27th ITS World Congress, Hamburg, Germany, 11-15 October 2021

Paper ID #

Stakeholder Considerations of Automated Driving in Infrastructure-Assisted Transition Areas

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Abstract

When cooperative automated vehicles (CAVs) emerge on urban roads, there will be situations where all levels of automation can be granted, and others where highly automated driving will not be allowed or feasible. Complex environments, missing sensor inputs or temporary road configurations are examples of such situations and at these locations CAVs are expected to degrade their level of automation. Such geographic areas are referred to as 'Transition Areas' and presumably are associated with negative impacts on traffic safety and efficiency, especially with mixed traffic. The H2020 TransAID project developed and demonstrated traffic management procedures and protocols to prevent or mitigate the negative effects of Transition of Control. These were evaluated in simulations (including V2X communications) and real-world implementations. This paper describes the most important results followed by findings from stakeholder workshops and dissemination events. The findings reflect the stakeholders' views on the TransAID results and automated driving in general.

Keywords:

AUTOMATED DRIVING, TRANSITION OF CONTROL, INFRASTRUCTURE

Introduction

As the introduction of automated vehicles becomes feasible, even in urban areas, it will be necessary to investigate their impacts on traffic safety and efficiency. This is particularly true during the early stages of market introduction, where automated vehicles of all SAE levels (SAE International, 2016), connected vehicles (able to communicate via V2X) and conventional vehicles will share the same roads. There will be areas and situations on the road where high levels of automation can be granted, and others where it is not allowed or not possible due to, for example, missing sensor inputs, the complexity of the situation, etc. At those locations, referred to as 'Transition Areas' (TAs), automated vehicles may initiate a change in automation level, thereby transition the control of the vehicle to the driver or perform a minimum risk manoeuvre (MRM).

It can be expected that especially at Transition Areas the simultaneous presence of automated, connected, and conventional vehicles will be challenging and possibly negatively affect safety and traffic efficiency. To cope with these challenges, TransAID developed and demonstrated traffic management procedures and protocols to prevent or mitigate the negative effects of Transition of Control (ToC) (i.e., the handover) at TAs. A hierarchical approach is followed where control actions are implemented at different layers including centralised traffic management, infrastructure, and vehicles.

First, simulations were performed to find optimal infrastructure-assisted management solutions to control connected, automated, and conventional vehicles at Transition Areas, considering traffic safety and efficiency metrics. Then, communication protocols for the cooperation between connected/automated vehicles and the road infrastructure were developed. Measures to detect and inform conventional vehicles were also addressed. Most solutions were then implemented as real world prototypes and/or demonstrated under real urban conditions.

The next section describes the most important results of TransAID[1] followed by findings from stakeholder workshops and dissemination events. A summary is given of the stakeholders' views[2] on the TransAID results and automated driving in general.

TransAID results

Simulation and vehicle models

As a basis for the simulation studies several vehicle models were implemented successfully to create the right behaviour for lane changing (including cooperative versions), car following (including (Cooperative) Adaptive Cruise Control) and ToC/MRM algorithms. These models were created using a solid theoretical background, however, the availability of real-world data for input and calibration was very limited.

From the baseline simulation runs we found that ToCs do not significantly disrupt traffic flow performance unless Cooperative Automated Vehicles (CAVs) establish increased car-following headways during the ToC preparation phase. Disruptions escalate in case of CACC driving, increased share of CAVs in the fleet mix, and the occurrence of multiple ToCs within a narrow temporal window and spatial domain. Furthermore, in the case that a ToC is unsuccessful or not possible, unmanaged MRMs (taking place in lane and not being guided towards safe spots) can induce significant traffic disruption as well. On the other hand, simulation results indicated that cooperative lane changes minimize the frequency of ToC/MRM and their consequent adverse impacts on traffic flow operations. The benefits of cooperative lane changing are amplified with increasing share of CAVs and especially upstream of lane drop locations.

