Investigation of Automated Vehicle Effects on Driver’s Behavior and Traffic Performance

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Abstract
Advanced Driver Assistance Systems (ADAS) offer the possibility of helping drivers to fulfill their driving tasks. Automated vehicles (AV) are capable of communicating with surrounding vehicles (V2V) and infrastructure (V2I) in order to collect and provide essential information about the driving environment. Studies have proved that automated driving have the potential to decrease traffic congestion by reducing the time headway (THW), enhancing the traffic capacity and improving the safety margins in car following. Despite different encouraging factors, automated driving raise some concerns such as possible loss of situation awareness, overreliance on automation and system failure. This paper aims to investigate the effects of AV on driver’s behavior and traffic performance. A literature review was conducted to examine the AV effects on driver’s behavior. Findings from the literature survey reveal that conventional vehicles (CV), i.e. human driven, which are driving close to a platoon of AV with short THW, tend to reduce their THW and spend more time under their critical THW. Additionally, driving highly AV reduce situation awareness and can intensify driver drowsiness, exclusively in light traffic. In order to investigate the influences of AV on traffic performance, a simulation case study consisting of a 100% AV scenario and a 100% CV scenario was performed using microscopic traffic simulation.

Outputs of this simulation study reveal that the positive effects of AV on roads are especially highlighted when the network is crowded (e.g. peak hours). This can definitely count as a constructive point for the future of road networks with higher demands. In details, average density of autobahn segment remarkably improved by 8.09% during p.m. peak hours in the AV scenario, while the average travel speed enhanced relatively by 8.48%. As a consequent, the average travel time improved by 9.00% in the AV scenario. The outcome of this study jointly with the previous driving simulator studies illustrates a successful practice of microscopic traffic simulation to investigate the effects of AV. However, further development of the microscopic traffic simulation models are required and further investigations of mixed traffic situation with AV and CV need to be conducted.

Keywords: Automated driving, Automated vehicles, Microscopic traffic simulation, Driver behavior, Traffic performance, Capacity
1 Introduction

Automated vehicles (AV) have passed miles of test runs on multiple road types under various traffic conditions. In near feature, a mixed traffic situation is likely to emerge where vehicles with different degree of automation will interact with non-automated vehicles (Gouy, 2013). Advanced Driver Assistance Systems (ADAS) such as adaptive cruise control, lane keeping assistance or emergency brake assist have already significantly affected the traffic performance. Soon, more assistance systems will be implemented in new vehicles and will affect the traffic performance.

In recent decades, the growing population has implied higher transportation demand which caused a bottleneck for traffic networks and further city development (Wei, 2013). Studies have proved that automated driving illustrates the potential to decrease traffic congestion by enhancing the traffic capacity, improving the safety margins in car following and reducing THWs (Jamson, 2013).

Despite these encouraging factors, autonomous transportation raises some concerns such as possible loss of situation awareness, overreliance on automation and loss of required driving skills for resuming to manual control. These issues look more critical in case of system failure (Gouy, 2013). Besides, complex traffic situations like merging at ramps, lane closures, overtakings and crossing intersections need further investigation. Bearing in mind that most knowledge related to driving behavior in AV are based on driving simulator studies, real traffic condition needs to be examined (Amditis, 2015).

The aim of this paper is

- to examine the effects of AV on driver’s behavior through a literature survey;
- to investigate the possibility to evaluate the performance measures of a typical automated scenario using microscopic traffic simulation models.
- to investigate how well can a state-of-the-art microscopic traffic simulation model simulate the presence of AV?
- to investigate how do AV affect the traffic performance?

In order to achieve the aims, a broad literature review in the area of driving simulators and psychological studies was conducted. Then, a specific road network were modelled using the microscopic traffic simulation model VISSIM. Automated vehicle’s behavior was modelled based on the findings from the literature survey. Only one degree of automation was considered and in this case, all automated vehicles assumed to be highly automated.

2 Literature Review

Within the last thirty years of study and experiment on vehicle technology, vehicles that are capable of communicating with surrounding vehicles (V2V) and infrastructure (V2I) have been developed. These vehicles can collect useful information about the driving environment in order to assist the driver to fulfil the driving tasks and experience a convenient movement (Gouy, 2013).

