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Reducing travel delay by in-car advice on speed, headway and lane use based on downstream traffic flow conditions – a simulation study

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Abstract

A new advisory ADAS system is implemented in micro simulation to asses the effects on traffic flow as well as on safety. The system uses loop detector data from which situations may be recognized where advices are given to drivers in-car. Advice is given on speed, headway and lane use. Effectively the system allows drivers to respond to downstream traffic flow conditions that they can not yet observe. Additionally the system suggests an action to deal with downstream conditions while sufficient time is available to take action. This research focuses on a lane-drop location where advices are given such that traffic is more evenly spread over the two lanes after the lane-drop. Positive effects can already be found for small penetration rates while a substantial reduction of vehicle loss hours is found for larger penetration rates. The results furthermore indicate that CCC could be beneficial for traffic safety.

Keywords: advisory, ADAS, travel time, traffic flow, safety

1. Introduction

Intelligent Transport Systems (ITS) have gained much interest in recent years as a means to improve various aspects of the road system such as driver comfort, safety, emissions and travel time. Road-side systems have been successfully used for many years, including route information panels and ramp-metering (van den Berg et al., 2006). The extent of road-side systems is however inherently limited in its spatial coverage. In-vehicle systems offer more possibilities not only in spatial coverage but also in time resolution. Current in-vehicle systems assist the driver, who is still in control of the vehicle. These systems are often referred to as Advanced Driver Assistance Systems (ADAS). ADAS can be intervening, taking over part of the driving task, warning, supplying warnings to the drivers, or informative, simply providing information to the driver. Adaptive Cruise Control (ACC) for example maintains a preset speed just as a regular cruise control system, as well as follow a preceding vehicle at some safe headway if that vehicle is slower. An extended version of ACC is Cooperative Adaptive

Cruise Control (CACC). In such a system, each vehicle receives information of preceding vehicles which allows more stable control and an increase of comfort and safety. ACC and CACC systems can also be used to improve the capacity of road facilities, given the correct settings (Minderhoud, 1999). There are many other ADAS's such as lane departure warning, Intelligent Speed Adaptation (ISA) and the Congestion Assistant (van Driel & van Arem, 2010). For the Congestion Assistant, an intervening system, a travel time delay reduction of 30% and 60% was found for a penetration rate of 10% and 50% respectively.

In this paper we will focus on a new system which focuses on reduction of travel time delay through better utilization of the road by giving in-vehicle advices. The combination of an informative system with a focus on road performance offers the following benefits:

- As the driver is in control of the vehicle there are no liability issues.
- The system can easily be implemented in vehicles as it only requires a separate (or built-in) device.
- No infrastructural changes are required.

The research presented here is based on the Connected Cruise Control (CCC) system which is currently under development (Knoop et al., 2011). Figure 1 shows an overview of the system. Loop detector data and Floating Car Data (FCD) are received at the Traffic Management Centre (TMC) from which a traffic state estimation and prediction are made. In case of nearly saturated or over-saturated conditions, advices can be given to drivers to optimize the situation. Advices are given on speed, headway and lane use. Existing cellular communication technologies are used to send the FCD and advices between the in-vehicle unit and TMC. Loop detector data is readily available at the TMC.

An important benefit of the CCC approach is the spatial scale for which advices are given, namely for situations in the order of 1km downstream, allowing tactical maneuvers. Systems that work at a larger scale are for example 'Spitsmijden' (Ben-Elia & Ettema, 2011), or rush-hour avoidance, and in-car or road-side route guidance systems. Systems such as ACC and CACC however work on the operational level of vehicle control. Our hypothesis is that advising drivers for tactical maneuvers can optimize traffic in situations where regular traffic performs sub-optimal. Higher flows before break-down may for instance be achieved by distributing traffic more evenly over lanes and by creating conditions in which lane changes cause smaller disturbances. Research has shown that lane changes are at least a trigger for many breakdowns of traffic. In fact, Ahn & Cassidy (2007) show that all breakdowns under investigation were caused by lane changes. The gain of CCC is mainly provided by virtually extending the visual field of drivers by providing them specific advices on how to act to downstream conditions. In regular traffic, drivers are often not aware of what is best for traffic flow. Furthermore they respond to situations that are in line of sight, which often allows (too) little time for action.

