SAFER Pre-studies

Final Report

Reference	*CP58*
Project Title	Driver interaction with automated vehicles in real motorway traffic
Coordinator	VCC
Project Manager	Thomas Streubel (thomas.streubel@volvocars.com)
Project Duration	2022-03-30 – 2022-08-30

Contents

Summary

This project aimed to finalize a previous analysis and write the corresponding paper for publication. The publication with the title "Driver interaction with automated vehicles in real traffic" was submitted to the International Conference of Traffic and Transport Psychology. The extended results were presented at the conference in August 2022.

The data was collected within the L3Pilot project. Main research questions were the potential impact of automated driving (AD) on the interaction with other road users. Focus was on change in frequency and interaction during cut-in and rear-end events. Assuming that automated vehicles keep a safe distance and obey the speed limit, their behavior will differ from today's human driven traffic.

The results showed no increase of cut-ins nor rear-end events in AD versus manual driving. There is a difference in the motivation for the cut-in. In AD, there are significantly more mandatory cut-ins indicating that the AD function does not respond to vehicles on ramps trying to enter the highway in the same way humans do (open a gap or change lane). The differences in rear-end events are small and effects were only found in minimal distance and minimal acceleration of the rear vehicle.

Driver interaction with automated vehicles in real motorway traffic

1. Background

The interaction between manual driven vehicles and automated vehicles is so far only investigated in simulator studies or small scale field tests. It remains unknown if there will be significant changes until their introduction in real traffic. Within the EU project L3Pilot, a large scale field test was undertaken to investigate technical and traffic implications upon introducing a fleet of level 3 automated vehicles in real traffic.
Data post processing and evaluation was challenging as the signals can only deliver parts of the picture. For a conclusive perspective, the video data was reviewed and scenarios of relevance needed to be annotated.

2. Project set up

2.3 Purpose

The project enabled a deeper understanding of the interactions of automated vehicles in real world traffic. While the introduction of automation in traffic is expected to be a huge improvement in terms of safety, different interaction effects remain unknown until they are out in the field. A large scale field test as in L3Pilot gives valuable insight in what is awaiting in the future.

2.4 Objectives

The objectives were to finalize the analysis of cut-in and rear-end scenarios and finish the publication. The results were presented at the ICCTP 2022 in Göteborg, Sweden.

2.5 Project period

The project started in March and ended in August 2022.

2.6 Partners

The work was conducted mostly at SAFER for data access. It was a collaboration between Volvo Cars and Chalmers. Both partners have authors on the publication.

3. Method and activities

The data was collected within the L3Pilot project in collaboration with Volvo Cars. To assess automated driving, a baseline versus treatment approach was chosen, i.e. manual driving was compared to automated driving in the same traffic environment.
The test fleet consisted of four prototype vehicles with an Automated Driving Function (ADF). For baseline drives, there were six Volvo XC90s available. All vehicles were

equipped with logging devices to collect in vehicle variables as well as sensor signals about the surrounding traffic. Furthermore, cameras were installed to observe the drivers as well as the rear- and forward traffic.
Testing was conducted during daytime on the urban motorway called "Slingan" forming a ring around the center of Gothenburg, Sweden. This is a 2-3 lane road with central separation and a speed limit of 70 or 80 km/h. It consists of several tunnels and a large bridge on the west side. Due to it's urban surrounding, the motorway has several entrance and exit ramps and contains dense traffic during common rush hours. On the northern part, there is an intersection with a traffic light.