Jamson (2013) revealed that drivers using high vehicle automation preferred less lane changing in order to overtake slower moving traffic. In other words, the tendency towards automated-mode disengagement is less, especially in heavy traffic conditions although it may increase the journey time. Evidences show that driving automated vehicle is tedious in a long run, which reduce situation awareness and intensify driver drowsiness exclusively when the road is quiet and the traffic is light. Due to the fact of more driver inclination to involve in secondary tasks, it is worthy to mention that vehicle infotainment systems potentially distract drivers from their supervisory role (Jamson, 2013).

Gouy (2013, 2014) conducted series of driving simulator studies to investigate the effects of short THW on non-equipped vehicle drivers. Output of these studies revealed that the preferred THW of non-equipped vehicle drivers remains constant, while the adopted THW differentiates significantly
according to the applied traffic condition. This headway adaptation was especially observed in traffic conditions with short THW of 0.3 seconds. It’s concluded that presence of equipped vehicles in a platoon with short THW has a notable effect on tactical behavior of non-equipped drivers in terms of mean THW (Gouy, 2014) and leads drivers of CV to drive closer to their preferred limits (Gouy, 2013). In addition, Gouy (2014) observed that numerous participants spent more time under their ‘critical’ THW threshold of 1.0 second. In other words, drivers tend to reduce their THW while driving close to a platoon of vehicles maintaining shorter THWs.

Although a lot of efforts have been devoted to elaborate vehicle automation concept as far as possible, there is still more adjustment needed to present trustful transportation means. Wei (2013) believed that due to limited capability of autonomous vehicles to perceive and cooperate with driving environments in heavy traffic conditions, these vehicles won’t perform as well as human drivers (Wei, 2013). As a supporting statement to that, Jan Becker, director of engineering and automated driving of Bosch, explained that the current sensors are not sufficiently robust to let the driver stay out of the driving loop. Andreas Mai, director of smart connected vehicles at Cisco, added that even Google’s latest autonomous car is only able to drive in pre-mapped area. Nevertheless, it has faced some difficulties while navigating in rainy and snowy weather conditions (TU Automotive, 2015). Due to the obstacles in front of self-driving vehicles, John Capp, GM’s director of electrical controls and active safety technology believed that we still have 20 to 30 years to achieve fully autonomous vehicles (USA Today, 2013).

For these reasons we can say that the self-driving or autonomous vehicle would be more of a futurity outcome of next decade.

2.1 Benefits of Automated Driving

According to different studies in the past, Gouy (2013) collected some valuable statistics and data about the usefulness of ADAS and automated driving. Result of an investigation by Treat et al. (1979) has shown that in 93% of the accidents in a 2,258 road accident samples, human error was a contributory factor, while research by Sabey and Taylor (1980) revealed that 95% of the road accidents are partially and 65% of them wholly due to human errors. Although the mentioned studies are somewhat outdated, more recent studies, such as Gouy (2013), still acknowledge their validity by citing them.

ADAS and automated driving can help to overcome the human errors and thereby improve safety, traffic performance and fuel efficiency. Previous studies have revealed that the proper choice of various ADAS can improve the overall flow of the traffic network (Kesting, 2008). Furthermore, automated systems bring the possibility to keep tight THW in road network without affecting traffic safety (Rotfuchs, 2015).

By presence of AV with V2V and V2I communication, vehicle platooning can be practiced which can practically reduce the gap between vehicles in a platoon. As a result, the capacity of the road network can increase (Ntousakis, 2015). Therefore the number of lanes can be decreased (which ends up to a denser road) and can be replaced by wider sidewalks and bicycle lanes. In other words, we also encourage passengers to use cleaner transport modes. Thus saving more space and smoother traffic flow are the effects of automated driving as well. Moreover, it can be assumed that by growth of automated vehicle’s presence, the probability of shared use of cars transport mode such as carpooling will be strengthen. In other words, AV can provide the opportunity to increase vehicle occupancy, i.e. more passengers in each vehicle rather than more private cars (Fagnant, 2013).