The aim of the research in this paper is to investigate the effectiveness of such a system. As CCC is still in development, the presented system is not implemented as depicted in figure 1. Floating car data is omitted and no traffic state estimation or prediction is performed. Instead, loop detector data is directly used to trigger advices. Effective ways to formulate and give the advices, as well as driver responses to advices and compliance are currently unknown. We assume perfect compliance and capability to follow the advices. Advices may be beneficial in many situations such as an on-ramp, weaving section, stop-and-go waves and lane-drop locations. Here we focus on the latter case, for which a tailored advice algorithm is developed focusing mainly on alleviating the left lane after the lane-drop as this lane becomes oversaturated while the right lane has spare capacity. Besides the traffic performance, a preliminary investigation regarding safety is also performed.

The paper is structured as follows. The next section elaborates on the methodology of our research. Section 3 discusses the implementation of the CCC system that was used in simulation. Section 4 gives the experimental setup of which section 5 gives the results. Finally, a discussion and conclusions are given in section 6.

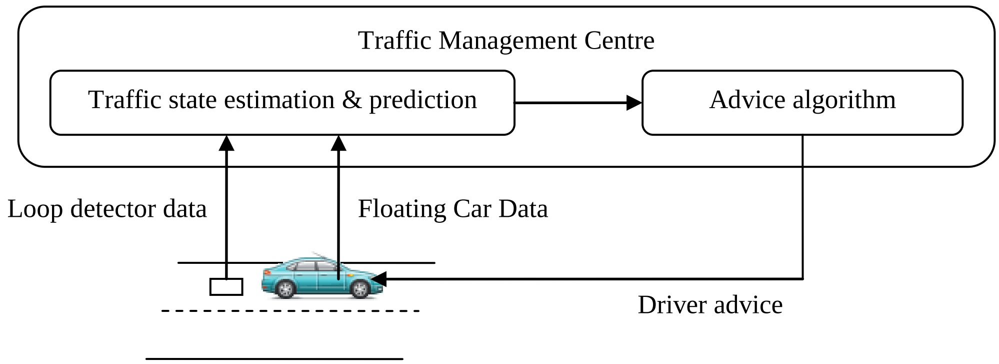

Fig. 1. Overview of the Connected Cruise Control system.

2. Methodology

2.1. Simulation environment and traffic model

The used simulation environment is the ITS modeller (Versteegt et al., 2005), a software platform designed by TNO which allows the implementation of user-defined microscopic traffic models. The ITS modeller is a plug-in into the commercial simulation software Paramics. In this study the lane-change and car following model are replaced with the models described in Schakel et al. (2012). The lane-change model is the Lane change Model with Relaxation and Synchronization (LMRS). This model has been developed to represent Dutch freeway traffic with a focus on the distribution of traffic over different lanes, which is essential in evaluating the improvements of advices on lane-use. Furthermore, it is the only model to our knowledge which implements both relaxation and synchronization. Relaxation implies that drivers accept small headways during a lane change which is increased smoothly afterwards (Laval & Leclercq, 2008). Synchronization is the adaptation of speed to allow an easier lane change, e.g. lane change preparation. Both relaxation and synchronization have effect on the stability and capacity of road facilities. These are important phenomena in relation to the speed and headway advices.

The car-following model is an adaptation of the Intelligent Driver Model, referred to as the IDM+, which is described in more detail in Schakel et al. (2010). It is very similar to the IDM which has realistic traffic flow stability and shockwave properties. The extension was mainly performed to allow more reasonable capacity values in combination with reasonable parameter values. Model parameters are equal to the parameters used in Schakel et al. (2010), as the road stretch to which the model was calibrated is equal to the road stretch in this research.

2.2. Network and data

The network used is a section of the A20 from Rotterdam towards Gouda in the Netherlands as depicted in figure 2. We have used loop detector data of the morning rush hour from the 8th of June 2009, on which there was congestion at the lane-drop. An origin-destination matrix was derived using this data.

