Traffic Management for Connected and Automated Vehicles on Urban Corridors - Distributing Take-Over Requests and Assigning Safe Spots

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SHORT SUMMARY

In light of the increasing trend towards vehicle connectivity and automation, there will be areas and situations on the roads where high automation can be granted, and others where it is not allowed or not possible. These are termed ‘Transition Areas’. Without proper traffic management (TM), such areas may lead to vehicles issuing take-over requests (TORs), which in turn can trigger transitions of control (ToCs), or even minimum-risk manoeuvres (MRMs) where a vehicle can come to a full stop in a safe spot. In this respect, the TransAID Horizon 2020 project develops and demonstrates TM procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, with the goal of avoiding ToCs and MRMs, or at least postponing/accommodating them. This paper investigates how TM can successfully assist connected and automated vehicles (CAVs) when they are approaching ‘no automated driving’ zones (No-AD zone). Our simulation results indicate that a combined approach for distributing TORs and assigning safe spots significantly improves traffic efficiency and safety for such mixed autonomy situations in urban areas.

Keywords: Connected and Automated Vehicles (CAVs), Traffic Management (TM), V2X communication, Transition of Control (ToC), Minimum Risk Manoeuver (MRM)

1. INTRODUCTION

Control transitions are expected to comprise a significant source of traffic disruption prior to a fully cooperative, connected, and automated road traffic era. Semi-automated vehicles can explicitly function without human intervention within confined so-called Operational Design Domains (ODDs) beyond which control has to be reverted back to the driver (Czarnecki, 2018). Systems failures, infrastructure quality, complex vehicle interactions, weather conditions, human and other factors can induce control transitions (Favarò, et al., 2017), (Lu, et al., 2016). The latter can escalate to MRMs when drivers fail to resume vehicle control especially when they are engaged in tasks other than the primary driving ones. Thus, infrastructure-assisted traffic management based on V2X communication can play a vital role in mitigating the adverse effects of control transitions. Our work introduces measures that prevent collective occurrence (in time and space) of control transitions (Maerivoet, et al., 2019b) and guide vehicles in MRM mode towards safe harbours. These measures are disseminated employing the Maneuver Coordination Message (MCM) which allows the infrastructure to send individualised advices to specific vehicles (Correa, et al., 2019).
The proposed TM measures are examined with the use of the microscopic traffic simulator SUMO (Lopez, et al., 2018). An existing cooperative adaptive cruise model (CACC) was used to mimic the longitudinal motion of CAVs (Milanés & Shladover, 2014, 2016), (Porfyri, et al., 2018). The

default SUMO lane change model was parameterised based on real world lane change data to reflect realistic lateral CAV motion (Mintsis, et al., 2019). A novel transition of control (ToC) model was developed to emulate driver-vehicle unit (DVU) interactions during control transitions and vehicle motion during MRMs (Lücken, et al., 2019), (Mintsis, et al., 2019).

2. TRAFFIC MANAGEMENT

In the following, we combine two approaches developed as TM services in context of the project TransAID. The first service for '*Distributing Take-Over Requests'* (Lücken, et al., 2019), (Maerivoet, et al., 2019a) aims to prevent CAVs from performing ToCs at a specific position simultaneously. Therefore a scheduling algorithm, based on the current vehicle density within a defined road section, distributes all pending TORs for approaching CAVs to preserve a smooth traffic flow and avoid disruptions from collective ToCs. The second service for '*Assigning Safe Spots'* was added on top of the first service in a later project phase to address urban use cases when some of these planned ToCs fail and CAVs could be offered assistance by a TM to target possible safe spots, here presented as parking areas alongside a road section, when performing an MRM.

For the TM service to assign safe spots, we state that for each point in time t, each approaching CAV k in automated mode, and each reachable safe spot i, there exists a probability $P_t(k,i)$ that, if k is assigned to use safe spot i (in case of an MRM), this safe spot will be occupied at arrival. Given this probability $P_t(k,i)$ for safe spot occupancy and our objective to prolong driving in automated mode as long as possible, we establish a score $S_i = \alpha \cdot \Delta_i - P_t(k,i)$, for each pair $[k,i]$. We assume $P_t(k,i)$ to be a product of an overall parking probability and a factor to represent the number of approaching vehicles. Δ_i describes the distance between the safe spot i and the CAV k driven in automated mode. The parameter α serves to normalise Δ_i relative to the probability $P_t(k,i)$, e.g. α being the inverse range of a road-side unit (RSU) which would cover the observed approach area. With this scoring system in place, the following actions will be taken by the TM application to assign a suitable safe spot.

