Paper ID EU-TP0855

Infrastructure-based cooperative, connected and automated driving in a transition phase

Meng Lu[1*], Robbin Blokpoel[1], Julian Schindler[2]

1. Dynniq, The Netherlands

2. DLR, Germany

*Emails: {meng dot lu; robbin dot blokpoel} at dynniq dot com; julian dot schindler at dlr dot de

Abstract

In the domain of ITS (Intelligent Transport Systems), automated road transport has received high attention from industry, authorities and the general public. The perspective is that infrastructure-based cooperative, connected and automated driving is an option for enhancing traffic safety, traffic efficiency and energy efficiency, and for increasing comfort. The project TransAID (Transition Areas for Infrastructure-Assisted Driving) targets the transition phases between different levels of automation, and, more specifically, investigates the areas (called "Transition Areas") where this will happen (Transition Areas). The project will develop and demonstrate traffic management procedures and protocols to enable smooth coexistence of automated, cooperative, connected (equipped) vehicles and conventional (non-equipped) vehicles, especially in Transition Areas, in an urban environment. The paper will present the TransAID concept, research method and an initial architecture for addressing this specific issue.

Keywords:

automated driving, transition, cooperative, traffic management, traffic control

Introduction

Automated road transport has received high attention from industry (such as vehicle manufacturers, suppliers, ICT infrastructure service providers and telecom), authorities and the general public [Mohr, et al., 2016]. There are different levels of automated driving (see e.g. SAE J3016 [2014] and BASt [Gasser, et al., 2012]). Road transport automation will reach its limitations, especially during the phase of market introduction. There will be situations on the road, which the system will not be able to handle properly. These can be e.g. missing lane markings, a mismatch between the LDM (local dynamic map) in the vehicle and the detected surrounding, situations which can only be solved by breaking regulations (e.g. an obstacle which needs to be overtaken while overtaking is prohibited) or by driver intervention (e.g. four cars arriving at a 4-way-stop intersection at the same time), situations beyond system boundaries (e.g. sharp bend), and other types of complex situations in general. Whenever an automated vehicle is confronted with such a situation, it should – if this is possible within time - "ask" someone how to proceed or come to a safe stop automatically. In previous research, this "someone" has always been the driver of the vehicle who gave control to the system for a limited amount of time, e.g. while driving on a highway, e.g. HAVEit (2008-2010) [Flemisch, 2009]. In cases in which a situation that the system cannot handle was detected in advance, a transition of control to the driver was triggered. Dependent on the available time until the system is going to fail, the driver has to be brought back into the loop. During this take-over procedure, the driver needs to understand the situation and the reason for the oncoming system failure. In the best case, the driver also receives some hints how the situation may be solved manually in the best way. The control is ideally only transferred to the driver when acknowledged by a proper action, e.g. pressing a button or directly taking over control by steering, accelerating and/or braking. In case the driver is not able to take over control within the given time frame, an automatic "Minimum Risk Manoeuvre" is executed, leading to a safe stop of the vehicle, e.g. on the emergency lane of the highway (if present) or simply on the lane the vehicle is currently driving on.

The investigated automation level of the used vehicle automation in HAVEit was similar to SAE level 3, with tendencies to SAE level 4. The concept of the Minimum Risk Manoeuvre has been taken into account, e.g. in 2015 in the vehicle regulations developed for the Automatically Commanded Steering Function (ACSF) of the Working Party on Brakes and Running Gear (GRRF) of the United Nations Economic Commission for Europe (UNECE). In 2017, first SAE level 3 systems reach the series production. Although some prototypes of SAE level 4 and 5 vehicles are announced, basic questions remain:

1) What is the best action to be taken in case of an oncoming situation, which the vehicle system cannot handle?
2) What options are available when vehicle control cannot be easily transferred to a human driver, e.g. when the driver is asleep, or when control devices are not within reach of the driver, or when no control devices are available in the vehicle?

