffic; these points are more concentrated. This could also lead to shorter or longer rides by AVs in the actual situation. Despite of that, the number of vehicles driving on the road is the same and it is expected that this assumptions only leads to small changes.
- Chosen locations of the infrastructural interventions are based on the chosen location for passing lanes in the province of Fryslân on the N358.

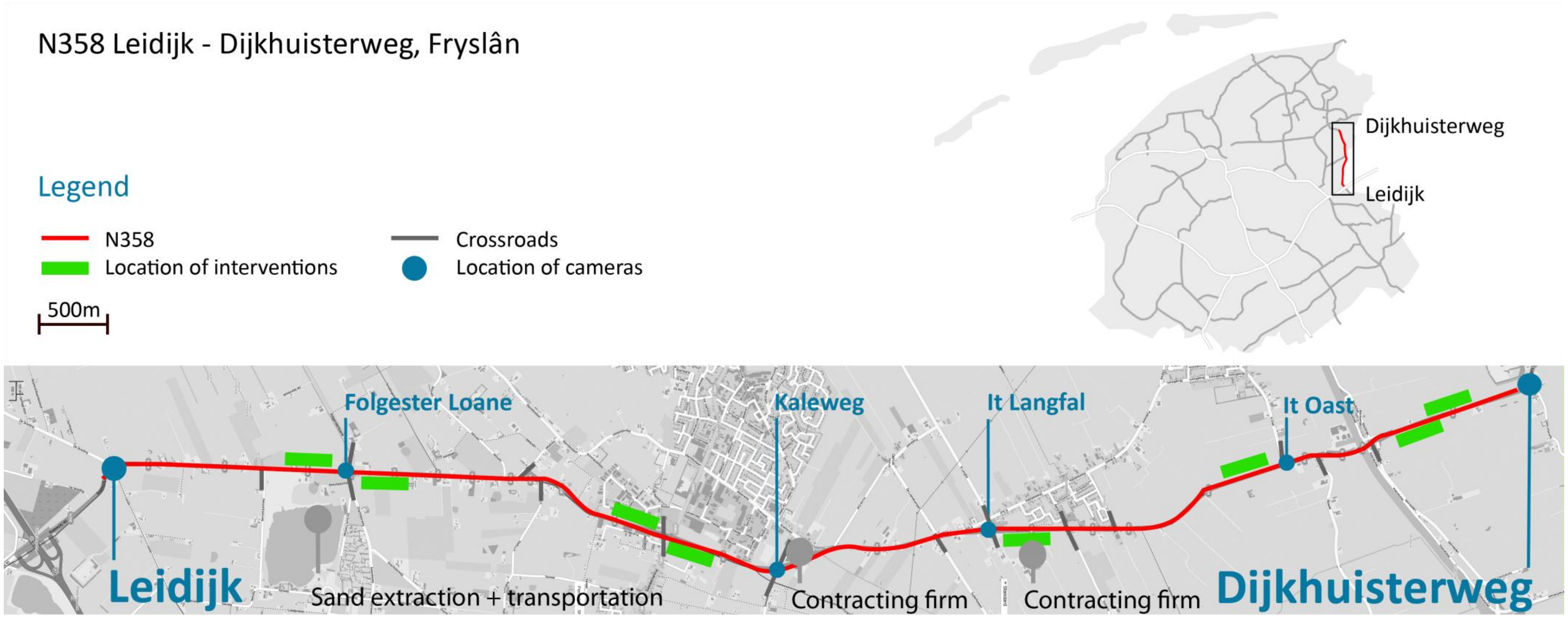


Figure 4-2Overview of the N358 between Leidijk and Dijkhuisterweg with the locations of the interventions and the measuring points (location cameras)

and plans for *Ovotondes* are not be taken into account in the network.

- Minor roads have a minimum length of 100m to give enough space for possible waiting queues.

The intersections in the network are, as is practice, either roundabouts or priority junctions without any traffic lights. For both intersections give way signs need to be used: at roundabouts traffic that enters the roundabout have to give priority to traffic that is already driving on the roundabout; at the other intersection traffic on the N358 has priority over the minor roads.

Figure 4-3 Focus of the analysis is mainly at the section between Dijkhuisterweg and Oude Vaart

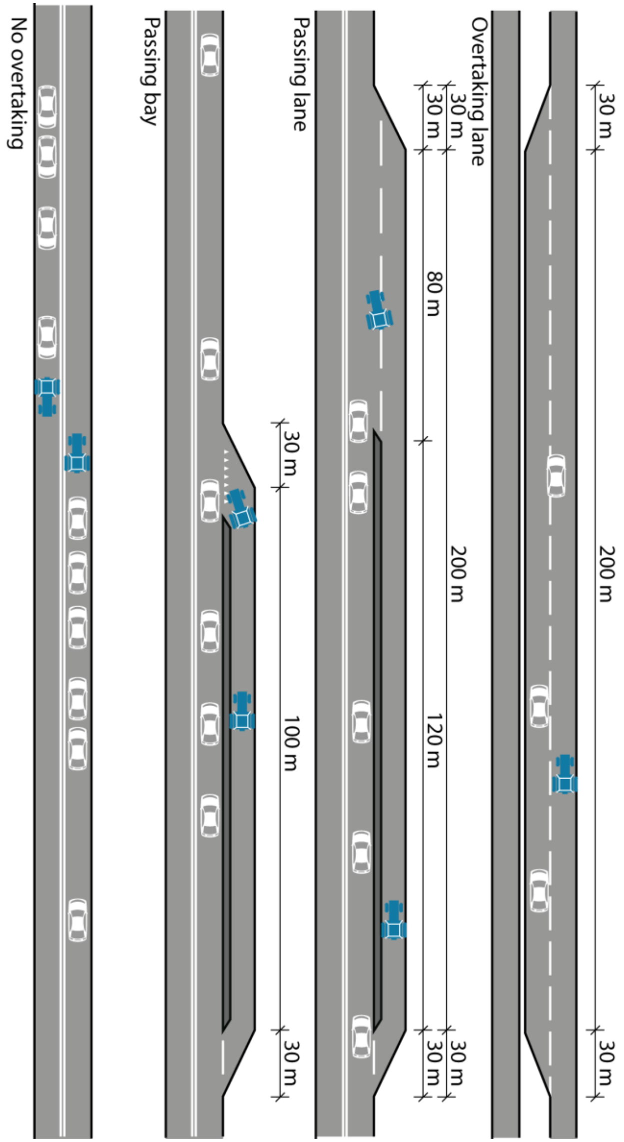


Figure 4-4 Overview of the design of the infrastructural interventions and the lengths of the specific lanes, entrances and exits.

Figure 4-4 gives an overview of the infrastructural interventions:

- **Overtaking prohibition**: the overtaking prohibition means a separation of lanes in opposite direction. This overtaking prohibition counts for all vehicles and assumed is that no vehicles are transgressing this rule. If no measures are taken, it is expected that not all traffic abides by the rules. Physical barriers are necessary to prevent overtaking manoeuvres.
- **Passing bay**: a passing lane at the right side of the main road where an AV is required to exit the main road, drive on the passing pay and wait till there is space and insert to the main road again. In this case the AV has to give priority to traffic on the main road. This intervention consists of a thirty meter long entrance, followed by a hundred meter long bay and finally a 16 meter long exit. At the exit, AVs have to give way to passenger cars and trucks on the main road section. It is assumed that all AVs make use of the passing bay.
- **Passing lane**: a passing lane follows the same principle as the passing bay; the AV is required to leave the main road to let other vehicle pass the AV and at the end the AV has to enter the main road again. Difference is that the passing lane is longer and the AV can drive with its desirable speed on the lane. The entrance 30 meters long, following by lane with a length of 120 meters, where the AV cannot turn on the main road (lane separation). After those 120m a lane of eighty meters plus an entrance of thirty meters where the AV can merge on the main road The idea is that the AV can drive with its own speed while other vehicle can take over the AV on a safe way. At a passing bay, an AV has to wait on the bay while other vehicle pass it.
- **Overtaking lane**: this lane is positioned at the left side of the main traffic lane. An overtaking lane is designed so that fast traffic has to overtake slower traffic; vehicle that want to overtake the AV have to exit the main lane, take over the AV and can insert on every possible moment back to the main lane again. The exit has a length of thirty meters, the length of the lane is two hundred meters and the exit is

thirty meters long again. At the end of the lane traffic there is no priority to one of the lanes given.

For the four interventions counts that overtaking is prohibited for all vehicles. Assumed is that no drivers disobey this rule. In practice, this will only be reached when a physical barrier between the driving directions is applied. When there is no physical barrier, it is expected that the compliance of the overtaking prohibition increases when overtaking opportunities are provided. This is the case for the passing bay, passing lane and overtaking lane.

4.4.2 Traffic demand data

Traffic volumes of passenger cars, trucks and AVs are measured in Fryslân. These volumes can be used to make an Origin-Destination matrix (OD matrix), which describes all origins and destinations for vehicles that make use of the network. From the measures at six locations traffic volumes at the N358 and through going traffic is known, but the exact routes are not known. Based on traffic volumes, through going traffic and on existing housing, companies and constructions (see Figure 4-2 where contracting firms and a sand extraction pit are located which generates many AVs) a division of traffic over the network is made. This is done manually, because the number of measuring points and the number of side roads are low, so with the information available a more realistic O/D matrix could be made than for instance with calibration tools which do not know where important origins and destinations are located.

When the traffic is calibrated to the OD matrix, a traffic demand table is used to determine the period using the OD matrix and distribution of traffic within that period. For every hour and every vehicle type a separate OD matrix is made, based on the measurements in Fryslân. There is no change in the distribution of traffic during this hour made.

The traffic volume is based on the measurements on the N358 in Fryslân. From vehicles other than AVs about 10% of the vehicles measured are trucks and 90% passenger cars. The same distribution is used as input in Aimsun. The number of AVs is also directly adopted from the measurements on the N358. The number of vehicles that enter the network in a time interval is known; for Fryslân this is measured per hour.

The way the traffic enters the network can also be derived from the measurement. In Aimsun, there are several ways to let the traffic enter the network. The exponential traffic generation in Aimsun approaches the real situation and is therefore applied. Figure 4-5 shows the exponential traffic generation, the headways between two vehicles at the input sections are sampled from an exponential distribution. The mean input flow (in vehicles/ second) is λ and the mean time headway is calculated by $1/\lambda$ seconds.

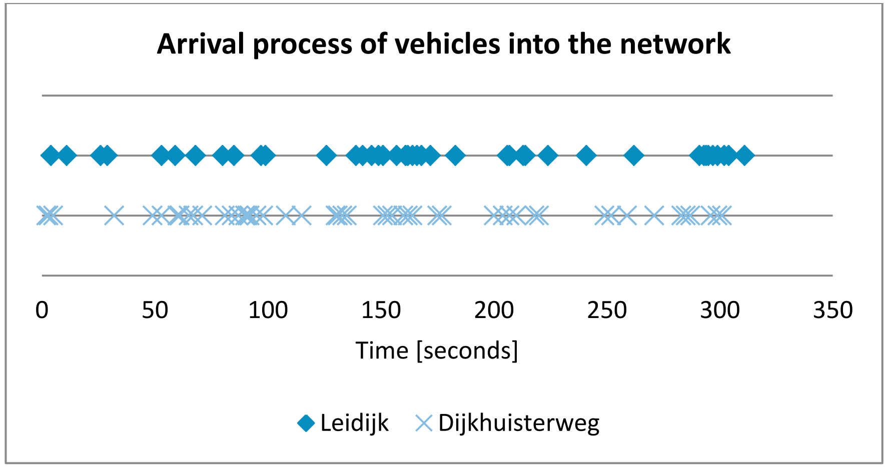


Figure 4-5 Arrival process of vehicles into the network at Leidijk and Dijkhuisterweg.

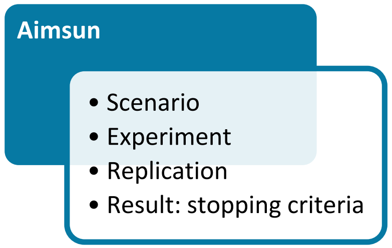
4.4.3 Simulation parameters

Simulation parameters for input can be vehicle attributes or local parameters. Vehicle attributes are characteristics of the vehicles driving in the network in Aimsun. In the Fryslân network there are three types of vehicles distinguished: passenger cars, average trucks and AVs. The passenger cars and trucks are already designed in Aimsun and calibrated to the Dutch system. However, AVs are not available yet in the Aimsun microscopic simulation model. Therefore an AV need to be designed for the model, which is done with information from AV distributors.

Local parameters: are parameters that affect vehicle behaviour, but which are related to road sections or traffic lanes instead and not at the level of vehicle type. This means that these parameters are applied locally to the vehicles while they are driving along the section or lane. Local parameters could for instance lane and section speed limits, turning speed, visibility distance at junctions and so on. No changes to these local parameters are made, so the calibrated local parameters to the Dutch situation are used. A schedule of the microscopic simulation model Aimsun and AV parameters are shown in appendix I.

4.5 Running the simulations

The interventions are simulated for different situations (scenarios) and per situations a several simulations are necessary to get an idea what the effects of the interventions are.



4.5.1 Scenarios

The interventions are tested with current traffic volumes and with other scenarios. At first for a whole day using the current traffic volume (which are measured in Fryslân). This other possible situations are changes in traffic volumes.

For all scenarios the speed of the AVs are the same. As mentioned before the actual speed limit for AVs is 25km/h, but in practice is measured that these vehicles drive often a lot faster with a speed on average 40km/h. Next to that, in future there is a chance that the speed limit for AVs increases to 40km/h. Therefore it is more realistic to simulate the situation with AVs driving faster than the actual speed limit.

Changes in intensities of AVs is something that could happen: it is expected that the number of AVs and the number of driven kilometres by AVs grows in future. This makes it logical to take also a higher number of AVs into account. It is also possible that the number of AVs decreases, due to change of the function of the area (for example no sand extraction pit any more or no agricultural area anymore).

Changes in intensities of other vehicles also possible. Starting point for different intensities is the assessment framework of Fryslân (see appendix F). In this schedule boundaries are set up at which traffic volumes certain interventions could be implemented. In all boundary classes of traffic intensities (except for the very low, <5000 veh/day) the interventions are tested: current 9000veh/day, high 13.000 veh/day and a low traffic volume of 6000 veh/day.

Table 4-2 Scenarios to test the effects of the infrastructural interventions on possible (current, future or extreme) situations.

Scenarios	Intensity AV	Low intensity (/1,5, about 6000 veh/day)	Current intensity (about 9000 veh/day)	High intensity (x1,5, about 13000 veh/day)
1. No Overtaking	Low (5 AVs/h)			
	Current (25 AVs/h)			
	High (50 AVs/h)			
2. Passing bay	Low (5 AVs/h)			
	Current (25 AVs/h)			
	High (50 AVs/h)			
3. Passing lane	Low (5 AVs/h)			
	Current (25 AVs/h)			
	High (50 AVs/h)			
4. Overtaking lane	Low (5 AVs/h)			
	Current (25 AVs/h)			
	High (50 AVs/h)			

Simulating the interventions with current traffic volumes

Starting point for the simulations is current traffic volume. This is a part of day (7-21h, when AVs are making use of the N385) of which measurements in Fryslân are done and for which the infrastructural interventions are tested. The simulation of one whole day is done to see the effect on infrastructural interventions by changes in traffic volumes. This gives an insight into the differences between the interventions and what scenarios might be interesting to analyse more intensively.

The simulation is done for one part of the network between Dijkhuisterweg and Oude Vaart (vehicles driving from north to south). This is a section where vehicles are coming into the network and driving along the N358 without intersections or traffic lights. The position of the infrastructural intervention lays about 400 meters from the entrance of the section.

Also simulations for the whole network are done (from Leidijk to Dijkhuisterweg in both directions) but results from the simulations are less reliable. Despite of that it could give an idea of the effect of all the interventions onto the network. The effects onto the network are not elaborated, because a microscopic simulation is done which shows more interesting results for a smaller part of the road.

Simulating scenarios

Next to the current situation, eight other scenarios for all infrastructural interventions are simulated. These scenarios are simulated for a whole day, but all for one hour. From the simulations of the current situation and the first simulations of the scenarios, a choice is made to analyse the most interesting scenarios more intensively.

Starting point for the scenarios is the 16:00hour of the current situation. This hour is taken, because the evening peak is already starting, but there is also a relatively large number of AVs driving on the road (about 25 in total). Using the starting points for the scenarios as mentioned in table 4-2, this leads to the overview of the scenarios, which are simulated at one time, see table 4-3. Because the scenarios are simulated during one time a warming-up and cooling down period is necessary, so that scenarios do not intermingle. More information about the warming-up period in the next paragraph.

4.5.2 Experiment: Warming up period

In Aimsun the simulation starts with an empty road. This makes the behaviour in the start of the simulation not realistic. It is desirable to start measuring when some vehicles have reached the end of the section that is modelled. That is why a warming-up period required in which already traffic enters the network so that there is a realistic situation at the start of the measurements. The length of this period is determined by making a number simulations of the current situation. From these simulations followed that about 15 minutes are necessary to fill the whole network, see Figure 4-6. Simulation of the scenarios is done in one model. For every low and current intensity a warming-up period and cooling down period of 15 minutes is used. For the higher intensities it takes more time to empty the network, because of traffic on the minor roads that have to wait longer. That is why for the high intensities a warming-up and cooling down time of 30 minutes is used.

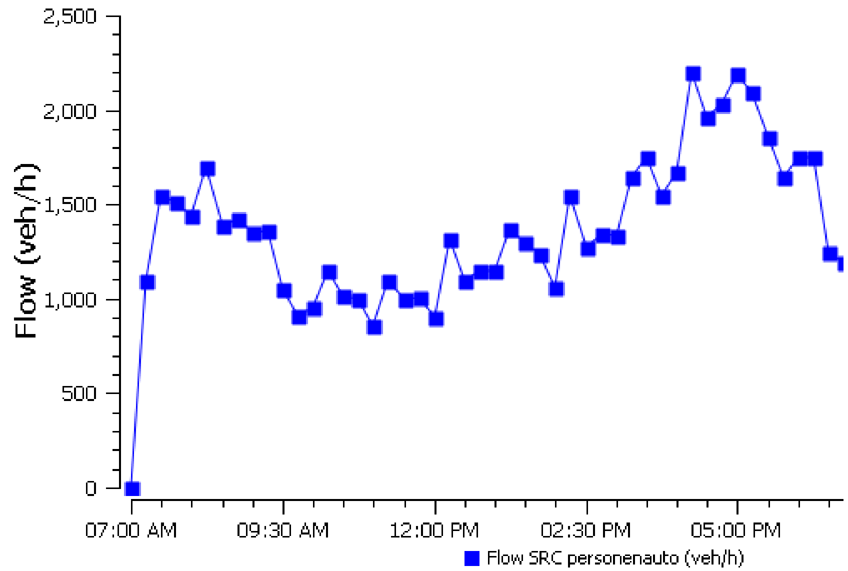


Figure 4-6 Traffic volume during the simulation, during the first 15 minutes the traffic volume is increasing. For that reason a warming up period of 15 minutes is necessary.

Table 4-3 Overview of the scenarios which are simulated in one model all for one hour. Green part is the time the scenario is measured, blue is the cooling down period and red the warming up period.

AV	low	current	high	low	current	high	low	current	high
Car + truck	low	low	low	current	current	current	high	high	high
Time	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour

4.5.1 Replication: number of simulations

A simulation in Aimsun is partly dependent of a draw. That is why the outcomes of the simulations are somewhat stochastic (e.g. the type of vehicle and its desired speed are drawings from a probability distribution of which parameters are given) and only one simulation is not be reliable. Therefore it is necessary to use different start values for the random generator in the input, so called different random seeds. A random seed assigns a vehicle to a lane in a random way (following a probability distribution) taking into account the OD matrix and also the vehicle parameters are following a probability distribution. As in real life no situation is exactly the same. By using different seeds, different situations are simulated and different outcomes are produced. To get a more outcome and a better impression of reality, the simulations needs to be repeated for several times. The differences between the seeds can be attributed to the inherent randomness of the traffic process. For every scenario the same seed numbers are used so that the scenarios are comparable to each other.

To determine the number of necessary simulations a consideration is made between the accuracy of the out coming data and the necessary simulation time. To restrict the number of seeds and to determine the necessary sample for estimating an average, the following (statistical) formula can be used (Van Soest, 1997):

$$n > \frac{Z^2}{d^2}\sigma^2 \qquad [5.1]$$

Where:

- n: minimal number of necessary observations
- Z: value depending on desired reliability
- d: desired accuracy
- σ: the standard deviation of the variable that have to be measured

By using the method of Van Soest, the size of the necessary sample (number of seeds) depends on the standard deviation of the measured variable, the desired accuracy and the desired reliability. So the more seeds are run, the more precise the final results will be.

To determine the number of simulations necessary of the N358 in Fryslân, a reliability of 95% is assumed. For a normal deviation a Z-value of 1,96 is applied for a reliability of 95% (two-sided) (Dijker & Knoppers, 2006). From a test simulation with 10 seeds, the standard deviation and desired accuracy (assumed is 5% of the average travel time and speed) are determined and the number of necessary simulations is calculated, see Table 4-4. From this is derived that a total of 28 simulations is necessary. This number of simulations is done for every scenario during this research.

Table 4-4 Overview of the determination of the number of simulations for the stream between Dijkhuisterweg and Oude Vaart

d=5% of average

	Speed [km/h]				**Travel time [s]**			
	All	**AV**	**car**	**truck**	**All**	**AV**	**car**	**truck**
Z	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96
σ	8.1	1.9	7.4	5.9	8.4	6.2	7.4	6.3
average	83.0	39.0	84.0	76.7	55.8	119.8	54.9	60.1
d	4.2	1.9	4.2	3.8	2.8	6.0	2.7	3.0
n	14.7	3.6	11.8	9.1	35.2	4.2	**27.6**	17.0

4.6 Simulation output

Output from the simulation are analysed for traffic safety and flow and from these results the effect on the environment are derived on a qualitative way. To determine which data needs to be analysed, output indicators are set up. Next to that, the output data needs to be processed to these indicators and then the indicators are assessed by the use of an assessment framework. Finally the output is tested by a robustness and validity test.

4.6.1 Output indicators

Statistical output data of the microscopic simulation in Aimsun is used to test the infrastructural interventions on its requirements. Requirements related to traffic flow, safety and environment are:

- Traffic safety: minimize impact and chance of accidents in relation to AVs on rural distributor roads and improve the 'feeling' of safety for road users, inhabitants, and drivers of AVs.
- Traffic flow: minimize the travel time loss for all road users on rural distributor roads and minimize the number of hindered vehicles (number of vehicles following the AV)
- Environment: minimize effect on environment (liveability, pollution, minimize costs)

Indicators for these requirements, which are output of the Aimsun microscopic simulation and which are used as assessment criteria are stated in table 4-5.

A reduction of accidents is the most direct way to measure safety effects, but these are too rare for analyses. Instead, the surrogate measures speed differences, number of conflict situations and time headways are used. User acceptance is also influences traffic safety. This cannot derived from the microscopic simulation and is therefore taken into account on a qualitative way (no output indicator given). Traffic safety is often the reason to take interventions, but at the same time, safety improving interventions should not negatively influence traffic flow and environment. Traffic flow is determined by travel times, travel time loss and queue lengths behind AVs. No output indicators are given for the environment, because this is analysed on a qualitative way and based on results of traffic flow and safety. For example, the hindrance of AVs and for AVs can have effect on noise and emissions. Besides, the effect on the integration into the landscape is taken into account. Also costs of the analysed infrastructural interventions are given, but this is also not based on output indicators.

4.6.1 Processing output

Simulation output in Aimsun is exported to access files. This data is converted to excel for further analysis.

The data is evaluated on one section or a combination of number of sections (stream level). That is done, because of the effect of AVs is mainly expected for individual vehicles and less for the whole traffic stream. The data is gathered in Aimsun in two ways: use the average data of a whole section or a combination of sections and detector data is used. On stream level, the data is analysed per fifteen minutes. With the detector data, with one detector at the beginning of the section and one at the end of the section, the effects of an AV per individual vehicle is analysed. For instance the delay per individual vehicle and the length of the rows behind the vehicle.

Table 4-5 Surrogate indicators for safety and output indicators for traffic flow.

Indicator	Description
Traffic safety	
Speed frequencies	The speeds of all vehicles driving on the road. This leads to an overview of speed frequencies. The higher the speed differences the larger the traffic safety risks.
Headways	The time headway between an AV and a following vehicle and the time a vehicle follows an AV with a minimum headway. In Fryslân, a time headway smaller than 8 seconds is assumed as a following vehicle (Hegeman & Dykstra, 2011). During this research the same upper value of 8 seconds is used.
Number of conflict situations	The number of conflict situations exists of the number of stops by a vehicle, the total number of AV followers and the number of vehicles that make use of the interventions and have to insert on the main traffic lane again. On a passing bay and lane these are the number of AVs using the intervention, on an overtaking lane these are the number of vehicles using the overtaking lane. The number of followers are the number of vehicles following AVs with a headway smaller than 8 seconds and the number of stops is the number of vehicles that actually have to stop on the section (speed is 0 km/h). Also the chance to follow an AV is determined.
Traffic flow	
Travel time	The total travel time of all vehicles that have make use of the road.
Travel time loss	The extra time needed to travel /pass a certain intersection or road section because of attendance of other traffic, in comparison with a situation with other traffic. In this case the extra travel time needed because of the attendance of AVs onto the road.
Queue length	The mean and maximum number of vehicles following one AV. This gives an overview of the length of the row behind an AV.

4.6.1 Assessment of the indicators

Aimsun generates output which can be used to analyse the infrastructural interventions. Output needs to be related to the factors that could influence the choice for a certain intervention. The output can be distinguished on different levels: network level, O/D-level, stream level (combination of a number of chosen sections), section level and lane level.. The effect of infrastructural interventions are mainly studied on a certain trajectory, so mainly a combination of (a number of) sections are analysed.

The infrastructural interventions are assessed using the established indicators. Dependent on the importance of an indicator for a province, a choice can be made for the desired intervention. Difference in importance can be caused by the fact that some provinces focus more on the importance of traffic safety, while others could focus more on traffic flow or the environment.

4.6.2 Evaluation

The infrastructural interventions are assessed per indicator, but also need to be tested on robustness and needs to be validated.

The robustness test analyses a number of scenarios on robustness by changing the location of the interventions. The effect of the interventions is determined between Dijkhuisterweg and Oude Vaart, where the interventions begins after 350m from the start of the section. Between It Sud and Rysloane the intervention is situated directly after the intersection. This section is used to see if this would result in other effects. The section between Oude Vaart and Dijkhuisterweg is used to see what the effect is of changes in the way traffic enters the section. The length of the sections are different, that is why the robustness is compared by the travel times per kilometre.

A validity test is used to determine the degree in which the microscopic simulation measures what is should measure. Therefore three thing are done:

discussion of the assumptions made during the research; comparison of the input with data from the measurements in Fryslân (for instance free flow speeds and some expert meetings are organised to ask for their expectations of the interventions and what they think of the outcomes of the model.

4.7 Conclusion

For the analysis of the chosen infrastructural interventions in chapter three, an experimental set-up is made in chapter four. The analysis is performed with the microscopic simulation model Aimsun. This model makes it possible to analyse the effects of infrastructural interventions for every individual vehicle. The quality of the Aimsun model is highly dependent on the availability and accuracy of the input data.

To analyse the interventions, the N358 is Fryslân is used. The input for the model derived from data gathered through the measuring method developed by Royal HaskoningDHV. The focus is mainly on traffic safety and traffic flow, but also environmental issues are taken into account.

In Aimsun scenarios consisting of a network description, traffic demand data and other parameters are used to create a model of reality.

Output of the Aimsun microscopic model is assessed by using output indicators for traffic flow and surrogate indicators for traffic safety (both quantitative). The effect of the interventions on environment are assessed in a qualitative way.

Finally an evaluation of the interventions is made by using a robustness and validation test.

5 Analysis of the infrastructural interventions

The results of the effects of the interventions simulated on the N358 in Fryslân between Dijkhuisterweg and Oude Vaart are discussed. First, a comparison is made of the infrastructural interventions for a whole day, related to traffic safety, flow and environment. This is done by using current traffic volumes, which are measured on the N358. Next, for different traffic volumes of both normal traffic and AVs, results of the interventions are compared. This is analysed per hour. To evaluate the results of the simulations a few tests are used: a robustness test of the interventions and a validity test of the simulation output. Finally, a comparison of the interventions is made using the three criteria: traffic safety, flow and environment.

5.1 Results interventions on traffic safety

In relation to traffic safety three surrogate indicators were determined (see chapter 4): speed distributions, number of conflict situations and the time a vehicle follows an agricultural vehicle (AV) with minimal headway.

5.1.1 Speed frequencies

Figure 5-1 shows the speed frequencies for respectively the overtaking prohibition and passing bay. The curves for the passing lane and overtaking lane look very similar to the passing bay, see appendix J. The figure shows that the differences between speed distribution is low, because most vehicles can drive within a speed around the speed limit. The main difference between the two distributions is the number of vehicles driving with a speed around 40-50km/h. Difference is that at no overtaking are more speeds that lie around 40km/h[13]. At the other interventions these speeds are shifted to 60-70km/h.

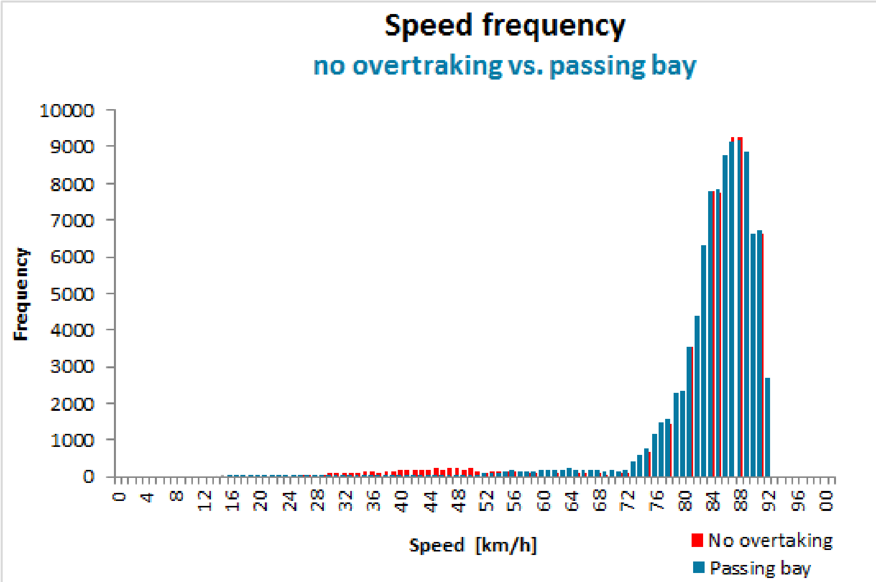


Figure 5-1 Speed frequencies for the overtaking prohibition and passing bay

[13] Note has to be made about the speed in general, which lies very high, the average even above the speed limit, which is caused by settings in Aimsun. This counts for all the analysed interventions, so the speeds are comparable.

Table 5-1 shows the percentage of vehicles driving with a lower speed than 45, 60 and 80km/h. This shows the same shift between the overtaking prohibition and the other interventions.

Table 5-1 Percentage vehicles with an average speed below 45, 60 and 80km/h

	% vehicles <45km/h	%vehicles <60km/h	% vehicles <80
No overtaking	2,67	5,09	16,43
Passing bay	1,03	2,85	16,07
Passing lane	0,93	2,79	16,85
Overtaking lane	1,01	2,91	16,16

5.1.2 Number of conflict situations

The number of conflict situations is determined by the number of vehicles that have to stop (to 0km/h), the number of vehicles driving behind an AV and overtaking manoeuvres (vehicles that make use of the intervention).