2.2 Challenges and Concerns

As discussed in the previous subsection, automated driving can bring safer transport, higher road capacity, less fuel consumption and smoother traffic flow. In spite of all reassuring technical results, highly AV raise a range of concerns. Each of them can partially disorganize the driving tasks or
potentially endanger the whole movement. Some of the most conceivable automation challenges are listed below:

- **Possible Loss of Situation Awareness**

  Indeed, vehicle automation brings along signs of fatigue. Although in-vehicle tasks potentially distract drivers from their supervisory role, drivers experiencing high level of automation show more tendency to become involved with secondary tasks (Jamson, 2013, Carsten, 2012). Ironically, if the system has low failure rate and high reliability, overreliance on the automation system will reduce the readiness for transition to manual control of the vehicle (Gouy, 2013, Johansson, 2014).

- **Degrading Driving Skills in Absence of Practice**

  Driving tasks include series of consequent cognitive actions which can be counted as an adventitious skill. In absence of practice, driver will lose these skills to control the vehicle manually (Gouy, 2013) which could lead to wrong decisions or longer transition times from automatic to manual driving.

- **Driver’s Poor Monitoring of the Automated Control System**

  Apparently, human beings are not well suited for supervising technical systems (Johansson, 2014). Especially when the vehicle drives well enough, driver gets distracted easily with eyes watching off road or amused by infotainment systems (Carsten, 2012, Merat, 2014).

- **System Failure**

  All of the above mentioned challenges will be more crucial in case of system failure. All software and hardware are human-made and possible to malfunction or crash. Therefore a new system architecture for highly AV is needed. Jan Becker, director of Engineering and automated driving at Bosch, states that today’s vehicles are fail-safe designed, and he believes that the future vehicles should be fail-operational produced so that if one of the components fails to operate, the rest of the vehicle automatic system afford to continue functioning (TU Automotive, 2015).

- **Loss of Connection with the Outside World**

  AV and especially autonomous vehicles operate intensely-dependent on the information provided by communication means. And what if the connection is lost? Information such as positioning for navigation via Global Positioning Systems (GPS) or Assisted GPS (A-GPS), communication to other vehicles (V2V) or infrastructure (V2I) and traffic control centers are some examples of undeniable need of these vehicles for communication. Supposing that the connection is lost by any chance, future vehicles must be self-sufficient from their surroundings and be practicable with their own sensors and internal automated systems (VDI, 2015).

- **Security**

  Nvidia’s perspective is to have a centralized super computer to handle all car’s numerous sensors which apparently creates a more reliable and efficient system. Nvidia CEO pointed out that infotainment systems may be under the exposure of hackers which they can access to vehicle control systems remotely. As a matter of fact, the safety features of the car should be independent of the automated driving, so that if any failure happened in automated driving mode (especially in fully autonomous vehicles), it will not affect the movement task (TU Automotive, 2015).

- **Certification and Legislation**

  In article 8 of Vienna convention on road traffic, it has been stated that: “Every moving vehicle or combination of vehicles shall have a driver” and in article 13: “Every driver of a vehicle shall in all circumstances have his vehicle under control...” (Vienna convention, 1968). Besides, UN/ECE regulation R79, which is based on Vienna convention, permits the automated steering only at lower
speeds (max 10 km/h). Consequently, current legislations are a hurdle for vehicle automation and new amendments are needed.

One of the possibilities of autonomous transportation could be right side overtaking permission on multi-lane highways (Chiang, 2013). Although this may be a more efficient way of road capacity use, but still concerns about unequipped vehicles interacting with equipped vehicles remain questionable and need further experimental research. The author believes that road administration department and the authorities need to consider this issue on the current driving regulations.

3 Method

For fulfilling the research aims, a specific calibrated microscopic traffic simulation model in VISSIM was used to estimate the effect of AV on relevant traffic performance measures. The employed traffic model had been locally calibrated for a real road network in terms of desired speed distribution, desired acceleration and fundamental diagram on macroscopic level. Further calibration on car following model (Wiedemann 99) and lane changing behavior values were performed in the current research work based on a research project by Leyn and Vortisch (2014).