Most likely, a vehicle will have no other option than to perform a Minimum Risk Manoeuvre and come to a well-controlled and safe stop somewhere on the road. This may be an issue of only limited impact when only few automated vehicles are on the road, but impact will substantially increase when the number of automated vehicles in traffic will rise as expected for the near future. Furthermore, it is reasonable to expect the transitions of control and the resulting Minimum Risk Manoeuvres will accumulate at specific locations, e.g. in the vicinity of missing lane markings, at locations for which the information of the digital map in inadequate, or at complex intersections. This will lead to areas on the road where the impact of such transitions will be relatively high.

In parallel to the developments in the area of automated driving, various message sets for communication from vehicles to infrastructure or between vehicles have been introduced offering a wide field of new possibilities, also in the field of transitions.

The paper targets one of the challenges of traffic management, i.e. automated vehicles in *Transition Areas*. The perspective is that infrastructure-based cooperative, connected and automated driving is an option for enhancing traffic safety, traffic efficiency and energy efficiency, and for reducing fuel consumption.

Definition of "transition areas" and the research concept

In the transition areas, many highly automated vehicles are changing their level of automation, for various reasons (see Figure 1). The EU-funded project TransAID (Transition Areas for Infrastructure-Assisted Driving) [TransAID Consortium, 2017] will investigate the impact of different levels of vehicle automation on existing traffic systems, for different penetration rates per vehicle automation type, in accordance with expected near-future market shares. Several new concepts for hierarchical traffic management systems (TMS) are being developed that offer certain advantages in such circumstances:

1) Vehicles may ask the TMS how a transition of control can be avoided. The TMS may provide additional assistance for the risky areas.
2) Vehicles may ask the TMS about the best available options in case a Minimum Risk Manoeuvre has to be performed. The TMS may take into account the overall traffic situation to identify optimal solutions for both the requesting automated vehicle and for the other vehicles (automated and not automated) on the road.
3) The TMS may prevent larger impacts by proactively taking into account possible oncoming problems. The TMS may e.g. separate vehicles with risky types of automation from the other vehicles by temporarily setting up dedicated lanes, or may reserve parking spaces which can be used as destination in Minimum Risk Manoeuvres.

TransAID will identify promising solutions and will estimate the level of improvement based on simulation studies. The most promising solutions will be implemented as real-world prototype to demonstrate the feasibility of the approach. The results will be used to formulate a guideline for stakeholders concerning useful measures for assuring smooth coexistence of automated/connected and conventional vehicles during the phase of the market introduction of vehicle automation systems.

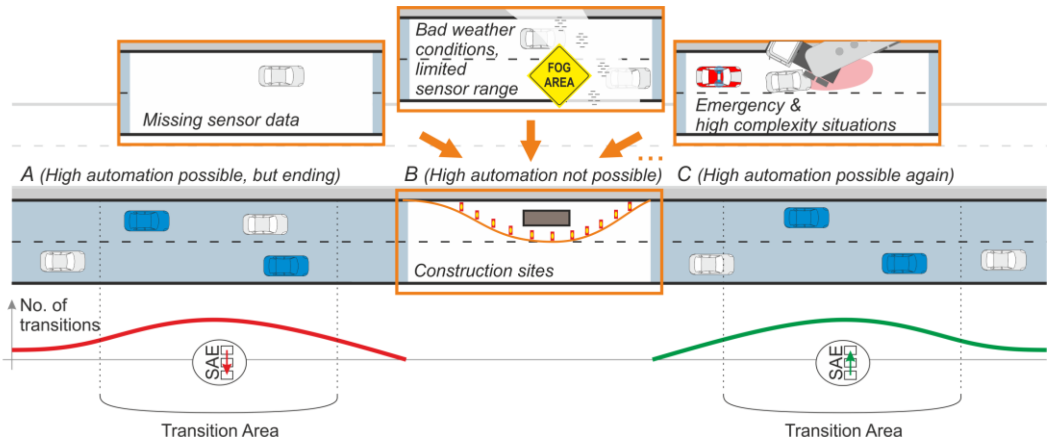
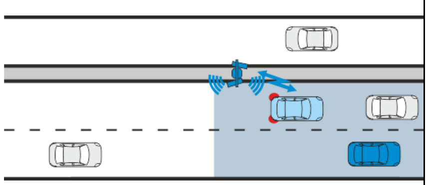
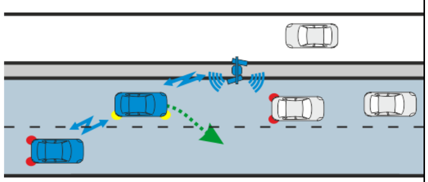
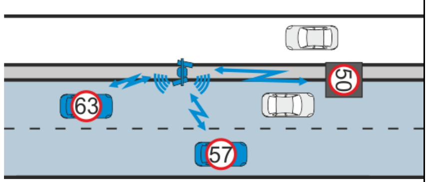