Number of stops

Figure 5-2 shows the percentage stops by an AV. Of other traffic no stops are shown, because this percentage is very small, <0,5%, and for all interventions about the same. The number of AVs that have to stop differs per intervention, for the overtaking prohibition and overtaking lane this is negligible. An AV almost never has to stop on a passing lane, so it seems at the moment the AV is driving on the last part of the lane where it can insert onto the main road again that the gaps are large enough to insert. At the passing bay the AV has to stop more often, because the AV has to give priority to traffic on the main road and there is not many space to keep on driving on the passing bay. If there is no gap big enough to merge into the main traffic stream again, the AV has to stop 1 time. Disadvantage is that the AV has to wait and has no speed anymore so when the AV inserts to the main traffic lane again, the vehicle still has to accelerate. This could lead to unsafe situations of traffic that approaches the AV.

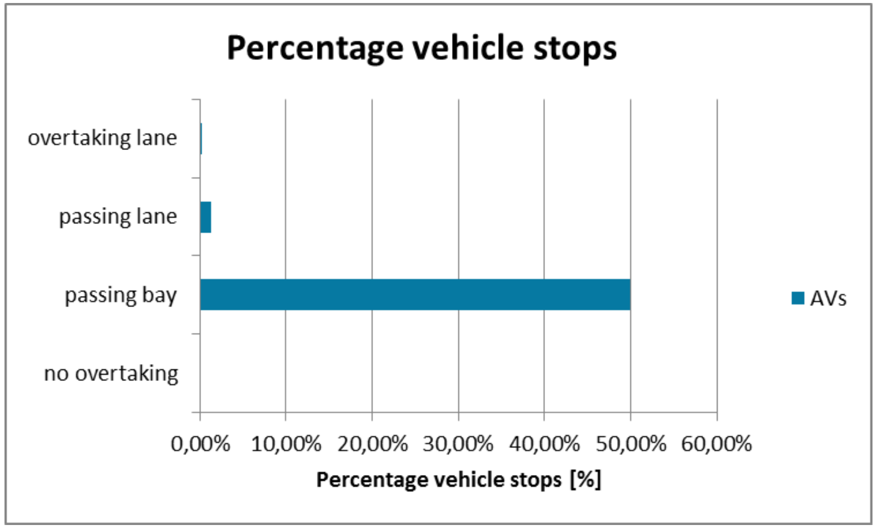


Figure 5-2 Average number of AV stops is the highest for a passing bay

Number of following vehicles

The share of vehicles that follows the AV at the end of the section is shown in figure 5-3. When it is not allowed to overtake an AV, the percentage of vehicles following an AV is almost 6%. With an intervention this is smaller: 2,5 and 2,6% for respectively the passing lane and overtaking lane. For a passing bay this is 2,2%. With a traffic volume of about 9000 vehicles per day, it means that at an overtaking prohibition leads to about 500 vehicles following and for the other interventions about 200 vehicles.

Number of passing vehicles

Figure 5-4 shows the number of vehicles that pass an AV by making use of an intervention. This number is zero for the overtaking restriction and for other intervention most of the times 1-4 vehicles pass the AV. The passing bay leads to a more high number of vehicles that can pass one AV. In case of the

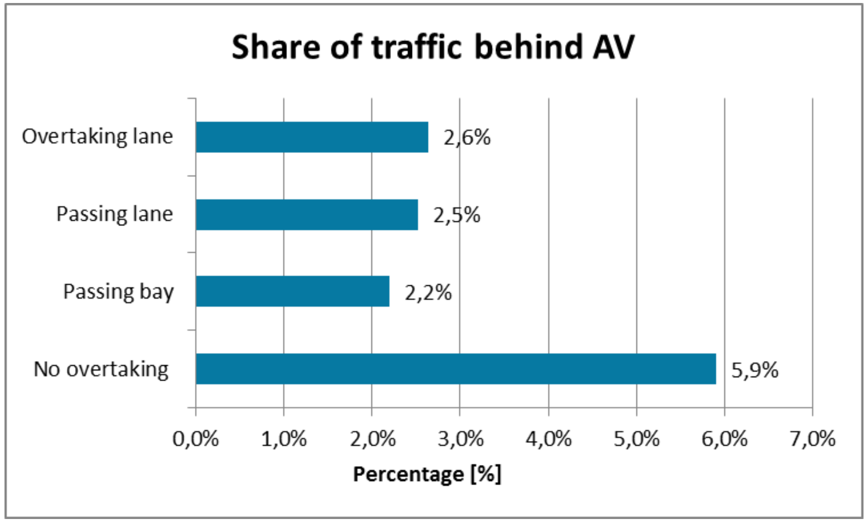


Figure 5-3 The share of traffic behind an AV is largest when overtaking is not allowed.

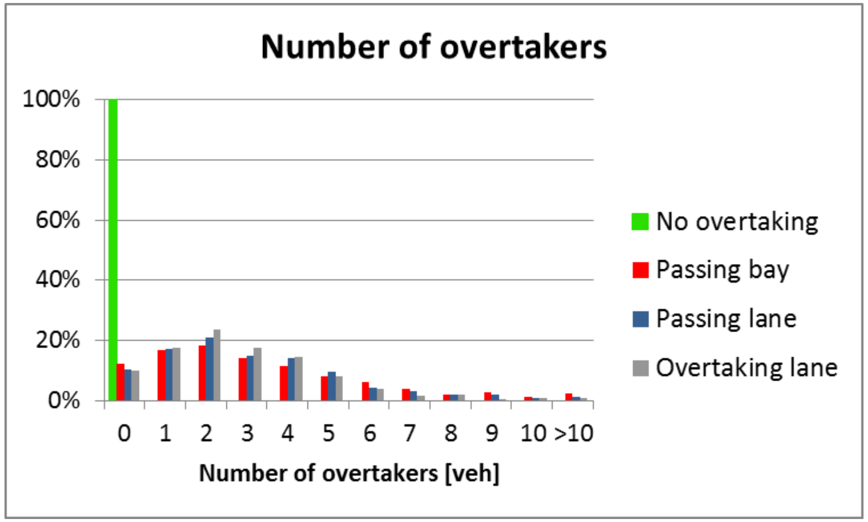


Figure 5-4 A passing bay leads to more vehicles that pass the AV, the overtaking prohibition to none passing vehicles.

interventions no overtaking manoeuvres are counted, because its assumed that all vehicles comply with the overtaking prohibition.

A conflict situation is also the inserting of AVs into the traffic when coming from a passing bay or passing lane and on an overtaking lane for the other vehicles merging into the traffic. The number of vehicles that needs to merge onto the main traffic lane again is zero when there is an overtaking prohibition, at a passing bay and lane this are all the AVs driving on the road and in case of overtaking lane all vehicles that make use of it. For this reason an overtaking lane leads to most exiting and inserting movements.

5.1.3 Headways

The time vehicles follow an AV with a headway smaller than 8 seconds is shown in figure 5-5. For the overtaking prohibition counts that some vehicles are following more than a minutes. For the other interventions the following times are shorter, but some vehicles still have to follow the AV for a minute. The longer the a vehicle has to follow an AV, the higher the chance on irritation of the following vehicle and chance (on the desire) to make an overtaking manoeuvre if possible. So for the overtaking prohibition this risk is higher than for the other vehicles. For the other interventions the following time is for most vehicle is not higher than 20 seconds.

5.1.4 User acceptance

For traffic safety also the user acceptance plays a role for infrastructural interventions, which is determined on a qualitative way. An overtaking prohibition leads to longer rows behind the AV than the other interventions and therefore it leads to a higher desire to overtake the AV and with that a higher risk to offenses. The other interventions provide relatively safe overtaking possibilities, which decrease the chance of overtaking manoeuvres via the opposite driving directions. At a passing bay is the chance high for an AV that it has to wait. This waiting time can discourage drivers of AVs to use the passing bay. The chance that a passing lane and overtaking lane are accepted by users are higher, because AVs have almost no extra hindrance and other traffic has opportunities to overtake the AV on a relatively safe way.

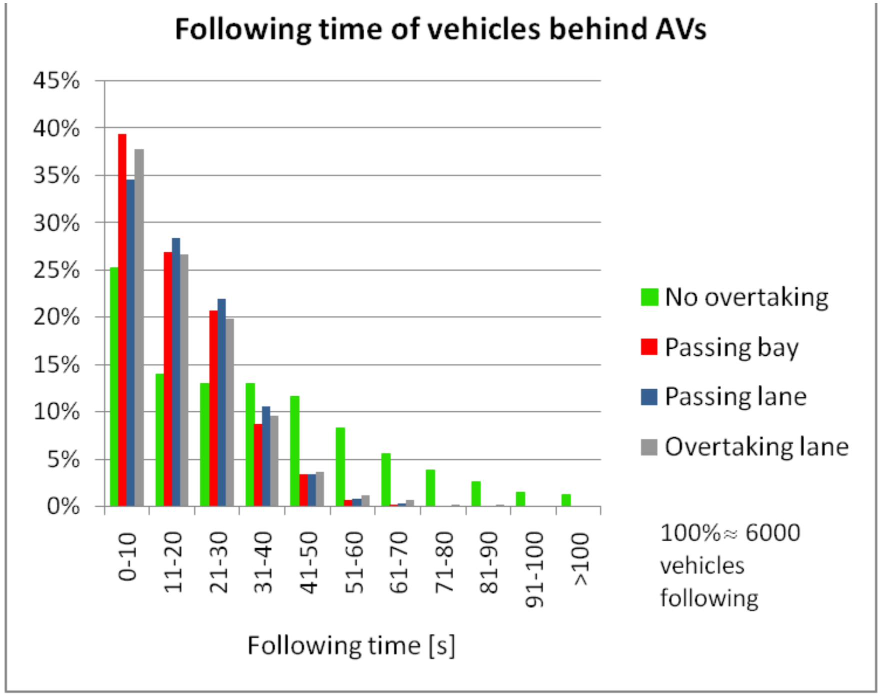


Figure 5-5 Following time of vehicles behind an AV (with a headway smaller than 8 seconds)

5.1.5 Conclusion

For an overtaking prohibition are the speed differences larger in comparison with the other interventions The larger the speed differences the higher the risks on unsafe situations. The number of conflict situations consist of the number of stops, number of following vehicles and following time of vehicles behind an AV. The more conflict situations, the larger the risk on unsafe situations. The number of stops is high for the passing bay, which means an AV has a high chance that it needs to stop (about 50%). This leads to AVs that have to merge on the main section without having speed and therefor unsafe situations. The stopping time is negligible for the other interventions. The number of vehicles that can pass an AV due to the intervention is zero for the overtaking restriction and often zero to five vehicles for the other interventions. The number of following vehicles is higher for the overtaking restriction. This percentage is almost 6% for the passing bay, and around 2,5% for the other interventions. The same counts for the following time, where more vehicles follow with a longer time at an overtaking restriction than at the other interventions.

All the surrogate indicators for traffic safety give an indication of possible risks. From the above results can be concluded that the overtaking prohibition leads to the highest risk. The passing bay can also lead to high risks, because an AV often has to merge from a standstill on the main traffic lane. The passing lane and overtaking lane are comparable. Difference is that at the passing lane the AV has to merge on the main traffic lane and at the overtaking lane the fast traffic. Difference in merging behaviour is not further analysed. This depends on driving behaviour at the intersection and can be best analysed in practice. Next to that, user acceptance needs to be taken into account. The chance that a passing lane and overtaking lane are accepted by users are higher than an overtaking prohibition and passing bay, because AVs have almost no extra hindrance and other traffic has opportunities to overtake the AV on a relatively safe way.

5.2 Results interventions on traffic flow

Differences between the interventions on traffic flow are analysed for travel time, travel time loss and length of the rows.

5.2.1 Travel time and travel time loss

Table 5-2 shows the results of the effect of infrastructural interventions and, at the current traffic volume, on travel time for cars and trucks. The first traffic flow indicator is average travel time, of which the differences per vehicle (cars and trucks) are small for all the infrastructural interventions. The average travel time per vehicle is 55 seconds with an overtaking prohibition and 51 seconds with an overtaking lane. The passing lane and overtaking lane lead to an average travel time of 54 seconds on the section. The difference between de overtaking lane and the other intervention can be clarified by the possibility of also overtaking cars and trucks. The travel time loss at an overtaking prohibition is on average per vehicle 2,6 seconds and at the other interventions 1,6-1,9 seconds.

Table 5-2 Effects of infrastructural interventions on the N358 between Dijkhuisterweg and Oude Vaart on traffic flow for cars and trucks.

Cars and trucks (v90)	No overtaking	Passing bay	Passing lane	Overtaking lane
Total travel time cars + trucks [s]	236930	231770	232630	219300
Average travel time (v90) [s]	55.1	53.9	54.1	51.0
Standard deviation average travel time [s] (v90)	11.1	5.6	5.7	6.7
Average travel time loss in relation to free flow (86km/h) [s]	2.9	1.6	1.9	1.8
Standard deviation travel time loss [s]	11.1	5.6	5.7	6.7
Average queue length [veh]	7	2	3	3
Standard deviation queue length [veh]	5	2	3	3
Maximum queue length [veh]	47	21	23	21

The standard deviation of the travel time and travel time loss do show a difference. An overtaking prohibition leads to a standard deviation twice as large as the other interventions (on average 11 seconds for the overtaking prohibitions and about 6 seconds for the other interventions). These high standard deviations can be clarified by the difference between traffic that follows an AV the whole length of the section and traffic that does not get hindered by an AV at all. So, a number of vehicles have a lot higher travel time due to AVs, while other vehicles have no travel time loss at all. The travel time loss for passenger cars during the day is shown in Figure 5-6. This shows the difference between the overtaking prohibition and the other interventions. Other results of the whole day (average travel time, total travel time and speeds are shown in appendix J.

Table 5-3 shows that the effects of the interventions on travel times of AVs is opposite of the effects for cars and trucks. The overtaking prohibition leads to the shortest travel times for AVs, on average per vehicle 118 seconds. The passing bay leads to the highest travel time and loss for an AV, respectively 125 and 6 seconds. The standard deviation of the travel time and travel time loss do not show large differences between the interventions.

Table 5-3 Effects of infrastructural interventions on the N358 between Dijkhuisterweg and Oude Vaart on traffic flow for AVs.

AVs	No overtaking	Passing bay	Passing lane	Overtaking lane
Total travel time AVs [s]	4492	4746	4537	4518
Average travel time [s]	118,2	124,9	119,4	118,9
Standard deviation average travel time [s]	20,2	20,4	20,7	20,7
Average travel time loss [s] in relation to free flow (38km/h)	0	6,6	1,2	0,6
Standard deviation travel time loss [s]	20,2	20,4	20,7	20,7

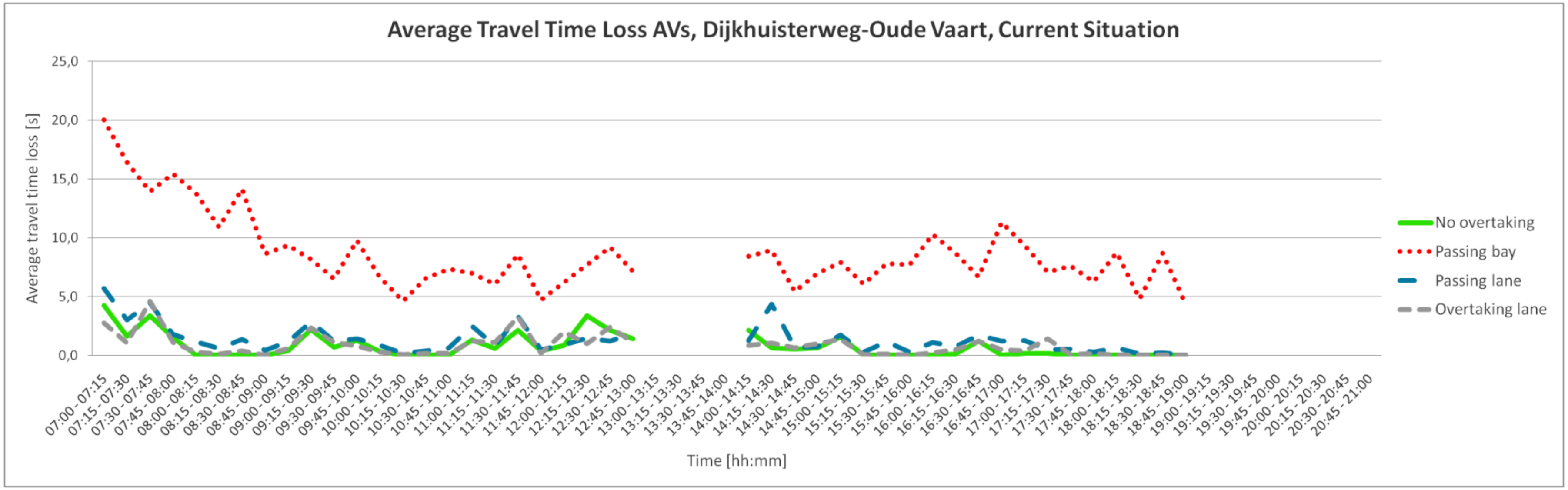


Figure 5-6 Average travel time loss of AVs for the whole day between Dijkhuisterweg and Oude Vaart

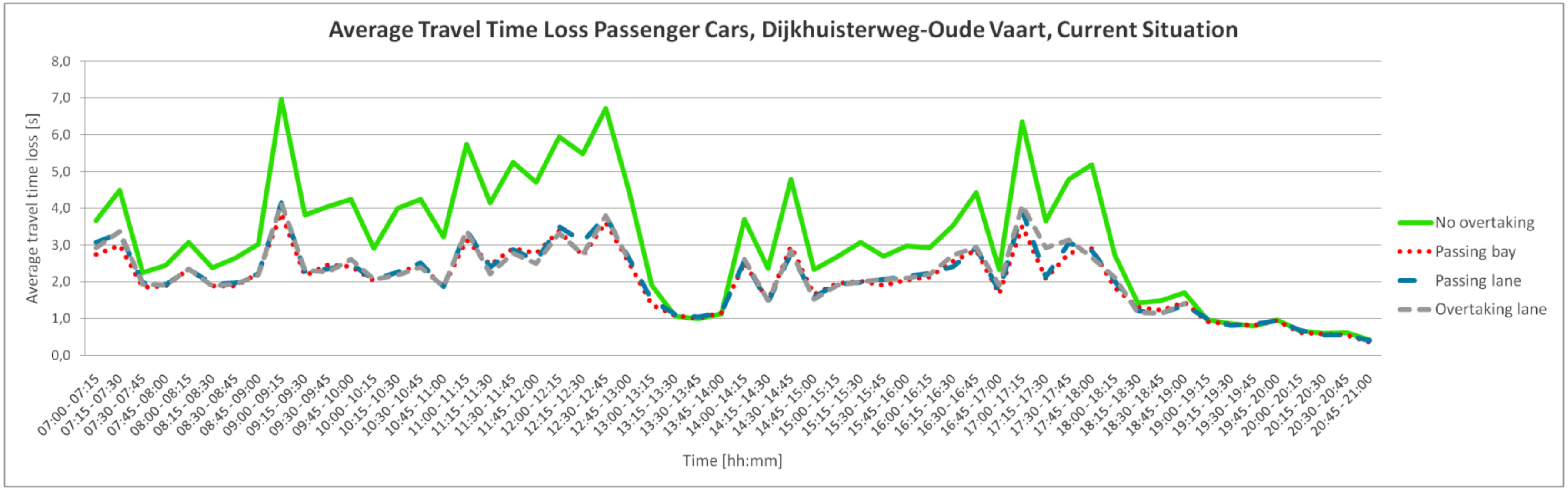


Figure 5-7 Average travel time loss for passenger cars for the whole day between Dijkhuisterweg and Oude Vaart

5.2.1 Queue lengths

In figure 5-8 an overview of the length of the rows behind AVs is given and which length is most common per intervention. The last used indicator for traffic flow is the length of the row behind an AV. With current traffic volumes the rows consisting of 5 to 8 vehicles are most common for an overtaking prohibition. For the other interventions rows with 1 to 4 vehicles are most common. From the figure can be concluded that the differences between the passing bay, passing lane and overtaking lane are about the same. The passing bay is slightly more favourable than the other two when looking at the length of the rows. This can be caused by the fact that the AV has to wait onto the passing bay till it can enter the road again. While the AV waits more traffic can pass the AV. The length of the rows when there is an overtaking prohibition are longer; where at the other interventions most rows have a length of four vehicles, with an overtaking prohibition most rows have a length of 8 vehicles. The attendance of a vehicle in a row behind an AV or a vehicle approaching such a row leads to higher safety risks.

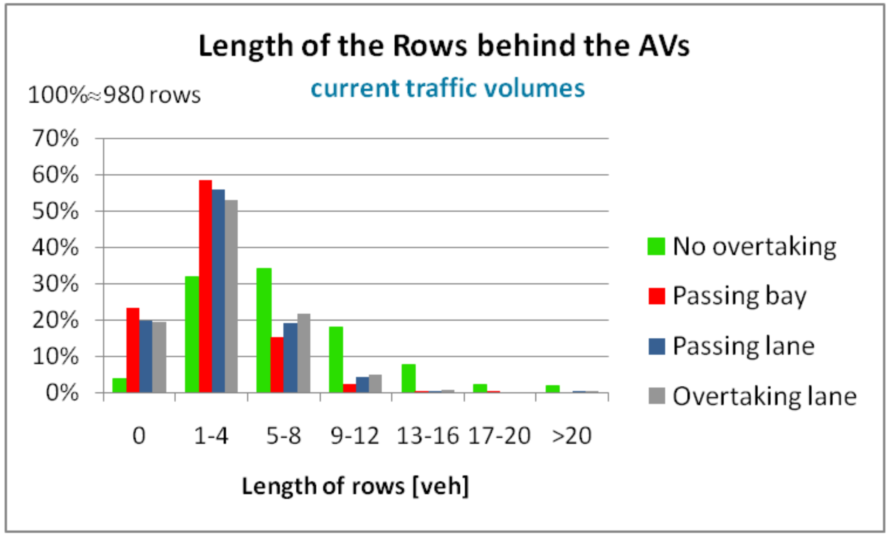


Figure 5-8 Length of the rows behind the AVs driving on the N358

5.2.2 Conclusion

From the results on travel time and travel time loss for interventions can be concluded that the differences in travel time and the average loss per vehicle are very low. Although the average loss is very small, some people can have a large of delay. This is to see in the standard deviation. Especially in the no overtaking intervention the standard deviation in travel time and the loss is high. This can explained by the differences between followers and no followers: some vehicles drive behind an AV the whole length of the road, while others do not see an AV at all while their driving on the N358. The deviation is smaller for the other interventions, because of the ‘overtaking opportunity.’

The effects of the interventions on travel times of AVs is opposite of the effects for cars and trucks. For AVs the passing bay is the least favourable, because in many cases the AV has to stop and wait till there is space to insert on the main traffic lane again. On a passing lane is the chance to insert without any hinder larger and in most cases the AV can keep on driving with its desired speed. The AV can drive with its desired speed at an overtaking lane and overtaking prohibition, so this has no influence on travel time.

For AVs the passing bay is the least favourable, because in many cases the AV has to stop and wait till there is space to insert on the main traffic lane again. On a passing lane is the chance to insert without any hinder larger and in most cases the AV can keep on driving with its desired speed. The AV can drive with its desired speed at an overtaking lane and overtaking prohibition, so this has no influence on travel time.

The last used indicator for traffic flow is the length of the row behind an AV. With current traffic volumes the rows consisting of 5 to 8 vehicles are most common for an overtaking prohibition. For the other interventions rows with 1 to 4 vehicles are most common.

5.3 Results interventions of environment

From the effects of the interventions on traffic flow and safety, an indication can be given about the effects on the environment.

First a comparison between the construction and the necessary space of the interventions is made. For an overtaking prohibition it is necessary to make a separation between the driving directions, whether or not with a physical barrier. For the passing bay an existing hard shoulder or parking bay could be reconstructed. In the case of Fryslân, a totally new interventions are constructed.

This has already more impact on the environment than only a separation of driving directions on an existing road. The passing lane is longer than the passing bay, so needs more space. The construction of the overtaking lane has most impact on the environment, because the main traffic lane needs to be replaced to the right. This is necessary to make space for the overtaking lane at the left side of the main traffic lane.

Noise hinder and emissions are based on the number of conflict situations, see 5.1.2. For the overtaking prohibition the number of conflict situations is largest for cars and this counts for AVs for the passing bay. In both situations this leads to acceleration and deceleration movements and noise pollution. On the passing lane and overtaking lane there are also acceleration and deceleration movements, but is expected to be a little smaller than the passing bay and overtaking prohibition.

5.4 Results of interventions with change in traffic volumes

The effect of changes in traffic volumes is analysed on the percentage vehicles behind an AV, travel time, travel times loss and the length of the rows behind the AV.

Table 5-4 shows the percentage of vehicles that follows and AV for all scenarios (except for the low number of AVs, because these effects are negligible and not further taken into account). This table shows that the number of hindered vehicles increases when the number of AVs or other traffic increases. More AVs has a higher effect than a high traffic volume of other traffic.

Table 5-4 Percentage vehicle behind AV for the scenarios.

		low	current	high
No overtaking	low			
	current	6	6,2	7,8
	high	14,5	17,1	17,9
Passing bay	low			
	current	3,2	3,6	3,9
	high	7,9	9,9	9,5
Passing lane	low			
	current	3,2	3,4	3,8
	high	7,3	8,9	10,4
Overtaking lane	low			
	current	3,4	4	4,1
	high	8,2	9,6	13,4

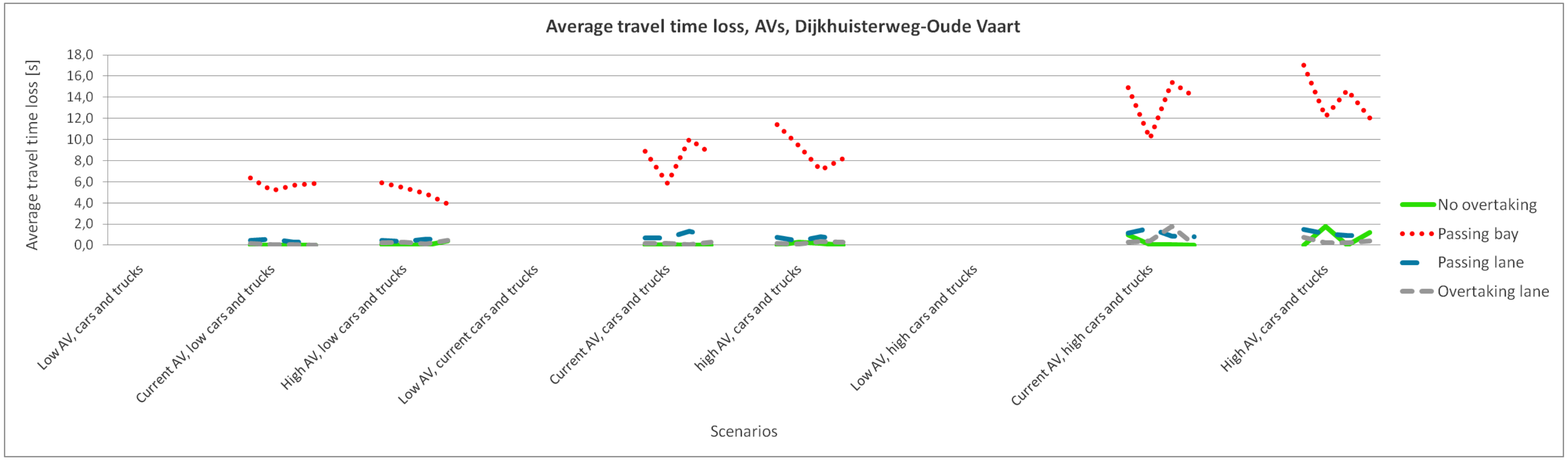


Figure 5-9 Average travel time loss AVs for different scenarios

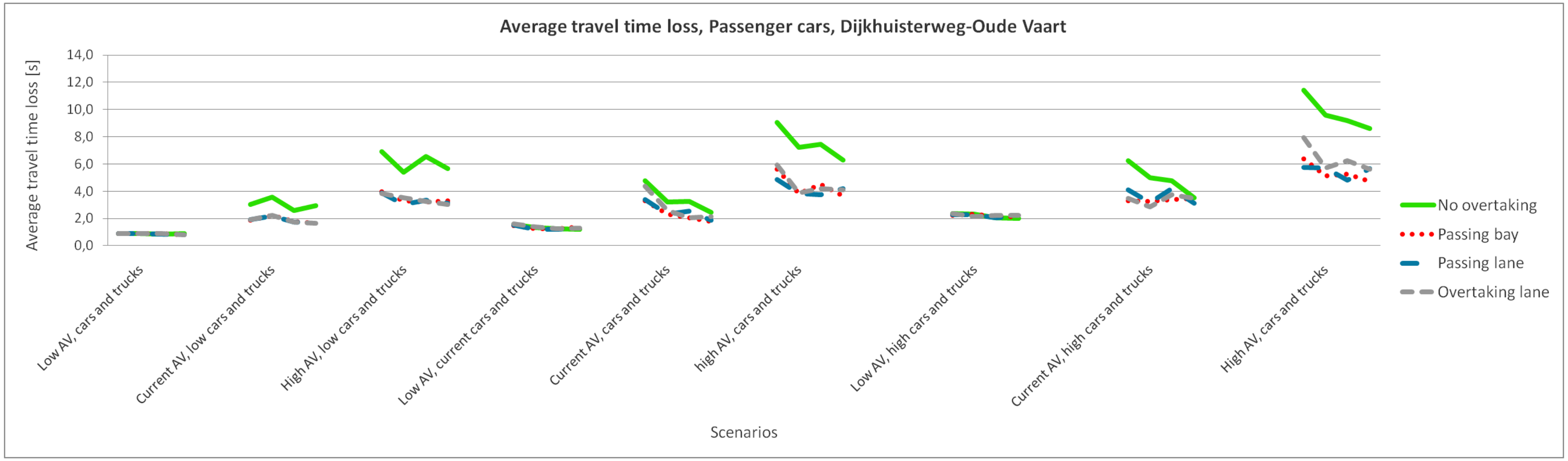


Figure 5-10 Average travel time loss passenger cars for different scenarios

The effect on travel time is shown in appendix J In figure 5-9 and figure 5-10 the effects on travel time loss are shown for all scenarios. From the figures can be concluded that on average the effects on travel time due to different intensities are very low, expect for the overtaking prohibition for passenger cars and the passing bay for AVs. The effects seems to be enlarge when the intensities grow. What changes a lot is that the number of rows increase when there are more AVs and that the length of the rows are longer when there are more cars and trucks, see figure 5-11 till 5-15. The low intensities of AVs lead to no AVs driving between Dijkhuisterweg and Oude Vaart, so these results are not taken into account.

From the results can be concluded that the negative effects of AVs increase when the traffic volume is increasing. A growth in the number of AVs has more impact than growth of the traffic volume of other traffic. Despite of the more negative effects, the ratio between the interventions remains about the same: the passing lane and overtaking lane are still the best solutions to reduce impact on safety, flow and environment at other traffic volumes. Only at very high traffic volumes for AVs and other traffic the effect of the overtaking lane decreases.

