De effecten van autonome voertuigen binnen de bebouwde kom

Luuk de Vries – Sweco Nederland B.V. – luuk.devries@sweco.nl
Jeroen Quee – Sweco Nederland B.V. – jeroen.quee@sweco.nl

Bijdrage aan het Colloquium Vervoersplanologisch Speurwerk
22 en 23 november 2018, Amersfoort

Samenvatting

De ontwikkeling van autonome voertuigen heeft zich het afgelopen kalenderjaar gestaag voortgezet. Bijna dagelijks zijn er nieuwberichten over geslaagde en minder geslaagde stappen in de ontwikkeling. Hoewel de volledige autonome auto (SEA level 5) nog enkele 'jaren' ontwikkeling nodig heeft, zijn er ondertussen legio voorbeelden van experimentele versies van (volledig) autonome voertuigen. De technologieën die de werking van autonome voertuigen mogelijk maken, zitten in een niet te stoppen ontwikkelingsflow en ook in Nederland zijn meerdere pilots in voorbereiding.

De autonome auto zal veel impact hebben op de openbare ruimte, met name binnen de komgrenzen. De vraag hoe deze er over een aantal jaren uit zal zien is zeer relevant voor stadsplanners. Binnen de reeds beschikbare literatuur ligt de focus vooral op autonome voertuigen binnen kleine pilot-gebieden en het autonoom rijden op snelwegen. Het is echter een kwestie van tijd alvorens we diezelfde autonome voertuigen op de wegen binnen de bebouwde kom zullen treffen. En dit betekent dat op enig moment in de toekomst, het autonome voertuig zich ook tussen de kwetsbare verkeersdeelnemers, zoals voetgangers, fietsers en motorrijders zal gaan voortbewegen. Ofwel; we kunnen kriebels in de stad verwachten!

De meest intuïtieve aanpak om het effect van autonome voertuigen op het verkeerssysteem in de stad te beschrijven, begint bij de meeste onderzoeken met het opstellen van een of meerdere toekomstscenario's. Vanuit deze toekomstscenario's wordt vervolgens beredeneerd hoe de stad en het bijbehorende verkeersysteem er in de toekomst zal gaan uitzien, welke technologische ontwikkeling er voor de autonome voertuigen wordt verwacht en met welke aantallen autonome voertuigen we te maken zullen krijgen.

In deze paper betogen we dat aan de hand van empirisch onderzoek in verschillende verkeerssimulatiestudies, de effecten van autonome voertuigen op de Key-Performance Indicators (KPI's) van de verschillende wegtypen binnen de bebouwde kom, voornamelijk afhankelijk zijn van de (macroscopische-) uitgangspunten waarmee een toekomstscenario tot stand komt. De impact op de KPI's (lees: mobiliteitsindicatoren) is derhalve relatief weinig afhankelijk van de optimalisatie van het gedrag waarmee het autonome voertuig geprogrammeerd wordt.

In de presentatie op het CVS wordt nader ingegaan op de (cijfermatige) bevindingen van de onderzoeken van Sweco naar de effecten van autonome voertuigen in twee verschillende stedelijke netwerken (Eindhoven en Hoogezand-Sappemeer). Hierbij worden de effecten van autonome voertuigen op de verschillende wegtypes binnen de bebouwde verder uitgediept.

1. Introduction

Mobility in urban areas is increasing and causes major problems in the field of acces and environment. Traditional approaches, such as further road expansions supported by additional public transport services and smart traffic systems are already reaching their maximum potential. Therefore, other transitions in mobility and new technologies are necessary to facilitate mobility in the city and increase livability. Autonomous driving is often presented as a promising technology with potential to keep the cities of the future attractive and livable (and as a reference to this year's CVS theme; a city without too many distracting jitters).

A recent impact study towards explicating the effect of autonomous vehicle and its effect on society and policy making in The Netherlands, has been executed by the combination of Arcadis and TNO under the name: "*Impactstudie autonome voertuigen*". Within the period of the study, November 2017 to March 2018, this scenario study has been conducted on the effect of autonomous vehicles differentiated to degrees of urbanization. Ranging from the level of metropolitan-density (e.g. the city center of Amsterdam) to rural area's (e.g. Lutjebroek). The developed scenarios were calculated through with use of the Quick Scan Tool developed by TNO. The outcomes of this study reveal that the effects of autonomous are not irrefutably beneficial to social, economic, spatial and mobility development compared to a future without autonomous vehicles.