I. For each CAV k approaching a generic No-AD zone, we determine a score S_i related to the parking accessibility of each safe spot i. Simultaneously, the RSU informs all approaching vehicles about the No-AD zone via V2X communication.
II. Based on a map with scores for each available pair $[k,i]$, the safe spot with the maximal S_i will be reserved to the respective CAV tentatively.
III. It is examined if at the current driving speed the designated safe spot is in reach when performing a ToC with a maximum ToC lead time t_{lead} during an MRM.
IV. If a safe spot is in range and the designated position for the scheduled ToC by the TOR distribution service is exceeded, t_{lead} is adjusted so that the CAV can target its safe spot position accordingly within the dynamics of the MRM.
V. The RSU sends an MCM with a TOR advice and assignment safe spot advice to the respective CAV. The CAV either successfully performs its ToC or starts its MRM targeting the cached safe spot.
VI. The RSU continuously receives information about position and driving status of all CAVs via V2X communications. The TM service eliminates a CAV from its assignment, either after successfully performing its ToC or after arriving at the designated safe spot position.

Figure 1 illustrates the aforementioned steps in combination with the service for distributing TORs.

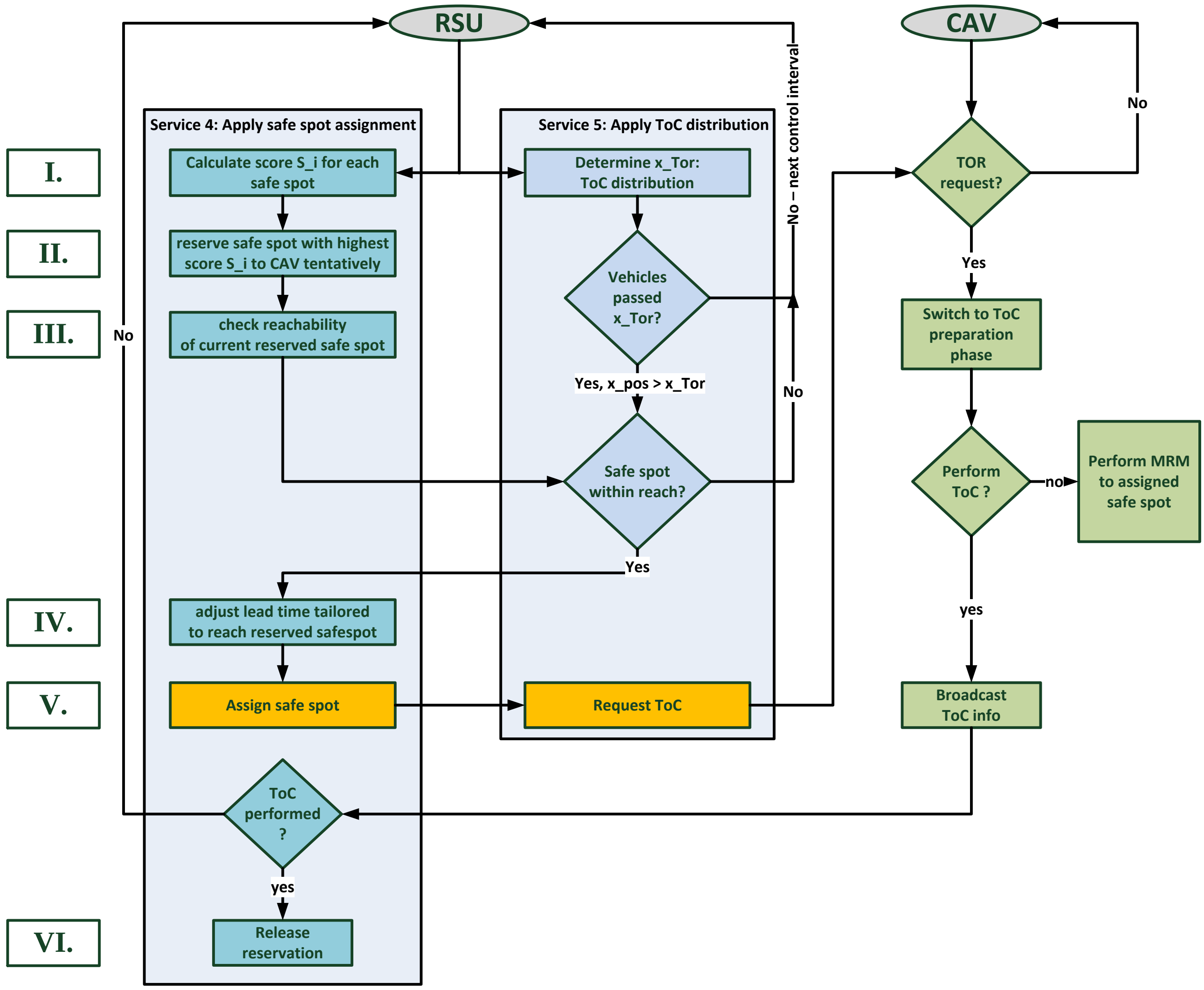


Figure 1: Flowchart of the application combining TM services for distributing TORs and assigning safe spots

3. SIMULATIONS

To investigate the performance of the aforementioned TM applications, we consider an urban two lane traffic scenario (1.82 km) with vehicles approaching a No-AD zone. Approaching CAVs will be informed by the TM via an RSU to perform a ToC and, if required, to target a specific safe spot in case of an