TRAFFIC MANAGEMENT OF AUTOMATED VEHICLES IN TRANSITION AREAS

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INTRODUCTION

As automated vehicles (AVs) emerge on public roads, it is vital to investigate their impacts on safety, traffic efficiency and the environment. This becomes particularly essential during the early stages of AVs market introduction, when AVs of different SAE levels, connected vehicles (able to communicate via V2X) and conventional vehicles will share the same roads with varying penetration rates. During this mixed traffic period, there will be areas on the roads where high automation cannot be granted due to missing sensor inputs, highly complex situations, human factors, etc. Thus, many AVs will be changing their level of automation while moving between these areas. We refer to these areas as "Transition Areas" (TAs). Without proper traffic management, system-initiated take-over requests, which in turn can trigger transitions of control (ToCs), or even minimum-risk manoeuvres (MRMs) if drivers fail to resume vehicle control, will be frequently encountered in TAs. In this respect, the TransAID Horizon 2020 project ('Transition Areas for Infrastructure-Assisted Driving') develops and demonstrates traffic management procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, with the goal of avoiding ToCs and MRMs, or at least accommodating them.

METHODS

To identify situations relevant to the TransAID project, TransAID looked into state-of-the-art literature, held a workshop with road authority stakeholders, consulted advisory board members and interviewed experts. The findings were combined to identify the aspects of TAs and ToCs in general. Eventually, it was identified that many of them could significantly affect automated vehicle behaviour and possible trigger conditions. Considering the uncertainties regarding these aspects and triggering conditions (much also depends on future developments), it was clear that a generic framework was required to approach the study of TAs. Thus, three generic measures were proposed: a) prevent ToC/MRM, b) manage or support ToC/MRM, and c) distribute (in time and space) ToC/MRM, that were used for the development of five services (Table 1) to manage traffic upstream, along, and downstream of TAs (TransAID D2.1, 2018).

No.	TransAID Services
1	Prevent ToC/MRM by providing vehicle path information.
2	Prevent ToC/MRM by providing speed, headway and/or lane advice.
3	Prevent ToC/MRM by traffic separation.
4	Manage MRM by guidance to safe spot.
5	Distribute ToC/MRM by scheduling ToCs.

Table 1 List of the TransAID services

A use case was designed for each of these services including corresponding general descriptions, timelines, road networks, vehicle modelling requirements, traffic demand levels, and traffic compositions (TransAID D2.2, 2018). Baseline simulations were run and compared against traffic management simulations. Impact assessment was conducted with respect to three factors: a) impacts on traffic efficiency (network-wide and local impacts), b) safety critical events (Time-to-collision (TTC) < 3 s), and finally c) environmental impacts (CO_2 emissions).

RESULTS

A complete overview of the results can be found in (TransAID D4.2, 2019). In the first service, path information was provided to AVs to circumvent road works via a bus lane. Simulation results indicated that overall traffic efficiency and CO_2 emissions remained unchanged, while traffic safety was improved significantly. Safety critical events were reduced ranging from 45% to 70%, depending on the level of service (LOS) (HCM, 2010) and traffic composition (percentage of AVs). The reduction was larger in case of less traffic and more AVs.

The second service was applied to a motorway merge area where AVs are given speed advice to merge onto the motorway. The service slightly increased average network speed and slightly decreased CO_2 emissions, especially in case of higher demand (LOS C). The impact on safety was more pronounced with a reduction of critical events around 75%.

The third service was applied to a merging situation where two two-lane motorways merge into one four-lane motorway. The idea is to harmonise traffic by assigning the outer lanes to AVs, thereby reducing close interactions between non-automated vehicles and AVs in the merging area. Only in case of higher shares of AVs (> 25% level 2, > 25% level 3) in combination with LOS B or C, improvements were observed in throughput at the cost of slightly lower average network speeds and a decrease in safety. In short, rearranging traffic to dedicated lanes shows largely similar performance to "uncontrolled merging" (i.e. no measures). However, we hypothesise that separating traffic can outperform uncontrolled merging when cooperative manoeuvring is applied.

For Service 4 both an urban and motorway scenario were studied with similar network layouts. On a two-lane road we created safe spots upstream of a road works zone on the left lane for AVs to stop in case they reach the limit of their operational design domain (ODD) (Czarnecki, 2018). In this case the open right lane remains unblocked. As expected, traffic, safety and environmental benefits are realised. Only in case of congestion, when traffic is already moving slowly, the improvement diminishes.

Finally, a 'no automated driving' (no-AD) zone was simulated along the downstream part of a two-lane motorway for the 5th service. The zone can represent different situations (e.g. road works, geofence, weather, accident) that prevent AVs from staying in automated driving mode. It is assumed that AVs increase their headway before handing over control to the driver. When this happens in a concentrated fashion just before the no-AD zone, traffic flow is impacted. We therefore distribute these handovers in time and space upstream of the zone. It was found that this service greatly smoothens out the disturbances caused by the handovers and improves traffic efficiency.