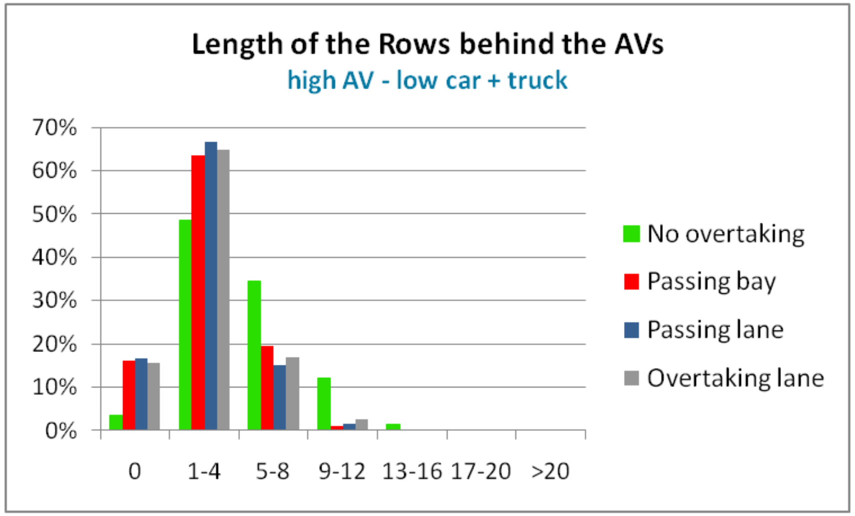


Figure 5-11 Length rows, high AV – low car + truck

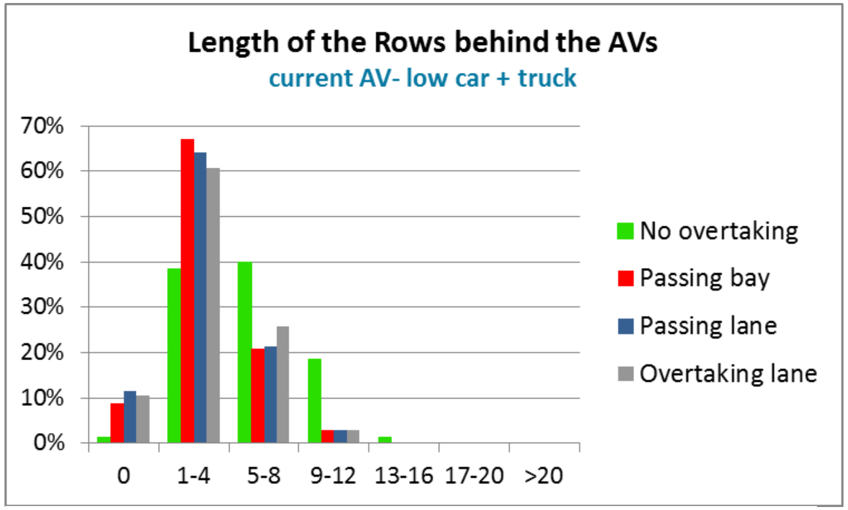


Figure 5-12 Length rows, current AV – low car + truck

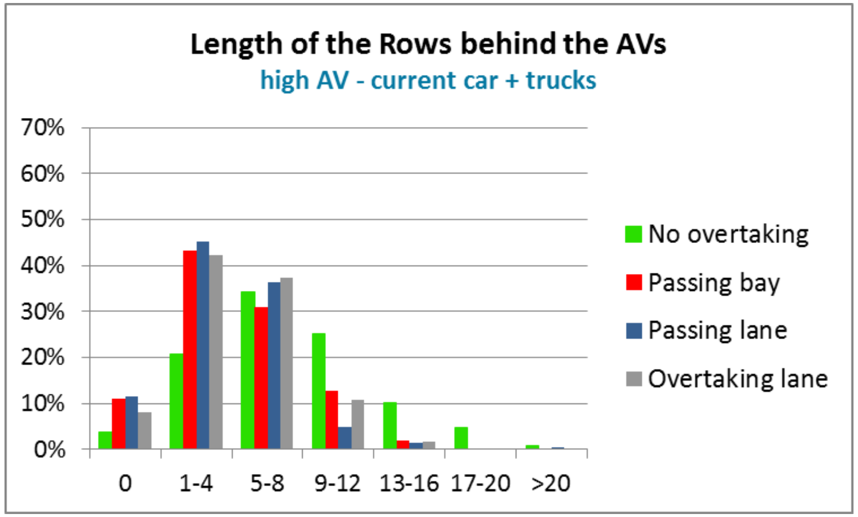


Figure 5-13 Length rows, high AV – current car _truck

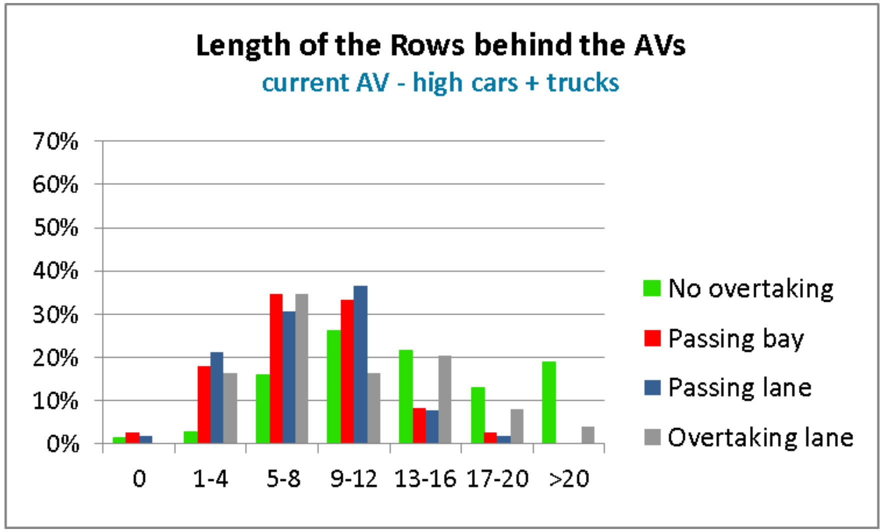


Figure 5-14 Length rows, current AV – high car + trucks

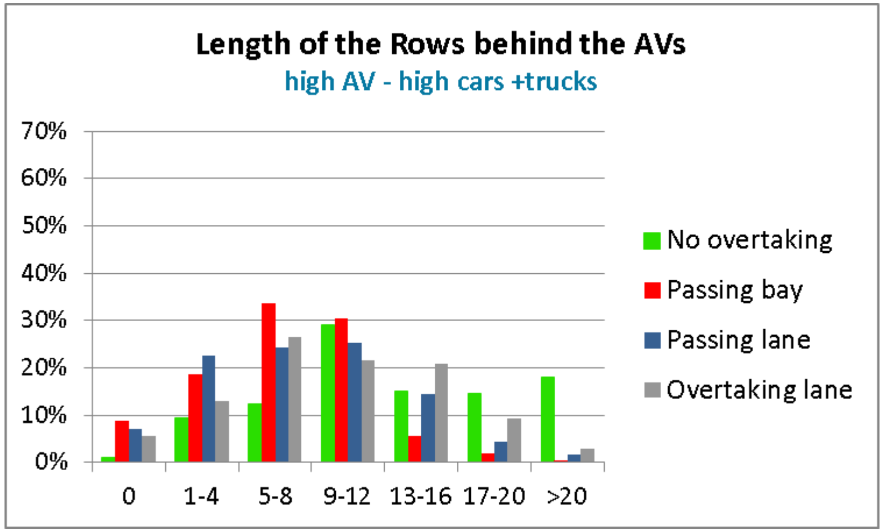


Figure 5-15 Length rows, high AV – high cars + trucks

5.5 Robustness of the interventions

Robustness is tested to see what the effect of changes in location and traffic volume are. The interventions are tested on changes into traffic volumes which are already discussed in the scenarios and tested to the position of the interventions into the network. The different locations are compared to travel time loss.

The interventions are analysed between the Dijkhuisterweg and Oude Vaart

- Dijkhuisterweg – Oude Vaart
- Oude Vaart – Dijkhuisterweg: other way traffic enters the section
- It Sud – Rysloane: intervention directly after intersection.

From table 5-5, figure 5-16 and figure 5-17 can be concluded that the differences between the locations are small. It is interesting to see that the interventions between It Sud and Rysloane have a higher, although the difference is small, travel time per kilometre than the other locations. This could be caused by the location which is right behind an intersection: not many vehicles are following at the start of the intersection and approach the vehicle later in the section. These later approaching cars can 'pass' the AV if the interventions lie not directly after the intersection, else they have to follow from the moment they approach till the AV leaves the road again.

Table 5-5 Travel time per kilometre of the three locations

	No overtaking	Passing bay	Passing lane	Overtaking lane
Average travel time per km AVs				
Dijkhuisterweg - Oude Vaart	93.9	103.4	98.1	97.9
Oude Vaart – Dijkhuisterweg	97.5	107.9	99.9	98.4
It Sud – Rysloane	99.4	109.1	99.3	99.37

	No overtaking	Passing bay	Passing lane	Overtaking lane
Average travel time per km cars + trucks				
Dijkhuisterweg - Oude Vaart	44.3	43.5	43.6	43.8
Oude Vaart – Dijkhuisterweg	44.8	44.1	44.3	44.2
It Sud – Rysloane	46.5	45.8	45.8	46.0

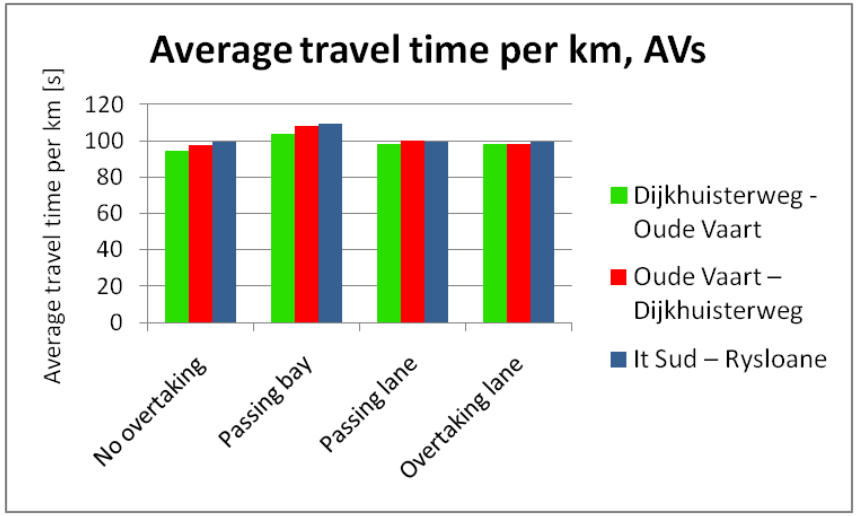


Figure 5-16 Average travel time per km, AVs at different locations

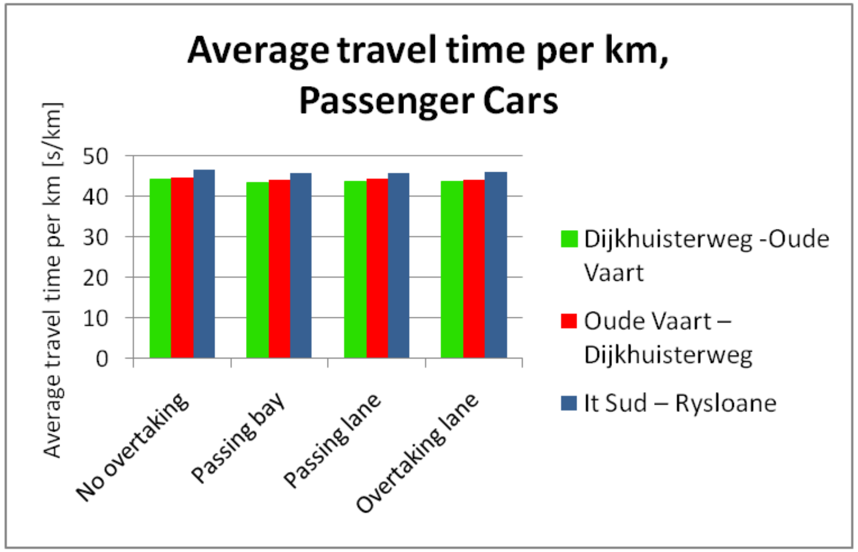


Figure 5-17 Average travel time per km, passenger car at different locations

5.6 Validity of the simulations

A validity test is done to see whether the method used and the output of the simulation is reliable. Two things are done: discussion of the assumptions and simplifications made during the research and what the effect of these are and expert meetings are done to ask for their expectations of the interventions and what they think of the outcomes of the model.

5.6.1 Assumptions and simplifications of the simulations

Aimsun needs input to create traffic and perform the simulation. The quality of the simulation is highly dependent on this input. For this reason the input characteristics are discussed on how realistic these are and what the effect of the assumption are. Discussed are the composition of the network and its interventions, the traffic composition and formation of the OD matrix.

The N358 in Fryslân is the network that is built into the Aimsun model as realistic as possible, but on a few points the network is simplified. The size of the network is based on Autocad drawings from the province of Fryslân. This means the dimensions of the network are the same as in reality. Towards production and attraction points, a simplification is necessary. Only at the ends of the simulated roads traffic enters or leaves the network. All private entrances and exits are not modelled. Consequence of this assumption is that there are fewer locations where the traffic enters or leaves the traffic; these points are more concentrated. This could also lead to shorter or longer rides by AVs in the actual situation. Despite of that, the number of vehicles driving on the road is the same and it is expected that this assumptions only leads to small changes.

The length of all minor roads is at least 100 meters. This is done to give enough space for possible waiting queues. This means effects on more than 100 meters upstream from the connection to the N358 are not taken into account.

For every intervention only one type of design is chosen and constructed in Aimsun. Another design of an intervention, the effects and quality could be different. Not for every infrastructural intervention are guidelines available. For this reason are the designs of the interventions based on existing interventions or guidelines of interventions that are closely related to the intervention. For example the design of the overtaking lane is closely related to a 2+1 lane, passing bays are already constructed Gelderland and passing lanes in Zeeland and tests with different types of passing lanes in Fryslân.

The interventions are a designed in such a way that overtaking via the opposite direction is not possible. In practice this could be reached by a physical barrier between the driving directions or by increasing the level of enforcement. It is also assumed in Aimsun that all AVs make use of the passing bay and passing lane. Also when there is no traffic following the AV. Interviews with drivers of AVs and evaluations in practice should point out whether AVs make always use of the intervention. The locations of the infrastructural interventions are based on the chosen location for passing lanes in the province of Fryslân on the N358. Robustness tests with different locations have given a first indication of the effect of different locations, see paragraph 5.5.

The traffic composition in the network of vehicles other than AVs is 90% passenger car and 10% trucks. This division is based on the measurements, so the same division as in reality. The traffic volume in the network is based on measurements in Fryslân and provides therefore a realistic situation. Despite of that, the data of only one day is used. This day may not be representative for all days in the year, because the number AVs depends for instance strongly on the season and weather circumstances. Here for several scenarios with different traffic volumes are analysed, see paragraph 5.4.

The traffic volume is measured with cameras and loops. AVs are observed with cameras in both directions. So the simulated traffic volumes are similar to the observations of that day (19-05-2011).

One type of AV is assumed, but in reality there are a lot of types of AVs. The vehicle parameters of the AV are chosen in such a way, that the vehicle can drive within a large range of speed. In reality differences in speeds between the AVs are also large, so this makes it already more realistic. Also for the passenger cars and trucks one type of vehicle is taken into account (only an average vehicle type), but difference in driving behaviour between the vehicles increases differences between vehicles, which makes it more realistic.

The origins and destinations of all traffic is not all known, because no routes are determined during the measurements. The traffic volume is only based on six cameras next to the road. The start of the network is at Leidijk where the number of vehicles that enter the network is measured, same counts for Dijkhuisterweg. Between those points only from four other points the traffic volume is known. What else is known is the number of through going traffic from every counting point to other counting points. From this information, the number of vehicles entering the network, leaving the network and between Leidijk and Dijkhuisterweg can be determined. In combination with important locations, that generates or attracts traffic, an OD matrix is made. These important locations could be for example municipalities and contracting firms. The vehicle routes can differ from reality, but the OD is created on such a way that the number of vehicles counted with the cameras are comparable to the number of vehicles driving on the network in Aimsun.

5.6.2 Expert meetings

The infrastructural interventions are discussed with three experts. Expert meetings are done with:

- Arie Vijfhuizen, senior advisor traffic design, traffic safety and spatial planning, Royal HaskoningDHV
- Harm Dijkstra, Project leader infrastructural projects and advise, province Fryslân
- Rinus Jaarsma, emeritus Wageningen University “Technische Infrastructuur en Inrichtingsvoorwaarden

To the experts was asked what effects they expect from the interventions on traffic flow and safety and what they think is the best soluation of the four interventions.

From the expert meetings can be concluded that in theory an interventions can work very good, but In practice the user acceptance and psychological part plays an important role. For instance, if people have the feeling that the intervention will delay them, they will not use it. And if people have to follow an AV, they have very soon the desire to overtake the vehicle.

Result from the expert meeting is that all experts give a negative advise for an overtaking prohibition, because they say it lead to larger travel time loss than the other interventions. Besides, driver behaviour plays an important role: people that have to follow an AV have a tendency to overtake an AV. This also occurs when this is not allowed. This increases safety risks. Expectations for the passing bay is that it is not a good solution for AVs. The passing lane, and even more the overtaking lane are expected to be good solutions in relation to traffic flow and safety.

5.6.3 Conclusion

From the discussion on assumptions made can be concluded that the micro simulation gives an indication about the effects of the infrastructural interventions at the specific location which is evaluated. This means the method can be used to analyse the impact of infrastructural interventions for a specific location. As mentioned before the results of the micro simulation are highly dependent on the input. The input is mainly based on measurements in Fryslân and which leads to a representation of reality. The input which is based on measurements can even be more precise, but than the costs of the measurements need to weigh against the accuracy of the method. The network can be built on a very realistic way in Aimsun. A disadvantage is that with a micro simulation no unexpected situations such as collisions occur and at the moment no safety characteristics can directly be derived from the model. It is expected that future simulation models are focusing more on traffic safety issues, so more information from the models can be derived to do a prediction to the effects on traffic safety. It is advisable to combine the microscopic simulation with driver simulator tests to analyse driver behaviour on and around infrastructural interventions or analyse the usage of the interventions in practice.

Expert meetings show that the psychologies also play an important role in the effectiveness of the interventions. If the road users think they lose a lot of time by using the intervention (for instance an AV on a passing bay in busy situations), people do not use intervention. In general, the expectations of the experts for traffic flow and safety are comparable with results from the interventions.

The simulation focuses a one location, so no general conclusions can be drawn yet. More measurements and simulations of other situations are necessary to make a more general conclusion on the effects of infrastructural interventions.

5.7 Synthesis

This paragraph recaps on the effects of the interventions at the section between Dijkhuisterweg and Oude Vaart on traffic flow, safety and environment. The overtaking prohibition is taken as reference situation to compare the other interventions with. For the assessment +,- and 0 are given. These have the following meaning:

0: neutral, comparable to the overtaking prohibition

+: scores better than the overtaking prohibition

++: scores way better than the overtaking prohibition

-: scores negative in comparison to the overtaking prohibition

--: scores very negative in comparison to the overtaking prohibition.

Results of the comparison are given in Table 5-6. Explanation to this table:

All the surrogate indicators for traffic safety give an indication of possible risks. From the results on traffic safety can be concluded that the overtaking prohibition leads to the highest risk. The passing bay can also lead to high risks, because an AV often has to merge from a standstill on the main traffic lane. The passing lane and overtaking lane are comparable. Difference is that at the passing lane the AV has to merge on the main traffic lane and at the overtaking lane the fast traffic. Difference in merging behaviour is not further analysed. This depends on driving behaviour at the intersection and can be best analysed in practice. Next to that, user acceptance needs to be taken into account. The chance that a passing lane and overtaking lane are accepted by users are higher than an overtaking prohibition and passing bay, because AVs have almost no extra hindrance and other traffic has opportunities to overtake the AV on a relatively safe way.

From the results on travel time and travel time loss for interventions can be concluded that the differences in travel time and the average loss per vehicle are very low. Although the average loss is very small, some people can have a large of delay. This is to see in the standard deviation. Especially in the no overtaking intervention the standard deviation in travel time and the loss is high. This can explained by the differences between followers and no followers: some vehicles drive behind an AV the whole length of the road, while others do not see an AV at all while their driving on the N358. The deviation is smaller for the other interventions, because of the 'overtaking opportunity.'

The effects of the interventions on travel times of AVs is opposite of the effects for cars and trucks. For AVs the passing bay is the least favourable, because in many cases the AV has to stop and wait till there is space to insert on the main traffic lane again. On a passing lane is the chance to insert without any hinder larger and in most cases the AV can keep on driving with its desired speed. The AV can drive with its desired speed at an overtaking lane and overtaking prohibition, so this has no influence on travel time.

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In relation to environment, starting with the required space, the overtaking lane and to a lesser extent the passing lane need most space and are therefore the most difficult to embed into the landscape. The overtaking prohibition does not costs extra spatial integration: almost no extra adjustments are necessary. In relation to air and noise pollution a closer look is taken to the acceleration and deceleration movements (number of stops and length of the rows). In this case the passing bay scores poorly, because the AV needs to decelerate on the passing bay and accelerate from a standstill. On the contrary, in case of an overtaking prohibition, other traffic needs to decelerate to follow the AV and drive at a speed with less ideal combustion. The passing lane and overtaking lane have positive effects on noise and pollution. With these interventions, less acceleration and deceleration is required, more traffic is able to drive with a more constant speed.

An estimation of the costs is given. It is expected that the overtaking restriction costs less and the passing lane and overtaking lane cost most due to the size of the interventions.

Table 5-6 Assessment framework

	No overtaking	Passing bay	Passing lane	Overtaking lane
Traffic safety				
Speed differences		+	+	+
Conflict situations		0	+	+
Following time		+	+	+
User acceptance		0	+	++
Traffic flow				
AVs		--	-	0
Cars + trucks		+	+	++
Environment				
Space		-	-	--
Pollution		0	+	+
Costs				
		-	-	--

Summarizing, the results of this study show that there is not one best intervention on rural distributor roads to reduce negative effects of AVs on traffic safety, flow and environment. The overtaking lane and passing lane score slightly better on traffic safety and flow, but also require the most space and are probably the most expensive.

5.8 Conclusion

Effects of the interventions are determined by the results of the simulations. For these simulations, the following general conclusion of the interventions can be drawn. Towards (surrogate measures of) safety, the overtaking prohibition scores worse, while the overtaking lane has the best score. The passing lane does not differ much from the overtaking lane. Towards traffic flow, the average travel time is not much affected by the interventions. The standard deviation of travel time in case of the overtaking prohibition is twice as high as for the other interventions. The same differences between the overtaking prohibition and the other interventions accounts for the number of vehicles in the queue behind an AV. Towards the environment, the overtaking lane requires the most space, closely followed by the passing lane. Effects on noise and pollutions are ambiguous: with the overtaking prohibition, both reduce for the AVs and increase for the other traffic. The effects for the other measures are opposite. Summarizing, the results of this study show that there is not one best intervention on rural distributor roads to reduce negative effects of AVs on traffic safety, flow and environment. The overtaking lane and passing lane score slightly better on traffic safety and flow, but also require the most space and are probably the most expensive.

6 Conclusion and recommendations

Goal of the research 'effectiveness agricultural vehicle interventions on rural distributor roads' is to develop a method for impact analysis of infrastructural interventions on rural distributor roads, which are taken to reduce negative effects of agricultural vehicles (AVs) on traffic safety, flow and environment. The microscopic simulation model Aimsun is applied for this impact analysis and turned out to be a useful tool. The model enables comparison of the impact of the studied infrastructural interventions: an overtaking prohibition, passing bays, passing lanes and overtaking lanes. These interventions were modelled on the N358 in Fryslân. For this road, the network and traffic intensities of both other traffic and AVs of one day were used to calibrate the model. Besides this 'real' data of one day, the effects of the interventions were studied with varying intensities of both other traffic and AVs. For these simulations, the following general conclusion of the interventions can be drawn. Towards (surrogate measures of) safety, the overtaking prohibition scores worse, while the overtaking lane has the best score. The passing lane does not differ much from the overtaking lane. Towards traffic flow, the average travel time is not much affected by the interventions. The standard deviation of travel time in case of the overtaking prohibition is twice as high as for the other interventions. The same differences between the overtaking prohibition and the other interventions accounts for the number of vehicles in the queue behind an AV. Towards the environment, the overtaking lane requires the most space, closely followed by the passing lane. Effects on noise and pollutions are ambiguous: with the overtaking prohibition, both reduce for the AVs and increase for the other traffic. The effects for the other measures are opposite.

Summarizing, the results of this study show that there is not one best intervention on rural distributor roads to reduce negative effects of AVs on traffic safety, flow and environment. The overtaking lane and passing lane score slightly better on traffic safety and flow, but also require the most space and are probably the most expensive.

Although different intensities of both other traffic and AVs are simulated, it is recommended to model other existing roads in the Netherlands, to verify the effects of the interventions on other locations. More detailed real life information on traffic flows, intensities of AVs and origin and destinations of all traffic of other location in the Netherlands will improve the validity of the simulations and therefore the outcomes. Supplementary, research in acceptance of the interventions (e.g. do AV always use a passing bay? Does other traffic obey to an overtaking prohibition?) and into driving behaviour on (the end of) the passing lane and overtaking lane is required.

6.1 Answers to research questions

The main research question is divided into six key questions, described in chapter 1. This paragraph recaps the research questions and summarises the findings.

1. *On how many rural distributor roads are AVs allowed and to what problems leads the attendance of AVs on these and other type of roads?*

AVs are allowed on about 75% of the in total 8.000 kilometres rural distributor roads in the Netherlands. On most of these roads overtaking of AVs is allowed too. This does not count for situations where the sight distance is limited.

Both the allowance of AVs and overtaking of AVs conflicts with sustainable safety approach. According to this approach it is neither desired to allow AVs on rural distributor roads nor to allow overtaking of other vehicles. Reason for this are the speed and mass differences between AVs and other traffic (no homogeneity, no forgivingness); reduction of traffic flow on road sections (functionality of the road); clearness for other road users that AVs make use of the road (recognisability) en for other road users it is not always clear what they can expect from the driving behaviour of an AV. At other roads, AVs can also conflict with the sustainable safety approach, for instance an AV combined with bicyclists on a parallel road leads to large differences in size and mass. The same counts for urban areas, and are also the liveability plays a role. No further research to these other roads is done.

The number of fatalities involving AVs has been stable around 16 per year in the past years of which about 5 happen on rural distributor roads. This seems low, but one can say that every traffic fatality is one too many. Moreover, a worrisome trend is that the number of fatalities involving AVs stays constant where the total number of traffic fatalities decreases. And, the impact, i.e. the severe accidents involving AVs is increasing. The severe accidents happen mainly on rural distributor roads, due to the high speeds of other traffic. On these roads speeding, speed differences, driving behaviour, design of the AV and roads design are the main cause of accidents.

Besides accidents, AVs cause hindrance on rural roads. But this is relatively low. Only a few vehicles have a relatively high delay. The vehicles that have to follow an AVs for a while, experience a feeling of losing a lot of time. So for a number of individual roads users the attendance of an AV on the road can be annoying.

2. *What indicators/ effects of AVs need to be determined?*

The effects of AVs are analysed for traffic safety, flow and environment. An overview of the studied indictors related to traffic safety and flow are given in table 6-1. For safety, surrogate measures are used, since the most direct indicator to measure safety, the number of accidents, happen to rarely for analyses. User acceptance, which influences traffic safety, cannot be derived from the simulation, but is studied qualitatively instead. The studied indicators for the environment space being taken up, noise and pollution. All in a qualitative way, although noise and pollution impacts are substantiated with model outcomes as the number of stops and length of the queue behind an AV.

Table 6-1 Surrogate indicators for traffic safety and indicators for traffic flow.

Indicator	Description
Traffic safety	
Speed differences between AVs and other traffic	The speeds of all vehicles driving on the road. This leads to an overview of speed frequencies. The higher the speed differences the larger the traffic safety risks.
Headways	The time headway between an AV and a following vehicle and the time a vehicle follows an AV with a minimum headway. In Fryslân, a time headway smaller than 8 seconds is assumed as a following vehicle (Hegeman & Dykstra, 2011). During this research the same upper value of 8 seconds is used.
Number of conflict situations	The number of conflict situations exists of the number of stops by a vehicle, the total number of AV followers and the number of vehicles that make use of the interventions and have to insert on the main traffic lane again. On a passing bay and lane these are the number of AVs using the intervention, on an overtaking lane these are the number of vehicles using the overtaking lane. The number of followers are the number of vehicles following AVs with a headway smaller than 8 seconds (see headways) and the number of

Indicator	Description
	stops is the number of vehicles that actually have to stop on the section (speed is 0 km/h). Also the chance to follow an AV is determined.
Traffic flow	
Travel time	The total travel time of all vehicles that have make use of the road.
Travel time loss	The extra time needed to travel /pass a certain intersection or road section because of attendance of other traffic, in comparison with a situation with other traffic. In this case the extra travel time needed because of the attendance of agricultural vehicles onto the road.
Maximum and mean queue length behind the AV	The mean and maximum number of vehicles following one agricultural vehicle. This gives an overview of the length of the row behind an AV.

3. *How could the effects of AVs on traffic safety and flow be determined on a quantitative way?*

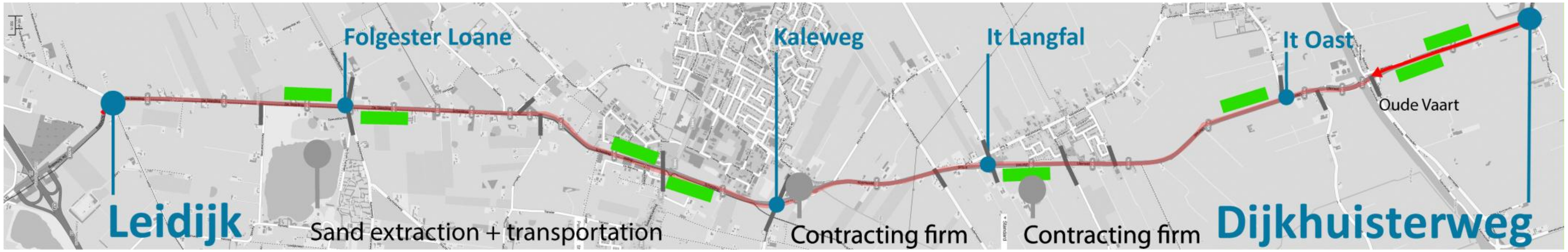
The method used to determine the effects of AVs on traffic flow and safety by making use of the existing microscopic simulation model Aimsun. AV characteristics are inserted to make it possible to determine effects of AVs. Other possible methods are a driver simulator , manual calculations and tests in practice. These methods are more expensive and have less flexibility in controlling and chancing circumstances such as intensities and interventions. With a microscopic simulation it is possible to analyse the effect of an AV on other traffic, to determine the effects of infrastructural interventions for every vehicle and is it possible to determine what the effects of changes into traffic volumes are. The effects on traffic flow and safety are quantified by the output of Aimsun using the (surrogate) indicators.

To study the effects of the interventions, the N358 in Fryslân is built into Aimsun. Figure 6-1 shows this road. This road was also used for the development of the AV measuring method and therefore real intensities of other traffic and AV are known. The intensities of one day, 19-05-2011 are used. On this day, the intensity of other traffic varies between 160 And 630 Per hour (between 7:00-21:00h). Intensities of AV vary between 1 and 20 per hour.

4. *Which AV interventions are available, which could reduce traffic flow, safety and environmental problems related to AVs driving on rural distributor roads?*

There are several types of AV interventions available. With the 'mobility ladder'

Figure 6-1 Overview of the analysed road, the N358 in Fryslân



available interventions are divided into seven categories: spatial planning; policy, pricing and service; traffic management and user behaviour; vehicle interventions; optimization of usage, dynamic traffic management; changes to current infrastructure and new infrastructure. This research focuses on changes to current infrastructure. Several provinces apply infrastructural interventions for AVs driving on rural distributor roads, such as passing bays and passing lanes. Problem is that these interventions are different per province and that the exact impact of those interventions is not exactly known yet. Besides, the different solutions per province can have influence on the predictability on a negative way and can lead to unclear situations for road users on rural distributor roads. Not focussing on the other interventions does not mean the other available interventions should be excluded. Instead, it is important to take all possible solutions into account when allowing AVs to drive on rural distributor roads. Interventions that are further analysed in this research are an overtaking prohibition, a passing bay, a passing lane and an overtaking lane. All are shown in Figure 6-2.