Figure 1 - Illustration of Transition Areas (marked in blue) [TransAID Consortium, 2017]

Use cases

In TransAID some specific use cases will be investigated for optimising traffic flow, efficiency and safety in transition areas with regard to mixtures of conventional and cooperative, connected and automated vehicles (see Figure 2).

	**Transition to high levels of automation** The optimal behaviour and timing when switching to higher SAE levels is calculated by the infrastructure depending on the overall situation. This includes speed changes and probable joining of platoons.
	**Lane changes** Due to high traffic loads on certain lanes the traffic management might recommend certain vehicles to change lane or even to take an alternative route. V2X-communication or variable traffic signs are used to inform the driver and/or the vehicle automation system.
	**Speed changes** The infrastructure may optimise the traffic flow by changing the recommended speed for groups of vehicles. Connected/cooperative vehicles may get individual recommendations for a maximised impact.

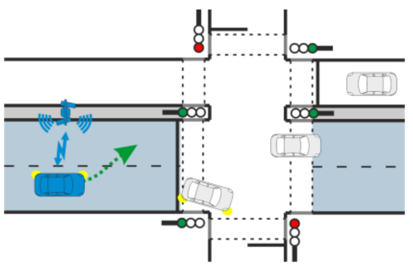
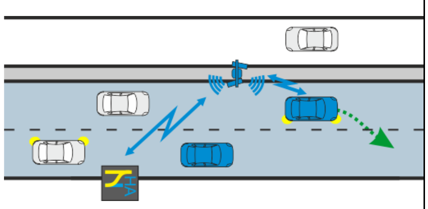
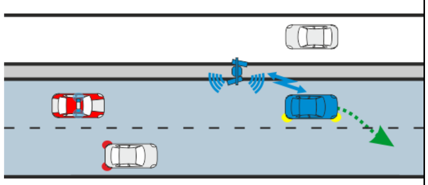
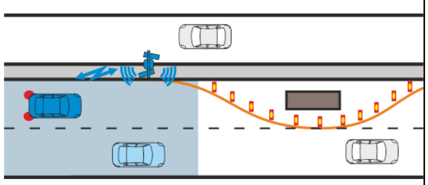
	**Intersection handling** Intersections require special handling, as e.g. vehicles may be guided to other lanes due to turning manoeuvers. Signalised intersections are also used to influence the traffic flow when this is beneficial for downstream transition areas.
	**Traffic separation** In certain circumstances it may be beneficial to separate vehicles of specific automation levels into dedicated lanes, e.g. highly automated driving on the right, all others on the left. For certain roads this may also be introduced on a permanent basis.
	**Emergency situations** Arrival of emergency vehicles has a large impact on traffic situations. All other vehicles ought to give way, this is not different for automated vehicles. Traffic management can help both the traffic and the emergency vehicles to proceed safely, by deciding on optimal behaviour, especially in or near transition areas.
	**Transition to lower levels of automation** The infrastructure can provide support in the process of automated vehicles transferring back control to the driver, especially when reasons for the need of transition can be given (e.g. near construction sites). Also, the infrastructure can provide guidelines for the optimal behaviour and timing. In case of a failed transition, optimal types of Minimum Risk Manoeuvres can be suggested by the infrastructure.

Figure 2 - TransAID use cases [TransAID Consortium, 2017]

Method

To develop and demonstrate infrastructure-assisted traffic management procedures, protocols and guidelines for smooth coexistence between automated, connected and conventional vehicles especially in transition areas, an overall approach is proposed (see Figure 3). The TransAID method includes two iterations. Iteration 1 deals with scenarios of low complexity (marked in blue); iteration 2 refines the results and adapts to scenarios of high complexity (marked in green). The dotted arrows represent the close coupling of the linked tasks, in rapid response to changed requirements.