DISCUSSION AND CONCLUSION

Simulation analysis showed that most of the services improve safety, traffic flow and reduce CO_2 emissions. In general, the idea of providing information to AVs (Service 1 & 2), be it a path around an obstacle (e.g. road works), or speed and/or lane advice to prevent a ToC, mitigates the negative impacts of downward ToCs. In addition, when prevention is not feasible, distributing ToCs in time and space (Service 5) showed to be a very effective measure. As failsafe measure, Service 4, also seems promising.

The results of Service 3 (traffic separation) were mixed and highlighted some issues that also exist in the other scenarios. AVs need time and space to implement the requested manoeuvres and without coordination the advised manoeuvres might impact traffic in a negative way thereby negating the expected positive effect of the request. Another observation is, that the advices cannot always be followed by all vehicles. This is either due to local traffic conditions, or in practice because of communication issues. Thus, it is meaningful to combine the services and implement a hierarchical approach as proposed by the TransAID project. Hence, for example, some AVs can perform distributed ToCs while others are provided with information to keep their automation. In the case of incidental failure, the automated vehicle can also be guided to a safe spot.

The aforementioned results pertain to specific scenarios and are based on several assumptions regarding AV capabilities. These assumptions are mainly based on literature and expert interviews, but do not necessarily rely on evidence-based facts. In the second half of the project, we will advance the services and apply them to different scenarios to evaluate their effectiveness and assess to what extent they can become generic.

Having services of a generic nature means they can be applied to a wide range of scenarios regardless of the specific attributes of the transition area. Since currently little is known about which situations exactly result in TAs and those situations also can change over time due to new vehicle types, software upgrades and/or changes in infrastructure, it is useful to continuously monitor the network for TAs (TransAID D4.1, 2018).

To effectively and systematically manage TAs on a large scale and for multiple AV fleets and multiple road authorities, we propose a trusted third party (and where possible mandated) intermediary service. This will then act as the single-point-of-contact for road authorities and traffic participants (or indirectly, via their OEMs). Based on status and disengagement information from AV fleet managers and traffic management plans from road authorities, this intermediary service acts as a delegated traffic manager who digitally implements the TransAID infrastructure support measures. With support of the right tools, an operator continuously monitors in real-time traffic operations and vehicle disengagement activity (based on triggers and scenarios), then identifies TAs, and finally selects the appropriate measures. An advantage of this service is that measures taken by AV-fleet managers and road authorities can be coordinated and harmonised across multiple AV fleets and geographical areas (managed by different road authorities). Moreover, smaller and/or rural road authorities, which may not have backend centres or not a suitable operational overview of traffic conditions on the road, can benefit from an intermediary service that can perform this task for them. With the added high-level management of TAs in addition to the development of measures on a local level, we foresee that TransAID measures can be more effective. The concept of the intermediary service approach adopted within TransAID's traffic management scheme is depicted in Figure 1.

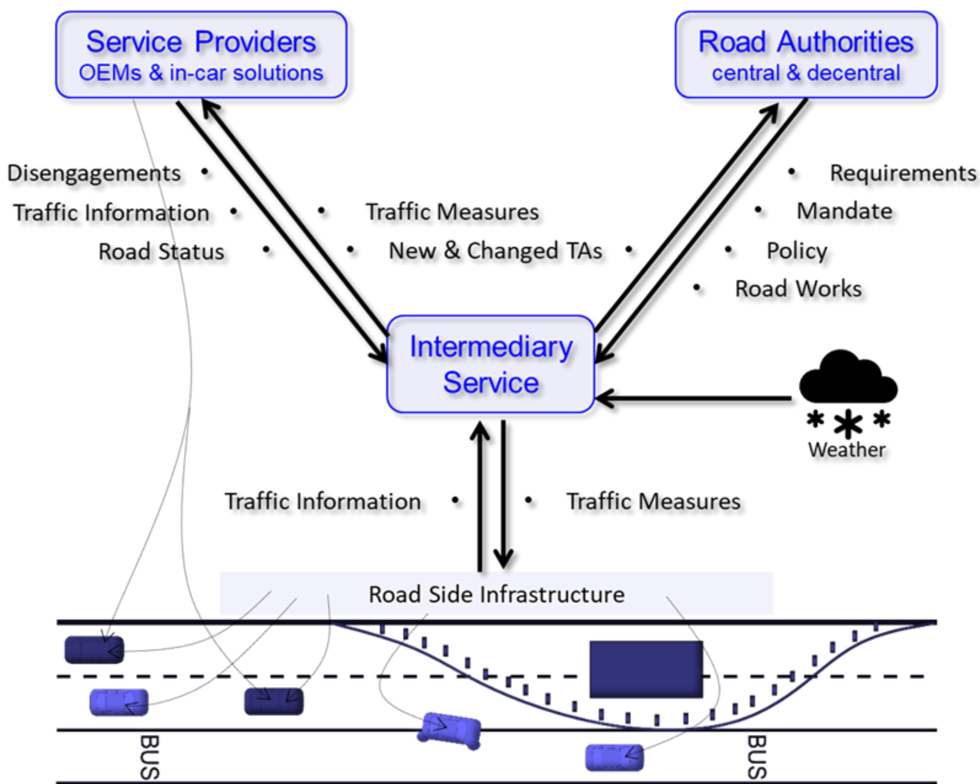

Figure 1 Schematic overview of TransAID's intermediary service approach

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