Within the same timeframe as the study of Arcadis and TNO (2018), Sweco Netherlands has performed multiple scenario studies towards quantifying the effects of autonomous vehicles on the cities of the future as well. The scope of these studies is predominantly focused on the technical and behavioral changes expected due to introduction of fully autonomous vehicles, the so called *microscopic effects* (Withagen, M. (2017), De Vries, L.O., Quee, J., Withagen, M. (2017), Vries de, L.O. (2018), Laag van der, P. (2018)).

These studies have in common with the study of Arcadis and TNO that the starting-point of each (case-) study is a scenario analysis, in which one or more scenarios are developed based upon a mix of literature and expert judgement. The scenarios are consequently used as a basis for further calculation of the effects of autonomous vehicles through use of state-of-the-art traffic modelling software. In the study of Arcadis and TNO: the Quick Scan Tool. In the studies of Sweco: Paramics Microsimulation and VISSIM Microsimulation.

In this paper we highlight the quantitative results of the research performed by Sweco Netherlands towards the effect of autonomous vehicles within different types of urban areas within the case study areas: Eindhoven and Hoogezand-Sappemeer, chosen as being representative for the investigated urban transport system characteristics. Additionally we compare these quantitative results to the study of Arcadis and TNO as to find out which aspects of autonomous driving might and/or will dominate the future.

2. Scenario Development

With respect to urban design, scenario building is a commonly used tool for researchers and policymakers to define different transition paths and a scope for assessment for each of the scenarios. Within the scenarios of the KiM (2015) two commonly used dimensions are: expected level of car sharing (acceptance) and expected level of automation (technological development). Within these dimensions the following characteristics are distinguished: *no car sharing* versus *full car sharing* and *conditional/high automation* versus *full automation* (SEA level 5). These characteristics were also used in the research of Arcadis & TNO (2018).

Within the study of Withagen (2017) additional suitable dimensions for usage were distinguished within the scenario development phase, focusing on an urban context. Through use of expert judgement, interviews and literature research a total of four additional suitable dimensions for scenario development besides the two already developed by the KiM (2015). These are: "connected vs un-connected", "traditional behavior or new behavior", "individual or collective" and "efficiency vs experience". As the issue of concern within this research was to show the possibilities of autonomous vehicles within a microsimulation environment, assumed was that in all scenario's full automation is achieved. Therefore the technological development dimension in the KiM scenarios was swapped for the "efficiency vs experience" dimension. The latter tries to capture the effect that autonomous vehicles have on the Value of Time (VoT) of the user.

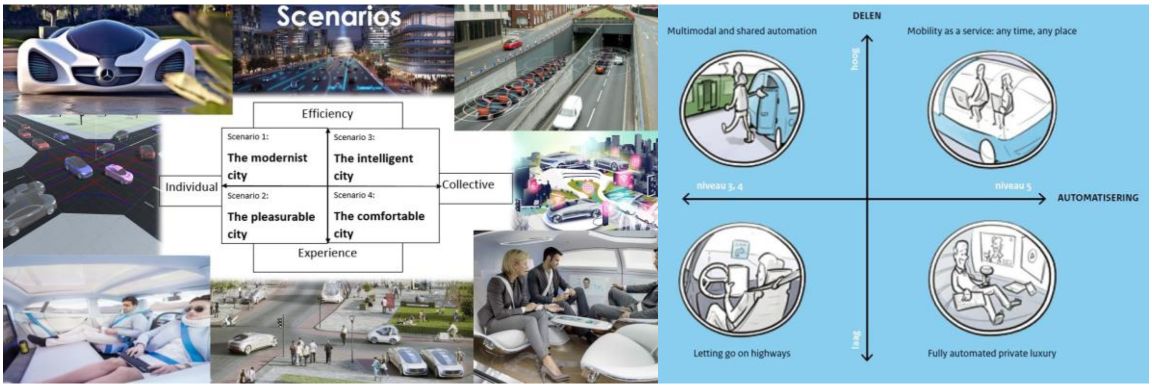

Figure 1: *Autonomous Vehicle Scenarios (left: Withagen (2017), right: KiM (2015).*

In all cases substantial differences between scenario's are chosen to warrant clear distinction between scenarios and get a feeling for the bandwidth and/or maximum impact to be expected within each scenario. This allows for (relative) comparison between scenarios. Additionally, through use of a simulation environment, calculation tool and/or via expert judgement based upon a ripple scheme (Milakis et al. (2015)), the effects of autonomous vehicles upon the mobility in the future can be described and/or quantified. This ripple scheme is visualized in figure 2.