A case study consisting of two scenarios was performed in order to make an investigation of the AV’s effects in the road network. Each link segment (such as autobahn, weaving area, off-ramp, arterial, street, etc.) was defined independently with specific driving behavior of the car following model and lane change behavior for passenger cars and HGVs.

3.1 Traffic Network Specification

The modeled traffic network is a segment of an autobahn which contains remarkable road sections such as weaving area, off-ramp, on-ramp and secondary urban roads all in one model. This autobahn section is 3 kilometers long and has three lanes. The weaving area is 470 meters long with 4 lanes.

The simulations represent a complete day and the vehicle inflow was fed to the model gradually with 15 minutes intervals. For more accuracy, the autobahn link has separate vehicle input of passenger cars and heavy goods vehicles (HGVs). Nevertheless, the vehicle input of north and south bound includes a mix of 98% of passenger cars and 2% of HGVs.

The focus of this study has been especially drawn to consider the performance measures of east-bound autobahn and the weaving segment leading to the off-ramp which are the critical road segments in traffic network. Results from this simulation study are compared with the findings of literature survey to determine the potential positive effects of AV on traffic performance measures, such as density, travel time and average speed. The output of this study will be further used for implementation in VISSIM as a future research work.

3.2 Scenario Description

Two different scenarios were simulated. First, a baseline scenario with only CV was simulated. Although driver’s lack of attention plays a significant role for road accidents (see subsection 2.2), there is no citable data that can be used to model the duration and probability of temporary lack of attention in the microscopic traffic simulation model VISSIM. Therefore, we have assumed that a 0.5s duration with a probability of 1.0% can indicate the real driving style of drivers in the autobahn segment. In order to evaluate the validity of this assumption and its effect on the model results, a sensitivity analysis was conducted, which is presented in section 4.1.

After adjustments on the CV scenario, one AV scenario was developed based on a duplication of the CV scenario. The presence of AV in VISSIM was modelled by adjusting the driver behavior parameters in the car following and lane changing model. All vehicles in the AV scenario were assumed to be highly
automated. Therefore, no temporary lack of attention was assumed for the AV. In order to simulate the presence of the AV, the following parameters were adjusted based on the findings from former research work:

- The maximum area around the car that can be scanned and covered up by the state of the art radar and ultrasonic sensors is 200 meters (Laquai, 2011). Therefore, the parameters ‘Maximum look ahead and look back distance’ were set to 200m.
- Minimum look ahead and look back distance specify the least possible/visible distance in which a driver can recognize and react accordingly, i.e. this distance can be zero in case that the front or rear vehicle drives as close as possible to this vehicle and block the visibility area of it. Since in highly automated vehicles ADAS will take care of this issue, this parameter will be controlled via vehicle’s sensors. To take into account any signal interference and coverage limitation, the parameters ‘Minimum look ahead and look back distance’ were set to 150 m.
- Number of observed vehicles has been separately calculated for each link segment based on the sensor/radar coverage up of 200 m (Laquai, 2011) and the assigned free flow speed. The values varies between 6-8 observed vehicles.
- AV bring the possibility to keep tight THW in road networks without affecting traffic safety (see section 2.1). According to the study conducted by Gouy (2014), the parameter ‘Headway time (CC1)’ was set to 0.3 s.
- In highly AV, drivers won’t override the speed limit in the automated driving mode and the vehicle speed may at a maximum deviate by ±2 km/h from the speed limit. Therefore, upper and lower bound of all desired speed distributions were adjusted to ±2 km/h relative to the speed limit.
- Due to the fact that highly AV will be informed about their route decisions in advance, they will change lanes earlier towards the next connector along the route. Therefore, the option ‘Advanced merging’ was activated.
- Highly AV communicate with each other and announce their movement decision to the surrounding vehicles. As a result in lane changing situations, the trailing vehicle in the target lane will try to change lanes itself to the next lane in order to make appropriate room for the lane changing vehicle. Thus, the option ‘Cooperative lane change’ was activated with ‘Maximum speed difference’ set to 3.0 km/h and ‘Maximum collision time’ set to 10s (Leyn, 2014).
- Overtaking on the same lane for left and right side were activated (Chiang, 2013).
- Vehicle routing decisions were set to the early entrance of the vehicles in the network for the AV. Bearing in mind that drivers in the CV scenario are informed about their upcoming route decision just 1.0 kilometer earlier than the weaving segment.