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[1] Full results can be found in TransAID deliverable 8.2 which is available on the TransAID website: www.transaid.eu

[2] A full report on the stakeholder workshops and dissemination events cam be found in TransAID deliverable 8.1 which is available on the TransAID website: www.transaid.eu

TransAID use cases and results

Building upon the vehicle models, simulations and the defined use cases, specific traffic measures were developed to mitigate the effects of ToC events in transition areas. The traffic measures were implemented to study their effectiveness. Specifically, for each of the selected use cases the effects of the TransAID measures are evaluated regarding emissions, safety, and efficiency.

There is a trade-off between traffic safety versus traffic efficiency (as measured via throughput and travel times). It is often inherently difficult or even impossible to optimise both in the same context. Hence, typically a policy choice needs to be made, as to which of the two will have to be prioritised. Otherwise, results either improved or remained similar for all use cases and KPIs, except for use case 3.1 (see Table 1).

All use cases have in common that a reduction of MRMs is possible by providing infrastructure advice. Such advice, and the availability of safe spots (i.e., areas where a vehicle can safely stop), clearly reduces the number of stopped vehicles blocking the road.

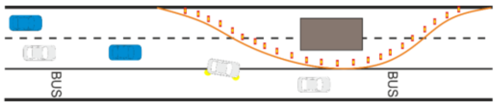
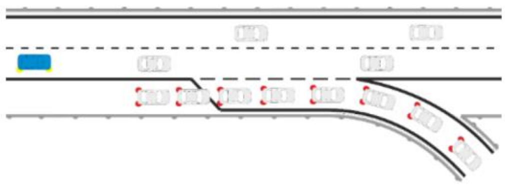
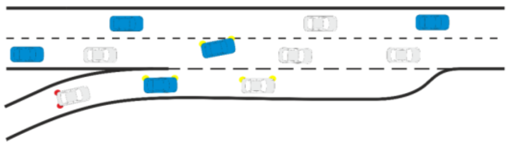
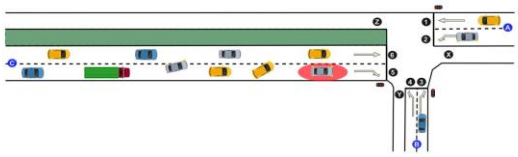
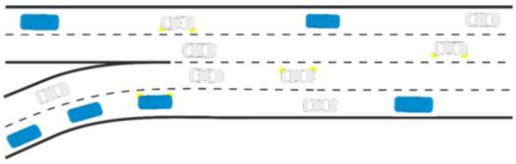
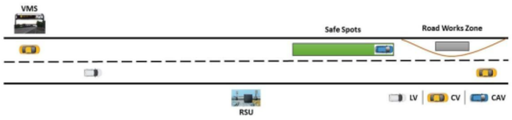
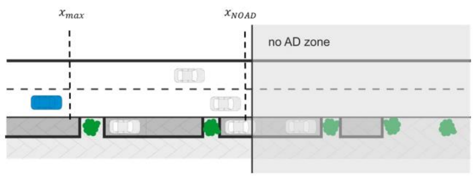
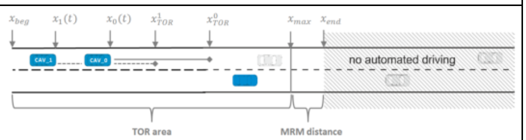
There is also a heavy dependence of the results on the mixture of vehicle types, in addition to the observation that less efficient traffic management performance is obtained for a higher Level Of Service (LOS; HCM 2010). The latter is in part logical, as for higher LOS there is more prominent congestion and the physical limits of the infrastructure remain a hard obstacle. By itself this is not a problem for TransAID, as the focus of the traffic management schemes is to prevent/postpone traffic breakdowns before they occur.

V2X Communications

While implementing and testing the traffic measures TransAID also identified or created the needed message sets and protocols to implement the measures using V2X communications. To that end, no new message sets were needed, but (minor) extensions to CAM, DENM, MCM and MAPEM were necessary. Especially MCM from the Manoeuvre Coordination Service (MCS) is key to multiple types of use case. Therefore, it is necessary to define a MCS that is valid for all types of scenarios. Aligned with the work of ETSI and by actively contributing, TransAID has proposed a MCS where the infrastructure takes an active role to facilitate the manoeuvres of vehicles and to increase the overall traffic flow and safety.