Figure 2: *The ripple effect of automated driving. Milakis, D., Van Arem, B., & Van Wee, B. (2015).*

In the study of Withagen (2017) all four scenarios were analyzed and compared by modelling autonomous vehicles within the city of Eindhoven. Van der Laag (2018) chose one scenario for a more in dept analysis. This scenario choice was made by identifying the most plausible trends and developments within a different area of research (respectively Hoogezand-Sappemeer). In both studies the focus therefore shifts from trying to find 'all' possible effects of autonomous vehicles to a more thorough investigation towards a specific area within the urban environment (e.g. roundabouts, traffic lights, weaving sections etc.).

3. Effects of autonomous vehicles on key performance indicators

3.1 Overview of recent studies

Within the most – if not all – studies towards autonomous driving an attempt is made to identify the key driving forces and its effect upon future mobility. We are interested in changes in congestion, land use, vehicle use, travel costs, economy, safety etc., which are caused when (fully) autonomous vehicles are used more and more. And as these indicators are generally KPI's used in governmental mobility policies, research towards the effect that autonomous vehicles can have on each of these KPI's is important. Preferably we would like to know not only the relative magnitude of changes expected for each KPI (e.g. positive/negative), but also an empirically determined effect, based upon direct observation or experience.

As in the current mobility environment the modal share of autonomous vehicles and their respective level of automation is more or less zero, no real-world empirical data is available. For quantification of the effects of autonomous the studies considered in this paper use a tool/method. This tool effectively translates the scenario's inputted, into outcomes on one or more KPI's within a certain study area (mobility environment). In the table below, the studies, their respectively used tool, application area and output variables are described.

Table 1: *Overview of used tools, application area and output variables (KPI's)*

Study	**Used Tool**	**Case Study Area**	**Output variables**
TNO & Arcadis (2018)	Quick Scan Tool	Province of North-Holland	Vehicle km's Modal split Vehicle loss hours
Withagen (2017)	Paramics Microsimulation	Eindhoven	Traffic flow performance (urban level) Vehicle loss hours
Van der Laag (2018)	PTV Vissim Microsimulation	Hoogezand-Sappemeer	Traffic flow performance (local / intersection level) Waiting time, queue length

We identify in the results of these studies that the KPI's can be influenced by 1st, 2nd and 3rd order effects as described in the ripple scheme of Mikalis (2015). De Vries (2018) recently argued that a differentiation of macroscopic and microscopic effects needs to be made to be able to accurately quantify the effects which autonomous vehicles have within the built environment. In this context macroscopic effects can be considered to be the effects that autonomous vehicles will have on macroscopic variables; value of time, changes in modal-split, changes in traffic demand, spatial and parking consequences (etc.). The microscopic effects are effects caused by the autonomous technological development. These affect driving behavior, average velocity, route choice, vehicle connectivity, headways (etc.). To fully grasp the effect of autonomous vehicles on a KPI, one has to consider both. Especially in areas where either macroscopic or microscopic effects might dominate the effect on the KPI.

Based upon the results of all three studies we expect that the main challenge for mobility lies within in the urban area where macroscopic and microscopic effects interact. It is in this area that effects might cancel one another out, or even strengthen each other. This is visualized in the Venn-diagram in figure 3.

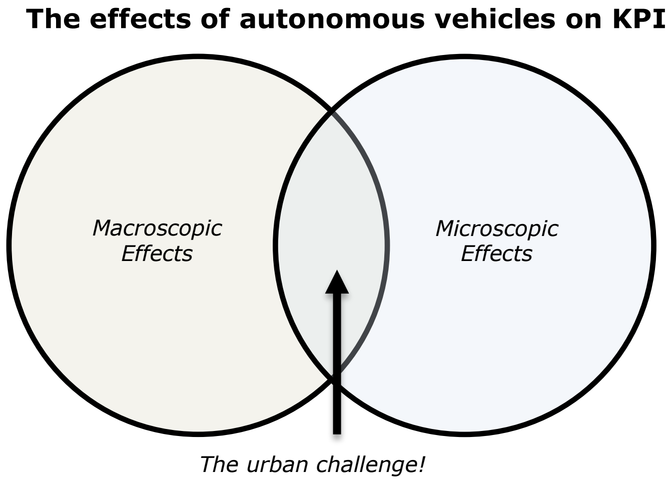

Figure 3*: The effects of autonomous vehicles on KPI's, emphasis on the urban challenge*