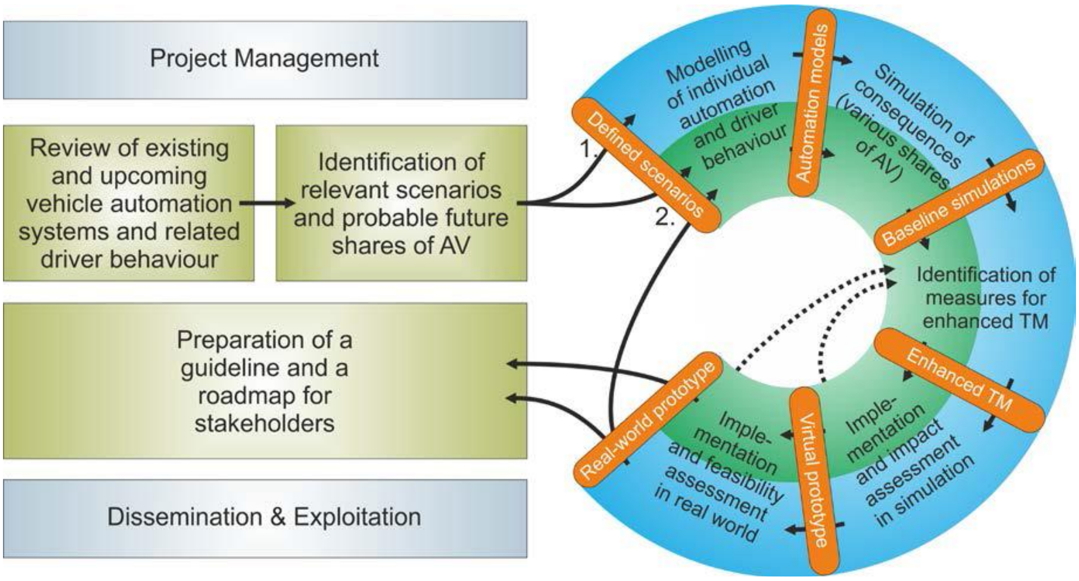


Figure 3 - Illustration of TransAID method [TransAID Consortium, 2017]

Simulation architecture

It is important to keep the simulation as accurate as possible, but also interoperable with real-world systems for ease of use. Compared with previous research [Robbin, et al., 2017], an added complexity in TransAID is that vehicles have to shift between different driver models: automated, transition and regular manual driving. Calibration of these models will be part of the work. The planning and control of the motion of automated vehicles will be modelled in detail. Various transition cases are distinguished, for example expected and unexpected transitions, varying by the state of the vehicle, and the situation it is in. In addition, for the regular driving mode, the interaction with automated vehicles also requires a specific model.

Simulation speed is another important requirement for impact assessment. Fast simulation allows for more extensive evaluation of scenarios, and in general traffic engineers expect at least 10x real time speed for a network with 5 complex intersections on a contemporary desktop PC. For this reason, it will not be feasible to simulate each vehicle with several separate processes as in a real vehicle. This would result in over a number of individual processes communicating with each other and running in parallel. In addition, V2X messages for communication are ASN.1 UPER encoded. This means values can start and end halfway a byte. Encoding and decoding are therefore quite computationally intensive.

Figure 4 presents the simulation architecture, based on selecting required components from the hardware architecture and adding new ones specifically required for simulation.