The traffic management measures designed in TransAID also require that CAVs and road infrastructure units have an accurate perception of the environment. In addition to the MCS, TransAID has contributed to the evaluation and evolution of ETSI's Collective Perception Service (CPS) for cooperative perception. We have demonstrated that cooperative perception can improve CAVs perception capabilities when the trade-off between the perception capabilities and communications performance is balanced. Furthermore, the reliability of V2X communications has been addressed in TransAID using different and complementary techniques: compression, congestion control and acknowledgements.

Table 1 – Overview of the TransAID use cases and results[3].

Use case	Efficiency	Safety	Emissions	Comments	Schematic overview of the use case
1.1	~	+	~	Safety critical events reduced by 45% to 70%, depending on LOS and traffic mix.	
1.3	+	+	+	For higher traffic intensities and a larger share of AVs, the effects diminish but are still positive. When the queue grows too large and vehicles stop on the main road, safety and efficiency are affected strongly.	
2.1 (1st)	~	+	~	Large safety improvement and marginal improvements for both efficiency and emissions.	
2.1 (2nd)	-	+	-	This use-case identified a clear trade-off between safety and throughput, depending on merging settings.	
2.3	+	+	+	As long as traffic remains stable all effects are positive, performance becomes worse on all KPIs when breakdown occurs, but still less severe compared to the baseline.	
3.1	~	-	~	Safety is severely affected due to increased number of cut-in lane-changes. Increased CAV share and cooperative manoeuvring seems promising to improve the results.	
4.2 (1st)	~ (U) ~ (M)	+ (U) + (M)	+ (U) + (M)	Large safety improvements. Safety effects are smaller for a higher % of AVs / LOS.	
4.2 (2nd)	~ (U) + (M)	+ (U) + (M)	+ (U) + (M)	Increased share of AVs and higher LOS dimish the safety effects, as expected.	
4.1 + 5.1	+	+	+	Large improvements on all measures. Higher traffic intensities result in relatively larger improvements.	
5.1	+	+	+	Large improvements on all aspects due to the smoothening of disturbances.	

[3] ~ no change, + improvement, - decrease, U - Urban, M - Motorway, 1st / 2nd - project iteration.

Communication with non-equipped vehicles

Besides the V2X communication, the communication to unequipped vehicles was of importance and consisted of two parts. On the one hand, infrastructure needs to inform unequipped vehicles about issues on the road. On the other, automated vehicles themselves should provide information about their actual state to their surroundings, to avoid negative impacts.

With regards to the infrastructure information, it needs to be mentioned that visual information on signs, variable or static, will never be as precise as V2X communication could be, especially when looking to individual advices. Nevertheless, infrastructure can provide valuable information also to unequipped vehicles by signage, e.g., in terms of speed limits, distance (gap) advice or dynamic lane assignments. It will be required to create additional road signs dealing with automated vehicles, at least showing that, e.g., an area is prohibited for automated vehicles or an area where only automated vehicles are allowed.

Regarding signals from automated vehicles, TransAID's solution of having LED light strips at the back of AVs will be beneficial in any case, but the exact content of such lights needs to be defined by performing more detailed analyses of such components. This goes to all external and dynamic HMI components of automated vehicles. In this light, it will be crucial to have an intuitive way of understanding the automation related additional information. One key question in this area is if driving with enabled automation should be indicated by an additional external light, and if so, where should this light be and what colour?

Integrating V2X into the simulations

Combining the work on the traffic measures and communications, the iTETRIS framework (Rondinone et al., 2013) was used to evaluate the selected use cases while deploying the traffic measures using V2X. The goal was to see if the V2X communications impacted the effectiveness of the measures in any way.

After adding V2X, the simulation results for the project's first and second iteration use cases showed very similar results to the previous evaluation. All traffic measures were found robust enough to show the same results with real V2X as with ideal V2X (i.e., no missed messages, perfect signal, etc.), even considering increased traffic demand and thus more V2X enabled vehicles. There were some minor differences between the realistic V2X and ideal V2X implementations, but those could be traced back to easily fixed technical aspects.