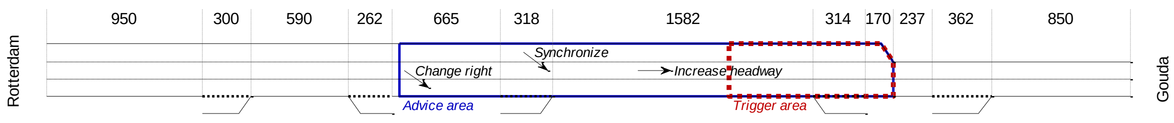

Fig. 2. Highway network of the A20 with section distances [m], areas and basic advices indicated.

3. Advices and implementation

3.1. Advice strategy

From the detector data it was found that traffic on the middle lane does not change to the right lane before the lane-drop. Consequently, the flow on the left and middle lanes is combined on the left lane after the lane-drop, which may cause a nearly saturated or even oversaturated situation while the right lane is still underutilized. Lane changes from the left lane before the lane-drop may additionally cause perturbations which finally cause traffic breakdown on the middle lane. Advices are aimed to alleviate both problems and are shown in figure 2. Traffic on the middle lane will receive a lane change advice to move to the right lane before the lane-drop. Traffic that remains on the middle lane will receive an advice to increase the headway, which will create gaps for merging traffic from the left lane, allowing smoother lane changes. Also, large headways have a stabilizing effect on traffic flow. Finally, traffic on the left lane will receive a speed advice to reduce the speed difference with the middle lane (i.e. synchronization), again allowing smoother lane changes.

These advices will only be effective (and reasonable to drivers) in nearly saturated conditions. Therefore triggers were defined in which the system should turn on and off. Detector data used for the triggers is located at four cross-sections in a 1km area before the lane-drop, referred to as the trigger area. The data are 1-minute aggregate measurements and the system will check the triggers each minute. Triggers to turn the system on are:

- Total flow at any cross-section is 67 veh/min (4020 veh/h) or higher.
- Highest flow at any detector on the left or middle lane is 34 veh/min (2040 veh/h) or higher.
- Lowest speed at any detector on the left or middle lane is 80 km/h or lower.

For the system to activate, two of these three conditions need to be met. This prevents too much flickering of the system. Triggers to turn the system off are defined as:

- Total flow at any cross-section is 58 veh/min (3480 veh/h) or lower.
- Highest flow at any detector on the left or middle lane is 30 veh/min (1800 veh/h) or lower.
- Lowest speed at any detector on the left or middle lane is 90 km/h or higher.

All off conditions needs to be met for the system to deactivate. Because of the differences in the on and off trigger values, the system will remain active for some time. To allow drivers enough time to perform the advices, advices are given in an area of 3km upstream of the lane-drop, this is referred to as the advice area which overlaps with the trigger area.

3.2. Speed advice

Speed advice is intended to decrease speed differences between lanes which should allow for easier lane changes. If speed advice is given on either the left or right lane, drivers will adjust their desired speed (v_0) to the leading vehicle in the middle lane. This may cause situations where the current speed (v) is higher than the desired speed, for which the IDM+ is not applicable. For $v > v_0$ the acceleration term of the IDM actually results in large decelerations. The acceleration term of the car-following equation is therefore limited to a maximum deceleration of m. Leaving out the interaction term regarding a leading vehicle, acceleration towards a desired speed is defined as in equation (1), where a is the acceleration parameter of the IDM. For m we assume a value of $1 \mathrm{m/s^2}$.

$$\frac{dv}{dt} = a \cdot \max\left(1 - \left(\frac{v}{v_0}\right)^4, -m\right) \tag{1}$$