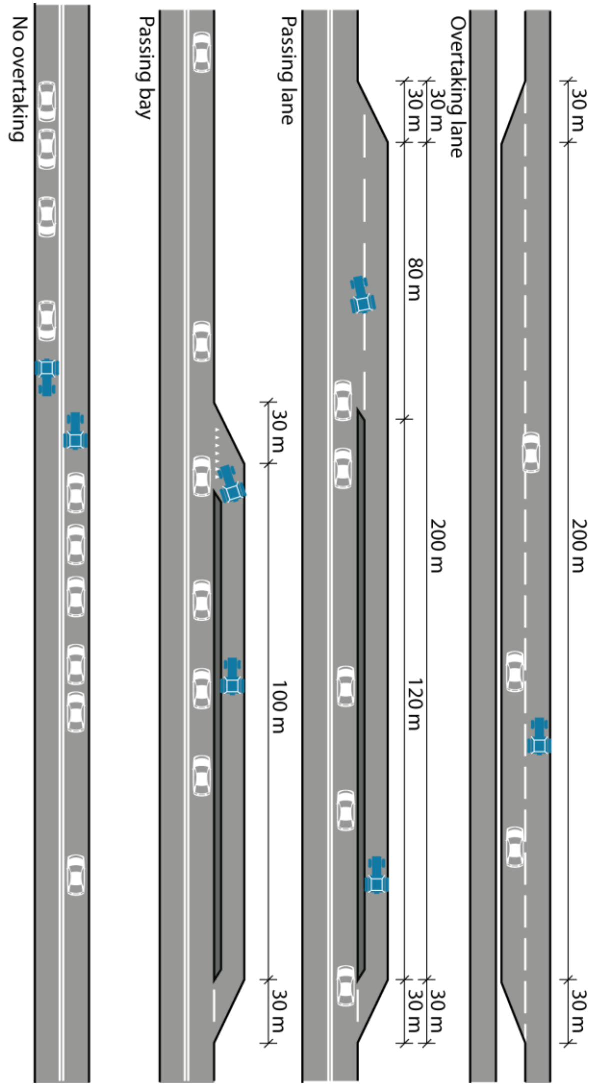


Figure 6-2 Interventions that are further analysed: an overtaking prohibition, a passing bay, a passing lane and overtaking lane

5. *What are the effects of the studied intervention for AVs on rural distributor roads on traffic safety, flow and environment?*

The effects are analysed for the road section between the Dijkhuisterweg and Oude vaart, a road stretch of 1250 metres. On this section one passing bay at each side, one passing lane and one overtaking lane was simulated.

Effect on traffic safety

First used surrogate indicator for traffic safety are speed differences. All interventions show that the average speed on the trajectory between Dijkhuisterweg and Oude Vaart of most vehicles lies around 80km/h. The speed distribution is similar for all interventions. A small difference between the overtaking prohibition and the other interventions is the shift of the small peak around 60-70 km/h to 40-50km/h.

The second safety indicator is the number of conflict situations, which consist of the number of stops (speed 0km/h); the number of hindered vehicles by an AV and the chance to get hindered by an AV; and the number of vehicle that uses the intervention and needs to merge back to the main traffic lane. Vehicles that need to stop are only AVs on a passing bay and in rare cases on a passing lane. The chance to get hindered by an AV without overtaking and with current traffic volumes is 0,06. At higher traffic volumes (for both cars & trucks and AVs) this chance increases. The chance to get hindered by an AV between Dijkhuisterweg and Oude Vaart and in case of an overtaking prohibition is almost twice as high as the other interventions (passing bay 0,022 and at an passing and overtaking lane 0,025). The number of vehicles that needs to merge onto the main traffic lane again is zero when there is an overtaking prohibition, at a passing bay and lane this are all the AVs driving on the road and in case of overtaking lane all vehicles that make use of it. For this reason an overtaking lane leads to most exiting and inserting movements.

The third used indicator for traffic safety is the following time behind an AV. The overtaking prohibition leads to longer following times behind an AV than the other interventions. A passing bay leads to the shortest following times, but the differences with the passing lane and overtaking lane are small.

For traffic safety also the user acceptance of both other traffic and AVs plays a role for infrastructural interventions. An overtaking prohibition leads to longer rows behind the AV than the other interventions and therefore it leads to a higher desire to overtake the AV. When there is no physic barrier, driver will disobey the overtaking prohibition. The other interventions provide relatively safe overtaking possibilities (no opposing traffic on the same lane), which decrease the overtaking desire at other locations. The user acceptance of the passing bay by the AVs determines the usages. When traffic intensities increase, AVs might have to wait a while before being able to merge back on the main lane again. This waiting time can discourage drivers of AVs to use the passing bay. The chance that a passing lane and overtaking lane are accepted by users are higher, because AVs have almost no extra hindrance and other traffic has opportunities to overtake the AV on a relatively safe way.

Effects on traffic flow

The first traffic flow indicator is average travel time, of which the differences per vehicle (cars and trucks) are small for all the infrastructural interventions. The average travel time per vehicle is 55 seconds with an overtaking prohibition and 51 seconds with an overtaking lane. The passing lane and overtaking lane lead to an average travel time of 54 seconds on the section. The difference between de overtaking lane and the other intervention can be clarified by the possibility of also overtaking cars and trucks. The travel time loss at an overtaking prohibition is on average per vehicle 2,6 seconds and at the other interventions 1,6-1,9 seconds.

The standard deviation of the travel time and travel time loss do show a difference. An overtaking prohibition leads to a standard deviation twice as large as the other interventions (on average 11 seconds for the overtaking prohibitions and about 6 seconds for the other interventions). These high standard deviations can be clarified by the difference between traffic that follows an AV the whole length of the section and traffic that does not get hindered by an AV at all. So, a number of vehicles have a lot higher travel time due to AVs, while other vehicles have no travel time loss at all.

The effects of the interventions on travel times of AVs is opposite of the effects for cars and trucks. For AVs the passing bay is the least favourable, because in many cases the AV has to stop and wait till there is space to insert on the main traffic lane again. On a passing lane is the chance to insert without any hinder larger and in most cases the AV can keep on driving with its desired speed. The AV can drive with its desired speed at an overtaking lane and overtaking prohibition, so this has no influence on travel time.

The last used indicator for traffic flow is the length of the row behind an AV. With current traffic volumes the rows consisting of 5 to 8 vehicles are most common for an overtaking prohibition. For the other interventions rows with 1 to 4 vehicles are most common.

Environmental effects

Finally the effects of the interventions on the environment, starting with the required space. The overtaking lane and to a lesser extent the passing lane need most space and are therefore the most difficult to embed into the landscape. The overtaking prohibition does not costs extra spatial integration: almost no extra adjustments are necessary.

In relation to air and noise pollution a closer look is taken to the acceleration and deceleration movements (number of stops and length of the rows). In this case the passing bay scores poorly, because the AV needs to decelerate on the passing bay and accelerate from a standstill. On the contrary, in case of an overtaking prohibition, other traffic needs to decelerate to follow the AV and drive at a speed with less ideal combustion. The passing lane and overtaking lane have positive effects on noise and pollution. With these interventions, less acceleration and deceleration is required, more traffic is able to drive with a more constant speed.

6. *How widely applicable are the results of the method used?*

The microscopic simulation model Aimsun is a useful tool to compare the impact of infrastructural interventions on a specific location. The results of the microscopic simulation depend on the input. The input for this study is based on measurements in Fryslân, which lead to a representation of reality for this location.

With the available data of the N358, the vehicle type 'agricultural vehicle' is defined in Aimsun and simulated. There is no reason to assume that agricultural vehicles in Fryslan differ from other provinces, therefore this vehicle type can be used for the Netherlands. In other countries, with other legislation, the behaviour of AVs might differ, for which adjustments of the AV in Aimsun are required.

What does differ on other roads in the Netherlands, are intensities of both other traffic and AVs and the lay-out of the road. To cover the first, within this study simulations are made with different intensities of other traffic and AVs. The extremes, i.e. 5 to 25 AVs per hour and 6000 to 13000 vehicles/day, are covered and therefore it is concluded that the results found for these intensities are applicable for all roads in the Netherlands. But, these intensities are only modelled on the N358. The curvatures of a road is therefore not varied. Therefore more measurements and simulations of other situations are necessary to make a more general conclusion on the effects of infrastructural interventions.

Moreover, practice of further research should show if no unexpected driving behaviour and offenses occur. Unfortunately this cannot be simulated in Aimsun, but can have influence on the impact of the infrastructural interventions.

In future a more general judgement about the impact of infrastructural interventions can be given by making more often use of the microscopic simulation model Aimsun for the impact analysis of infrastructural interventions and compare the results with situations in practice.

Answer to the main research question:

What method can be used to show the effectiveness of infrastructural interventions to minimize possible negative effects of agricultural vehicles on rural distributor roads on flow, safety and environment, given the measured intensities?

The microscopic simulation model Aimsun is used for the impact analysis of infrastructural interventions. It gives a good indication of the possible effects of the interventions in comparison with each other and for a specific location, with varying intensities of AVs and other traffic. The results of this study show firstly that the negative effects on traffic safety and traffic flow of AVs on rural distributor roads are limited. Secondly, there is not one best intervention on rural distributor roads to reduce negative effects of AVs on traffic safety, flow and environment. The overtaking lane and passing lane score slightly better on traffic safety and flow, but also require the most space and are probably the most expensive.

Despite of the conclusion that micro simulation is a good method for this study, one should keep in mind that a microscopic simulation an approximation of reality. No excessive behaviour or offenses of traffic rules are simulated. Supplementary studies, such as a driver simulator study or evaluation of interventions after installation in practice is required to study unexpected effects in practice.

6.2 Recommendations

This research ends with recommendations to improve the method, Aimsun, and more general recommendations towards interventions on rural distributor roads to reduce negative effects of AVs.

6.2.1 Recommendations for the microscopic simulation model Aimsun

The output of the microscopic simulation model Aimsun (and all other simulation models) gives an approximation of reality. The model can be a useful tool for the cross-comparison of interventions, but no general conclusions on the interventions should be derived from the results. For this reason it is recommended to use the tool for cross-comparison of infrastructural interventions on a specific location.

The origin and destination matrix for the simulated network was estimated, based on seven observation point on the N358. No routes were measured, which made the determination of the OD-matrix difficult. It should be determined if it is worth the investment to determine the route of each vehicle or that an estimation already satisfies.

During the research is made use of surrogate indicators for traffic safety, because the number of accidents is low. These measure give a good indication of safety, but do not cover all safety risks. Unexpected driving behaviour and offenses are not studied. It is expected that future simulation models are focusing more on traffic safety issues, so more information from the models can be derived to do a prediction to the effects on traffic safety. For the moment, it is advisable to combine the microscopic simulation with driver simulator tests to analyze driver behaviour on and around infrastructural interventions or analyze the usage of the interventions in practice with for instance camera observations. These methods could be a valuable complement to the microscopic simulation model.

During the research only one design per infrastructural interventions is built in Aimsun. A different design could influence the quality of the intervention. It is therefore advisable to do more research to changes in design for the most interesting interventions, for instance research to different lengths of the intervention.

It is expected that in near future passing lanes in Fryslân will be constructed. It is recommended to analyse the effects of the passing lanes in practice. This can be compared with the results of this research and can say more about the validation of the method used in this research.

In reality it is often allowed to overtake AVs. During this research a start was made with an overtaking model in Aimsun. However this model is not valid at the moment yet. It would be interesting to develop this overtaking model further and make it reliable. This makes it possible to see what happens when drivers are offending the overtaking prohibition and to make a simulations of current situations where overtaking is allowed.

During this research only one day is simulated So the simulated traffic volumes are similar to the observations of one day, in this case 19-05-2011. Although scenarios with varying intensities of both other traffic and AVs are simulated too, it is advised to validate the model with real date from another day. And also, for another road.

6.2.2 Recommendations for further research

When a road authorization is looking for a (alternative) route for agricultural traffic, it is recommended to start in an early stadium of the research with involvement of actors. This are for instance parties like TLO, CUMELA and residents. It is advisable to road authorizations to find out if there are no other alternative routes in rural areas, for instance separate AV paths or alternative routes via access roads, before deciding on using a rural distributor road for AVs. When there are no alternatives other than a rural distributor road, an AV could be allowed to make use of this road. Infrastructural interventions could improve the situation when AVs make use of this road, but also all other available interventions should be considered.

When road authorizations want to do something about ‘the problem with AVs’ they should start with gaining more insight in what the problem is. Observations of intensities and driving behaviour are necessary to verify whether interventions are necessary and, if so, which intervention is best for their situation.

At the start of this research calculations of the impact of AV on traffic flow are also made with a macroscopic model. It is interesting to compare the simulation output with calculations made for this specific location that is used.

This research is a follow up of the development of an agricultural measuring method. Thanks to this research this measuring method is now applied in Groningen and Drenthe, to study the effects of AVs on traffic flow and driving behaviour. It is advisable to compare the output of the measurements with the measurements in Fryslân to see if there are differences and similarities on rural distributor roads at different locations.

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Glossary

English	Dutch	Description
Distributor road	Gebiedsontsluitingsweg	Road type with basis: flowing of traffic on road sections and exchange of traffic at intersections.
Fatal accident	Verkeersongeval met dodelijke afloop	Traffic accident with deadly casualties.
Injury	Verkeersongeval met persoonlijk letsel	Traffic accident with personal harm.
Lot	Kavel	A defined piece of land as a whole registered.
Moving bottleneck	Bewegend knelpunt	A situation in which a slow-moving vehicle, for instance an AV or truck, disrupts the continuous flow of the general traffic.
Rural	Buiten de bebouwde kom	Area outside the urban area
Travel time loss	Reistijdverlies	Extra travel time caused by delay

Appendix

A. Agricultural vehicle characteristics and laws and regulations
B. Rural distributor roads in the Netherlands; characteristics
C. Elaboration on the ‘moving bottleneck’ model
D. Measurement results and calculations for the Province of Fryslân
E. Available measurement methods
F. Assessment frameworks
G. Agricultural areas and companies in the Netherlands
H. Choice methods to predict the effects of infrastructural interventions
I. Description of the Aimsun simulation software
J. Results of the simulations

A. Agricultural vehicle characteristics and laws and regulations

Laws and regulations for agricultural vehicles

In the Netherlands, for agricultural vehicles there are vehicle regulations which are part of the law for road regulations (Wegenverkeerswet 1994). In the regulations are permanent (user) demands described, such as maximum dimensions, mass, lightning and so on, which should be taken into account when these vehicles make used of public roads. These guidelines for AVs below, under the title 'vehicle characteristics.'

Since 2005, there is an EU-approval applied which sets permanent demands for brakes, lighting, mirrors, maximum dimensions, mass and axis loads. A starting point of this approval is that there should be a national registration of agricultural vehicles, such that a distinction can be made between vehicles that meets the requirements and which do not. Since there is no national registration and no registration duty in the Netherlands, a change in the law or a registration system for agricultural vehicles is necessary. On this moment these changes are still not implemented, so a license plate, registration and so on is still not necessary. A driver license is expected to be implemented in 2014 (CROW, Kennisplatform Verkeer en Vervoer, 2006).

Vehicle characteristics

In the laws and regulations in the Netherlands, the maximum dimensions, weight and axle loads are determined. An overview of these dimensions is given in Table 0-1 and. These dimensions do not count for vehicles with an exemption. Vehicles with a width of 3-3.5 meters need an exemption to make use of public roads. Vehicles that have width of more than 3.5 meters need special transport facilities (CUMELA, 2011).

Comparison with other countries

In comparison with other European countries, the Netherlands has relatively little laws and regulations for AV in relation to the driver license, license plate and dimensions of the vehicles (De Onderzoeksraad voor Veiligheid, 2010). The most important difference between the Netherlands and most other European countries, like Germany of Belgium are the following:

- **Driver license:** the Netherlands is one of the few countries in which a driver of an AV does not need a driver license to make use of public roads. Expected is that the driver license for AV will be implemented in the Netherlands at the start of 2014.
- **Registration/ admission test:** on this moment, there is no registration or admission test for agricultural vehicles. This means there is no registration of the number of agricultural vehicles and an admission test to test the vehicle to the regulations. This also means no license plate and no periodic motor vehicle test. In most other countries registration and a license plate is necessary to make use of public roads.
- **Dimensions:** while in the Netherlands the maximum width of an agricultural vehicle is 3 meters or even 3,5 meters with an exemption, in most countries the maxim width of an AV is 2,55 meters or less.
- **Speed limit:** in the Netherlands the speed limit for AV's is 25km/h, while most vehicles can already 40km/h or more. One of the reasons for this is, that in other countries speed limits for agricultural vehicles are already 40/km/h or even 60km/h (Germany). Agricultural vehicles are all imported from other countries in which this speed limit is already higher. In the Netherlands these vehicles while not be tested, so it is possible to use AV's who can drive a lot faster than the current speed limit in the Netherlands.

Table 0-1 Maximum size, weight and axis loads (CROW, 2002)

	Width [m]	Length [m]	Height [m]	Weight [ton]	Max aslast	
					Powered axle [ton]	Non-powered axle [ton]
Agriculture or forestry tractors	3	12	4	18 (2 axles) 24 (3 axles)	11,5	10
Motor vehicles with limited speed	2,6	12	4	50	10	10
Motor vehicles with limited speed (as self-driving machinery)	3	12	4	50	12	12
Supporter	3	12	4	-	10	10
Supporter with massive tyres	120kg per centimetre width of tread					
Exchangeable pulled machine	3	12	4			
Agricultural tractor or with suporter or with exchangeable pulled machine.	3	18	4	50	11,5	10
motor vehicles with limited speed with laden supporter	3	18	4	50	10	10

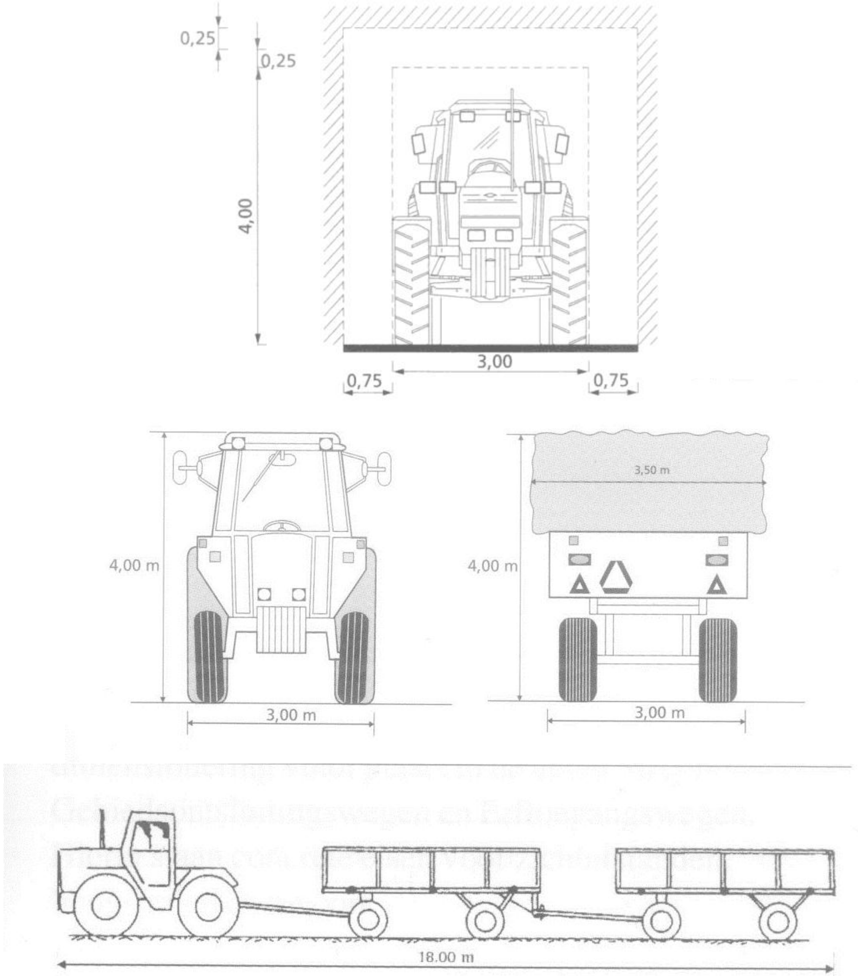


Figure 0-1 Gauge and dimensions of a design vehicle AV (CROW, Kennisplatform Verkeer en Vervoer, 2006) (CROW, 2002)

Deceleration characteristics of agricultural vehicles

There are requirements for the braking power of agricultural vehicles. At a maximum construction speed of 30km/h, the deceleration should be at least 2,4m/s^2. For a construction speed of more than 30km/h, this should be at least 3,1m/s^2. This means a stop distance (reaction time + braking distance) for an AV with a speed of 25km/h is about 15 meters and for an AV driving 40km/h about 30 meters. The stop distance is about 30-50% longer than that of a passenger car. The braking distances are for an AV without a dumper, trailer or other equipment. The braking distance with this equipment will be even longer. There are no requirements for the deceleration for trailers (SWOV, 2010). In comparison with other vehicles: a passenger car has an average deceleration of 4,0m/s^2; a van3,7m/s^2; a medium truck (15 ton) 3.2m/s^2 and a large truck (38 ton) 3.0m/s^2 . So the deceleration rates of an AV could be compared with those of a large truck (Dijkstra & Drolenga, 2006).

Power classes

Agricultural vehicles can be divided in three power classes:

- **Light**, 20 kW - 75 kW: these are light tractors used for the agriculture, for example for protection of crops and plants, killing weeds or fertilization of the land.
- **Middle**, 75 - 150kW: these are middle heavy vehicle that can be used for broad activities in as well agricultural as well as cattle farms, for instance for transport of cattle and harvest.
- **Heavy**, > 150kW: heavy agricultural tractors, which are mainly used for harvest, pick-up and transport activities. These vehicles are often putting in by mixed wage companies for instance for soil activities.

Most used class is the middle class from 75 to 150kW (Onderzoeksraad voor Veiligheid (OvV), 2010).

B. Rural distributor roads in the Netherlands; characteristics

Requirements for rural distributor roads:

	Sustainable safety	EHK
Maximum speed	80km/h	
Separation of roadways	Hard or not possible to override	Continuous double axis marking (without overtaking), discontinuous 9-3 line (with overtaking)
Forbidden categories	Complete separation of bicycles, mopeds, tractors and other motor vehicles with limited speed	Complete separation of bicycles and mopeds. Agricultural vehicles are undesirable, but could be allowed.

Dimensions

The cross section for a rural distributor road following the guidelines from the manual for road design in the Netherlands looks as follows:
Lane width: 2,75m
Continuous double axis marking: 0,15m
Total width (without hard shoulder): 7,5m.

Following the EHK for smaller existing roads (where no space is available):

Dimension	Manual road design [m]	EHK [m]
Lane width	2,75	2,70-2,75
Marking axis	Double with a width of 0,15m; inner space 0,8m	0,15 with inner space 0,2-0,8m

On many of these roads it is allowed to take over agricultural vehicles.

Route choice of road users is mainly based on:

- The time needed for a certain replacement
- The reliability of the replacement, in terms of travel time
- The comfort of driving on the route.

The trajectory speed is the average speed of passenger car vehicles on a certain trajectory, that can be reached under good sight and weather circumstances.
The desired trajectory speed on rural distributor roads has been determined on at least 60km/h.
The trajectory speed mainly depends on: density of the traffic, share of trucks, curvature of the road, and the number of intersections with speed restriction facilities.

When agricultural traffic is permitted on the road, it is advisable to use bigger dimensions than the minimal sizes, because of the large size of agricultural vehicles, which can cause unsafe situations or berm damage.

C. Elaboration on the 'moving bottleneck' model

Without overtaking

Model to determine effects of agricultural vehicles

Botma has used the model of Lighthill & Witham to describe the effect of a slow moving vehicle on the traffic flow. With the application of Botma, it is possible to calculate the following:

- Size of the disruption
- Time of the disruption
- Number of hindered vehicles
- Extra travel time

The computation of the size of the effects of an AV are described below.

These effects depend strongly on:

- The length of the ride of the AV (X)
- The speed of the AV (V_{AV})
- The intensity (q_1) and the average speed (u_1) of other traffic in the same direction of the AV.

It should be clear that the longer the length of the ride, the lower the speed of the AV, the higher the effects of AV are.
How these effects can be calculated is written down below.

Size of the disruption:
The size of the disruption can be characterized by the maximum length of the row behind the agricultural vehicle. The length of the row can be expressed by the number of vehicles in the row.
The maximum length of the row caused by the agricultural vehicle is at the moment the agricultural vehicle leaves the road. The maximum length of the row can also be shown in the time-space diagram; this is the blue line in Figure 0-2:

The maximum length of the row can be calculated by (C.1):

$RL = X * k_r (1-vs_1/ v_{AV})$ (C.1)

Where:

- X is the length of the ride of the AV
- K_r is the density of the row behind the AV
- v_{s1} is the speed of the shockwave between free flow and the row behind the AV.
- v_{AV} is the speed of the AV

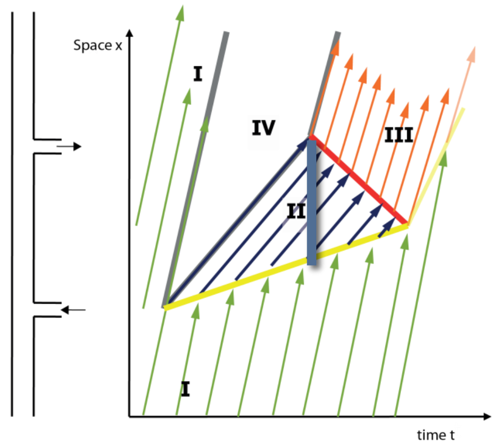


Figure 0-2 Maximum length of the row (blue line) and the distance between the point where the AV leaves the road and where the row dissolves (red line).

So the maximum length of the row depends on the length of the ride of the AV, the density of the row, the speed of the transition between the free flow and the row behind the AV and the speed of the AV.

When the AV leaves the road the row dissolves downstream, but it can still grow upstream. When the intensity is low (<capacity of the moving bottleneck) only a few vehicles have hinder of the agricultural vehicle and the row dissolves very fast. When it is busy on the road (<capacity of the moving bottleneck) the queue grows at the tail.

The distance between the point where the AV leaves the road and where the row dissolves is the red line in Figure 0-2.

This distance can be calculated by (2.2):

$$X_s = X [1 - (1 - vs_s / v_{AV})/ (1 - vs_2/ vs_1) \qquad (2.2)$$

Where:
vs_s is the speed of the shockwave between the row behind the AV and capacity.

Time of the disruption:

The total time of the disruption (T_s) is the time of the row on the road caused by the AV and the time in which traffic only rides in capacity conditions, see Figure 0-3. This disruption depends of the length of the ride, the speed of the AV (so the time the AV is on the road, T) and the intensity and speed of other traffic during free flow and capacity conditions see (C.3).
It is also possible to only determine the time of the existence of the row (T_r), see (C.4). The row consists of the vehicles that drive in the row behind the AV. This is dependent on the length of the ride and the speed of the AV and the ability of the traffic to dissolve the row (speed of the transitions from capacity to free flow).

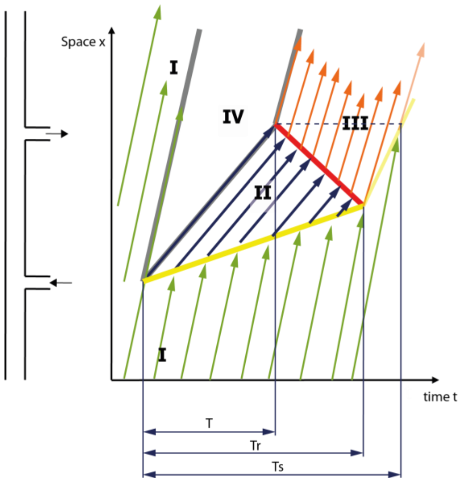


Figure 0-3 Times of disruption

$$T_s = X (q_c / v_{AV} - q_1 / u_1) / q_c - q_1) \qquad (C.3)$$

$$T_r = X (1 - vs_2 / v_{AV}) / (vs_1 - vs_2) \qquad (C.4)$$

Number of hindered vehicles:

The total number of hindered vehicles N_t can be divided into the vehicles which have driven in the row behind the AV and in capacity conditions and in the vehicles who only have driven in capacity conditions, but not in the row. The first mentioned vehicles are the ones who pass the dark yellow line, the last mentioned vehicles are the vehicles who pass the light yellow line in Figure 0-2.
It is logical that the vehicles in the row have more delay than the vehicles who only drove in the capacity conditions.
The total number of hindered vehicles can be calculated by (C.5):

$$N_t = X (1/ v_{AV} – 1/ u_1) q_1 * q_c / (q_c - q_1) \qquad (C.5)$$

Where:
u_1 is the average speed of traffic in free flow conditions
q_1 is the intensity during free flow conditions
q_c is the intensity during capacity

Travel time loss

The total *extra* delay R_t of all hindered vehicles depends on the length of the ride and the speed of the AV and the intensity of the traffic during free flow and capacity. This total extra travel time can be calculated by (C.6):

$$R_t = 0,5X^2 (1/ v_{AV} – 1/u_1)^2 q_1 * q_c/(q_c - q_1) \qquad (C.6)$$

This extra travel time is the extra travel time of the vehicles that were driven in the row as well the travel time of the vehicles who had hinder of the capacity conditions.

From (C.5) and (C.6) a formula can be derived to determine the average extra travel time ($\bar{R}_t$)

$$\bar{R}_t = 0,5 X (1/ v_{AV}) – 1/ u_1) \qquad (C.7)$$

(Botma, 1981)

Discussion of the formulas:

In the formulas some assumptions are done which should be mentioned, because the model is only an approximation of the reality:

- The time it takes for an AV to enter and leave the road is not taken into account. This means it is assumed that the time needed for the manoeuvres is 0. In reality an AV needs some time to turn off the road. This time is not very high and will only lead to an almost negligible extra travel time.
- In the model the distribution of traffic over time and space is homogeneous and stationary during free flow conditions (constant over time and space). In reality there will be fluctuations in the distribution of. Different kind of distributions could be taken to determine effects of agricultural vehicles. This could lead to more fluctuations in the traffic flow, so sometimes the delay could be higher and sometimes lower. This could lead to more valid results. In further analysis this should be taken into account.
- With this method it is not possible to determine the individual delay per vehicle, only the total delay of all vehicles together and the average delay per vehicle can be determined. The individual delay will depend on the moment the vehicle arrives behind the AV, the row or in capacity conditions. It could be interesting to see what the maximum delay of one vehicle is, but for a road authority individual consequences are often not relevant; they will mainly look to the delay of the traffic as a whole.
- The following behavior is assumed constant in the model. Following behavior differs in reality per person and per situation and in reality will lead to more fluctuations. These differences should be taken into account in further analysis.

With overtaking

For the overtaking the same theoretical basis and phases can be used than without overtaking. Main difference is that people in this situation are allowed to overtake AVs. Overtaking behavior can be described by the relation that given there is a permanent available desire to overtake, the

Low intensities, enough sight distance: no problem overtaking (flying overtaking possible). The traffic flow will not decrease negligible in this situation. Only extra maneuver is overtaking, which could have influence on (the feeling) of traffic safety.

Number of hindered vehicles

The number of hindered vehicles is assumed to be the same as the number of the hindered vehicles in comparison with the situation without overtaking, because also vehicles that overtake the vehicle are hindered (have to make an extra maneuver). Note should be made about the vehicles at the tail of the queue: vehicles that were driving for a very short moment at the tail could in the situation with overtaking not be hindered.

Travel time loss with overtaking

With the measuring method of DHV the number of overtakers is known. Therefor the gaps and sight distance are not necessarily needed to calculate the travel time loss.
Travel time loss in comparison with the situation without overtaking can be calculated as follows:

$$R_{overtaking} = q_i/N_i * R_t \qquad (C.8)$$

Where:
N_i is the number of overtaking vehicles
Where R_t is the extra travel time without overtaking ($R_t = 0{,}5X^2\ (1/V_{AV} - 1/u_1)^2\ q_1*q_c/(q_c - q_1)$)

This formula gives the idea all overtakers directly overtake the AV. In practice this not seems to be thruth; most overtakers use the accelerating strategy. Extra following time should be included.

Row behind the AV

The row behind the AV will be calculated on the same way as in the situation without overtaking, but taking the number of overtakers into account.

D. Measurement results and calculations of the Province of Fryslân

Measurement in Fryslân

From data of the measurements in Fryslân it is possible to determine several effects of agricultural vehicles (see **Fout! Verwijzingsbron niet gevonden.**). With the available data it is possible to calculate travel time delay and the number of hindered vehicles. This will be done by the method of Botma as mentioned in 2.2.1 for situations where overtaking is not allowed as well as situations where it is allowed.