Real world feasibility testing

As a final step in our use case assessment, the feasibility of measures and communications introduced were implemented in real-world demonstrators. The real-world implementation was done by performing three different feasibility assessments. Two of them have been performed on test tracks in Germany, and one on public roads in The Netherlands.

On the test tracks, several detailed tests of all scenarios have been performed, revealing that all traffic management measures could be successfully integrated and applied to automated vehicles in all use cases and scenarios. This includes the successful setup of the RSI and the automated vehicles. It must be mentioned, though, that the implementation was done in a prototypic way.

The development of related series products would require much more testing under real world conditions, which will be challenging at the current time since no highly automated vehicles are present on the roads. Nevertheless, it is very important to start the investigations at present times. As standardisation of messages is happening already now, and it is very important to include the role of the infrastructure at this stage.

Intermediary services as a governing framework for Transition Areas

In addition to the design and technical implementation of traffic measures in simulation and the real world, TransAID gained some insights on issues of a less technical nature. For example, it was determined a close collaboration between OEMs and (N)RAs would be beneficial in the identification and managing of TAs. To facilitate such a collaboration TransAID proposes a traffic management framework in the form of an intermediary service provider, acting as a trusted (and possibly mandated) third party. The framework allows TransAID to be scaled up and generalised. We approached this from both a technical and a business-oriented perspective. For TransAID to become part of a complete traffic management system, we focused on the technical side on how to detect transition areas, select (and possibly combine) services, and then detect when they are most appropriately timed for deployment. To this end, detection can be done via the infrastructure (e.g., road sensors or even digital communication infrastructure), via the OEMs, or by comparing an infrastructure's newly defined ISAD levels[4] (Infrastructure Support levels for Automated Driving) (Manganiaris, 2019; Amditis, 2019) to the Operational Design Domain (ODD)[5] of the vehicle.

Considering the mentioned technical challenges (detecting TAs, selecting services, and timing their deployment), the intermediary service bridges all these parties in such a way that the detection of TAs is performed in a centralised way, and OEMs and (national) road authorities have a single point of contact for providing and receiving information about TAs.

Another point where OEMs and (national) authorities could collaborate, is the legislation related to automated driving since an important gap in current modelling and legalisation is how (C)AVs would/should react when (given) advice and/or actions conflict with traffic laws. With the real-time coordinated instructions of a Traffic Management Centre, (C)AVs should drive adequately during their journeys. However, it is necessary to concern to what extent such instructions should/can be made, especially when considering legal issues. In addition, legal aspects like the definition of special

[4] ISAD levels define road infrastructure characteristics and capabilities in support of automated vehicles.

[5] The ODD is a description of the specific operating conditions in which the automated driving system is designed to properly operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/night time, etc.), prevailing traffic law and regulations, and other domain constraints.

signage for automated vehicles and their handling also need to be considered, as those aspects will take time. This also means signage at the roadside, including VMS content, and signage from automated vehicles to surrounding traffic.

Collaboration is also required regarding the definition and standardisation of V2X messages and protocols. The mechanisms proposed in TransAID to improve the reliability of V2X messages can be key in the near future. In general, V2X communications solutions require to be incorporated into standards to be effectively deployed. That is the case for, for example, collective perception solutions, message generation rules for manoeuvre coordination, V2X message compression or broadcast acknowledgement mechanisms. In TransAID we have been intensively working to promote and disseminate all the proposed solutions in top-tier journals and international conferences, as well as in organisations like ETSI and C2C-CC.

Findings from stakeholder workshops

The section above shows a broad range of aspects studied by TransAID in the very dynamic and rapidly evolving field of automated driving. During the project we gathered responses from stakeholder during several workshops, twinning activities, and dissemination events. An overview is given below. Observing the reports of all events, several recurring open issues, answers, and insights can be identified. This section provides an overview of those. Note, however, that many relate to the introduction of automated driving in general. TransAID focusses on a very specific problem (managing mixed traffic in transition areas) and we found that little is known about that problem, which confirms the need and timeliness of TransAID.