MRM. Parking facilities are distributed equidistantly alongside this urban corridor within the approach area. The availability of these potential safe spots, monitored by the RSU, is modelled as such, that erratic road-side parking activities occur as well, so that approximately 50% of the available slots are occupied during the simulation time. Figure 2 shows a schematic illustration of the scenario.

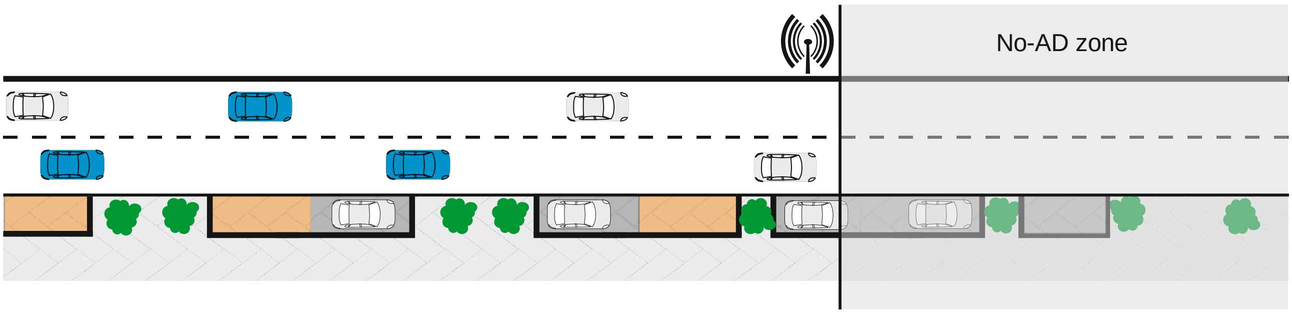


Figure 2: Scenario layout with possible safe spots (free parking slots marked in orange) ahead of a No-AD zone. Blue vehicles represent CAVs; grey vehicles indicate manual vehicles (MVs).

Varying traffic demand (see Table 1), vehicles mix (see
Table 2) and TM services, we conducted simulations in SUMO to assess the performance of the overall scenario behaviour. For every parameter combination we ran ten simulations, each for one hour of simulated time.

Table 1: Inserted vehicles per lane represented as Level of Service (LOS) B, C and D

Capacity (vehicles/hour/lane)	Level of Service (LOS)		
	B	C	D
1500 veh/h/l	825	1155	1386

Table 2: Traffic composition in percentages for different vehicle mixes. MV - manual vehicle; CV - connected vehicle; CAV - connected and automated vehicle; HGV – heavy good vehicle; LGV – light good vehicle

Vehicle Mix	MV	CV	CAV	HGV	LGV
1	61%	13%	13%	3%	10%
2	43%	22%	22%	3%	10%
3	17%	35%	35%	3%	10%

To showcase the impact of severe MRMs on traffic flow and safety, every *5min* we inserted a CAV with a prolonged driver response time of *200sec* into the scenario, which consequently results in a failed ToC by this respective vehicle. Therefore the CAV issues an MRM after exceeding the ToC response time, and if not assisted by the TM application, ultimately comes to full stop on its lane. Figure 3 shows a SUMO snapshot of the depicted situation.