Figuur 4.1: onderzoeksgebied N358, met de zes cameralocaties

Measurements in Fryslân

The measurements in the province of Fryslân are done on the N358

What has been measured in Fryslân:

- Intensities of agricultural vehicles and other traffic
- Rows behind the agricultural vehicle
- Travel time and speed of all AVs
- Travel times and speed of all other traffic
- Travel time delay of traffic due to the AV (only for AVs passing at least two cameras and compare 5 vehicles in front and 5 vehicles behind the AV, including the vehicles who have passed the AV).

Measures of behavior:

- Following time behind the AV per individual vehicle
- Overtaking strategy
- Overtaking time
- Time-to-collision with cars in the opposite direction: time till first oncoming vehicle.
- Distance between the AV and the car in front after overtaking)

In short the results of these measurements

Results of the measurements on Thursday 19 May.

Intensities Fryslân

In Fryslân, the intensity is measured of all traffic in one direction and the intensity of agricultural vehicles is measured in two directions.
To use the intensities of all traffic, the intensities measures of the one direction are mirrored between 7-21 hours. Outside this period there are no agricultural vehicles on the road and on this way the morning peak and evening peak are turned.
An overview of the intensities measured and mirrored (of other traffic in the southern direction) are in Table E-0-2 and Table E-0-3.

	Lei-dijk	Folgester Loane	Kaleweg	It Langfal	It Oast	Dijkhuister-weg
Number of motor vehicles (no AVs)	8744	9202	9644	7772	9594	9404

Table E-0-2 Intensity of traffic (without AV) on the N358 on 19-05-2011

Richting Noord (gemeten)

Uur	Leidijk	FolgsterLoane	Kaleweg	It Langfal	It Oast	Dijkhuisterweg
0	22	18	22	11	12	16
1	5	7	10	7	9	7
2	3	1	3	1	3	7
3	8	5	9	5	5	7
4	12	9	11	5	8	8
5	31	25	32	18	30	23
6	109	101	136	119	176	149
7	249	242	259	226	313	319
8	252	276	245	217	315	323
9	193	190	192	155	210	226
10	171	208	196	161	203	201
11	185	206	227	178	212	228
12	213	231	235	190	228	212
13	224	254	268	208	273	260
14	236	273	265	225	257	265
15	359	378	388	309	380	396
16	631	631	622	489	552	538
17	497	508	569	445	504	490
18	252	266	332	269	330	310
19	210	214	232	190	233	232
20	158	182	197	163	184	159
21	166	187	163	131	165	143
22	120	129	139	110	135	121
23	65	60	70	54	60	62

Richting Zuid (gespiegeld tussen 7 en 21)

Uur	Dijkhuisterweg	It Oast	It Langfal	Kaleweg	FolgesterLoane	Leidijk
0	16	12	11	22	18	22
1	7	9	7	10	7	5
2	7	3	1	3	1	3
3	7	5	5	9	5	8
4	8	8	5	11	9	12
5	23	30	18	32	25	31
6	149	176	119	136	101	109
7	159	184	163	197	182	158
8	232	233	190	232	214	210
9	310	330	269	332	266	252
10	490	504	445	569	508	497
11	538	552	489	622	631	631
12	396	380	309	388	378	359
13	265	257	225	265	273	236
14	260	273	208	268	254	224
15	212	228	190	235	231	213
16	228	212	178	227	206	185
17	201	203	161	196	208	171
18	226	210	155	192	190	193
19	323	315	217	245	276	252
20	319	313	226	259	242	249
21	143	165	131	163	187	166
22	121	135	110	139	129	120
23	62	60	54	70	60	65

Richting Noord (gemeten)

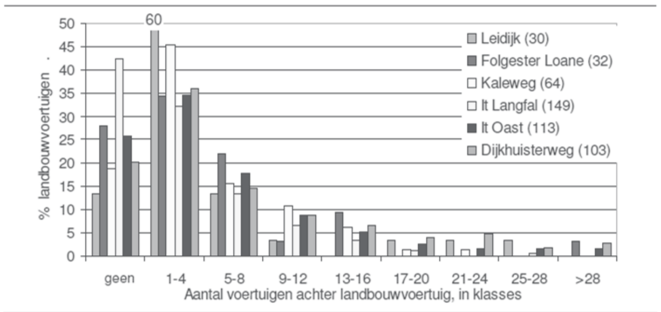
Uur	Leidijk	FolgsterLoane	Kaleweg	It Langfal	It Oast	Dijkhuisterweg
0						
1						
2						
3						
4						
5						
6						
7	0	0	1	1	1	1
8	2	2	1	2	3	6
9	1	1	1	4	3	3
10	1	0	3	4	3	2
11	3	3	1	3	4	6
12	1	1	0	2	2	3
13	1	1	1	8	6	5
14	0	2	0	0	3	4
15	1	0	0	4	5	3
16	1	1	3	7	3	2
17	0	0	1	1	0	0
18	0	0	0	2	1	1
19	0	0	0	4	0	0
20	0	1	0	2	1	0
21						
22						
23						

Richting Zuid (gemeten)

Uur	Dijkhuisterweg	It Oast	It Langfal	Kaleweg	FolgesterLoane	Leidijk
0						
1						
2						
3						
4						
5						
6						
7	2	0	0	1	1	1
8	2	3	1	0	1	1
9	5	3	4	0	1	0
10	3	4	3	1	1	2
11	6	6	6	3	2	1
12	5	3	2	0	1	2
13	3	4	8	1	2	0
14	3	3	4	3	1	0
15	2	2	2	2	0	1
16	2	3	4	0	0	0
17	4	3	6	3	0	0
18	1	3	3	2	0	1
19	0	0	2	0	0	0
20	0	0	1	0	0	0
21						
22						
23						

Table E-0-3 intensities of agricultural vehicles on the N358 on 19-05-2011

Diagram D: Length of the row behind the AV



Figuur 5.5: verdeling (procentueel) van volgrijlengtes per locatie

Travel time and average speed

Results from measurements in Fryslân:

Table E-0-4 Travel times and speed of other vehicles than AVs

	Reistijd voertuigen voor		Reistijd voertuigen na landbouwvoertuig					
Traject	landbouwvoertuig	#	wel ingehaald	#	extra	niet ingehaald	#	extra
Kaleweg - It Langfal	73	5	101	2	1,4	116	3	1,6
Kaleweg - Dijkhuisterweg	426	5	534	1	1,3	545	4	1,3
It Langfal - It Oast	117	5	151	5	1,3		0	
It Langfal - It Oast	117	5	130	4	1,1	176	1	1,5
It Langfal - It Oast	112	5	167	1	1,5	115	1	1,0
It Langfal - It Oast	114	5		0		368	5	3,2
It Langfal - It Oast	119	5	136	3	1,1	118	2	1,0
It Langfal - Dijkhuisterweg	413	2		0		433	5	1,0
It Langfal - Dijkhuisterweg	273	3	260	3	1,0	314	2	1,2
It Langfal - Dijkhuisterweg	224	5	233	0	1,0		0	
It Oast - Dijkhuisterweg	99	5	137	5	1,4		0	

	Leidijk	Folgester Loane	Kaleweg	It Langfal	It Oast
Number of vehicles counted between two cameras [veh]	1601	1063	1689	1592	1613
Distance between camera's X [m]	2100	4400	1400	2600	2000
Average travel time [min]	02:00	03:51	01:09	02:06	01:39
Average travel time [s]	120	231	69	126	99
st dev	00:12	00:37	00:09	00:14	00:14
st dev [s]	12	37	9	14	14
Speed [km/h]	63	69	73	74	73
Speed [m/s]	17.5	19.2	20.3	20.6	20.3

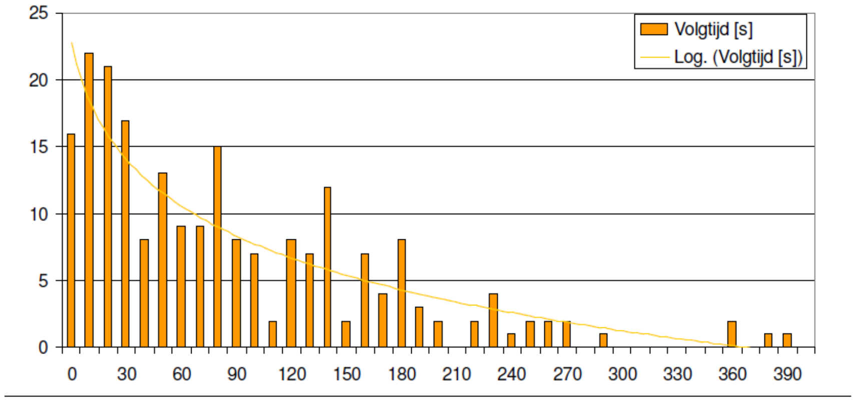
Table 0-5 Travel time characteristics AVs

	Leidijk	Folgester Loane	Kaleweg	It Langfal	It Oast
Number of AVs counted between two cameras	2	0	5	22	17
Average travel time [s]	205	-	143	213	210
Average speed [km/h]	36.9	-	35.2	43.9	34.3

Influence AVs on travel time of other motor vehicles:

Number of overtakers, position and strategy of overtakers

From the participating observation, about 50% of the vehicles overtook the agricultural vehicle. At some locations more overtakings were observed than on others. The most used overtaking strategy was accelerating overtaking.



Figuur 5.7: verdeling van de tijd dat voertuigen achter het landbouwvoertuig hebben gereden

Calculations Fryslân

With the data gathered in Fryslân, the following will be calculated:

- The extra travel time per vehicle and the average extra travel time for the total traffic stream.
- The number of hindered vehicles: all vehicles that will have delay or have to make extra maneuvers (for instance overtaking) because of the attendance of the AV on the road.
- The number of vehicles behind the AV.

The calculations will be done for a situation where overtaking is not allowed and for a situation where overtaking is allowed. For both situations, the delay and number of hindered vehicles will be calculated for two scenarios:

- Basic scenario:

For the calculations of the extra travel time, the number of hindered vehicles and the row of vehicles behind the AV, the method of Botma will be used.

Assumptions and simplifications:

- Average speed without AV based on measures will be used as free flow speed (based on the times when no AV is driving onto the road, between 0-7 and 21-0), see Table 0-7.
- Average speed of the AV is used per part (measured between every camera), see Table 0-7.
- Percentage of through going traffic and turning traffic is taken into account. For both the AVs and other traffic, see Table 0-8. Turning AVs and traffic will used half of the traject (distance between two cameras).
- Other assumptions and simplifications as used in the most simple version:
  - Capacity 2800 vehicles/ hour in both directions, 1400 vehicles/ hour per lane
  - Homogenous and stationary free traffic flow
  - AV divided on such a way, that there is no overlap of cars who have delay
  - Intensity other traffic measured in only one direction> mirrored between 7-21 (time AV drive on road)

Assumptions and simplifications:

- All other traffic drives 80km/h (when no AV on road)
- All AV drive with an average speed of 40km/h
- All AV only use half of the traject, all other traffic whole traject (per part)
- Capacity 2800 veh/h both directions, 1400 veh/h per lane
- Homogenous and stationary free traffic flow
- AV divided on such a way, that there is no overlap of cars who have delay
- Intensity other traffic measured in only one direction> mirrored between 7-21 (time AV drive on road), see Table 0-6. The intensity is mirrored to create a morning and evening peak and on the times AVs are driving onto the road. Outside this period there are no agricultural vehicles on the road.

- Extended scenario:

Table 0-6 Intensities of all traffic (except AVs) in both directions (mirrored between 7-21hour)

Richting Noord (gemeten)						
Uur	**Leidijk**	**FolgsterLoane**	**Kaleweg**	**It Langfal**	**It Oast**	**Dijkhuisterweg**
0	22	18	22	11	12	16
1	5	7	10	7	9	7
2	3	1	3	1	3	7
3	8	5	9	5	5	7
4	12	9	11	5	8	8
5	31	25	32	18	30	23
6	109	101	136	119	176	149
7	249	242	259	226	313	319
8	252	276	245	217	315	323
9	193	190	192	155	210	226
10	171	208	196	161	203	201
11	185	206	227	178	212	228
12	213	231	235	190	228	212
13	224	254	268	208	273	260
14	236	273	265	225	257	265
15	359	378	388	309	380	396
16	631	631	622	489	552	538
17	497	508	569	445	504	490
18	252	266	332	269	330	310
19	210	214	232	190	233	232
20	158	182	197	163	184	159
21	166	187	163	131	165	143
22	120	129	139	110	135	121
23	65	60	70	54	60	62

Richting Zuid (gespiegeld tussen 7 en 21)						
Uur	**Dijkhuisterweg**	**It Oast**	**It Langfal**	**Kaleweg**	**FolgesterLoane**	**Leidijk**
0	16	12	11	22	18	22
1	7	9	7	10	7	5
2	7	3	1	3	1	3
3	7	5	5	9	5	8
4	8	8	5	11	9	12
5	23	30	18	32	25	31
6	149	176	119	136	101	109
7	159	184	163	197	182	158
8	232	233	190	232	214	210
9	310	330	269	332	266	252
10	490	504	445	569	508	497
11	538	552	489	622	631	631
12	396	380	309	388	378	359
13	265	257	225	265	273	236
14	260	273	208	268	254	224
15	212	228	190	235	231	213
16	228	212	178	227	206	185
17	201	203	161	196	208	171
18	226	210	155	192	190	193
19	323	315	217	245	276	252
20	319	313	226	259	242	249
21	143	165	131	163	187	166
22	121	135	110	139	129	120
23	62	60	54	70	60	65

Table 0-7 Average speed per part without AVs and average speed of the AVs per part

	Leidijk - Folgester Loane	Folgester Loane - Kaleweg	Kaleweg - It Langfal	It Langfal - It Oast	It Oast - Dijkhuisterweg
Average speed without AVs [km/h]	66.3	73.3	78.2	78.4	77.7
Average speed AVs [km/h]	36.9	40 (not measured)	35.2	43.9	34.3

Table 0-8 Through going traffic, right side

<table>
<tr><th></th><th>Leidijk – Folgester Loane</th><th>Folgester Loane - Kaleweg</th><th>Kaleweg – It Langfal</th><th>It Langfal – It Oast</th><th>It Oast - Dijkhuisterweg</th></tr>
<tr><td>Total intensity</td><td>4371</td><td>4601</td><td>4822</td><td>3886</td><td>4797</td></tr>
<tr><td>Number of through going traffic</td><td>3077</td><td>2284</td><td>3374</td><td>3205</td><td>3397</td></tr>
<tr><td>%</td><td>66.35%</td><td>51.04%</td><td>64.40%</td><td>83.75%</td><td>69.24%</td></tr>
<tr><td>Total intensity AV</td><td>11</td><td>12</td><td>12</td><td>44</td><td>35</td></tr>
<tr><td>Number of through going AVs</td><td>2</td><td>0</td><td>5</td><td>22</td><td>17</td></tr>
<tr><td>%</td><td>18.18%</td><td>0.00%</td><td>41.67%</td><td>50.00%</td><td>48.57%</td></tr>
<tr><td rowspan="3">Passing more than 2 cameras</td><td></td><td></td><td></td><td colspan="2">13</td></tr>
<tr><td></td><td></td><td colspan="3">3</td></tr>
<tr><td></td><td></td><td colspan="2">1</td><td></td></tr>
</table>

Delay and hinder *without* overtaking

In this situation no overtaking is allowed. This means all vehicles that are approaching the AV at the back, have to follow the AV.

Basic scenario without overtaking

Input:

Description	Symbol	Value
Intensity without any hinder	q_1	See intensities Fryslân
Intensity during capacity	q_c	1400 vehicles/h/direction
Speed AV	V_{AV}	40 km/h
Free flow peed other traffic	U_1	80 km/h
Length of the rides of vehicles	X	See Table E-0-4
Length of AV rides	X_{AV}	

Extra travel time can be calculated via:

$Rt = 0,5*(X_{AV})^2\ (1/v_{AV}-1/u1)^2 * q1*qc/(qc-q1)$

This is the travel extra travel time in the row as well as the vehicles only driving in capacity conditions (if applicable).

The number of hindered vehicles will be calculated via:

$Nt = X_{AV}\ (1/v_{AV}-1/u_1)*q_1*q_c/(q_c-q_1)$

Calculated will be all hindered vehicles: those who drive for a while behind the AV, but also those who only drive for a short moment in capacity conditions caused by the moving bottleneck.

The maximum length behind one vehicle:
$RL = X\ (k_r\ (1-vs_1/v_{AV})$

Results from the calculations

Results of the calculations are shown on the next page.
From the results can be concluded that the total number of vehicles hindered is not high in comparison with the total number of vehicles, only 2.4%. But, the vehicles that are hindered will have indeed extra travel time: more than 30% on average. This means there are also vehicles with even more delay. When the total delay is divided over all traffic, the delay is considerably low, only 0.8% extra travel time per vehicle. The row behind the AV consists mostly of about 1-4 vehicles and 5-8 vehicles. Longer rows are uncommon in this situation. In comparison with the real situation (as measured in Fryslân), this seems to be low.

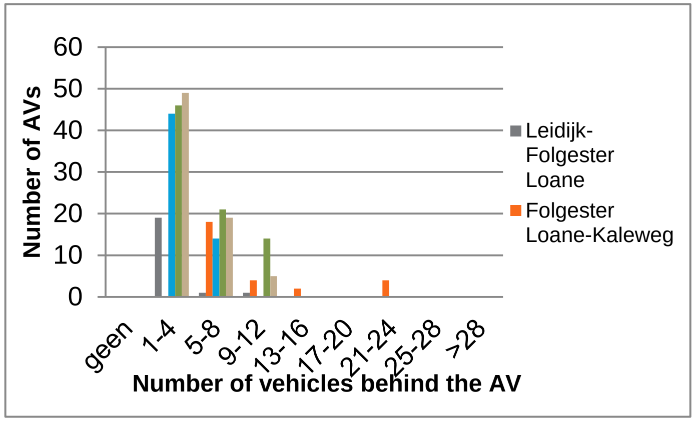
Table 0-9 Travel time delay and the number of hindered vehicles per part of the N358, basic scenario

	Number of other vehicles than AV		Number of agricultural vehicles (measured)		Extra travel time (s)		Number of hindered vehicles	
	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)
Leidijk-Folgester Loane	4371	4601	11	10	1185	1672	50	71
Folgster Loane - Kaleweg	4601	4822	12	16	5792	10292	117	208
Kaleweg - It Langfal	4822	3886	12	46	887	2148	56	136
It Langfal - It Oast	3886	4797	44	37	6952	8242	238	282
It Oast - Dijkhuisterweg	4797	4702	35	38	3821	4883	170	217
Total extra travel time					18638	27237	631	914

Table 0-10 Total travel time delay and number of hindered vehicles in both directions, basic scenario

Total travel time delay	45875	seconds	12.74	hours
Total travel time (free flow)	5133033	seconds	1425.84	hours
Extra travel time of total	0.89%			
Total number hindered vehicles	1307	vehicles		
Total number of vehicles	54358	vehicles		
Part hindered vehicles of total	2.4%			
Average travel time of a ride (without hinder)	94.43	seconds		
Average delay per hindered vehicle	35.1	seconds		
Extra average travel time hindered vehicles	37.16%			
Average delay per vehicle (not hindered)	0.84	seconds		
Extra average travel time per vehicle (not hindered)	0.89%			

Figure 0-4 Number of vehicles behind the AV, without overtaking, basic scenario



Extended scenario without overtaking

The extra travel time and the number of hindered vehicles will be calculated on the same way as in the basic scenario.

Results from the calculations

Results of the calculations are shown in Table 0-11 and Table 0-12.

From this results can be concluded that the extra travel time in this scenario is higher than for the basic scenario. This can be clarified by agricultural vehicles having an average lower speed and driving more kilometers. This also leads to more hindered vehicles and a higher extra travel time per hindered vehicle. The vehicles hindered by an AV have on average a 50% higher travel time.The total (free flow) travel time is lower, because the percentage of through going traffic is taken into account instead of all traffic going through). This means the extra travel time on average over all vehicles is higher than in the basic scenario; 1.8% instead of 0.9%.

Table 0-11 Travel time delay and the number of hindered vehicles per part of the N358, extended scenario

	Number of other vehicles than AV		**Number of agricultural vehicles (measured)**		**Extra travel time (s)**		**Number of hindered vehicles**	
	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)
Leidijk-Folgester Loane	4371	4601	11	10	1530	2158	57	80
Folgster Loane - Kaleweg	4601	4822	12	16	4782	8496	106	189
Kaleweg - It Langfal	4822	3886	12	46	2782	6733	100	241
It Langfal - It Oast	3886	4797	44	37	10059	11926	286	339
It Oast - Dijkhuisterweg	4797	4702	35	38	14313	18293	329	420
Total extra travel time					33466	47606	878	1270

Table 0-12 Total travel time delay and number of hindered vehicles in both directions, extended scenario

Total travel time delay	81072	seconds	22.52	hours
Total travel time (free flow)	4547320	seconds	1263.14	hours
Extra travel time of total	1.78%			
Total number hindered vehicles	1862	vehicles		
Total number of vehicles	54358	vehicles		
Part hindered vehicles of total	3.4%			
Average travel time of a ride (without hinder)	83.66	seconds		
Average delay per hindered vehicle	43.6	seconds		
Extra average travel time hindered vehicles	52.06%			
Average delay per vehicle (not hindered)	1.49	seconds		
Extra average travel time per vehicle (not hindered)	1.78%			

Delay and hinder *with* overtaking

In this situation it is allowed for traffic to overtake the AV. This means if there is a possibility for overtaking; the following vehicle(s) will overtake the AV. In Fryslân, half of all following vehicles overtook the AV. That is why for this situation will be assumed that 50% of the vehicles behind the AV will overtake the AV. The strategy for overtaking is assumed to be flying (directly overtaking). In the real situation the most used strategy is accelerating (first follow the AV and then take over), but the following time is unknown.

Extra assumptions and simplifications:

- *50% of the vehicles overtake the AV.*
- *All vehicles overtake the AV on a flying way. This means that is assumed the vehicles can overtake the AV directly.*
- *The extra time which is needed for the overtaking maneuver will be neglected.*

Basic scenario with overtaking

Results

The number of hindered vehicles is the same as in the basic scenario without overtaking, because all vehicles who take over the AV are also counted as hindered and the number of vehicles behind the AV is short (Table 0-13).
The extra travel time is half of the travel time of the extra travel time without overtaking, because half of the vehicles are assumed to overtake the AV immediately (Table 0-14). This also leads to a shift in the rows behind the AV; the rows are almost no longer than 4 vehicles (Figure 0-5).

Table 0-13 Travel time delay and the number of hindered vehicles per part of the N358, with overtaking, basic scenario

	Number of other vehicles than AV		**Number of agricultural vehicles (measured)**		**Extra travel time (s)**		**Number of hindered vehicles**	
	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)
Leidijk-Folgester Loane	4371	4601	11	10	593	836	50	71
Folgster Loane - Kaleweg	4601	4822	12	16	2896	5146	117	208
Kaleweg - It Langfal	4822	3886	12	46	444	1074	56	136
It Langfal - It Oast	3886	4797	44	37	3476	4121	238	282
It Oast - Dijkhuisterweg	4797	4702	35	38	1910	2442	170	217
Total extra travel time					9319	13618	631	914

Table 0-14 Total travel time delay and number of hindered vehicles in both directions, with overtaking, basic scenario

Total travel time delay	22937	seconds	6.37	hours
Total travel time (free flow)	4825281	seconds	1340.36	hours
Extra travel time of total	0.48%			
Total number hindered vehicles	1307	vehicles		
Total number of vehicles	54358	vehicles		
Part hindered vehicles of total	2.4%			
Average travel time of a ride (without hinder)	88.77	seconds		
Average delay per hindered vehicle	17.5	seconds		
Extra average travel time hindered vehicles	19.77%			
Average delay per vehicle (not hindered)	0.42	seconds		
Extra average travel time per vehicle (not hindered)	0.48%			

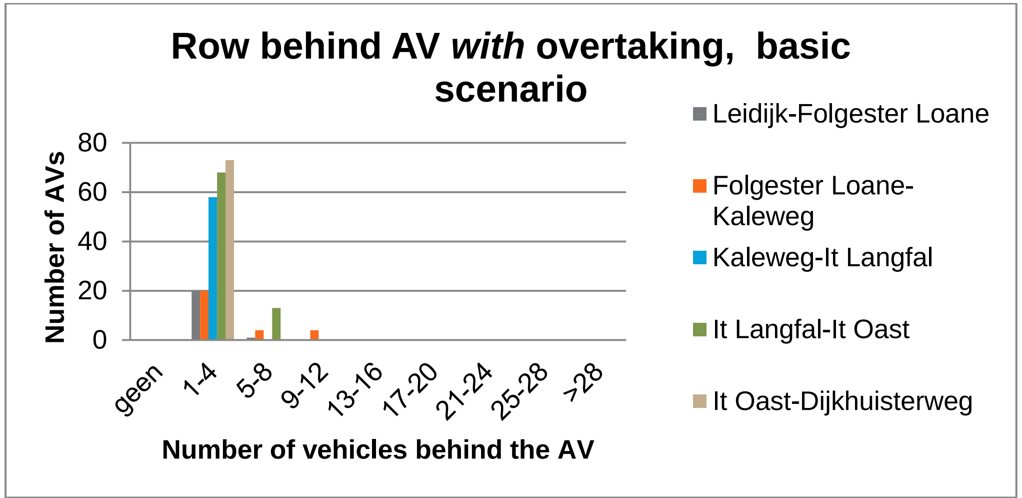


Figure 0-5 Number of vehicles behind the AV, with overtaking, basic scenario

Extended scenario with overtaking

The number of hindered vehicles is the same as in the basic scenario without overtaking, because all vehicles who take over the AV are also counted as hindered and the number of vehicles behind the AV is short (Table 0-13).

The extra travel time is half of the travel time of the extra travel time without overtaking, because half of the vehicles are assumed to overtake the AV immediately (Table 0-14). This also leads to a shift in the rows behind the AV; the rows are almost no longer than 4 vehicles (Figure 0-5).

Table 0-15 Travel time delay and the number of hindered vehicles per part of the N358, with overtaking, extended scenario

	Number of other vehicles than AV		**Number of agricultural vehicles (measured)**		**Extra travel time (s)**		**Number of hindered vehicles**	
	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)	Rechts (van Leidijk naar Dijkhuister weg)	Links (van Dijkhuister weg naar Leidijk)
Leidijk-Folgester Loane	4371	4601	11	10	765	1079	57	80
Folgster Loane - Kaleweg	4601	4822	12	16	2391	4248	106	189
Kaleweg - It Langfal	4822	3886	12	46	1391	3366	100	241
It Langfal - It Oast	3886	4797	44	37	5030	5963	286	339
It Oast - Dijkhuisterweg	4797	4702	35	38	7156	9147	329	420
Total extra travel time					16733	23803	878	1270

Table 0-16 Total travel time delay and number of hindered vehicles in both directions, with overtaking, extended scenario

Total travel time delay	40536	seconds	11.26	hours
Total travel time (free flow)	4547320	seconds	1263.14	hours
Extra travel time of total	0.89%			
Total number hindered vehicles	1862	vehicles		
Total number of vehicles	54358	vehicles		
Part hindered vehicles of total	3.4%			
Average travel time of a ride (without hinder)	83.66	seconds		
Average delay per hindered vehicle	21.8	seconds		
Extra average travel time hindered vehicles	26.03%			
Average delay per vehicle (not hindered)	0.75	seconds		
Extra average travel time per vehicle (not hindered)	0.89%			

Conclusion and Discussion

On most rural distributor roads overtaking is allowed. The situations without overtaking will therefore not often happen, but it gives an indication in situations where sight is bad or when the Province decides to implement an overtaking prohibition. In this case, the delay will be as twice as high in the situation with overtaking. For the total traffic stream this delay is small (up to 1,8% extra), but for individual vehicles the extra travel time could be a lot higher (on average 50% higher for hindered vehicles)

In the situation with overtaking the delay and hinder is less, but individual drivers can still have a lot delay (on average 26% higher for hindered vehicles).

From the calculations follow that most rows behind the AV are between 1-4 and 5-8 vehicles, but in reality these could be longer, because only the row per part(between two cameras) are taken into account. If the AVs will drive over a longer distance, the row will be longer. This will especially be the case between It Langfal-It Oast-Dijkhuisterweg, where almost half of the AVs are through going traffic.

Discussion of the method

The method as used for the calculations could give a realistic overview of the situation, but therefor still some improvements could be done:

- No flying overtaking, but accelerated overtaking. This means motor vehicles behind an AV will have to wait till there is a gap big enough to overtake. The following time depends on the intensity of traffic in the opposite direction (available gaps), sight distance and so on. In the calculations the following time is not taken into account.
- It is not possible or less possible to overtake at specific locations, so not on every part of the road the overtaking manoeuvres will be 50%.
- Not only passenger cars, but also trucks should be taking into account. This could influence the overtaking possibilities and time.
- Traffic should be distributed more randomly over the road. Now the traffic was equally divided onto the road.

E. Available measurement methods

At the moment, the measuring method of DHV is the only used method for measuring as well traffic flow as well as traffic safety characteristics in relation to AV's. Other available methods which can measure traffic flow or traffic safety characteristics in relation to AVs are the following:

- **Measurements with tubes:** this is a mechanical speed measurement combined with mechanical measurement devices. These devices are connected to tubes. These tubes will be tensed on the surface of the road. By replacement of air in the tubes, the number of motor vehicles and the speed of these vehicles can be measured. There can be made a distinction between driving directions, different vehicle categories and classes of speed. Because the length of the axis of agricultural traffic is almost the same as trucks, there can no distinction be made between agricultural vehicles and trucks. Agricultural vehicles are categorized under middle heavy vehicles. So if more information is needed other or additional devices should be used to get more information about the vehicle (Meerbeek, 2012).
- **Measurements with loops: in induction loop is a brass wire loop, placed in or underneath the road pavement.** With loops only the number of vehicles and the speed of the vehicles can be counted. When a vehicle passes the loop, the magnetic field will be disturbed and the vehicle will be counted. With a single loop the number of vehicles can be counted, the time of passage and the occupancy can be registered. By a double loop extra variables can be measured; speeds and length of the vehicle. This means just like tubes, vehicle categories can be determined. At the moment new methods will be developed to recognize every individual vehicle, so that one and the same vehicle can be recognized on more loops. For instance travel time and trajectory speeds could be determined by this method (Marshproducts, 2000).
- **Visual counting:** count the number of vehicles by hand at the road side (for instance by students). Only number and type of vehicles can be counted. No speed and safety characteristics will be taken into account and is not very useful to use it for measurements for several weeks.
- **Camera on a following vehicle:** a new method used by Meetel to analyse driving behaviour is putting a camera on a passenger car. The car have to wait on an AV with at least on vehicle following. The car with camera will follow the following vehicle of the AV and see what driving behaviour will occur. Idea of the method is that more naturalistic driver behaviour will be observed. A first test with the method was done on a rainy day, so almost no AVs were driving on the road and no measurements could be done (Meerbeek, 2012). That is exactly where a disadvantage of the method lies; waiting on an AV with a following vehicle and have the opportunity to follow these vehicles requires a lot of time to get enough measurements.
- **Interviews** ask people in a certain area how many rides they make with AV and how long and ask about their feeling of safety. Disadvantage of the method is that no through going traffic will be taken into account and it will also be a very intensive method without very objective results.
- **Analysis of the area:** determining frequencies of rides via information of the area, like position of all agricultural companies or companies that could generate or attract AVs, size of the lots, type of agriculture, number of access point to the distributor roads, possible routes and so on . Disadvantage is that a lot of information not available anymore and it will be very intensive to gather all the necessary data.