3.3. Lane change advice

Lane change advice is given to achieve a more even distribution of traffic over the available lanes. As measure, we use the density on the lanes which is estimated through flow counts and time-averaged speeds from detector data. Since there are two lanes after the lane-drop, ideally about 50% of traffic is on either lane. Lane change advices on the middle lane before the lane-drop are given if less than 50% of traffic is on the right lane at any detector in the trigger area. No new advices are given if any of the detectors in the trigger area has 60% of traffic on the right lane. As lane changes in (slightly) congested circumstances may have an adverse effect on traffic, lane change advices are only valid for a specific vehicle if the speed of this vehicle is above 100km/h. The number of vehicles that should receive a lane change advice is calculated such that the density will even out in the trigger area, which is then extrapolated to the advice area (e.g. multiplied by 3). We found that about 60% of lane change advices results in an actual lane change, probably due to the cancellation of the advice below 100 km/h. To compensate, the number of vehicles on the middle lane which will receive a lane change advice is divided by 60%. The slowest vehicles on the middle lane are selected as these are most likely to change to the right lane. Finally, all drivers in the advice area are advised not to change left from any lane and no lane change advice is given if the vehicle changed lane in the previous minute.

Driver response to lane change advice is integrated into the LMRS. Several incentives for lane changes are used in the LMRS which each result in a lane change desire, which are then combined into a single lane change desire. The lane change advice is modeled as an additional incentive. We assume that drivers experience an increase in lane change desire after receiving the advice, which results in increasingly assertive behavior in terms of adjusting their speed and accepting smaller gaps. For the first 30s we assume a lane change desire of d_{free} which is a threshold in the LMRS at which drivers will only change lane if there happens to be a suitable gap. The next 15s the desire is increased to d_{sync} which will trigger a driver to synchronize speed (and position) with the target lane as lane change preparation. For the next 15s the value is further increased to d_{coop} which will trigger a follower in the target lane to create a gap, e.g. to allow a cooperative lane change. After a total time of 60s the advice becomes invalid. The LMRS also uses smaller headway values for larger lane change desire for the gap-acceptance, which thus also depends on the lane change advice.

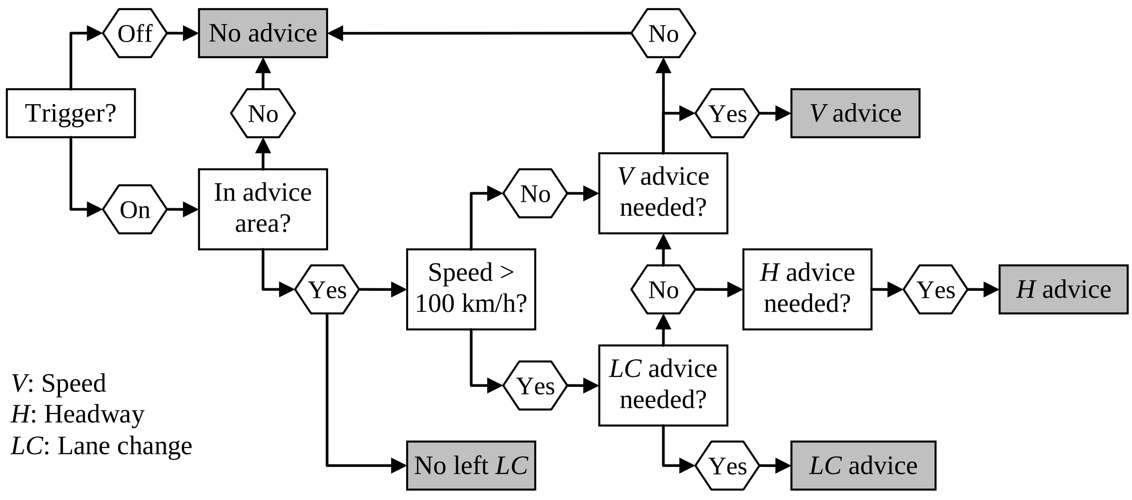

Fig. 3. Advice scheme.

3.4. Headway advice

To allow gaps for lane change vehicles, drivers on the middle lane may be advised to increase their headway to 3s. As the IDM responds rather strongly to headways that are shorter than desired, the desired headway value is not increased to 3s instantaneously. Instead it is assumed that the value will increase linearly to 3s over the course of 60s. Furthermore it is assumed that drivers will ignore the headway advice after having a new predecessor, unless the new headway is 2.5s or larger anyway. Similarly to the lane change advice, headway advice is not given if it was given in the previous minute.