3.2 Case study results

Within the case study results of Withagen (2017) for the city of Eindhoven we identify the following results to be the most interesting effects due to changes in microscopic vehicle behavior within an urban environment; (1) Increased acceleration and deceleration of autonomous vehicles has no beneficial effects on a microscopic level. This complies with the idea that 'racing from traffic light to traffic light' within a city doesn't have any time-advantages other than a higher fuel consumption; (2) a lowered aggression and increased awareness of vehicles (proper lane choice, lane change behavior and cooperative driving behavior) has a huge positive effect on capacity of merging/weaving-sections (up to 30% additional capacity). Yet on a network-level for the city of Eindhoven, only adds up to ~5% less vehicle loss hours.

The study by Van der Laag (2018) aimed at quantifying traffic flow on intersection level. From this study we consider the following example of a signalized intersection in Hoogezand-Sappemeer, within the VISSIM 10 traffic simulation model. In the left figure of figure 4 traditional vehicle behavior is depicted, in the right only autonomous vehicles are shown. We paused both simulations right after the last vehicle of the (5-car) platoon moving left to right, has passed the green light.

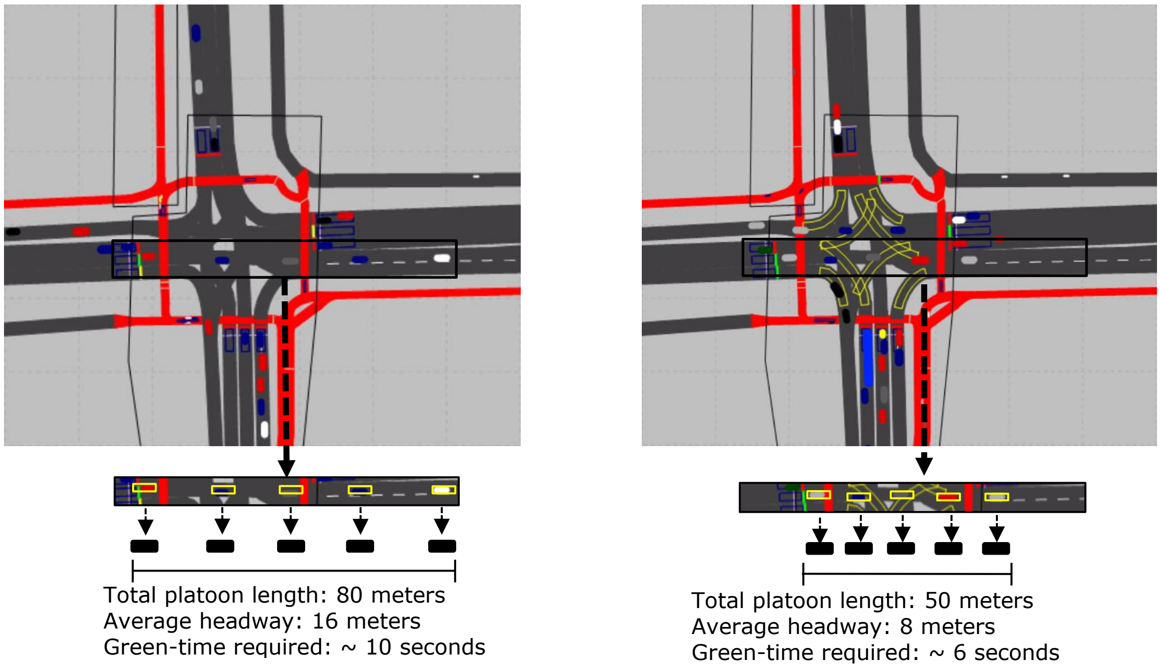

Figure 4: *Signalized intersection in Hoogezand-Sappemeer programmed within VISSIM. Left: Traditional vehicle behavior. Right: Autonomous vehicle behavior.*

The biggest difference between the two pictures is identified by the difference in headway between vehicles driving through the intersection. Due to autonomous vehicles being connected, reaction times at the traffic signal and platoon-dispersion, the so called: 'harmonica-effect' are non-existent. We can see that compared to traditional vehicle behavior the green-time and headway between vehicles are halved. In the autonomous simulation we therefore conclude that junction capacity will dramatically increases due to the inclusion of connectivity between cars (and infrastructure). If the KPI in this case would be to 'vehicle loss hours' or 'average waiting time', the microscopic effect would likely dominate any macroscopic effect caused by choice of scenario.