4 Simulation Results and Discussion

Each scenario was replicated five times and the average result are reported. The simulation resolution was set to 15 time steps per simulation seconds. Output data are presented in three different columns: ‘Total’ which represents the average value over the total 24 hours simulation horizon, ‘A.M.’ which represents the results during the a.m. peak (7:15-8:15) and ‘P.M.’ which indicates the results during the p.m. peak (16:15-17:45).

The simulation results of the CV and AV scenarios are presented in Table 1 and Table 2. The output of the CV scenario shows that the daily average density of the autobahn segment is 8.06 veh/km/lane, while this value reduced to 7.90 veh/km/lane in the AV scenario. It means that average density on the
autobahn in the AV scenario improved by 2.00% in a long run, while the improvement is only 1.65% in
the weaving segment. It should be noted that this slight shift in the daily average density of the weaving
segment ends to a notable change in its LOS from B to A (HCM, 2000). Specifically during the p.m.
peak with the approximately volume of 1650 veh/h/lane, average density has been shifted from 19.74
veh/km/lane in the CV scenario to 18.14 veh/km/lane in the AV scenario which shows 8.09%
 improvement in the road density. The same comparison for the weaving segment shows a 7.85%
 improvement in this crucial area.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Density (veh/km/lane)</th>
<th>Average Travel Time (s)</th>
<th>Average Travel Speed (km/h)</th>
<th>Standard deviation of speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>A.M.</td>
<td>P.M.</td>
<td>Total</td>
</tr>
<tr>
<td>CV</td>
<td>8.06</td>
<td>15.41</td>
<td>19.74</td>
<td>51.06</td>
</tr>
<tr>
<td>AV</td>
<td>7.90</td>
<td>14.80</td>
<td>18.14</td>
<td>50.79</td>
</tr>
<tr>
<td>Changes (%)</td>
<td>2.00</td>
<td>3.96</td>
<td>8.09</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Table 1: Microscopic simulation results of the autobahn segment and percentage changes

The average travel speed on the autobahn segment in the p.m. peak enhanced from 82.42 km/h in
the CV scenario to 89.41 km/h in the AV scenario which shows 8.48% growth. Mentioned parameter in
weaving segment during p.m. peak illustrates 7.86% improvement in the AV scenario. The results of
standard deviation of speed determine that AV drive between the predefined ranges of speed which
show a less dispersion around mean speed, specifically during the a.m. and p.m. peak in both road
segments.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Density (veh/km/lane)</th>
<th>Average Travel Time (s)</th>
<th>Average Travel Speed (km/h)</th>
<th>Standard deviation of speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>A.M.</td>
<td>P.M.</td>
<td>Total</td>
</tr>
<tr>
<td>CV</td>
<td>6.03</td>
<td>11.26</td>
<td>14.68</td>
<td>19.08</td>
</tr>
<tr>
<td>AV</td>
<td>5.93</td>
<td>10.92</td>
<td>13.53</td>
<td>19.17</td>
</tr>
<tr>
<td>Changes (%)</td>
<td>1.65</td>
<td>3.03</td>
<td>7.85</td>
<td>-0.50</td>
</tr>
</tbody>
</table>

Table 2: Microscopic simulation results of the weaving segment and percentage changes

The average travel time on the autobahn segment in the p.m. peak shifted from 53.27 s in the CV
scenario to 48.47 s in the AV scenario. A change of 7.50% is also perceived in the weaving segment
between the CV and AV scenarios in this time period. The results of the average travel time is consistent
with the average speed results. By taking a glance to the linear equation of motion, travel time is a
function of speed and is directly affected by its alteration. 9.00% in autobahn and 7.50% in weaving
segment during the p.m. peak are the reduction of the vehicle travel time in the AV scenario.