The full advice scheme is given in figure 3. In principle there is a descending priority order of lane change advice, headway advice and speed advice. Only the latter may be given when the speed is below 100 km/h.

4. Experimental setup

In this research we are interested in the possibilities of an advisory system as described at a lane-drop location. The selected network was chosen because our model has been calibrated on this network in Schakel et al. (2012). The presence of trucks and a busy off- and onramp around the lane-drop location form complicating noise to the situation of interest, and are therefore left out.

Different combinations of advices were tested. The basic scenario contains the advices as explained in the previous section, i.e. lane change advice from the middle to the right lane, headway advice on the middle lane and speed advice on the left lane. Additional advices which are tested in combination with the basic advices are:

- Lane change advice from the left to the middle lane, which may result in earlier and therefore less urgent and disruptive lane changes.
- Speed advice on the right lane, which allows drivers from the middle lane to change to the right lane.
- Headway advice on the right lane, which also allows drivers from the middle lane to change to the right lane.

These scenarios are performed with a penetration rate of 10%, at which an effect should be noticeable without requiring (higher) penetration rates which can not be expected in the coming years. Using the best advice combination, further scenarios are evaluated to investigate the influence of the penetration rate. Table 1 gives an overview of all scenarios. Each scenario is run with 30 different random seeds, from which stochastic effects can be averaged out.

Indicators are derived from which traffic flow performance can be assessed. Some additional indicators have been derived to investigate the influence of advices on traffic safety and to make a first qualitative assessment of the possible safety effects.

Table 1. Overview of scenarios.

Scenario nr.	Description	Penetration rate
0	Reference situation.	0%
1	Basic scenario with 3 advices.	10%
2	Basic + Lane change advice on the left lane.	10%
3	Basic + Speed advice on the right lane.	10%
4	Basic + Headway advice on the right lane.	10%
5	Best of 1-4 + Penetration rate of 2%.	2%
6	Best of 1-4 + Penetration rate of 5%.	5%
7	Best of 1-4 + Penetration rate of 10%.	10%
8	Best of 1-4 + Penetration rate of 20%.	20%
9	Best of 1-4 + Penetration rate of 40%.	40%

5. Results

5.1. Traffic performance

The duration of congestion for scenarios 0 through 4 is visible in figure 4a. It shows the average speed of all runs of each scenario through time. Two things are apparent from the figure; i) advices can improve the throughput and ii) the basic combination of advices (scenario 1) is the best combination. For scenario 2 it may be that lane change advice on the left lane results in lane changes that are performed before drivers on the middle lane have created sufficient gaps, such that lane changing is not as smooth as in scenario 1. Still, results are better than the reference scenario. The result of scenario 3 is even worse than the reference scenario. In fact, congestion may last until 7:25, which is much later than in the other scenarios. The reduction of speed difference with the middle lane apparently has little effect on the performed number of lane changes from the middle lane, but has a significant reduction of speed on the right lane as a consequence. In effect this advice probably extends any congestion from the middle lane to the right lane. Headway advice on the right lane, as in scenario 4, also shows a smaller improvement from the reference scenario. Similar as in scenario 3, though with much less significance, this probably just reduces the capacity of the right lane. Figure 4b shows the influence of the penetration rate on the mean speed. For very small penetration rates some results are already visible. Results improve for higher penetration rates, but even at 40% congestion can not be prevented completely. This is probably due to a too large traffic demand. Table 2 shows more results regarding different indicators. The same trend of improvement is visible for all indicators, except for the number of lane changes which has a minimum around 10% penetration rate. What is remarkable is the reduction of vehicle loss hours which is already 38% at a penetration rate of 10% and even 67% for 40% penetration rate.