In the case study results of Van der Laag (2018) for the city of Hoogezand-Sappemeer, the following conclusion was drawn; Introduction of connected autonomous vehicles, results in less reaction time and less (minimum) headway between vehicles. This has a huge positive effect on the KPI's connected to a (signalized) intersections. Average queue length for a signalized intersection diminishes by 46% and respectively the average waiting time by 7%. Additionally for the roundabouts in the network we measure an even bigger effect of 22% less waiting time for cars as a result of the new microscopic behavior of vehicles.

4. Conclusion & Discussion

The studies of Withagen (2017) and Van der Laag (2018) compared to the outcomes of the study of TNO & Arcadis (2018) identify all the same threat. Due to the introduction of autonomous vehicles, we are introducing an accessible, convenient and cost-effective new modality to the mobility system. De Vries (2018, p22) describes that: "*The arrival of autonomous vehicles goes hand in hand with changes in moving behavior of people in the city of the future. The biggest impact on the road network and complex modelling of autonomous vehicles is hidden behind these changes in behavior*".

Without intervention it is very plausible that this new modality will compete with favorable alternatives such as public transport, cycling and walking. Additionally we can expect huge changes on a macroscopic level as well. TNO & Arcadis (2018) reveal that the number of travelled kilometers by car, might increase up to 70% dependent on scenario choice.

For further insight in the studies of Withagen (2017) and Van der Laag (2018) a robustness-check was performed by increasing the traffic demand by 5% to see how much of the positive results would be mitigated. In both studies we saw that 5% of additional traffic annihilates the positive effects of autonomous vehicles due to microscopic driving behavior changes to zero.

We therefore conclude that the results of each study towards autonomous vehicles on KPI's of the road infrastructure within a city environment are dominated by the macroscopic effects that a scenario generates. The positive microscopic effects of autonomous driving are within our studies only noticeable when looking at the (microscopic-) level of intersections and road segments. But when considering KPI's on a network-scale, the microscopic effects of autonomous driving are barely noticeable.
For the urban area this may imply that the land use for infrastructure near traffic-light regulated intersections can be limited, but in general the studies show only limited possibilities for land use gains transformation (from traffic space to 'liveable space').

Additionally we found that current microsimulation software (i.e. Paramics and VISSIM) are suitable tools for the modelling of autonomous vehicle behavior. During both studies we found the visualized outcomes to comply with expected behavior. However, aspects where human behavior plays an important role, are difficult to model. E.g. Within the study of van der Laag (2018) we found that the KPI: *safety* on access roads is not objectively measurable within traffic models.

Finally we advise to consider careful scenario making when performing future studies towards quantifying the effects of autonomous vehicles. While extreme scenario's might give insight in bandwidths, the results TNO & Arcadis (2018) show that then very intrusive policy interventions are required to counteract the scenario effects. In our opinion it is more worthwhile to develop scenarios from a vision of the future city, which in practice is then implemented with hand-in-hand policy making. For example aiming at the interaction between bicycles and autonomous vehicles.

References

Kennisinstituut voor Mobiliteitsbeleid (KiM) (2015). *Chauffeur aan het stuur? Zelfrijdende voertuigen en het verkeer- en vervoersysteem van de toekomst*. Oktober 2015.

Laag van der, P. (2018). *Een scenario-onderzoek naar autonome voertuigen en de uitdrukking daarvan in microscopisch simulatiemodel VISSIM*. June 2018.

Milakis, D., Van Arem, B., & Van Wee, B. (2015). *The ripple effect of automated driving*. Paper presented at the Transport Research Day, Eindhoven

TNO & Arcadis (2018). *Impactstudie autonome voertuigen*. Provincie Noord-Holland, Vervoerregio Amsterdam. Juli 2018.

Vries de, L.O., Quee, J., Witthagen, M. (2017). *Hoe helpen autonome voertuigen de mobiliteit in de stad van de toekomst vooruit?* Prepared for the Colloquium Vervoersplanologisch Speurwerk. 23 en 24 November 2017, Gent.

Vries de, L.O. (2018). *De verborgen (model-) complexiteit van autonome voertuigen in de steden van de toekomst*. Prepared for PLATOS 2018, 14th of March 2018.

Withagen, M. (2017). *What insight can a microsimulation traffic model provide with respect to the impact of autonomous vehicles on urban mobility in the future?* November, 2017.