F. Assessment frameworks

Preconditions and starting points of the assessment framework (Royal Haskoning, 2004):

- The destinations of agricultural traffic should be still accessible for agricultural traffic.
- The alternative route should not have an extra detour factor, this is the shortest distance via a rural distributor road in comparison with the desired alternative route. The maximum detour factor is 1.4.
- The alternative route has a width of at least 5,5 meters (for low intensities 4,5 meters).
- Not a mixed settlement of agricultural and bicycle traffic on primary bicycle routes.
- One of the main elements is that an access road is taken as a basis as road for AVs to drive on. If there are not suitable routes on access roads, AVs could be allowed on rural distributor roads, but extra interventions should be taken to make the road suitable for AVs

Next to the assessment framework developed by the Province of Gelderland. Other assessment frameworks are available. An addition to the scheme of Gelderland is the scheme for essential recognition features (in Dutch the so called 'Essentiele herkenbaarheidskenmerken') Following this scheme, allowance of AVs on rural distributor roads (with partly allowing overtaking and special marking) should only be a phasing solution. In the final situation the main rural distributor road should be closed for AVs and a parallel road should be realised *(CROW, 2004)*. Following the guidelines, it would be preferably to have always a separate parallel road for AVs only. This is in practice not very realistic, because the costs are high in comparison the benefits and there not always space for these parallel roads. Another option is to combine AVs with bicycles on parallel roads, but this often leads to protest of residents.

The Province of Fryslân has developed another assessment framework based on intensities of traffic (no AVs) and intensity of bicycles. Rule of thumb used is that if there is intensity higher than 5000 vehicles/day, a parallel facility is needed for AVs.

The scheme of Fietsberaad (Fietsberaad, 2008) has developed a scheme to make a choice for combining AVs with bicycles, create parallel roads or downgrade the road. This is based on the intensities of bicycles and the number of access point to lots.

DHV has made an extension of the assessment framework of Gelderland (Baere, 2009). This states that rural distributor roads with intensity lower than 5000 vehicles/day do not need interventions for agricultural traffic; AVs could make use of these rural distributor roads without giving to much hinder. Next to that, an overview of possible interventions on rural distributor roads is added. When choosing what intervention on a rural distributor road is not taken into account.

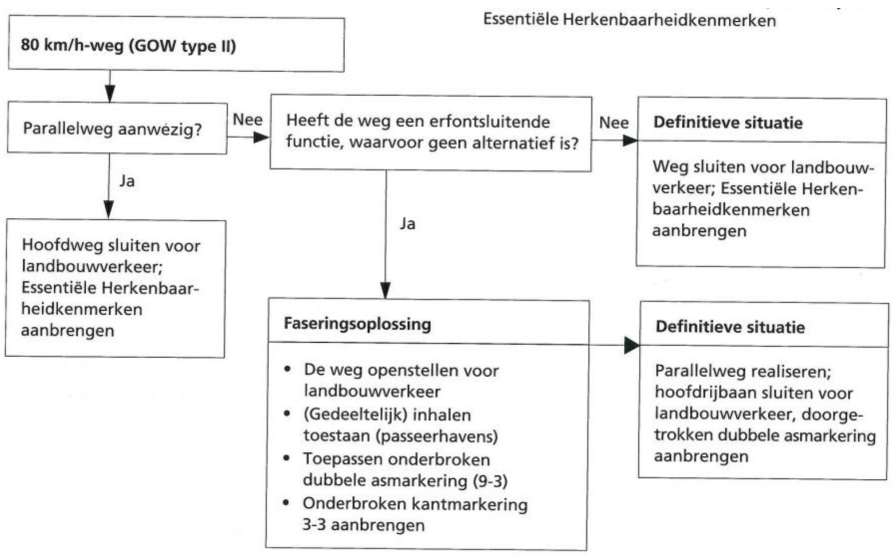
On the following pages other frameworks than the assessment framework of Gelderland can be found.

In short some assessment frameworks for AVs are discussed. All these schemes have a narrow focus, where only a few solution directions are taken into account. Next to that schemes are based on intensities of traffic, bicycles and number of access points to lots. No numbers of AVs driving on the roads are taken into account. This choice is probably made because the number of AVs is often not known. This lack of information and the few solution directions taken into account in the schemes makes it difficult for road authorities to make a good consideration of the possible interventions.

Next to that often parallel roads are advised to be the best solution for AVs, but the costs are high and benefits relatively low in comparison with those costs.

More research is necessary to possible agricultural vehicle interventions.

Relation agricultural traffic on main carriageway and essential recognition characteristics



Choice scheme Fietsberaad

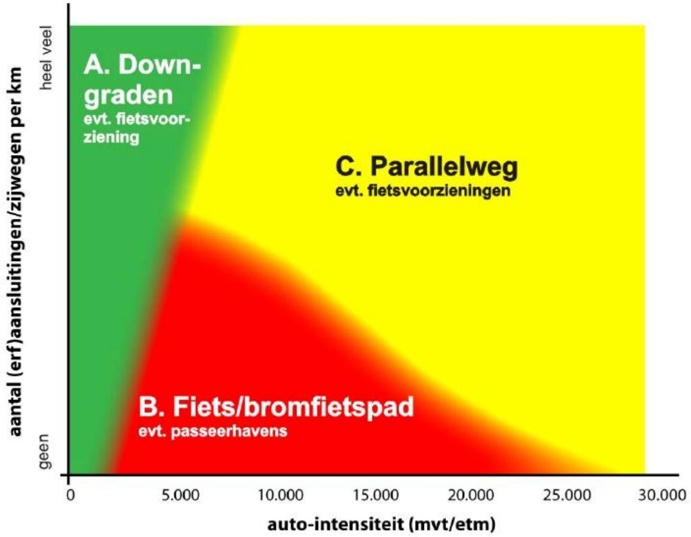


Figure 0-6 Relation agricultural traffic on main carriageway and essential recognition characteristics (CROW, 2004)

Matrix keuze toepassing LBPS (landbouwpasseerstrook) gebiedsontsluitingswegen buiten de kom

Verkeersintensiteit (I auto) => (0, 5000, 6000, 7000, 8000, 9000, 10000, 11000, 12000, 13000, 14000)

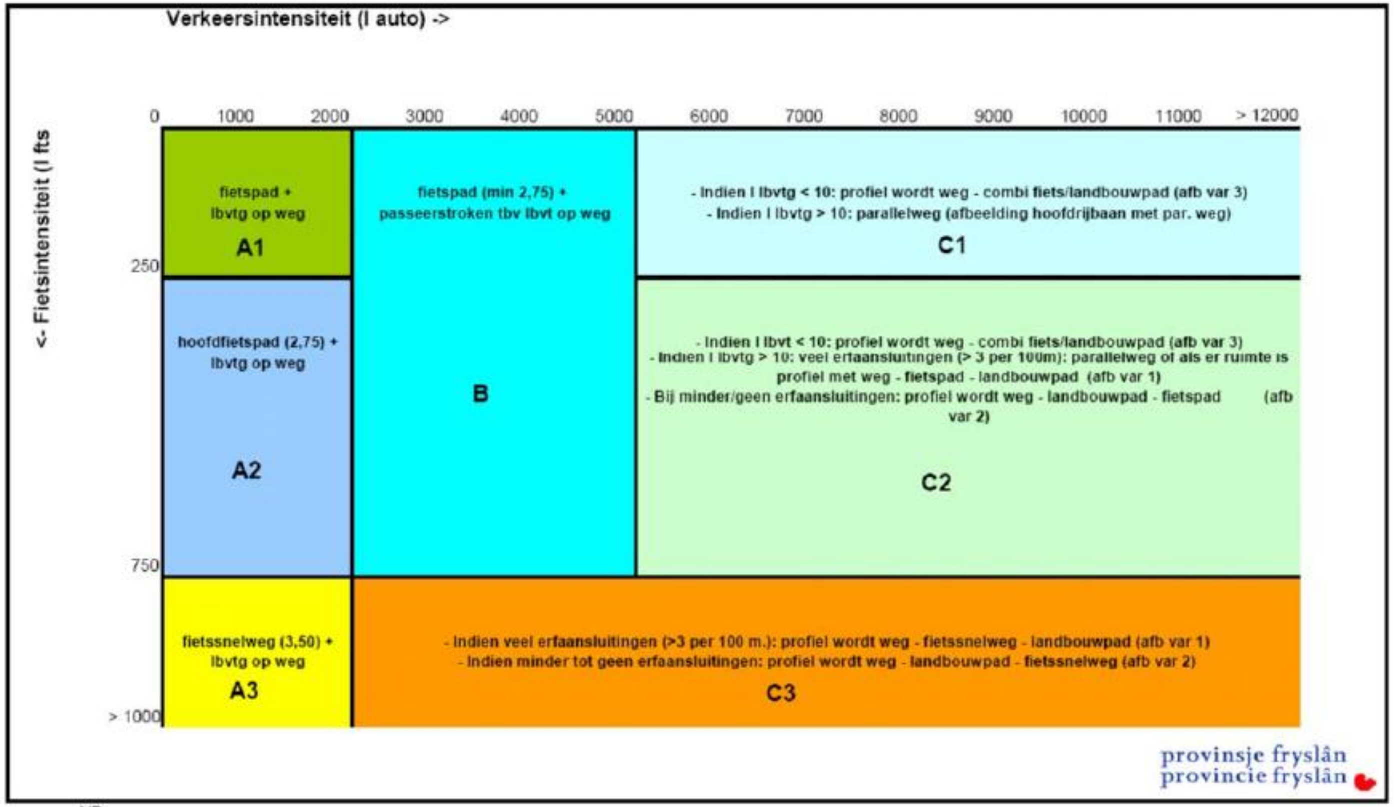
<= Globale ritlengte LBV (km)	0 – 5000	5000 – 8000	8000 – 12000	12000 – 14000
0 – 2	A	B	B	E
2 – 8	B	C Tussenafstand LBPS 1 en < 2 km Niet meer dan 3 LBPS (max. traject 4 en < 8 km)	D Tussenafstand LBPS 1 en < 2 km Niet meer dan 3 LBPS (max. traject 4 en < 8 km)	E
8 – 15	B	C Tussenafstand LBPS 2 en < 3 km Niet meer dan 4 LBPS (max. traject 10 en < 15 km)	D Tussenafstand LBPS 2 en < 3 km Niet meer dan 4 LBPS (max. traject 10 en < 15 km)	E
15 – 18	B	C Tussenafstand LBPS 3 en < 4 km Niet meer dan 4 LBPS (max. traject 15 en < 18 km)	D Tussenafstand LBPS 3 en < 4 km Niet meer dan 4 LBPS (max. traject 15 en < 18 km)	E
18 – 24	B	C Tussenafstand LBPS 4 en < 5 km Niet meer dan 5 LBPS (max. traject 18 en < 24 km)	D Tussenafstand LBPS 4 en < 5 km Niet meer dan 4 LBPS (max. traject 20 en < 24 km)	E

A	Geen passeerstrook	B	Geen passeerstrook, anders aanliggend onverplicht	C	Verplicht aanliggend anders onverplicht
D	Verplicht vrijliggend anders verplicht aanliggend	E	Geen passeerstrook, paralle voorziening		

provinsje fryslân
provincie fryslân

NB
In bepaalde verkeerssituaties is het wenselijk een waarde te kiezen die 1000 a 2000 mvt hoger is dan de daadwerkelijke verkeersintensiteit (I auto):
(waardoor bijvoorbeeld alsnog een verplichte LBPS gekozen kan worden)
- Indien de GOW een o.v. route is van het verbindende of ontsluitende net
- Indien het inhaalzicht minder dan 50% is
- Indien het een route betreft met een hoog aandeel spitsverkeer (bijv > 20%) t.o.v. de werkdagetmaalintensiteit
- Indien het een route betreft met een hoog aandeel vrachtverkeer (bijv > 10%) t.o.v. de werkdagetmaalintensiteit
- Indien het een route betreft met een hoog aandeel inhaalverbod (bijv > 40%)

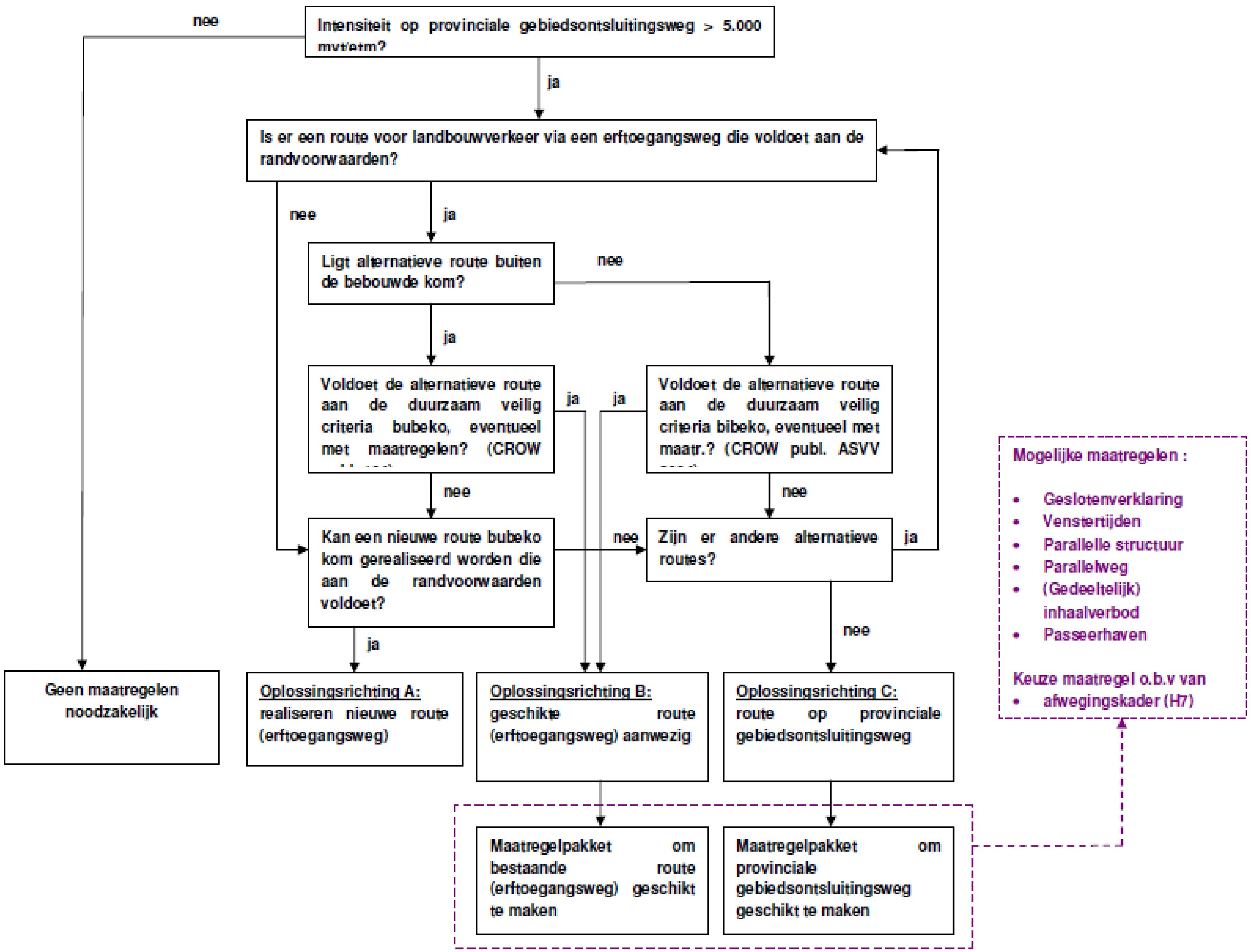
Verdere notities
- LBPS en met name wanneer de werkdagetmaalintensiteit 8000 mvt of hoger is, dienen zo veel mogelijk +/- 50 m na een rotonde en 550 à 600 m na verkeerslicht of bebouwde kom grens gesitueerd te worden (ivm hiaten om weer op de GOW in te voegen)
- LBPS dienen een lengte te hebben van 125 m, inclusief een inrijstuk van 1:8 en een uitrijstuk van 1:4
- LBPS dienen aanliggend een breedte hebben van 3,5 m en vrijliggend een breedte van 3 m
(enkel de lading van een lbv kan breder zijn dan 3 m wat bij een vrijliggende LBPS geen probleem is)



NB
In bepaalde verkeerssituaties is het wenselijk een waarde te kiezen die 1000 a 2000 mvt hoger is dan de daadwerkelijke verkeersintensiteit (I auto):
- Indien de GOW een o.v. route is van het verbindende of ontsluitende net
- Indien het inhaalzicht minder dan 50% is
- Indien het een route betreft met een hoog aandeel spitsverkeer (bijv > 20%) t.o.v. de werkdagetmaalintensiteit

Figure 0-7 Choice matrix for type parallel facilties at rural distributor roads

Addition to scheme of Gelderland, DHV:

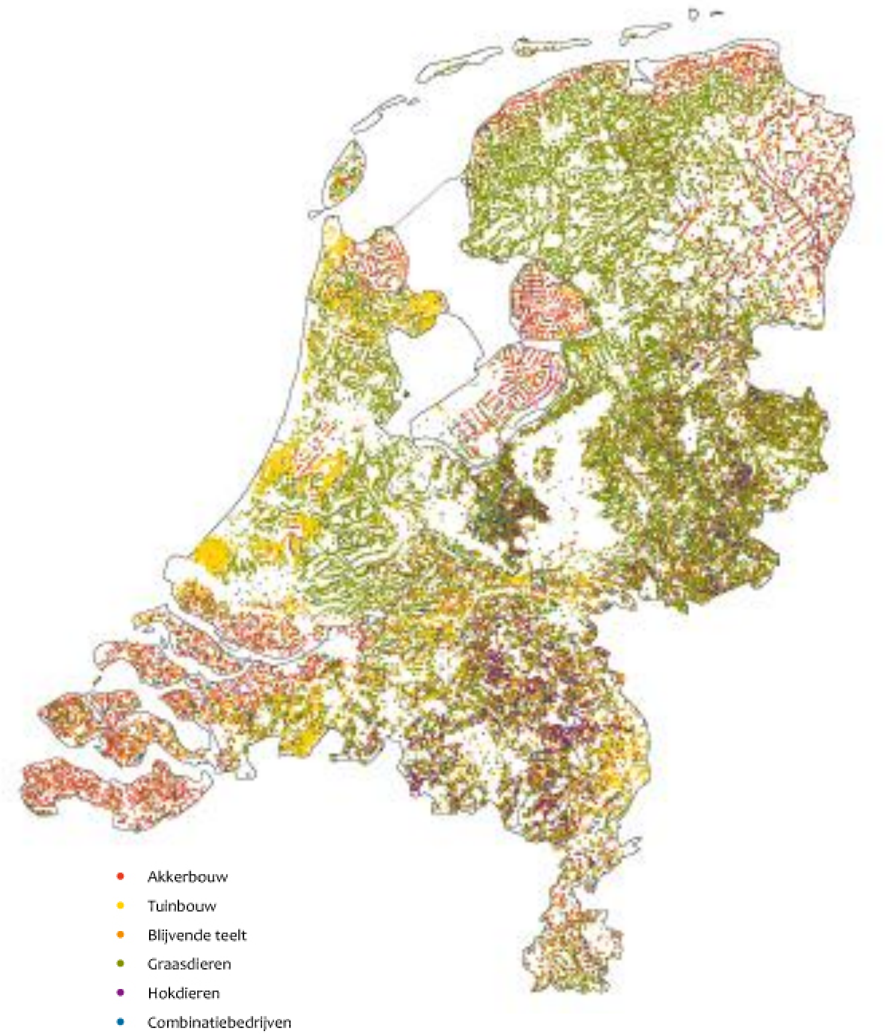


G. Agricultural areas and companies in the Netherlands

Agricultural areas

About 57% of the land in the Netherlands is used for agriculture (almost 2 million hectares).
From this area 60% is used for horticulture and arable farming, the other 40% is permanent grassland.
The number of agricultural vehicles that makes use of the public road depends strongly on the main agricultural category, the structure of the company, the size of the land, the distribution of the land and so on.
The spreading and category of agricultural companies depends on the local soil, historical and economic reasons.
An overview of the agriculture- and horticulture companies in the Netherlands in 2010 (to main farm type) is shown in Figure C.0-8 Overview of agriculture and horiculture companies.

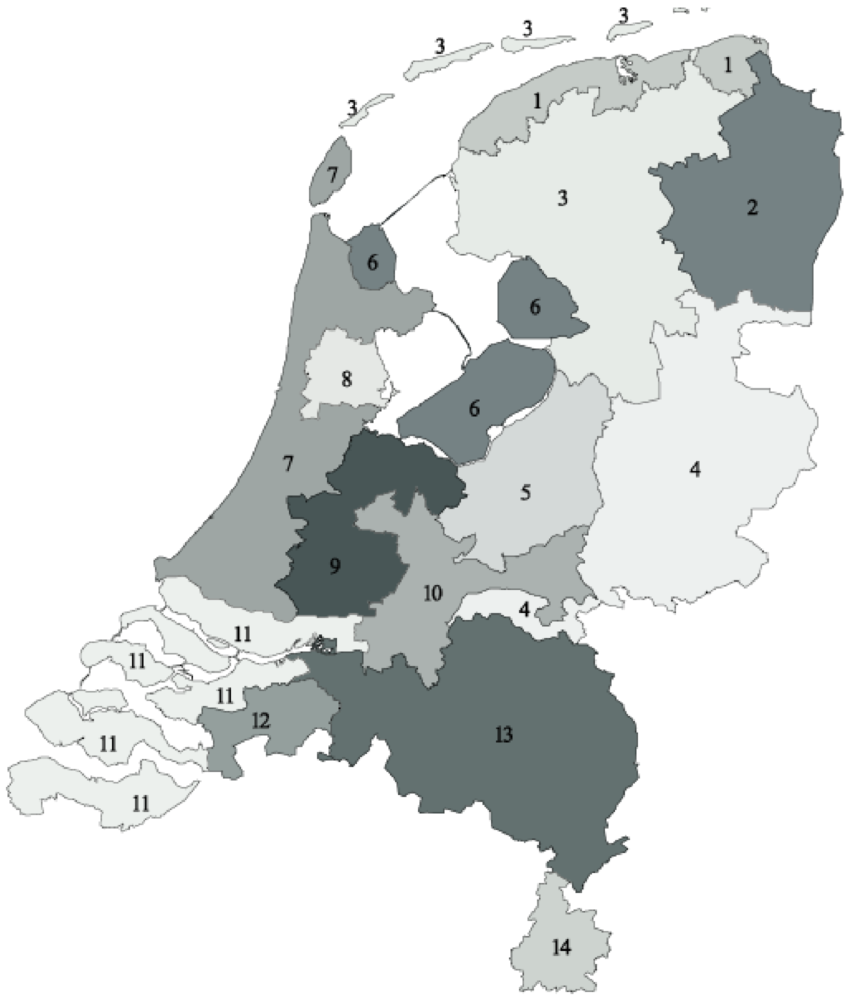
Figure C.0-8 Overview of agriculture and horiculture companies per main farm type in the Netherlands (Compendium voor de leefomgeving, 2011) →



Overview of agricultural regions in the Netherlands:

In the Netherlands, there are 14 groups of agricultural regions, the so called 14 groups-classification, see Figure C.0-9. These groups are a clustering of 66 agricultural areas in the Netherlands. These areas are used to gather agricultural information from.
(LEI, Wageningen UR; Centraal Bureau voor Statistiek (CBS), 2011)

Figure C.0-9 Overview of agricultural districts in the Netherlands →



1. Bouwhoek en Hogeland
2. Veenkoloniën en Oldambt
3. Noordelijk weidegebied
4. Oostelijk veehouderijgebied
5. Centraal veehouderijgebied
6. IJselmeerpolders
7. Westelijk Holland
8. Waterland en Droogmakerijen
9. Hollands en Utrechts weidegebied
10. Rivierengebied
11. Zuidwestelijk akkerbouwgebied
12. Zuidwest Brabant
13. Zuidelijk veehouderijgebied
14. Zuid Limburg

H. Choice methods to predict the effects of infrastructural interventions

Choice of method to predict effects of infrastructural interventions

To decide which tool is the most appropriate to predict the effects of infrastructural interventions for AVs, a consideration of possible methods will be made. Methods that can be used to predict the effect of infrastructural interventions are the following:

- **Tests in real situation:**
  - Test interventions that are already constructed on rural distributor roads (analysis of current interventions).
  - Test locations: make a test location to test different interventions.
- **Driving simulator:** test driving behaviour around infrastructural interventions by making use of a driving simulator.
- **Simulation studies:**
  - Microscopic simulation models: microscopic models simulate the movement and interaction of individual vehicles.
  - Macroscopic simulation models: these models are based on relationships of the flow, speed and density of the traffic stream. The simulation takes place on section level and not per individual vehicle.

Consideration of the methods:

- **Test in real situation:**
  - Test existing interventions: these tests are only possible if there are already infrastructural interventions constructed. This method cannot be used to predict the effect of those measures. Also no variations in for instance intensity and traffic distribution can be tested. What can be done with tests of existing interventions is to test the validity of the method that will finally be used for the tests of the infrastructural interventions.
  - Make a test location: a test location could be made to test possible infrastructural interventions. Advantage of the method is that driving behaviour on and around the interventions can be tested. Disadvantage of this method is that the effects of the interventions cannot be tested per situation. So no good consideration can be made for choice of the interventions on a specific location. Next to that, testing the infrastructural interventions in practice has some risks like possibility of accidents.
- **Driver simulator:** a driver simulator is a good way to test interventions and see the effects of driver behaviour near the infrastructural intervention. It can be both used by drivers of an AV as well as by drivers of other vehicles on the road. Disadvantage of the method is that a lot of test persons are needed to test the interventions and for every situation this should be done again. Next to that, only results of one vehicle (the person that 'drives' in the driver simulator) per time could be measured.
- **Simulation studies:** simulation models are an approximation of reality and are useful tools to experiment with new situations that do not exist. Disadvantage in non-existing situations is that the validity of the model is hard to predict. For the case of the interventions some measurements are done, which could be used to test the validity. Simulation models make it possible to change variables and see what kind of effect this has on the situation. Next to that, dynamic aspects can be handled (e.g. demand can be varied of time and space) and potentially unsafe situations can be simulated without real risk (again take validity into account). Disadvantage of simulation studies is that a lot of input characteristics and data are needed, but this data can be collected via the measurement method Royal HaskoningDHV. Also verification, calibration and validation of the model should be taken into account (Hoogendoorn, 2000).
  - Microscopic vs. macroscopic simulation models: The effects of AVs and the interventions will mainly have effect on local level; it is more interesting to see what happens per individual

vehicle on network level. That is one of the reasons why it is better to use a microscopic model instead of a macroscopic simulation model.

From the considerations is chosen to make use of microscopic simulation to see what the effects of infrastructural interventions for AVs are. This method is the most appropriate method for this research to test infrastructural interventions on various locations and with different variables like intensities.

6.2.3 Choice for microscopic simulation model

There are a lot of microscopic simulation models available. To make a choice for microscopic simulation model on a solid ground some requirements for the model are:

- Possible to use it for the Dutch road situation
- Possibility of overtaking is a pre.
- Program should be available for this research: if the program is not available to use for this research (it is for instance for intern use only), it will be difficult to make use of it.
- The program should be kept up-to-date: it should be possible to use it in future as well, so it is necessary that the model is kept up-to-date.

Possible microscopic simulation models which could be used to analyse:

- Aimsun: this is a microscopic simulation used in home at DHV. This is a lane based microscopic simulation model, but some tricks can be no overtaking possibilities. It is calibrated to the Dutch situation and already used for a lot of traffic studies in the Netherlands. It is a lane based model, which means the vehicles cannot overtake vehicles by making use the lane in the opposite direction. Despite of that, it is possible to allow vehicles overtaking by using a trick (place two lanes per direction on top of each other an insert some restrictions). The program is kept up to date and also new developments are coming up.
- Dracula: this model is developed by the Leeds University and was selected to be the most suitable for simulating simulations with and without overtaking and under a range of traffic, driver and visibility conditions (DHV, 2002). Despite of that, the model is not user friendly and not further developed in the last couple of years.
- Paramics: this model is developed by TNO as well as Grontmij separate from each other. At the moment the development at the side of TNO, there is no further development of the model and is expected to be outdated in a while. The model is still in use by Grontmij, but while being a competitor of DHV, use of the model is excluded.
- RuTSim: is a Swedish microscopic model developed by VTI. This model is already used for Dutch situations. It is usable for rural distributor roads with 2x1 lanes and overtaking is possible. The program is still kept up to date and under development by VTI. A large disadvantage of the model is that there is no distribution possibility of the program. This means it is only possible to use it at VTI in Sweden.
- Other lane based models like Fosim and Vissim: in general it is not possible to simulate overtaking manoeuvres.

For the simulation, the microscopic model of DHV will be used, because it fits best to the predetermined requirements. RuTSim would for this research be even a better model, but huge disadvantage is that for every time a simulation needs to be made, also a trip to Sweden has to be made.

I. Description of the Aimsun simulation software

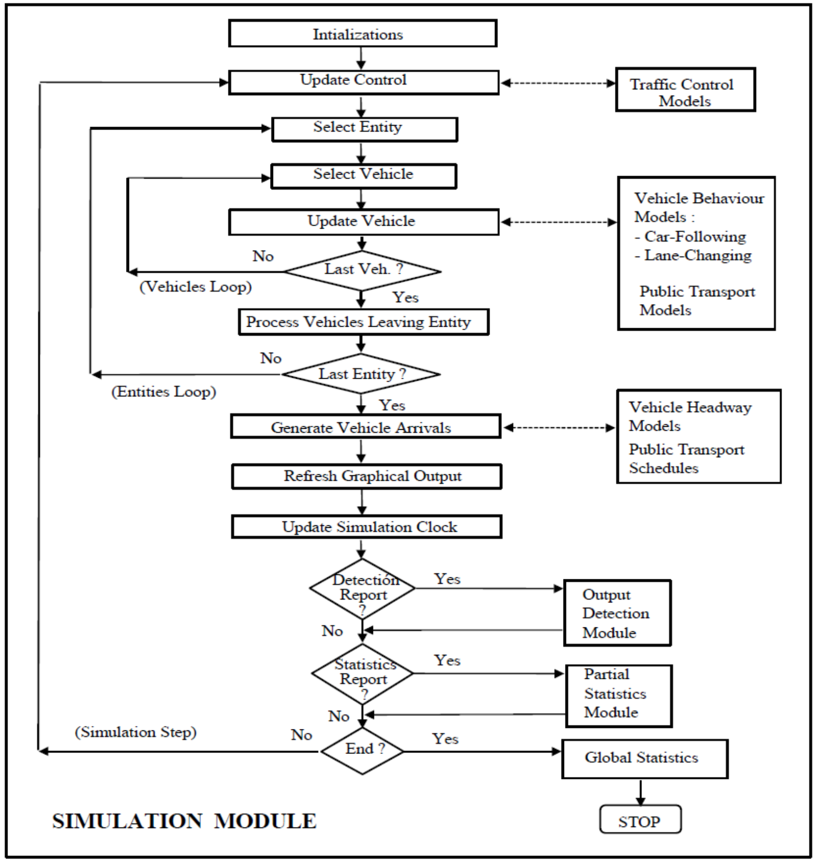
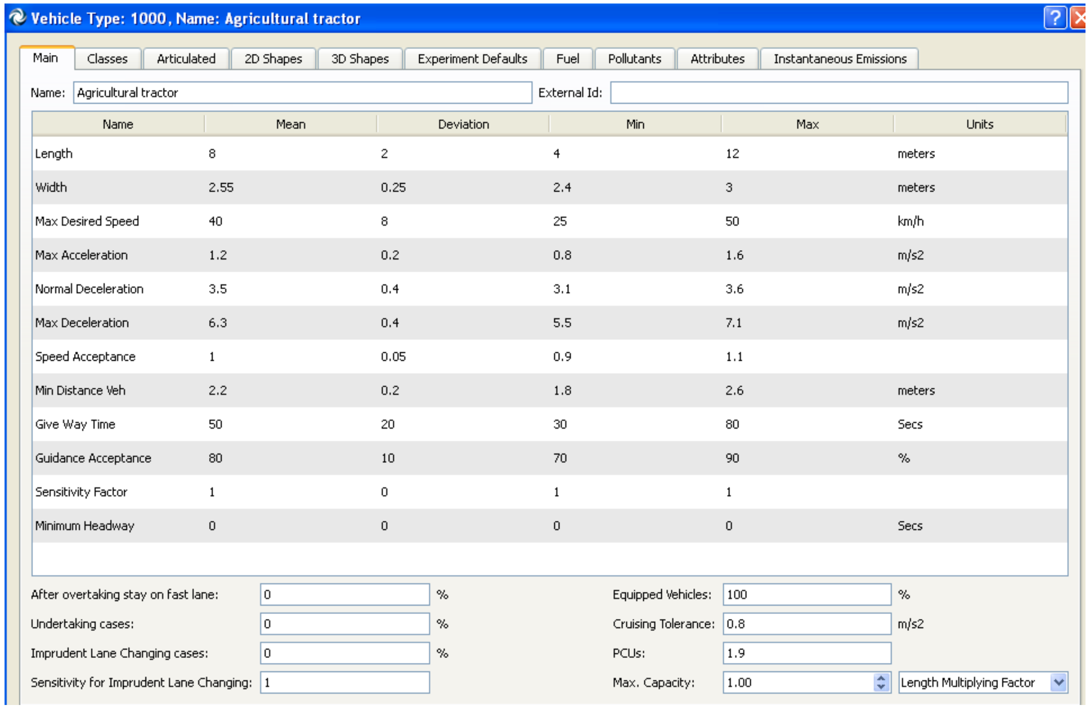


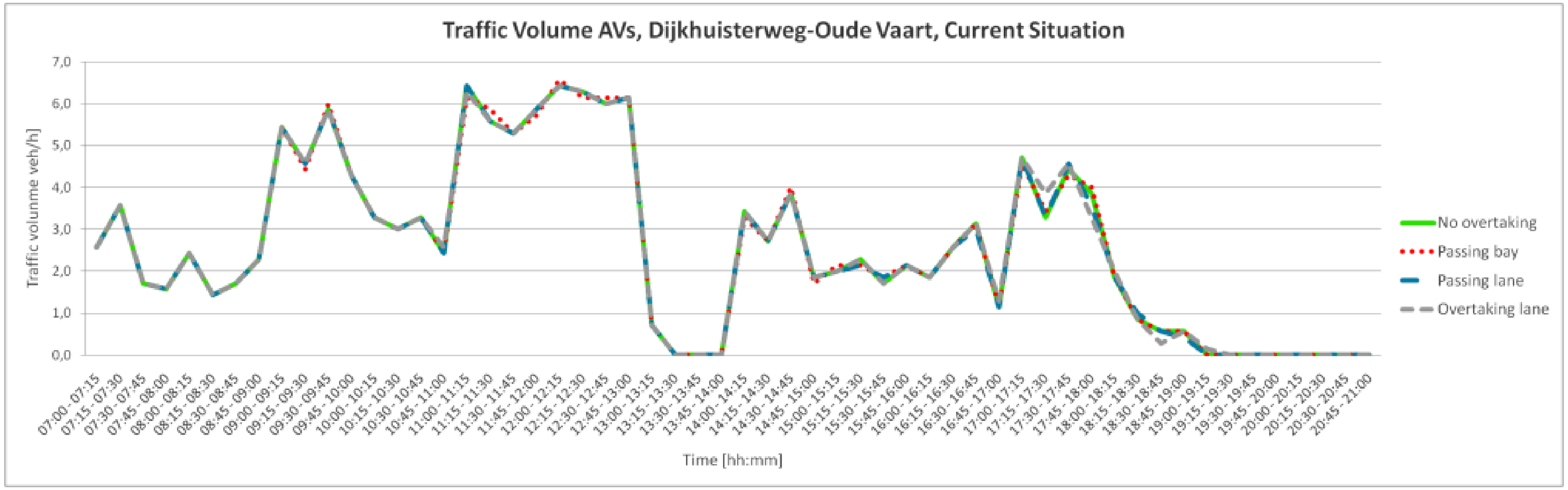
Figure 0-11 Overview of the microscopic simulation model AImsun.