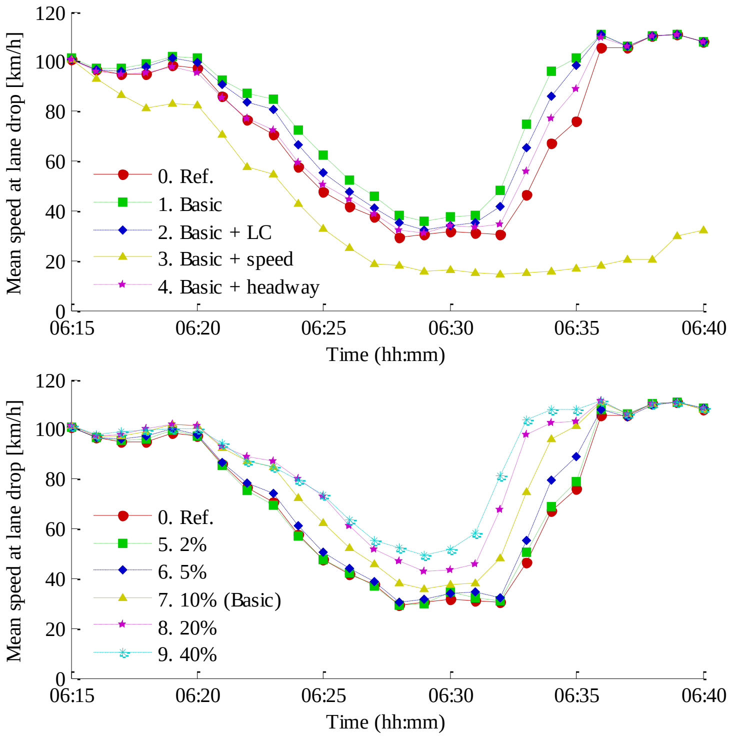

Fig. 4. (a) Speed comparison of advice combinations. (b) Speed comparison of different penetration rates.

Table 2. Overview of average indicator results.

Scenario nr.	0	5	6	7	8	9
Description	*ref.*			*penetration rates*		
Penetration rate [%]	0	2	5	10	20	40
Total travel time [h]	203.7	203.2	201.8	198.7	195.8	194.8
Vehicle loss hours [h]	13.2	12.6	11.2	8.1	5.3	4.3
Average speed [km/h]	102.9	103.2	103.9	105.5	107.0	107.6
Average density [veh/km]	18.2	18.0	17.3	15.6	14.5	13.7
Nr. of lane changes	4052	3943	3946	3779	3970	4043

5.2. Safety

Indicators of safety were also derived and are presented in figure 5. As the traffic performance is improved it is not surprising that the mean speed has increased. However, except for the number of lane changes all other safety indicators suggest a beneficial effect on traffic safety. The number of time-to-collisions (TTC) below 4s even reduces up to 81%. Although it is difficult to make estimations on the actual improvement of safety, it seems unlikely that safety will suffer with the advices used.

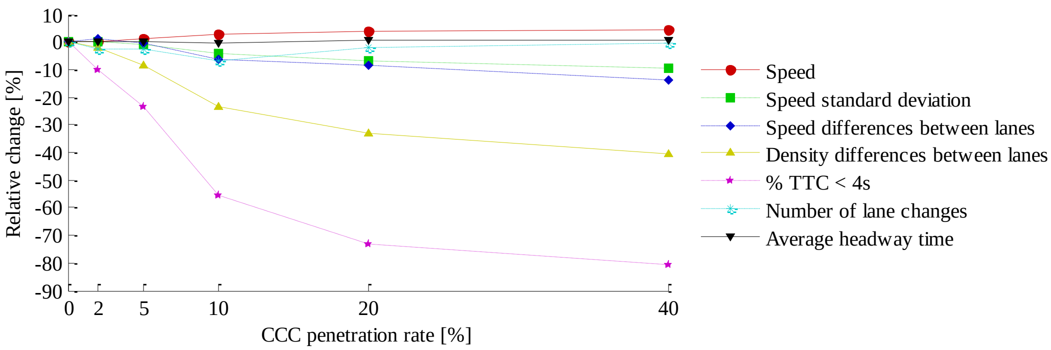

Fig. 5. Effect of penetration rate on safety indicators.