Main stakeholder workshops

- TransAID-MAVEN-CoExist Stakeholder workshop, 10 October 2017, Brussels
- TransAID-INFRAMIX stakeholder workshop, 9 October 2019, Graz
- TransAID final event, stakeholder workshop, 2 July 2020, online

International liaison activities

- TransAID-U.S. CAMP expert meeting, 25 July 2019, Detroit
- TransAID + ITS Japan / UtmobI expert meeting, 7-8 April 2020, online

Additional stakeholder consultation opportunities

- TransAID session and survey, 8 June 2019, IEEE-IV, Paris
- EU EIP workshop on ODD, 1 October 2019, Turin
- International workshop on ODD, 22 October 2019, Singapore
- Joint dissemination of H2020, CEDR projects and other initiatives related to CAVs and Infrastructure, 3 March 2020, Brussels

Identifying aspects of Transition Areas

The first stakeholder workshop was held at the beginning of the project and assisted by diverse representatives mostly coming from transport authorities or related R&D. The focus was on identifying relevant aspects to be considered for creation of use cases and scenarios at transition areas such as: the cause of disengagements, the transition of control process, expected levels of automated driving, relevant actors, etc. The short conclusion of that effort was that stakeholders and experts are currently not able to provide answers with sufficient details. We did get better answers on the separate aspects, but those vary a lot depending on who you ask. This can be explained by the fact that automated driving is still very much in development, implementations can be very different depending on the considered scenarios (e.g., passenger cars on motorways vs. urban areas, shuttles or 'pods' with no or limited controls, open road or closed off environments, level of automation, etc.), and even for the same scenario distinct implementers may have alternative approaches.

Infrastructure planning for automated driving

Those differences and the uncertainties that come with them are reflected in how road authorities responded to our inquiries. City plans and policies in terms of automated vehicles will to some extent depend on the type of service that is offered by automation (e.g., private automated cars or automated shuttles). Road authorities are uncertain if they should focus on supporting private automated cars through digital infrastructure and/or should focus on complementing public transport with automated shuttles. Most road authorities have a vision of a greener future with less cars in the cities which is supported by current policies (e.g., reducing household/parking ratio, introducing environmental zones, stimulating car sharing and MaaS solutions). However, they are searching for the right steps to reach that future. Specifically, they are searching for information on how vehicle automation can support their transport and societal goals: when will automated driving be available and what will be its capabilities? Multiple events concluded with the fact that regions and cities (and politicians in general) need such information to be able to effectively steer their vision and proactively plan for the future.

Vehicle and infrastructure communications

Though much is still uncertain, there is recurring consensus regarding the need for connectivity to support automated driving and above to extend the ODD and enable cooperation between vehicles and infrastructure which leads to higher safety, efficiency, and comfort. Most experts foresee a hybrid solution with both ITS-G5 and cellular connectivity capabilities. Digitalisation of infrastructure by enabling digital messages (computing) from existing roadside equipment, increasing, and improving road sensors and adding communication capabilities is seen as a 'no regret' step. To take the most advantage of TransAID services, it would require big efforts to digitalise road infra and dynamic (traffic management) schemes. Due to the effort, the services might not be feasible in the short term in urban scenarios. Therefore, it makes sense to start on motorways and then consider applicability to urban roads. Note: TransAID primarily focusses on urban scenarios.

Sharing data

To some extent there is also consensus for the need of sharing data on vehicle capabilities on the one hand and infrastructure (support) capabilities on the other. During the TransAID project, the concept of

ODD was encountered with increasing frequency. Transport Authorities expressed high interest in getting insights into the ODD restrictions of the OEMs and to define criteria for ODDs. The aim is to be in the position of allowing vehicles of different automation capabilities to use specific roads and to be able to control the use or number of automated vehicles in certain areas.