4.1 Sensitivity Analysis

In order to evaluate how sensitive the model results are to the assumptions on the parameter values
for ‘Temporary lack of attention’ in the CV scenario, a sensitivity analysis was performed. The
parameter ‘Duration’ was varied between 0 s to 2 s and the ‘Probability’ was varied between 0% to 20%.
The output data of sensitivity analysis is shown in Table 3.
The results indicate a trend toward denser link segment following with reduction of average travel speed and increase of average travel time are seen. Direct observation of the simulation revealed that the 2 s lack of attention creates a queue behind the distracted driver periodically. This of course significantly affects the performance of the road segment. On the other hand, it should be noted that by increasing the temporary lack of attention values, the model is gradually affected and no abrupt change in the output was observed.

Nevertheless, it is useful to perform sensitivity analysis for other parameters such as headway time (CC1), number of observed vehicles and advanced merging as future work.

<table>
<thead>
<tr>
<th>Duration (s) &amp; Probability (%)</th>
<th>Density (veh/km/lane)</th>
<th>Average Travel Speed (km/h)</th>
<th>Average Travel Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>A.M.</td>
<td>P.M.</td>
</tr>
<tr>
<td>0 s &amp; 0%</td>
<td>8.05</td>
<td>15.25</td>
<td>19.70</td>
</tr>
<tr>
<td>2 s &amp; 10%</td>
<td>8.19</td>
<td>15.66</td>
<td>20.66</td>
</tr>
<tr>
<td>2 s &amp; 20%</td>
<td>8.40</td>
<td>15.88</td>
<td>21.70</td>
</tr>
<tr>
<td>(0 s &amp; 0%) vs. (2 s &amp; 20%)</td>
<td>(%)</td>
<td>4.37</td>
<td>4.11</td>
</tr>
</tbody>
</table>

Table 3: Sensitivity analysis on temporary lack of attention and percentage changes

5 Conclusion and Future Work

The findings from literature review revealed that CV, driving close to the platoon of AV with short THW, tend to reduce their THW and spend more time under their critical THW of 1.0 second. Additionally, driving highly AV is tedious in a long run, which reduce situation awareness and can intensify driver drowsiness, exclusively in light traffic.

The conducted simulation study showed that the VISSIM microscopic simulation model to some extent can be modified to simulate the presence of AV within the network. Parameters such as ‘Look ahead/ back distance (maximum and minimum)’, ‘Number of observed vehicles’, ‘Cooperative lane change’, ‘Advanced merging’ and both side overtaking represent the performance of ADAS in AV. Nevertheless, other elements must be implemented in VISSIM to represent the communication characteristic of AV. Additionally, it should be noted that further research are needed to ensure more accurate input data about the driving characteristics of AV from car manufacturers in order to have a correct simulation of AV.

Based on the representation of AV used in this work (see section 3.2), the output of the simulation study showed a positive effect of AV on traffic performance. In details, average density of the investigated autobahn segment in the AV scenario remarkably improved by 8.09% during the p.m. peak. Average travel speed increased both on the autobahn (8.48%) and the weaving segment (7.86%) in the AV scenario. In addition, results of the average travel time was consistent with the average travel speed and showed a 9.00% reduction in the AV scenario during the p.m. peak. These outcomes verified the hypothesis that an improvement of average travel time and average travel speed could be expected in the AV scenario.

Results of the microscopic simulation in this study revealed that the positive effects of AV on roads are especially highlighted when the network was crowded (e.g. during the a.m. or p.m. peak). This can definitely count as a constructive point for the future of road networks with higher demands. Meaningful outputs of this case study, based on the input data from literature review, demonstrated the capability of VISSIM to simulate the presence of AV in great extent. The validity of the output values nonetheless
stays unknown awaiting for more accurate input data about the driving characteristics of AV and real field studies in future. Besides, more simulation studies on urban and rural roads with different traffic condition must be performed.

Simulation of mixed traffic scenario, i.e. presence a share of AV within the network, are necessary in order to evaluate the network traffic performance and examine the interaction between CV and AV. Driving behaviors of CV, such as preferred THW, will be affected facing the presence of AV keeping tighter headway (Gouy, 2014). The results can depict a real situation of road networks in near future.

Furthermore, performance information of AV such as CO₂ emission and fuel consumption have not been publicized so far, but it is possible to be set up in VISSIM nonetheless. Thus, the economic cost savings, fuel cost saving and emission rate can be calculated as a consequence.

Reference


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