6. Discussion and conclusions

In this paper we have assessed the possible impacts of an advisory in-car system at a lane-drop location. Our results were achieved by only considering passenger cars. Future work should investigate extensions of the advisory system in case trucks are included. Also, the effect of the off- and onramp that we have excluded should be investigated, as we found that moving traffic towards the right lane had adverse effects on the busy onramp just downstream of the lane-drop. Specifically, it should be investigated what advice strategy should be implemented. Advices in this research were simple and straightforward. More elaborate advices could be investigated including the advice to increase headway *only* if there is a merging predecessor in an adjacent lane, or to inform drivers about the end of the queue, increasing there willingness to accelerate. This would overcome the effect that drivers obtain a larger time headway in congestion (Treiber & Helbing, 2003), which inhibits efficient acceleration out of congestion.

The results of this research show that a significant reduction of vehicle loss hours can be achieved at a lane-drop by giving drivers specific advices on the speed and headway to adopt or which lane to drive on. We found a reduction of up to 67%, depending on the demand pattern and penetration rate. Advices only need to be given in a region just upstream of the lane-drop and are focused on a more even distribution of traffic over the lanes. This indicates that there are opportunities for improvement of the performance of the road system without large technological advancements or (partially) automated driving. From our simulation it thus appears that advising drivers on situations in the order of 1 km downstream enables drivers to perform actions which improve the overall traffic flow.

Our results also indicate that the used advices would have no adverse effects on traffic safety and could even improve safety through more homogeneous traffic and smoother lane changes. However, it is difficult to draw conclusions about safety as simulation does not allow an accurate quantification of safety effects.

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References

Ahn, S. & Cassidy, M. (2007). Freeway traffic oscillations and vehicle lane-change maneuvers. In *Allsop, R. E., Bell, M. G. H., and Heydecker, B. G., editors, Proceedings of the International Symposium of Transportation and Traffic Theory*, pp. 691–710.

Ben-Elia, E. & Ettema, D. (2011). Rewarding rush-hour avoidance: A study of commuters' travel behavior, *Transportation Research Part A: Policy and Practice*, Vol 45, issue 7, August 2011, pp. 567–582.

van den Berg, M., de Schutter, M. & Hellendoorn, H., (2006) *Effects of on-ramp and off-ramp metering on queue forming in urban traffic networks*, Proceedings of the 11th IFAC Symposium on Control in Transportation Systems, Delft, The Netherlands, pp. 130–135.

van Driel, C.J.G. & van Arem, B. (2010). The impact of a congestion assistant on traffic flow efficiency and safety in congested traffic caused by a lane drop. *Journal of Intelligent Transportation Systems*, 14(4), pp. 197–208.

Knoop, V.L., Schakel, W.J., Jonkers, E. & van Arem, B. (2011). Individual Travellers' Advice: System

Setup, Measures, and Expected Results , in: Proceedings of the 90th Annual Meeting of the Transportation Research Board, 23–27 January 2011, Washington D.C.

Laval, J.A. & Leclercq, L., (2008) Microscopic Modeling of the Relaxation Phenomenon Using a Macroscopic Lane changing Model, *Transportation Research Part B*, Vol. 42, 2008, pp.511–522.

Minderhoud, M.M. (1999). *Supported driving: impacts on motorway traffic flow*. TRAIL Thesis Series T99:4, Delft: Delft University Press.

Schakel, W.J., van Arem, B. & Netten, B. (2010). *Effects of Cooperative Adaptive Cruise Control on Traffic Flow Stability*, Proceedings of the 13th International IEEE Conference on Intelligent Transportation Systems (ITSC 2010), pp. 759–764.

Schakel, W.J., Knoop, V.L. & van Arem, B., (2012). *LMRS: An integrated Lane Change Model with Relaxation and Synchronization*, in: Proceedings of the 91st Annual Meeting of the Transportation Research Board, 22–26 January 2012, Washington D.C. (to appear in Transportation Research Record: Journal of the Transportation Research Board).

Treiber, M. & Helbing, D. (2003). Memory effects in microscopic traffic models and wide scattering in flow-density data, *Physical Review E 68*.

Versteegt, E., Klunder, G. & van Arem, B., (2005). *Modelling cooperative roadside and in-vehicle intelligent transport systems using the ITS modeller*, in: Proceedings 12th World Congress on ITS, "Enabling Choices in Transportation". San Francisco, CA, USA, 6–10 November 2005.