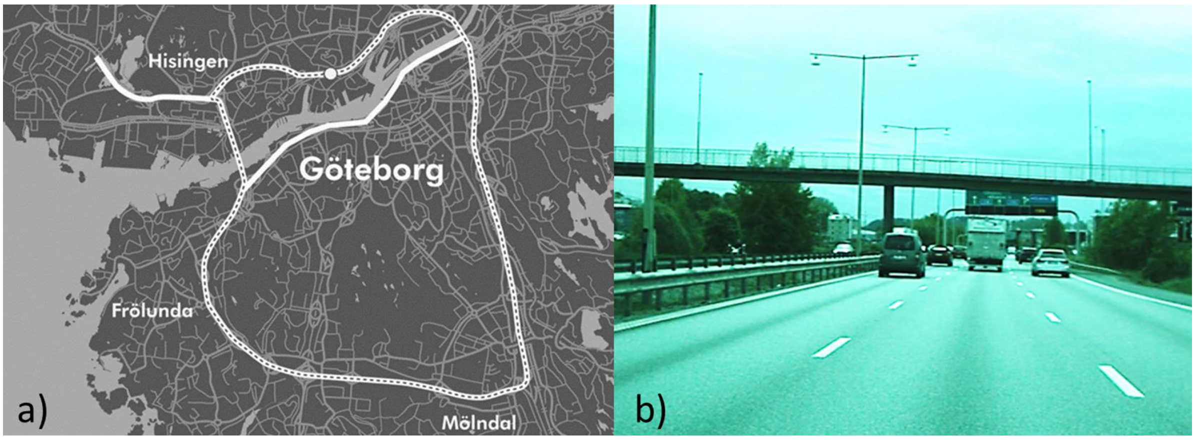


Figure 1 The public roads selected for pilot testing: a) Map of the selected segments on the Gothenburg ring road (dashed lines), b) forward facing camera view from a test vehicle.

For safety reasons, the AD vehicles were driven by eight professional drivers who were instructed to intervene only if necessary to guarantee safe operation. They collected 632 hours or driving data. The vehicles for baseline testing were driven by 149 regular drivers for one hour each.
The cut-in events were identified by following a common procedure in L3Pilot (REF) from the ego vehicle (EV) perspective. The cut-in event was defined as 'a cut-in vehicle (CV) changes (or initiates a lane change) to the lane of the EV such that the resulting scenario is following or approaching a lead vehicle (LV)', see Figure. The cut-in events were identified on motorways.
A manual review of the forward video together with other available data was performed to verify that there was an actual cut-in event. The actual cut-in events were annotated with the following categories: Cut-in motivation including Cut-in after overtaking the ego vehicle; Overtake a slower moving vehicle; Entry ramp - Entering from another road (before the cut-in, the vehicle was on another roadway); Exit ramp - Exiting the road (after the cut-in the vehicle will exit the roadway); Avoiding a work zone or other obstacle (static); Approaching an intersection in situations where the vehicle must change lanes to be in the correct lane to turn; Ending lane (the original lane on which the cut-in vehicle was traveling is ending); Other (other motivation that is not included in the above categories). Side: Cut-in from left lane; Cut-in from right lane. Number of lane changes: Single (the cut-in vehicle stays on the lane in front of the ego vehicle); Multiple (the cut-in vehicle is changing lane twice).

4. Results and Deliverables

We compared manual driving (baseline) with automated driving behavior (treatment) in two scenarios – cut-ins and rear-end approaches.

There was no change in frequency of cut-in events between baseline and treatment (see Table 1). On average, about 7 cut-ins were recorded in both driving modes.

Table 1 Frequency of cut-ins in terms of distance and time with operational design domain (ODD)

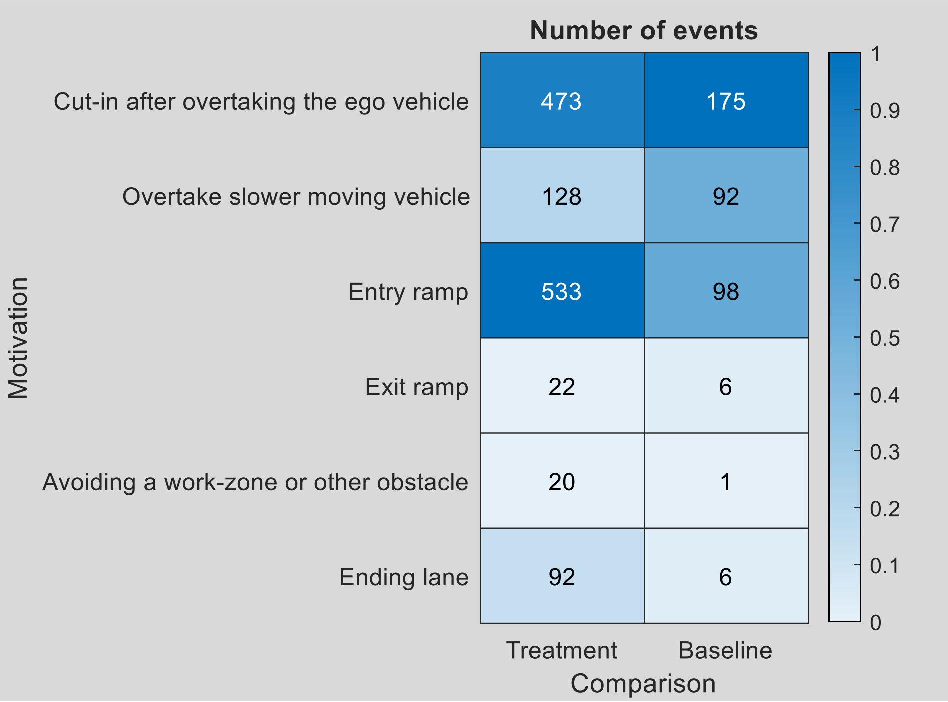
	Baseline	Treatment	Total
Number of events	378	1268	1646
Number of events per hour	4.6	4.3	4.4
Number of events per 100 km	6.9	6.9	6.9