On the other hand, OEMs indicated that a definition of an ODD is very complex to achieve and can depend on a lot of parameters, especially those influencing the vehicle's sensing side. Several such parameters may be defined, including sensor capabilities but also environmental aspects like direction of light, glare, reflection of materials, fog conditions, etc. Therefore, it was deemed to be impossible to have a common definition which would be valid for all vehicles and independent of their sensor setup. It was agreed that focusing on resulting driving capabilities instead of sensor capabilities would be helpful.

In short, within the field of automated driving there is an ongoing search for a framework through which the ODD can be defined. Note that such developments have recently started, e.g., the definition of ODD taxonomies in ISO 34503 or BSI PAS 1883, or the definition of open formats like OpenODD. In addition, if the ODD concept becomes successful it is not only important during the introduction of automated vehicles. It was also recognised that, for the foreseeable future, automated vehicles will always have limitations, despite expected advancements in the field. Therefore, the ODD remains important, also in the more distant future, to determine where the limits of automated driving are and to match the ODD to the infrastructure capabilities (see next paragraph).

In parallel to TransAID, INFRAMIX has introduced the Infrastructure Support Levels for Automated Driving (ISAD) concept (Manganiaris, 2019; Amditis, 2019). The ISAD concept is recognised as an important tool in the cooperation between different ITS stakeholders (primarily road authorities and OEMs). However, just like the ODD concept, ISAD is still under development and, for example, the aspect of HD maps is currently underexposed. It can be assumed that ISAD levels can be one of the parameters considered for ODD definitions. Consequently, by matching ISAD levels to the ODDs, one could, theoretically, identify mismatches which point to transition areas.

The need of sharing data between road authorities and OEMs for a correct and usable characterization of ODD and ISAD concepts was primarily supported by road authorities and researchers. Contrary, OEMs were identified to be more hesitant to share such information because of competition, possible liability issues, and because they (rightfully) foresee big challenges to define the ODD.

Intermediary services as a governing framework for Transition Areas

Because of the sensitivity of the information being shared, at least from the OEM perspective, TransAID had introduced the intermediary service concept. This service could act as a trusted (third) party to collect OEM information and publish aggregated and anonymised data which is needed for road authorities (i.e., city planning, traffic measures, etc.) and/or researchers. This concept (using standardised open definitions / reports) was generally supported, but somewhat hesitantly because of doubts whether it will work in practice and whether it would be accepted by OEMs. Nevertheless, the same service would also facilitate the consolidation of ODD and ISAD knowledge and could act as a single point of access (or a few of them) for both road authorities and OEMs. That could facilitate the cooperation between them (see TransAID D4.3 for more information).

Traffic regulations and liability

When talking about matching ODD to ISAD the topic of liability almost always comes up. For example, imagine a road being classified as able to reliably provide all the information that a given OEM would need to let his automated cars drive safely at SAE level 4 under a specific ODD. When some infrastructure component breaks down and consequently there is an accident, who is responsible? The driver, vehicle manufacturer, road operator or roadside equipment manufacturer? This is not an easy question and the need of new governing/regulatory framework is recognised with no exception. It is also recognised that cross-country differences further complicate such frameworks because of differences in the legal landscape. Something that was also observed when TransAID visited the US for a twinning event with the U.S. CAMP. Financial consequences because of liability (through lawsuits) can be quite substantial, which is one of the reasons U.S. OEMs are very hesitant when considering V2X infrastructure support for automated driving.

On the other hand, during events in Europe and Japan the infrastructure support (and hence communications) is welcomed by most stakeholders. Additionally, it was often acknowledged that there is the need to adapt traffic rules for automation, for example, to differentiate speed/relevance areas for different categories of vehicles. In addition, infrastructure must be authorized by road authorities to provide advices to vehicles (that possibly break traffic rules) in a fast and dynamic way or be mandated for recurrent situations. This was an important finding and points again to the need of new regulation.