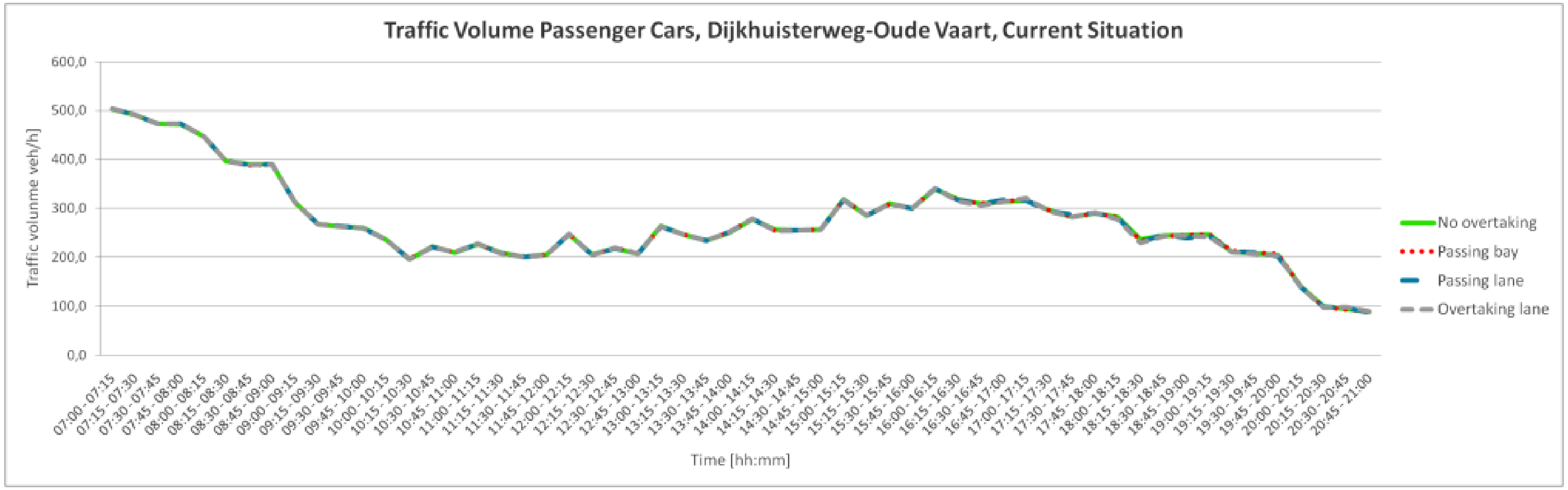


Name	Mean	Deviation	Min	Max	Units
Length	8	2	4	12	meters
Width	2.55	0.25	2.4	3	meters
Max Desired Speed	40	8	25	50	km/h
Max Acceleration	1.2	0.2	0.8	1.6	m/s2
Normal Deceleration	3.5	0.4	3.1	3.6	m/s2
Max Deceleration	6.3	0.4	5.5	7.1	m/s2
Speed Acceptance	1	0.05	0.9	1.1	
Min Distance Veh	2.2	0.2	1.8	2.6	meters
Give Way Time	50	20	30	80	Secs
Guidance Acceptance	80	10	70	90	%
Sensitivity Factor	1	0	1	1	
Minimum Headway	0	0	0	0	Secs

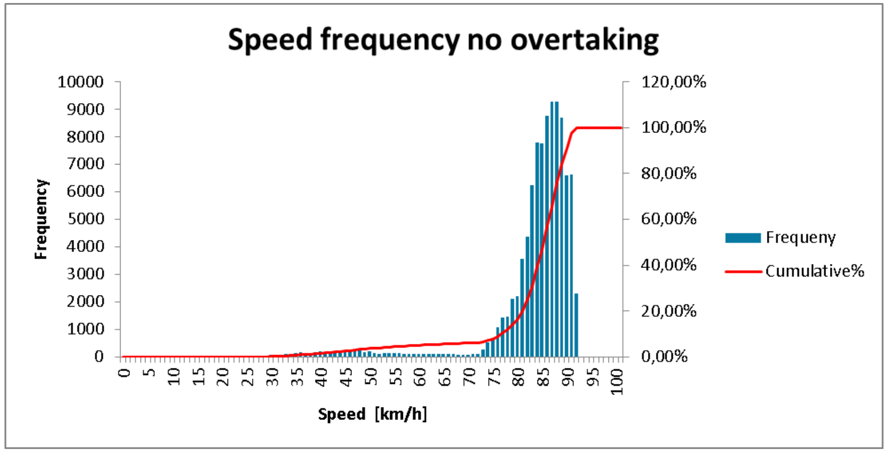
Figure 0-10 Agricultural vehicle parameters

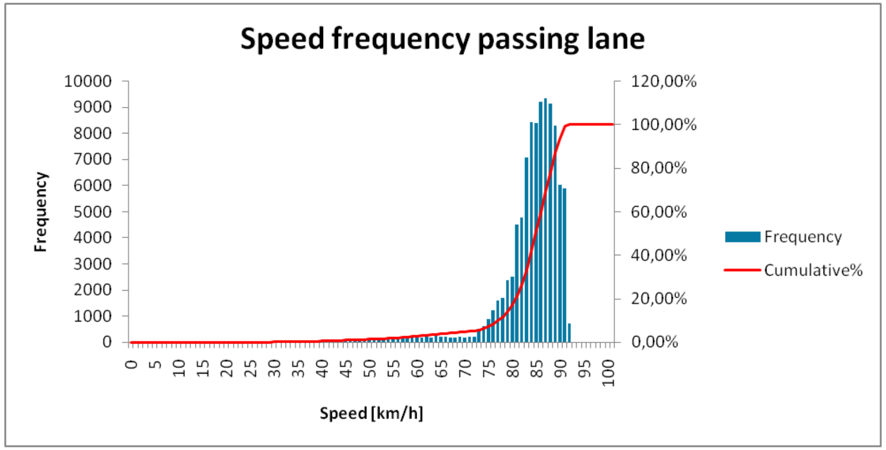
J. Results of the simulations

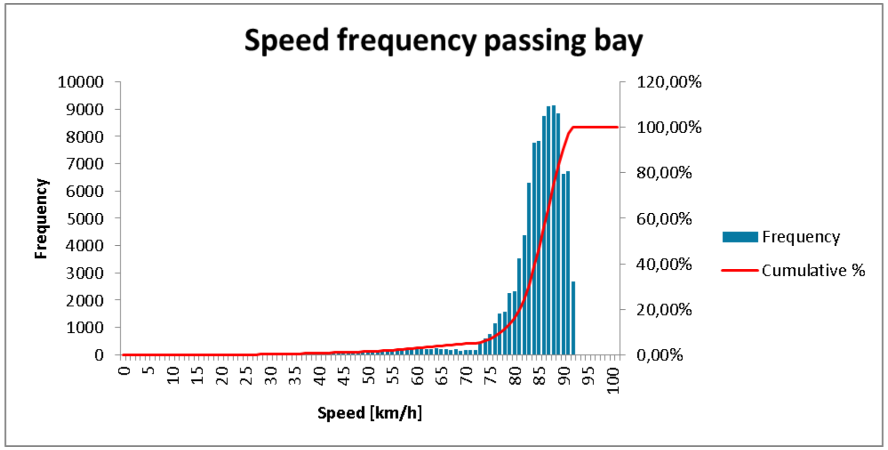


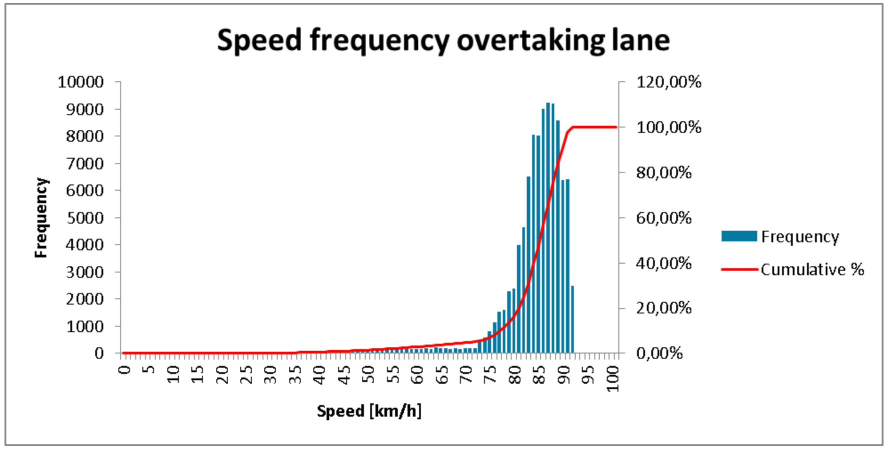


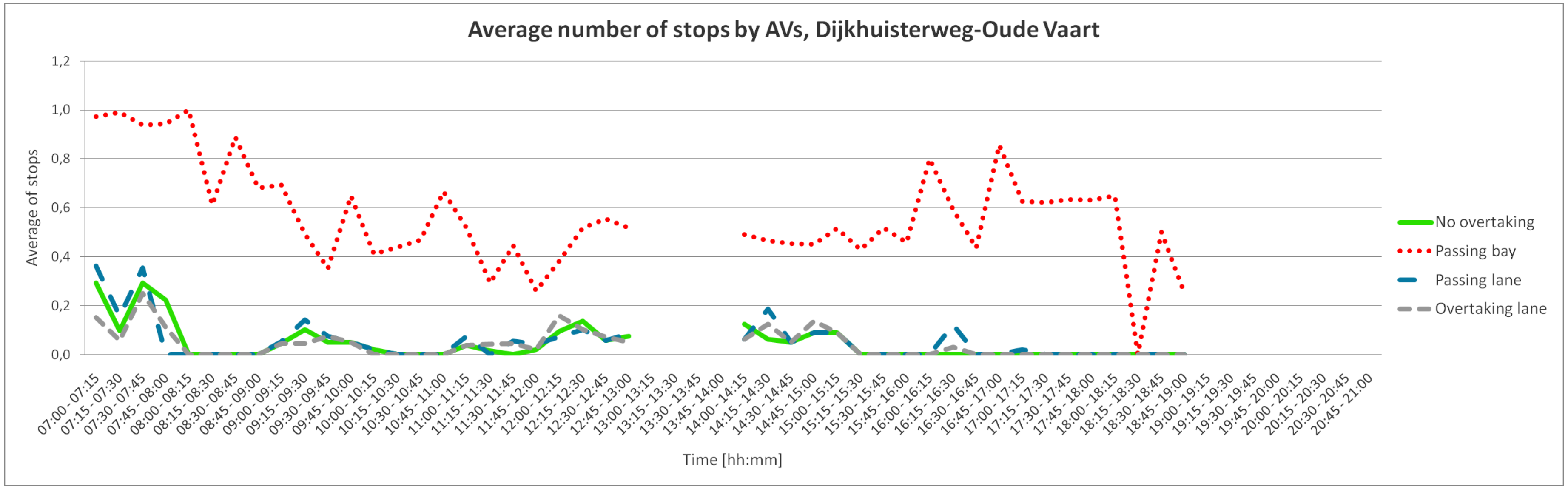
Results infrastructural interventions current situation:



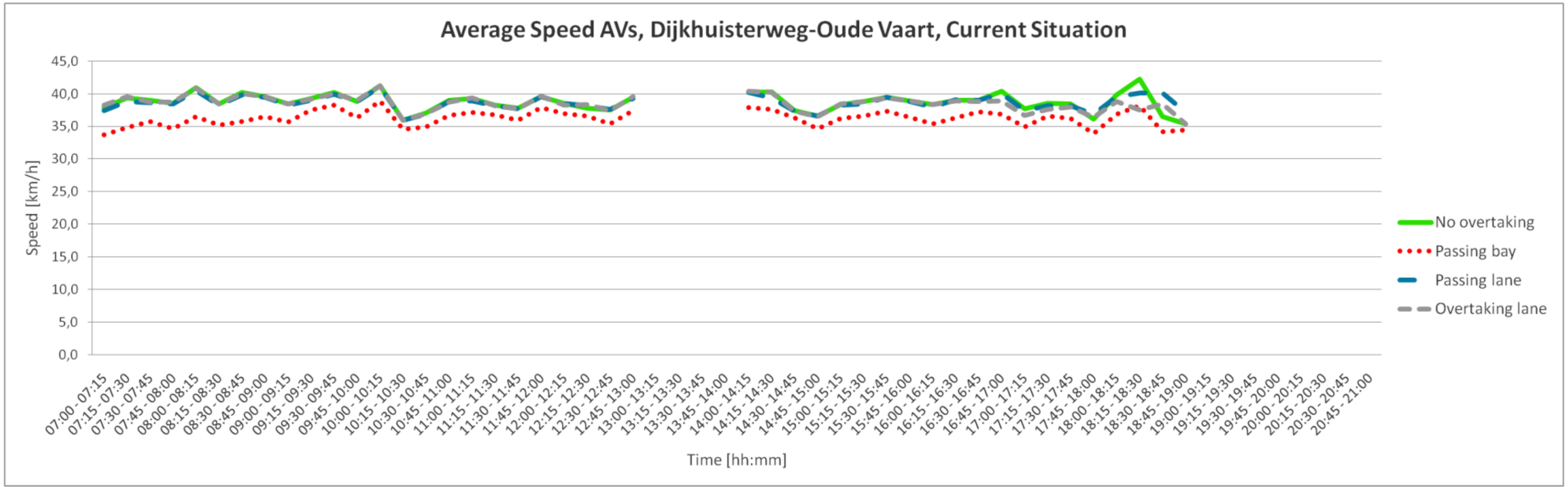


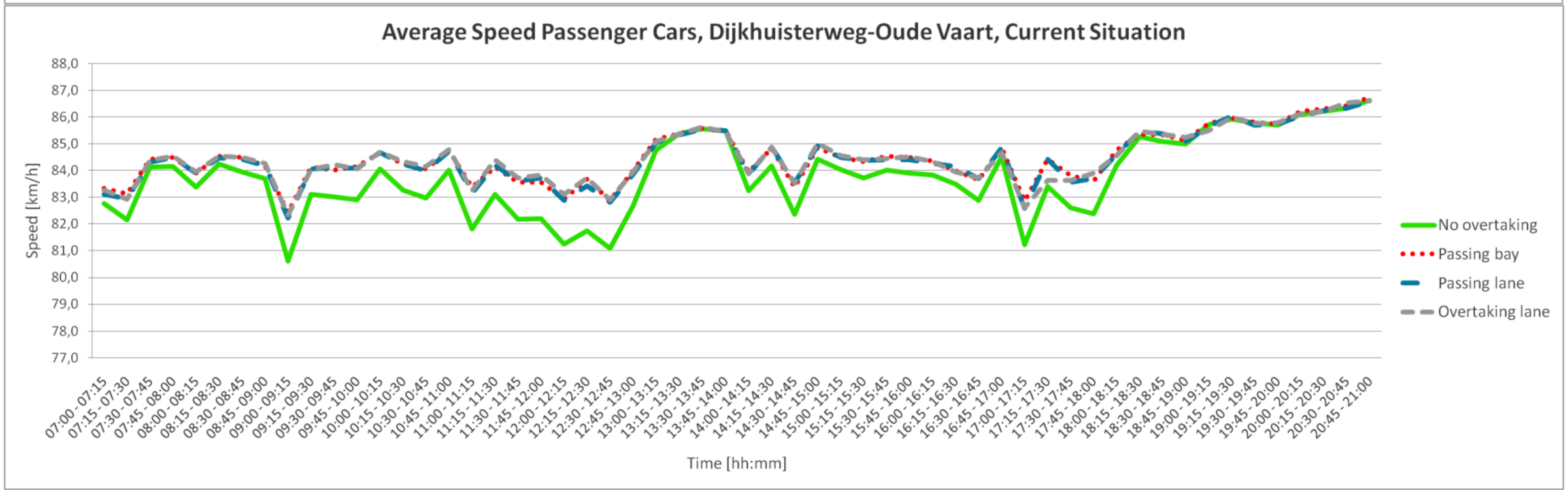


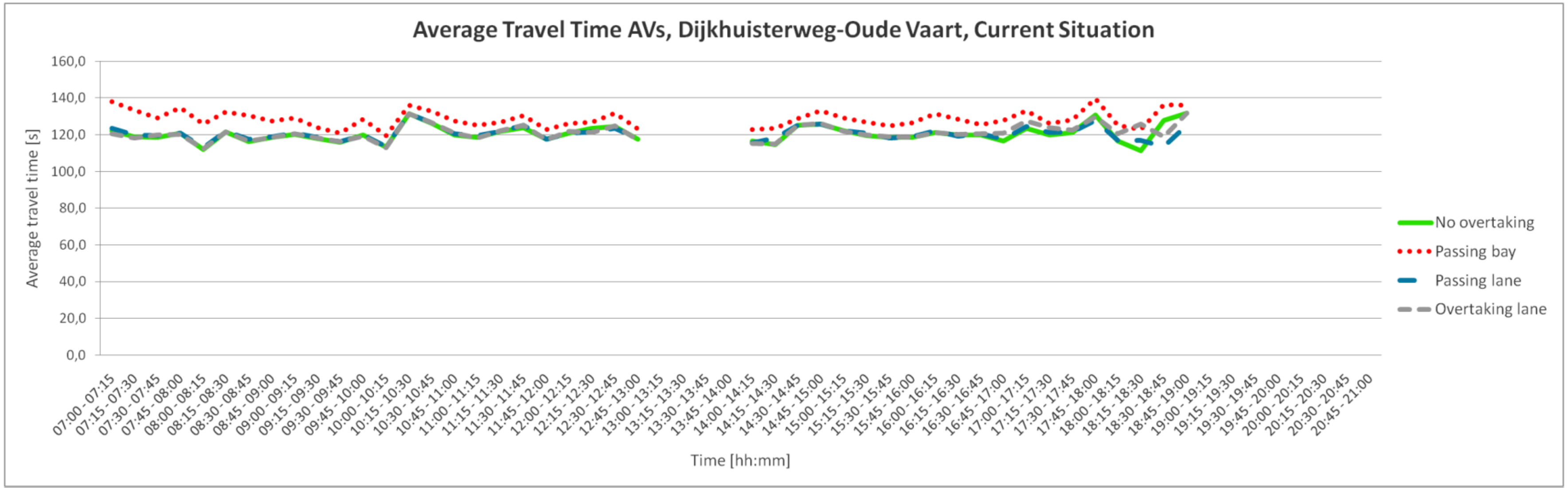


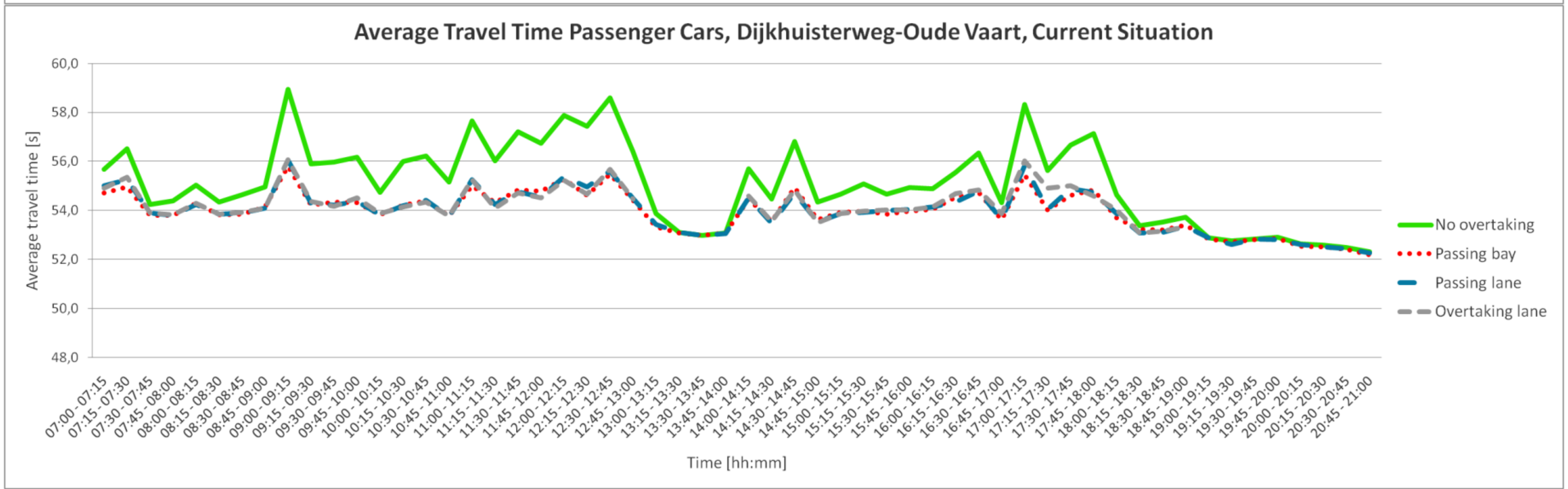


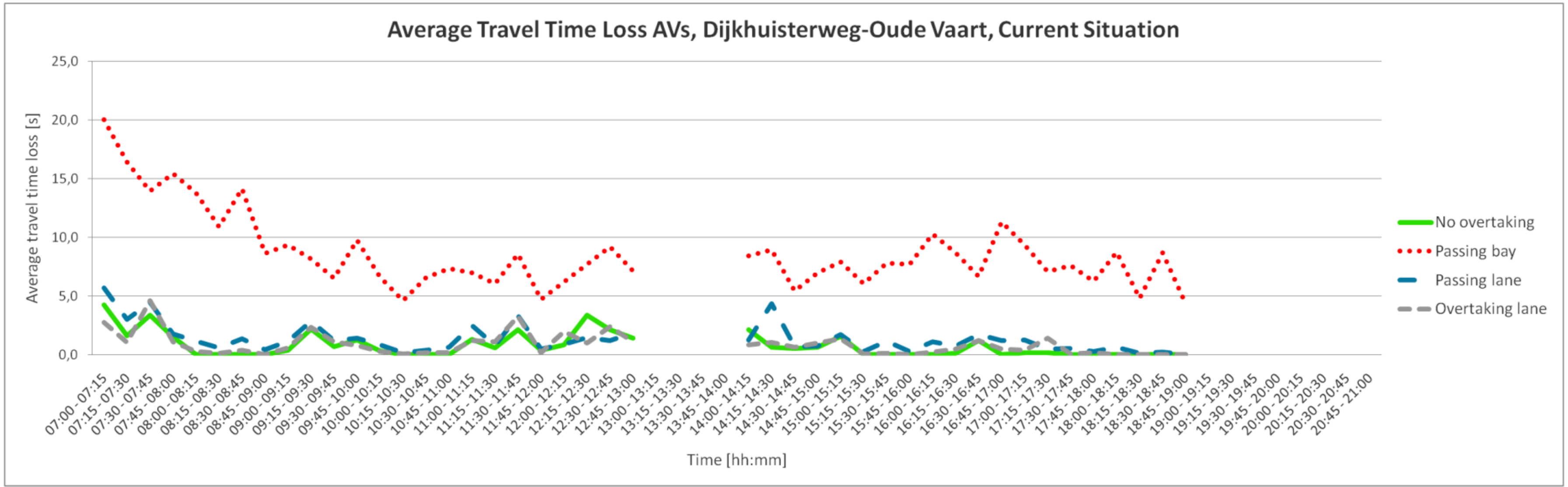
Average number of stops by AVs, Dijkhuisterweg-Oude Vaart
Average of stops
1,2
1,0
0,8
0,6
0,4
0,2
0,0
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane


Average Speed AVs, Dijkhuisterweg-Oude Vaart, Current Situation
Speed [km/h]
45,0
40,0
35,0
30,0
25,0
20,0
15,0
10,0
5,0
0,0
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane

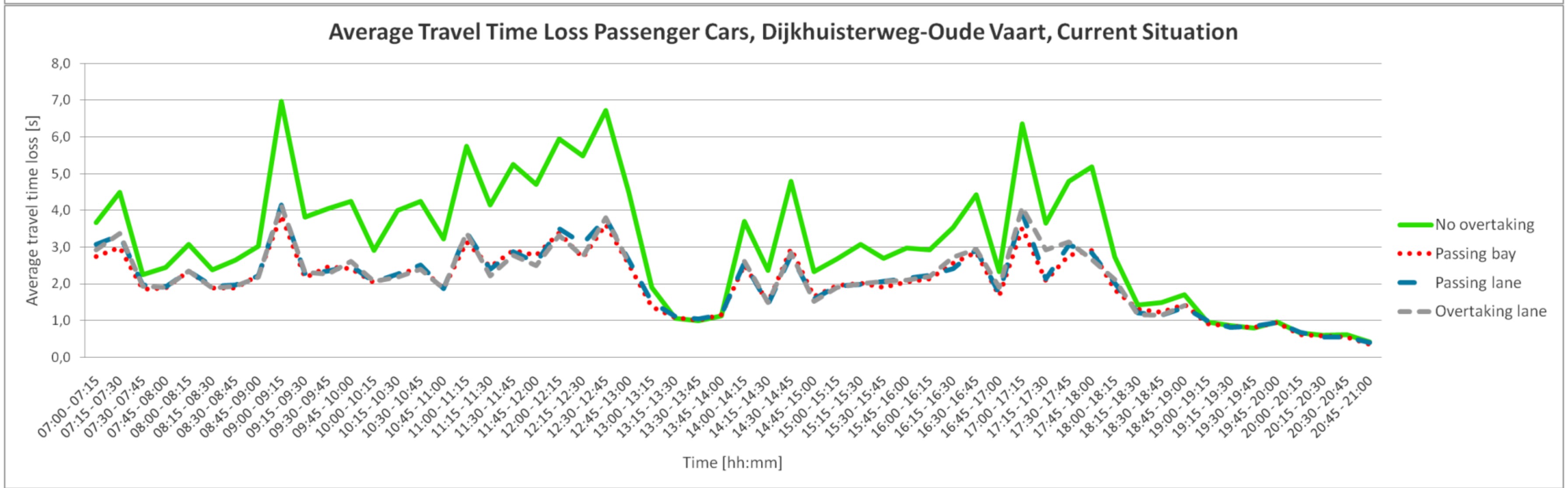

Average Speed Passenger Cars, Dijkhuisterweg-Oude Vaart, Current Situation
Speed [km/h]
88,0
87,0
86,0
85,0
84,0
83,0
82,0
81,0
80,0
79,0
78,0
77,0
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane


Average Travel Time AVs, Dijkhuisterweg-Oude Vaart, Current Situation
Average travel time [s]
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane

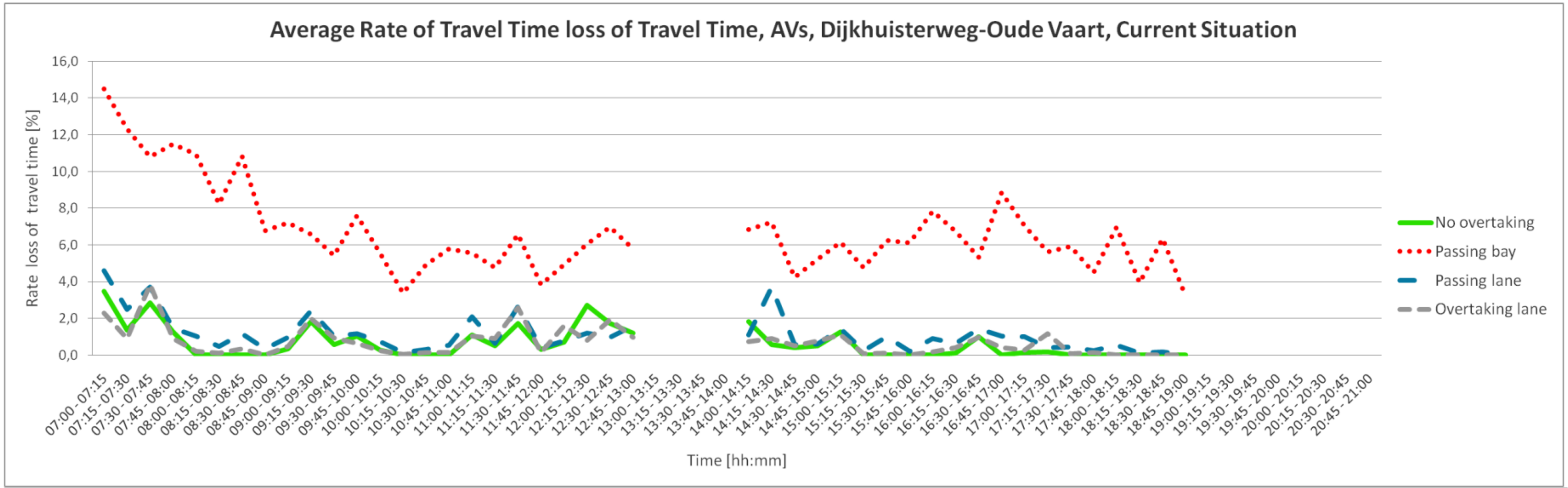

Average Travel Time Passenger Cars, Dijkhuisterweg-Oude Vaart, Current Situation
Average travel time [s]
60,0
58,0
56,0
54,0
52,0
50,0
48,0
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane

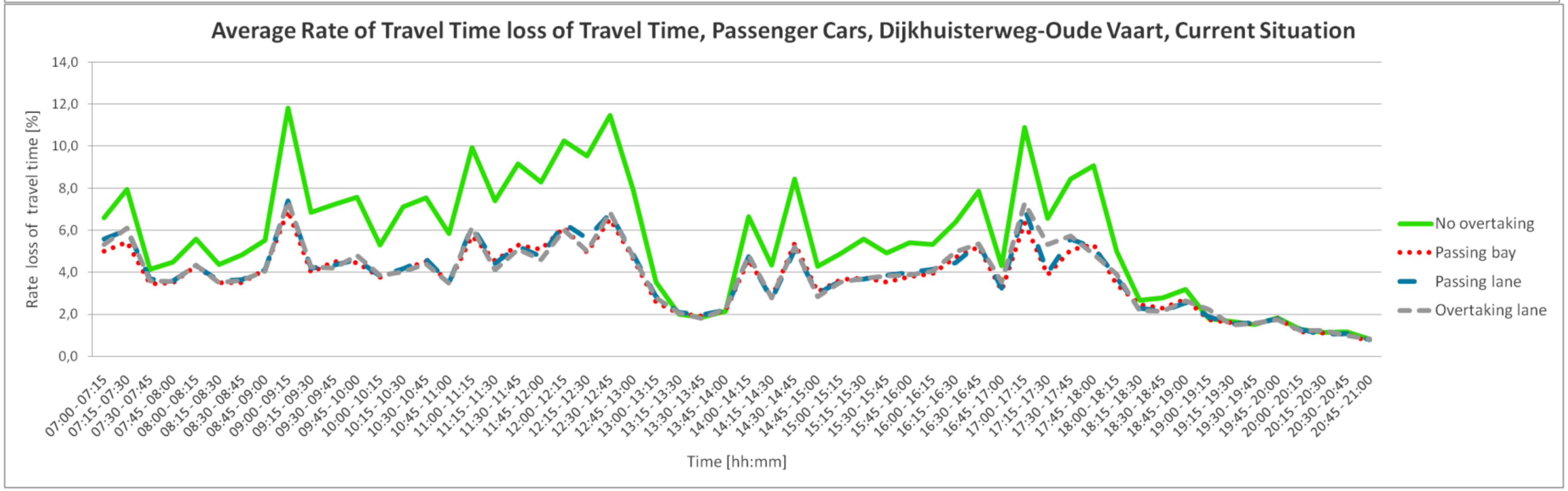


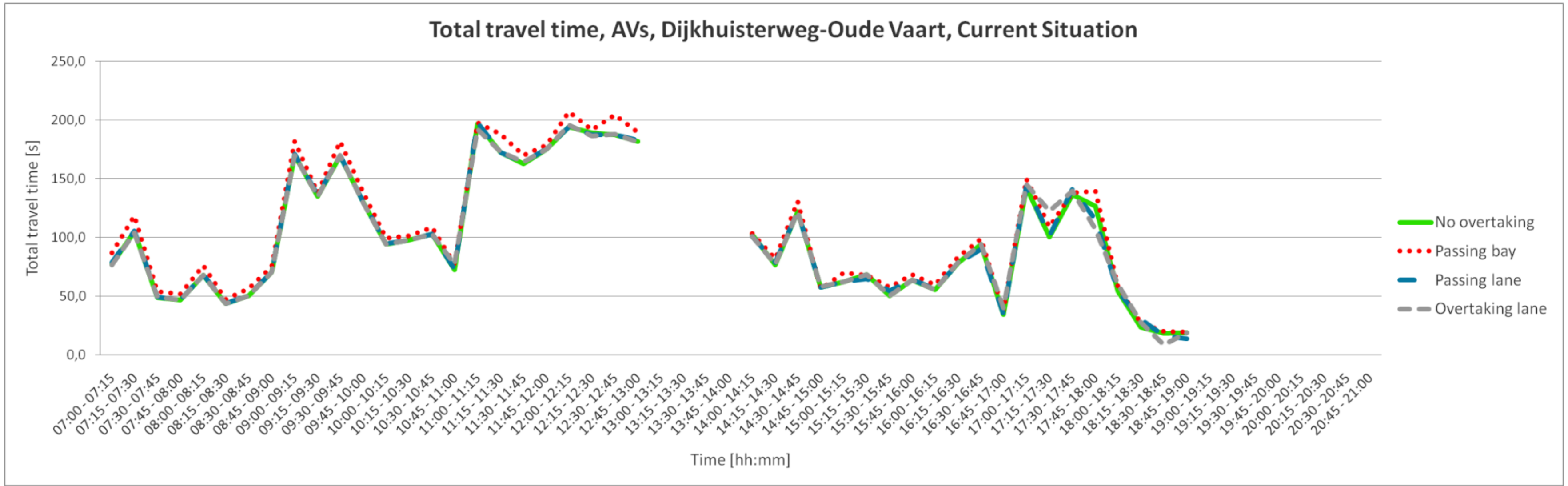
Average Travel Time Loss AVs, Dijkhuisterweg-Oude Vaart, Current Situation
Average travel time loss [s]
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane



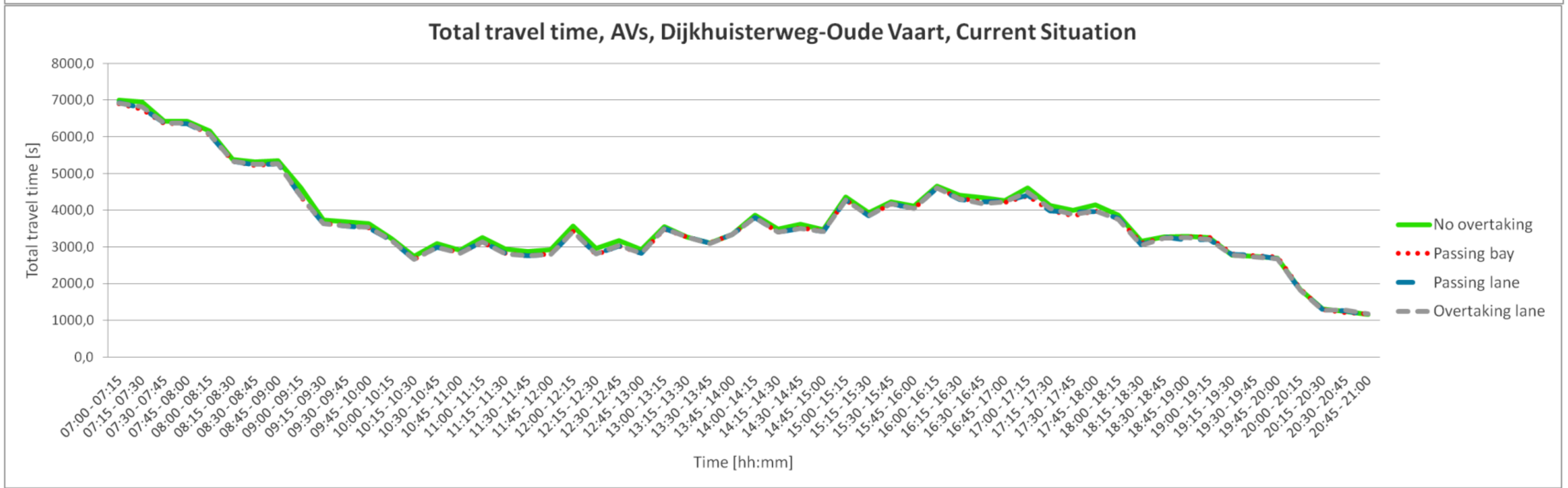
Average Travel Time Loss Passenger Cars, Dijkhuisterweg-Oude Vaart, Current Situation
Average travel time loss [s]
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane


Average Rate of Travel Time loss of Travel Time, AVs, Dijkhuisterweg-Oude Vaart, Current Situation
Rate loss of travel time [%]
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane


Average Rate of Travel Time loss of Travel Time, Passenger Cars, Dijkhuisterweg-Oude Vaart, Current Situation
Rate loss of travel time [%]
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane

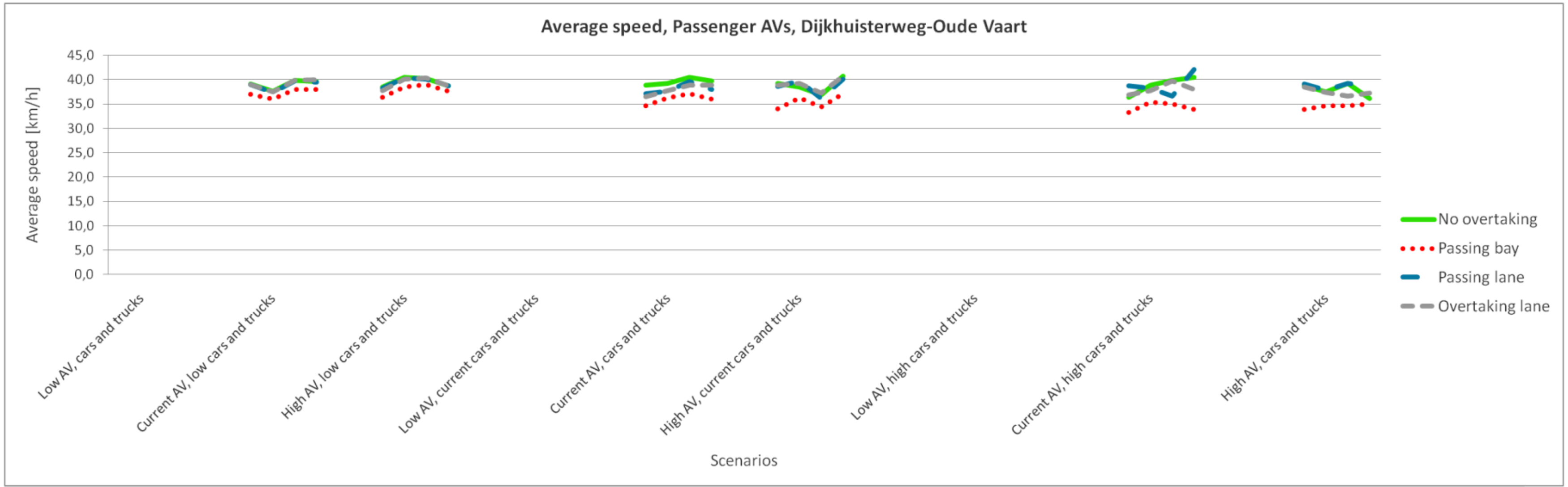


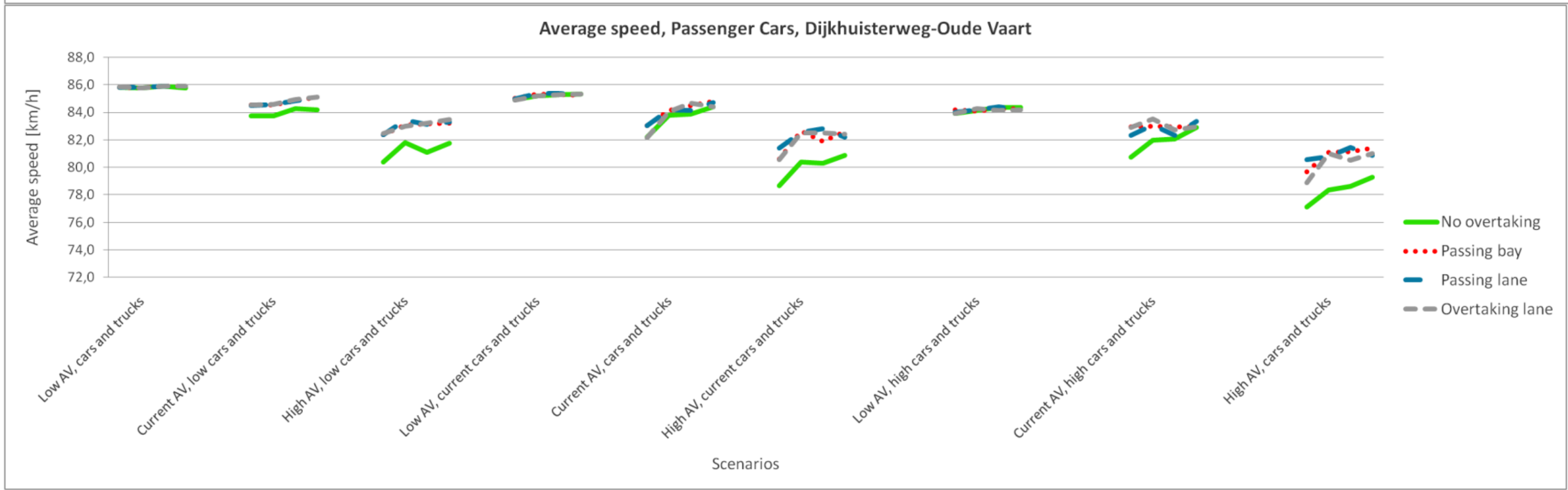
Total travel time, AVs, Dijkhuisterweg-Oude Vaart, Current Situation
Total travel time [s]
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane

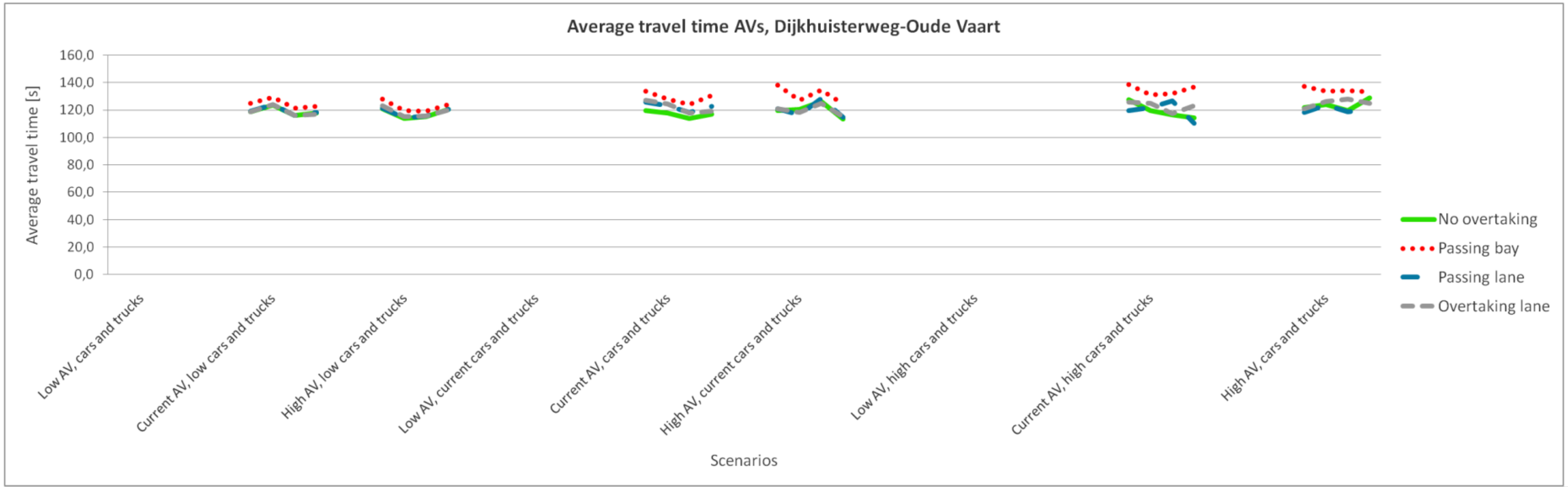


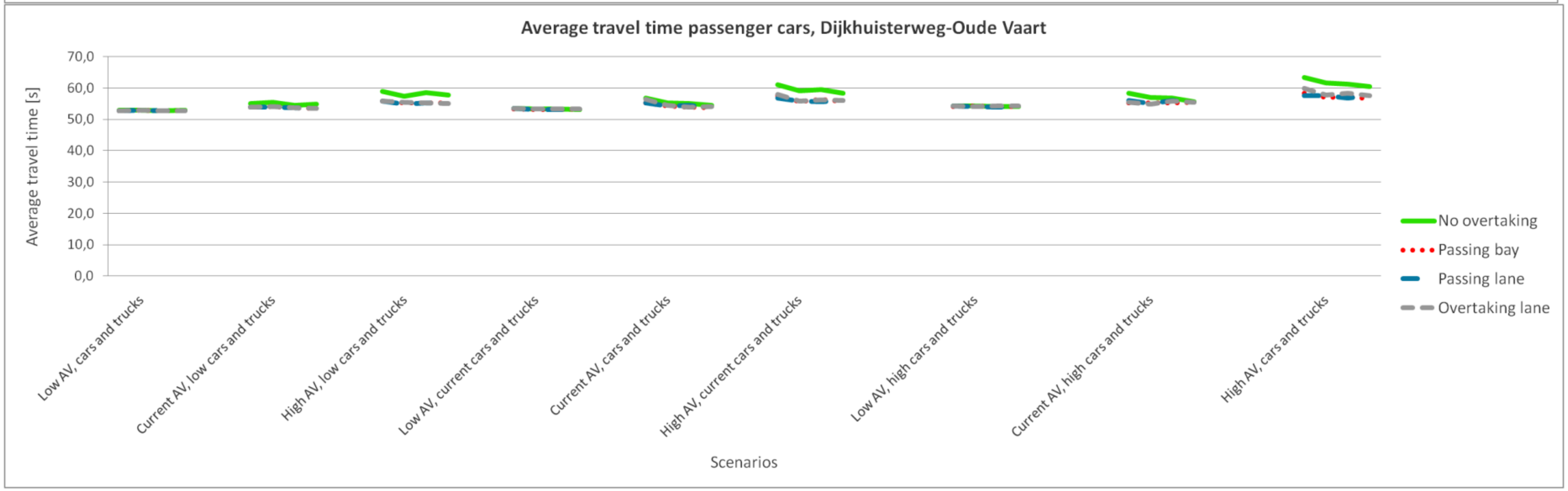
Total travel time, AVs, Dijkhuisterweg-Oude Vaart, Current Situation
Total travel time [s]
Time [hh:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane

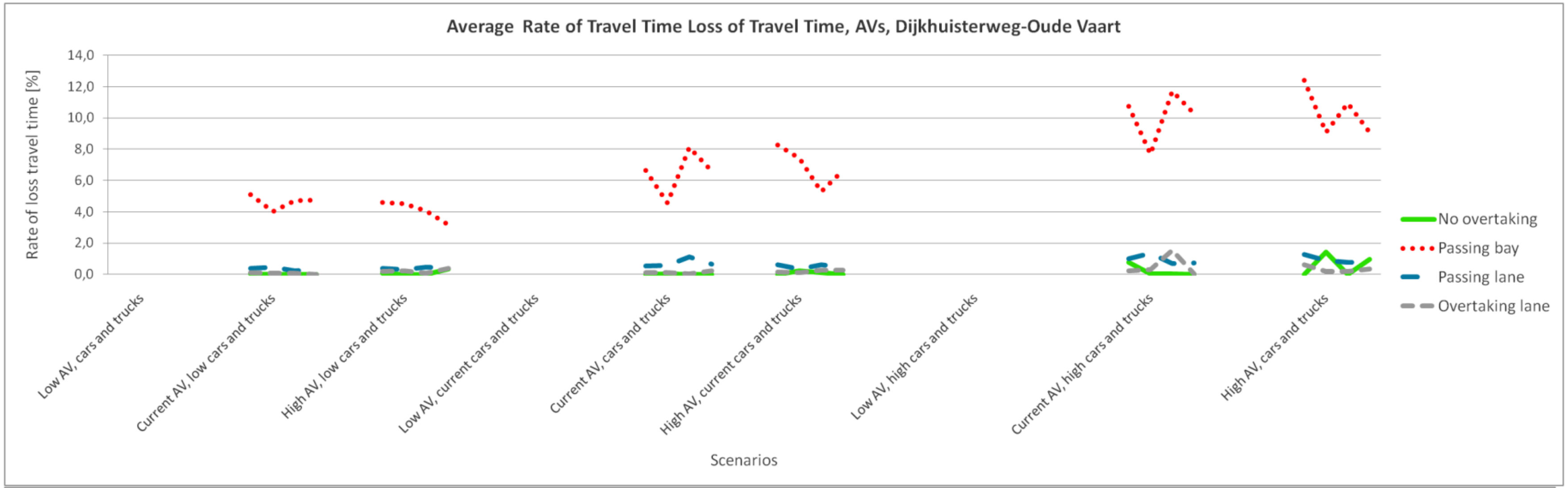
Results OV-DHW Scenarios

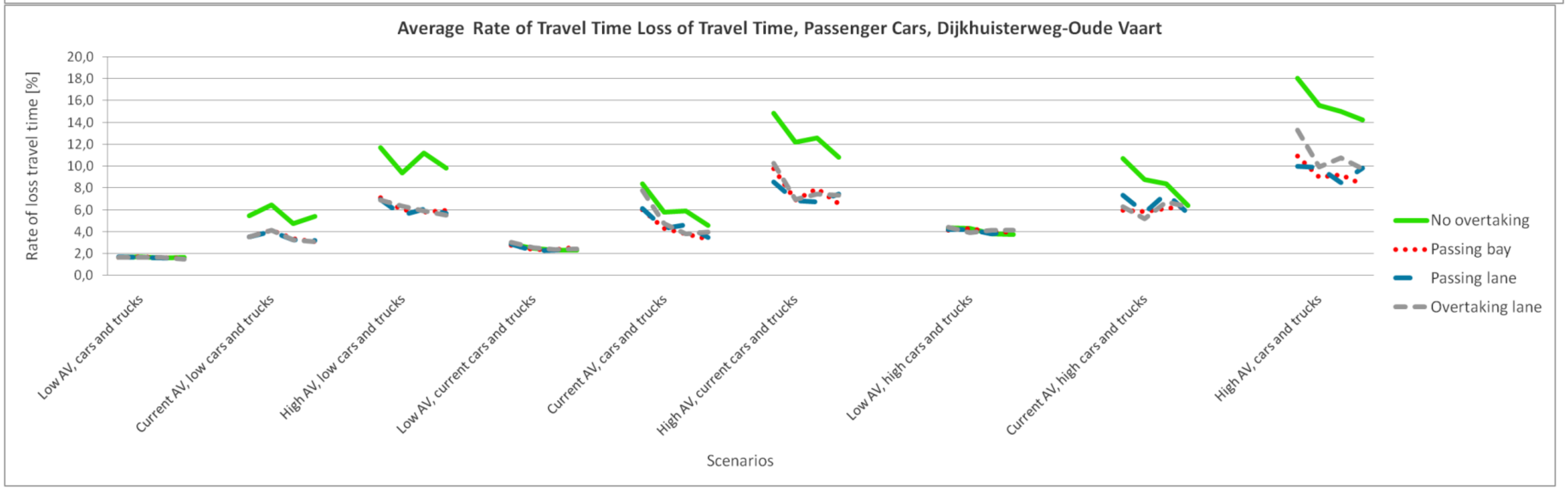




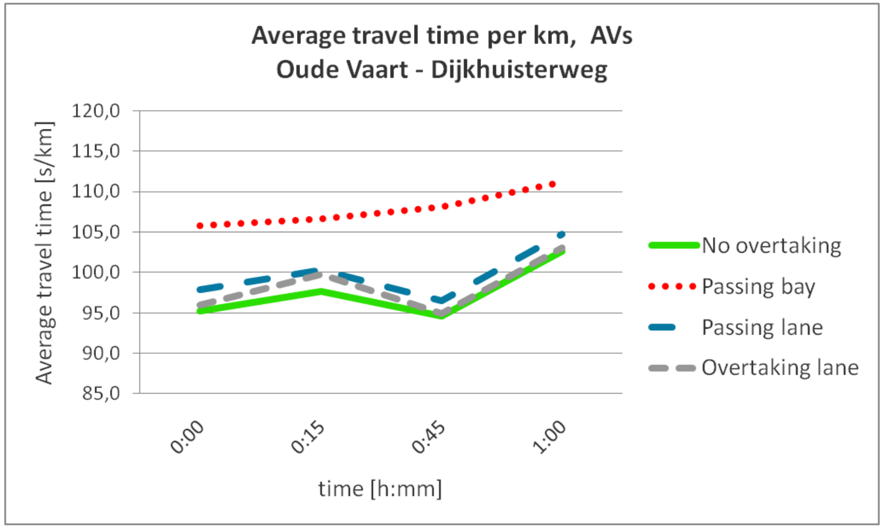

Average travel time AVs, Dijkhuisterweg-Oude Vaart
Average travel time [s]
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
Low AV, cars and trucks
Current AV, low cars and trucks
High AV, low cars and trucks
Low AV, current cars and trucks
Current AV, cars and trucks
High AV, current cars and trucks
Low AV, high cars and trucks
Current AV, high cars and trucks
High AV, cars and trucks
Scenarios
No overtaking
Passing bay
Passing lane
Overtaking lane

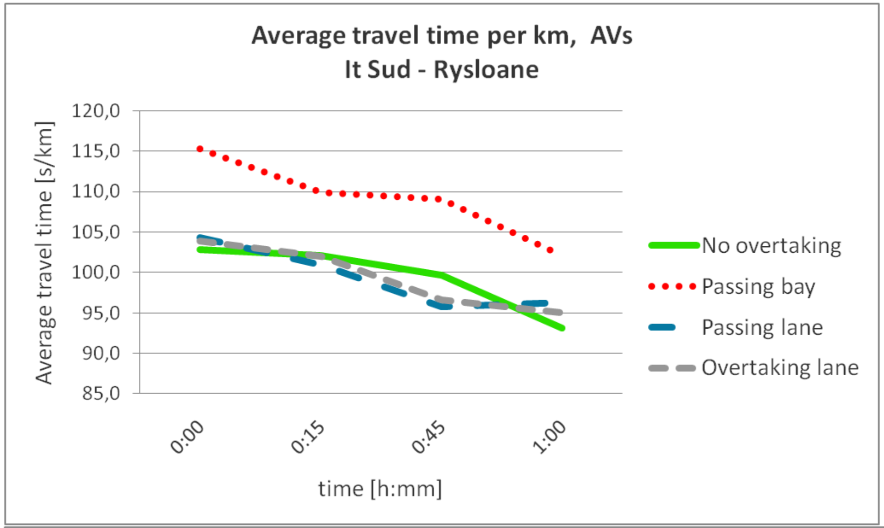

Average travel time passenger cars, Dijkhuisterweg-Oude Vaart
Average travel time [s]
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
Low AV, cars and trucks
Current AV, low cars and trucks
High AV, low cars and trucks
Low AV, current cars and trucks
Current AV, cars and trucks
High AV, current cars and trucks
Low AV, high cars and trucks
Current AV, high cars and trucks
High AV, cars and trucks
Scenarios
No overtaking
Passing bay
Passing lane
Overtaking lane

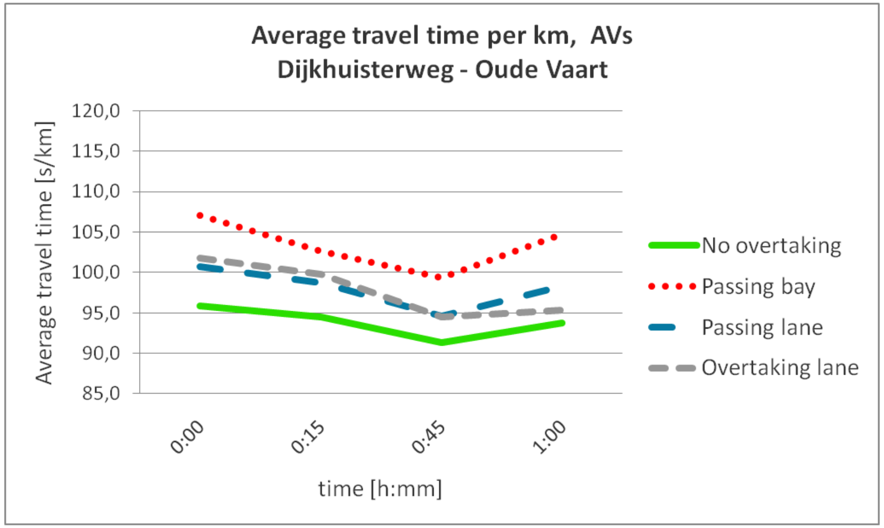

Average Rate of Travel Time Loss of Travel Time, AVs, Dijkhuisterweg-Oude Vaart
Rate of loss travel time [%]
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
Low AV, cars and trucks
Current AV, low cars and trucks
High AV, low cars and trucks
Low AV, current cars and trucks
Current AV, cars and trucks
High AV, current cars and trucks
Low AV, high cars and trucks
Current AV, high cars and trucks
High AV, cars and trucks
Scenarios
No overtaking
Passing bay
Passing lane
Overtaking lane

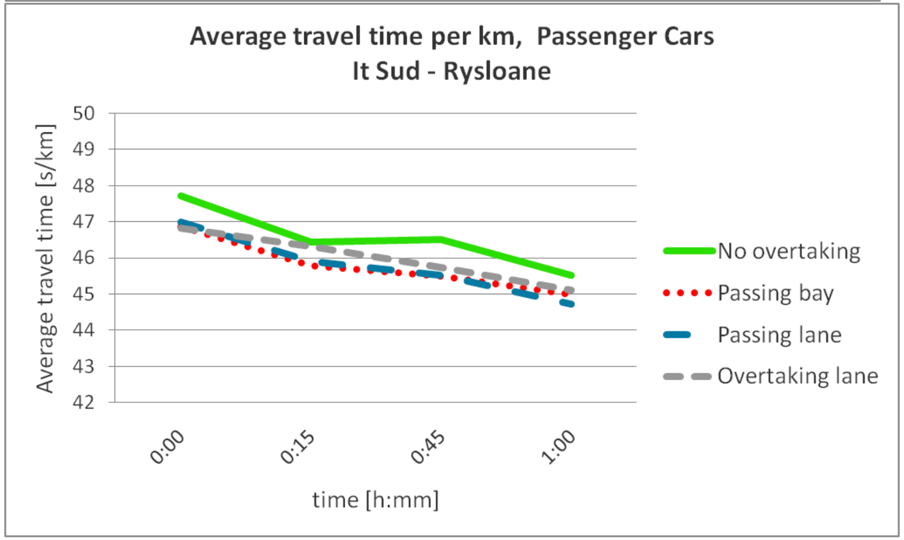

Average Rate of Travel Time Loss of Travel Time, Passenger Cars, Dijkhuisterweg-Oude Vaart
Rate of loss travel time [%]
20,0
18,0
16,0
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
Low AV, cars and trucks
Current AV, low cars and trucks
High AV, low cars and trucks
Low AV, current cars and trucks
Current AV, cars and trucks
High AV, current cars and trucks
Low AV, high cars and trucks
Current AV, high cars and trucks
High AV, cars and trucks
Scenarios
No overtaking
Passing bay
Passing lane
Overtaking lane

Robustness


Average travel time per km, AVs
Oude Vaart - Dijkhuisterweg
Average travel time [s/km]
120,0
115,0
110,0
105,0
100,0
95,0
90,0
85,0
0:00
0:15
0:45
1:00
time [h:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane


Average travel time per km, AVs
It Sud - Rysloane
Average travel time [s/km]
120,0
115,0
110,0
105,0
100,0
95,0
90,0
85,0
0:00
0:15
0:45
1:00
time [h:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane


Average travel time per km, AVs
Dijkhuisterweg - Oude Vaart
Average travel time [s/km]
120,0
115,0
110,0
105,0
100,0
95,0
90,0
85,0
0:00
0:15
0:45
1:00
time [h:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane


Average travel time per km, Passenger Cars
It Sud - Rysloane
Average travel time [s/km]
50
49
48
47
46
45
44
43
42
0:00
0:15
0:45
1:00
time [h:mm]
No overtaking
Passing bay
Passing lane
Overtaking lane