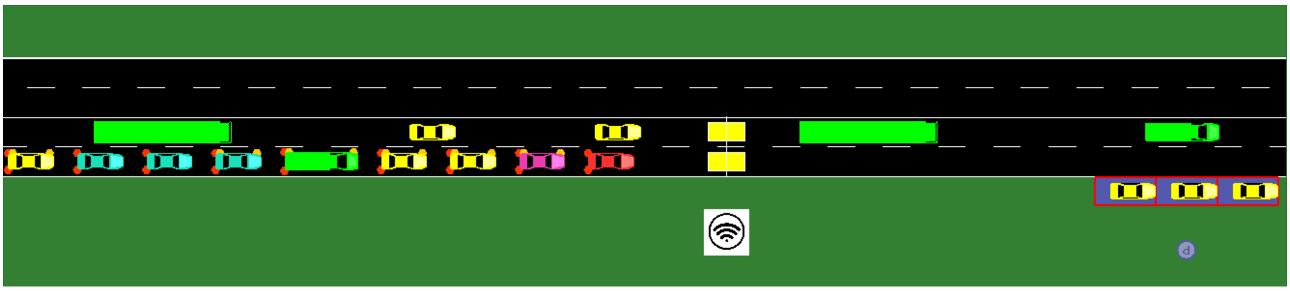
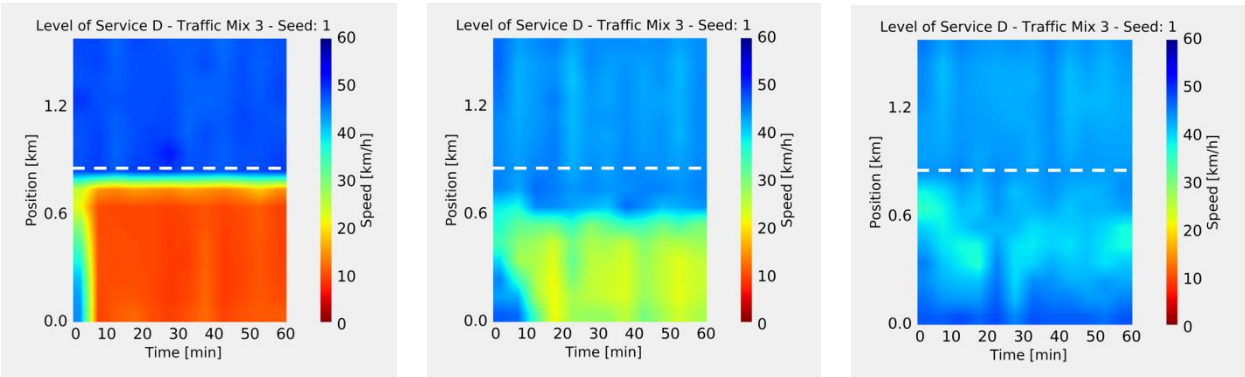


Figure 3: Detailed view of key event in the SUMO scenario. The red vehicle performing an MRM on the right lane disrupts traffic flow and causes numerous braking manoeuvres by following vehicles. Vehicle colour indicates driving status: red – MRM; yellow – MV; green – LGV/HGV; coloured – automated mode (CAV/CV)

4. RESULTS AND DISCUSSION

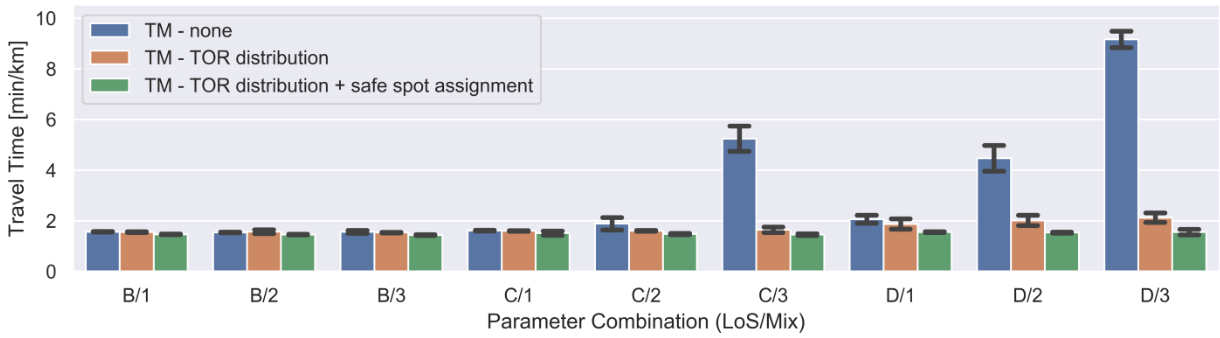
Figure 4 exemplarily shows the tempo-spatial dynamics for a particular simulation run varying the application of a TM service. When no service is provided, the average speed in the approach area ahead of the No-AD zone drastically decreases due to consecutive ToCs occurring at the entry of the No-AD zone (see red area below white, dashed line in panel (a)). The accumulation of these perturbations creates a bottleneck formation that consequently results in a traffic jam (red area in panel (a)). In presence of TOR distribution, traffic conditions improve significantly, although solitary MRMs induce local disruptions which noticeably reduce the average speed within the approach area (see yellow spots in panel (b)). When applying both services simultaneously most of the disturbances due to ToCs and MRMs vanish and we observe only slight variances in measured speed within the approach area (see light blue spots in panel (c)), which we explain with the overall scenario behaviour that includes the erratic road-side parking activities.