Feedback on TransAID solutions

Stakeholders were also asked specifically what they thought of the five TransAID services which were created and studied. In general, the services are positively received, except for traffic separation (i.e., service 3: separating automated vehicles from non-automated vehicles by assigning different lanes - see use case 3.1 in Table 1). Our own studies confirm that the needed space upstream of a transition area, the needed ITS-G5 coverage and degree of coordination needed, make it hard to utilise the potential of that service. During multiple events, service 2 “provide speed, headway and/or lane advice” was pointed out as the most promising service (see use cases 2.1 and 2.3 in Table 1).

Though traffic separation as a mitigating measure was dismissed, it was indicated dedicated lanes for automated vehicles could be considered as an incentive for automated driving to reach long term goals of safety/efficiency. However, due to possible reduced capacity (blocking a lane for remaining traffic), it is best to use dynamic assignment which considers the traffic composition. At the beginning and end of dedicated lanes there is a likelihood for a transition area which could need some form of support measures as introduced by TransAID. In addition to dedicated lanes, a large group foresees areas where automated driving should not be allowed. This directly confirms another possible reason for future transition areas.

In addition to the TransAID services, remote operation is an emerging possible solution at least for management of level 4 automated public transport (e.g., autonomous shuttles or pods) in edge cases and transition areas, when the vehicles operate without a steward in the vehicle. It would be interesting to investigates its effectiveness with similar evaluations means as those utilized by TransAID.

Simulation validation

Feedback was not only sought on the usefulness of the services, but also the implementation of them through our simulations. For a correct validation of services, it is important that the vehicle models (i.e., the behaviour of (non-)automated vehicles) are accurate. Regarding lane change modelling, it was recognized that lane change behaviour of automated vehicles is expected to be more conservative (in terms of safe gaps) compared to manually driven vehicles. However, this implies increased heterogeneity in mixed traffic conditions (legacy – automated – connected and automated vehicles). To avoid this effect, it was suggested that automated vehicles could be developed to adopt more human-like approaches in terms of lane changing, but this would be a big challenge.

With respect to modelling/simulating transition of control procedures, it was confirmed that drivers should be allowed to take-over vehicle control during such and minimum risk manoeuvres. Also, it was confirmed that in such situations, vehicles should always be guided to a safety harbour (e.g., side-street location) to prevent safety-critical situations on the mainline lanes (e.g., rear-end collisions due to stop in lane).

Conclusion

In conclusion, from an innovation standpoint these are exciting times for aspects regarding automated driving and its relationship with road infrastructure and traffic management. As we have experienced, the uncertainties will not disappear soon, or new uncertainties will arise. Nevertheless, what can be observed from the sequence of stakeholder consultation events is that there is steady progression in the collective understanding of the relation between vehicle automation and infrastructure and the possible implications to the stakeholders involved. By now it seems that there is a common interest, even by vehicle manufacturers, to develop a comprehensive standard and/or taxonomy for classifying operational design domains of automated vehicle systems and infrastructure support levels of automated driving. Yet, these efforts are still at an early stage.

Acknowledgments

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723390. The consortium consists of: Deutsches Zentrum für Luft- und Raumfahrt (DLR), Dynniq UK, Hyundai Motor Europe Technical Center, MAP Traffic Management, Transport & Mobility Leuven, University Miguel Hernandez de Elche and Centre for Research and Technology Hellas.

References

1. Amditis, A. et al. (2019), *Road Infrastructure taxonomy for connected and automated driving*. In: Cooperative Intelligent Transport Systems, Towards high-level automated driving, IET, Chapter 14. p. 309-325.
2. HCM 2010: *Highway Capacity Manual*. Washington, D.C. :Transportation Research Board, 2010.
3. Manganiaris, S. et al. (2019), *D5.4 Infrastructure Classification Scheme*, INFRAMIX project deliverable, https://www.inframix.eu/wp-content/uploads/D5.4-Infrastructure-Classification-Scheme.pdf
4. Rondinone M. et al. (2013), *iTETRIS: A modular simulation platform for the large scale evaluation of cooperative ITS applications*, Simulation Modelling Practice and Theory, vol. 34, pp. 99–125, May 2013, doi: 10.1016/j.simpat.2013.01.007.
5. SAE International. (2016). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles* (No. J3016_201609) (p. 30).