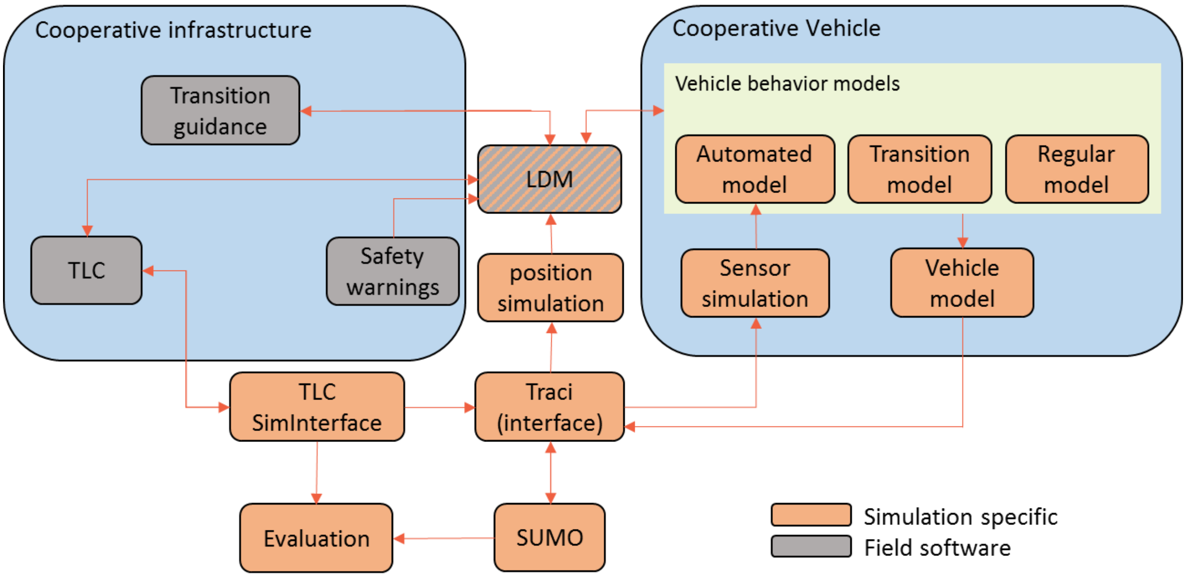


Figure 4 - High level simulation architecture

For interoperability analysis, the components that are identical to the real-world implementation are shown in grey, while simulation-specific components are shown in orange and one adapted element in grey/orange striped. Important for the striped element is that the interfaces to the grey elements should stay the same. Both the vehicle and the intersection have a shared LDM now. This is because the communication units have been removed, as these would require large amounts of computational time for encoding and decoding messages. Systems connected to this LDM will not notice a difference; the same data is still present in the same format.

The simulation architecture contains several new components shared between the vehicle and the intersection. The most important one is SUMO, an open source traffic simulation software package [Krajzewicz, et al., 2012]. In principle any other simulation package could be used as well. The interface towards SUMO is called Traci and can be used to retrieve at any time data of relevant parameters of the simulation, e.g. vehicle speed, position, route, detector status, vehicle ID on detector. The interface can also be used to change parameters during the simulation, e.g. signal head status, vehicle speed, vehicle route. Positioning simulation replaces the actual positioning sensor of the vehicle. As Traci offers a precise position, it is not realistic to use this for simulations. The results of this simulated position are used to replace the regular CAM messages received by the LDM. A separate TLC interface for simulation is moved out of the cooperative intersection to emphasize that for simulation several additional functionalities had to be added. Signal heads, infrastructure sensors and traditional priority have been integrated with this interface as the actual hardware is not present and it has to connect to Traci for this. Evaluation is a new component required for impact assessment, TLC and SUMO logging is used for this. Lastly, the platoon green wave component from the TMC connects directly with the TLC using the same interface as in the real world (just like the LDM and queue estimation components).

The cooperative vehicle can select from several different vehicle behaviour models. The main, as already introduced, are automated, transition phase and regular manual driving. Within these models, several sub-models can exist. For instance for platooning, automated vehicles can be divided into three modes, catch-up to join a platoon, following mode and leader mode. For transition phase driving, these are expected and unexpected handovers; and for manual driving, the environment is a key influential factor.

Apart from this the vehicle model has been simplified. Positioning and other sensors have to be replaced by sensor simulation, which then acquires its data from Traci. The simulation software mostly simulates one-dimensional movement and lateral lane positions. Lane changes are simulated using discrete sub-lanes. The decision whether to change lanes is evaluated based on positions of vehicles in the other lane. This means the automation functionality also has to focus on the longitudinal dimension, while modelling the lateral speed of a lane change is needed to determine the sub-lane correctly. As the automation functionality has no actuators to interact with, a vehicle model is required to translate the outputs of real-world automation into speed, lane and route information for Traci. These vehicle models should include variation between individual vehicles to simulate a realistic spread in, for example, acceleration capabilities.