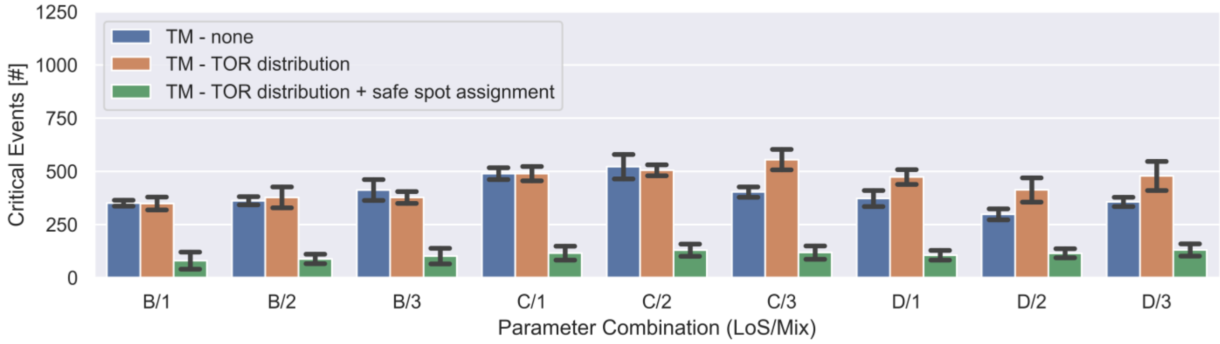
(a) – without TM   (b) – TOR distribution   (c) – TOR distribution + safe spot assignment

Figure 4: Exemplary time-space diagrams for measured speed (averaged over both lanes) of the simulated scenario for LOS D – Traffic Mix 3 of a single run. White dashed lines indicate the entry position of the No-AD zone.

When overseeing the aggregated simulation results, traffic efficiency is improved accordingly, in particular from applying TOR distribution (see Figure 5, panel (a) orange bars compared to blue bars). In regard of traffic safety, we evaluate the number of critical events measured as TTCs lower than *3seconds*. In Figure 5, panel (b) we observe a significant improvement when applying the service of assigning safe spots for all parameter combinations. Since severe MRMs disappear due to this service, heavy braking manoeuvres and sudden lane changes by following vehicles reduce considerably which has a major positive effect on the number of critical events. It becomes also apparent, that the sole service of distributing TORs does not improve traffic safety for this scenario (see Figure 5, panel (b) blue and orange bars).



(a)



(b)

Figure 5: Average results per parameter combination varying LOS, traffic mix, and TM service. Panel (a): Travel Time [min/km]; Panel (b): Number of critical events with TTC below 3sec

5. CONCLUSIONS

Current advancements in V2X communication will enable future TM procedures to address individual CAVs for managing mixed autonomy situations and lead to a safer and more efficient traffic system. This research investigates the impact of ToCs and MRMs in transition areas when TM aims to assist CAVs in approaching no automated driving zones to ensure a coordinated and non-critical occurrence of control transition. The simulation results indicate that our combined approach for *distributing TORs* and *assigning safe spots* significantly improves traffic efficiency and safety for such mixed autonomy situations in urban areas. Encouraged by these results, our upcoming research will focus on communicational aspects in order to assess the effectiveness of such an infrastructure based support via V2X messaging.

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