The minimal time headway showed a significant effect (*p<.05, Z=2.37, effect size: 0.13)*. It indicates the minimal temporal distance between the vehicle under test and the vehicle that cuts in. This is slightly closer in baseline compared to treatment and corresponds to the expectation that the automated vehicle drives slightly slower (significant difference – *p<.001, Z=-10.66*).

In treatment there are about 2.3 greater odds of a vehicle not braking in a cut-in event than in baseline. So, the automated vehicle response significantly more often with braking compared to manual drivers.

The distribution of cut-in events based on motivation is shown in Table 2. The cut-in motivation showed 2.6 greater odds to be mandatory in treatment. Main motivation there is cut-in due to entering from an entry ramp. In baseline, the main motivation is to avoid following a slower lead vehicle. Investigations into the side from where the cut-in occurs, the cut-in characteristic between single lane change and multiple lane change (cut-through) and the presence of a lead vehicle showed no differences between baseline and treatment.

Table 2 Cut-in events based on motivation



In rear end events, there was no significant difference in the frequency of approaches from behind. The comparison of several indicators showed that there is an effect in minimal distance ($p<.001$, $Z=-14.79$) and in the minimal acceleration of the rear vehicle ($p<.001$, $Z=-14.75$). The minimal during a rear-end event is slightly smaller in treatment versus baseline. The minimal acceleration during a rear-end event is slightly larger in treatment compared to baseline. Both average relative velocity and minimal time headway of the rear vehicle towards the ego vehicle show no significant differences.

5. Conclusions, Lessons Learnt and Next Steps

For cut-in events, there was no increase in frequency between manual and automated driving. Investigating deeper into cut-in motivation, we found an increase in mandatory cut-ins especially at ramps. This indicates that the system under investigation had some limitations. As human drivers tend to indicate their intention of letting another vehicle enter the highway by creating a gap or changing lanes, the automated driving system shows no reaction to vehicles in other lanes. This could have some implications on the external perception of AD behavior.

In rear-end events, there were no effects found in relative velocity and time headway of subsequent vehicles between manual and automated driving. Small effects were found on the distance kept and the minimum acceleration of the subsequent vehicle. These small effects could relate to the rather dense traffic on the city highway around

Gothenburg. The automated vehicles were going with the traffic flow and seemed to not have stand out in their behavior. It also indicates that human drivers were able to identify the AD as a slower vehicle and reacted appropriately.

6. Dissemination and Publications

The results were presented at the International Conference on Traffic and Transport Psychology (ICTTP) 2022. An extended abstract is published in the proceedings. As a potential invite to a special issue of Transportation Research Part F is still outstanding, we consider submitting the full paper at another peer reviewed journal.

7. Acknowledgement

We want to thank our colleagues Alessio Violin and Pierluigi Olleja for their support and help in annotating the data and preparing the evaluation.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 723051. The sole responsibility of this publication lies with the author(s). The author(s) would like to thank all partners within L3Pilot for their cooperation and valuable contribution. Special thanks to Alessio Violin who supported this work with annotations, data extraction, and valuable discussions.