Looking at the cooperative infrastructure functionality, the grey boxes indicate that the components are the same as on the street. Simulation-specific functionality is only included in the TLC SimInterface. Important requirements are that this interface should be in charge of the timing, and that the controller should be able to run with variable clock speed, to allow the simulation to run as fast as the computations permit. Since the project still has to elaborate and more precisely define the use cases, some extra infrastructure systems may be added that may need sensor simulation (like for the automated vehicles).

Conclusion and further research

TransAID (Transition Areas for Infrastructure-Assisted Driving) aims to develop infrastructure-assisted traffic management procedures, guidelines and protocols for a smooth coexistence between automated, connected and conventional vehicles during the market introduction phase of ICT technologies for automated driving. It focuses on transition areas in urban and rural environments (e.g. arterial roads with signalised intersections). The paper targets one of the major challenges of traffic management with respect to automation, i.e. automated vehicles in *transition areas*. An initial TransAID simulation architecture is proposed, which will be further developed during the project.

Further research will target:

1) Evaluation and modelling of current automation prototypes and related driver behaviour.
2) Assessment of the impact of transition areas on traffic safety and efficiency. Establish requirements for enhanced traffic management procedures.
3) Development of infrastructure-assisted management procedures and protocols to control connected, automated and conventional vehicles at Transition Areas.
4) Definition of V2X message sets and communication protocols for the cooperation between connected/automated vehicles and the road infrastructure.
5) Development of procedures to enhance the detection of conventional vehicles and obstacles on the road and to inform and/or influence drivers of conventional vehicles.
6) Integration, testing and evaluation of the TransAID infrastructure-assisted traffic management protocols and procedures in a simulation environment. Validation and demonstration of these protocols and procedures by means of real-world prototypes at test sites.
7) Provision of a guideline to stakeholders regarding the requirements for traffic infrastructure and traffic management in for transition areas considering mixed traffic.

Acknowledgements

The paper presents some preliminary results of the EU-funded project TransAID (Transition Areas for Infrastructure-Assisted Driving) under the Horizon2020 Framework Programme, Grant Agreement No. 723390. The initial architecture will be further developed during the project. The authors especially thank the TransAID consortium partners for their kind support, especially those who have substantially contributed to writing Part B of the DoW (Description of the Work). The introduction of TransAID is based on the DoW.

References

1. Mohr, D., Kaas, H.-W., Gao, P., Wee, D., Möller, T. (2016). Automotive revolution – perspective towards 2030: How the convergence of disruptive technology-driven trends could transform the auto industry. McKinsey & Company, New York.
2. SAE (2014). Taxonomy and definitions for terms related to on-road motor vehicle automated driving systems. Standard J3016, issued 2014-01-16. Society of Automotive Engineers
3. Gasser, T.M., Arzt, C., Ayoubi, M., Bartels, A., Bürkle, L., Eier, J., et al. (2012). Legal consequences of an increase in vehicle automation, BASt reports F83, Bergisch Gladbach.
4. Flemisch, F., Griesche, S., Schieben, A., Heesen, M., Kaussner, A., Niemann, J. (2009). Deliverable D33.3: Validation of preliminary design by simulation.

   Retrieved in June 2017 from: www.haveit-eu.org/displayITM1.asp?ITMID=24&LANG=EN

5. TransAID Consortium (2017). TransAID (Transition Areas for Infrastructure-Assisted Driving) Description of Work, TransAID Consortium, Brussels. (restricted)

6. Blokpoel, R., Lu, M., Přibyl, O., Dariani, R. (2017). Interoperable architecture between simulation and pilots for cooperative and automated driving. Paper ID SP0849. In Proceedings: The 12th European Congress on Intelligent Transport Systems. Strasbourg.

7. Krajzewicz, D., Erdmann, J., Behrisch, M., Bieker, L. (2012). Recent development and applications of SUMO - Simulation of Urban Mobility, *International Journal On Advances in Systems and Measurements*, Issue 5, pp.128-138.