CONNECTED CRUISE CONTROL
An advisory system for efficient traffic flow

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ABSTRACT

Connected Cruise Control (CCC) is an advisory system that enables drivers to drive more efficiently. The system gives advice towards an efficient traffic flow on headway, speed and lane use based on a traffic state prediction. An in-vehicle system will receive the advice and filter it according to relevance and safety, based on map and camera data. CCC can mitigate sub-optimal human behaviour without extensive technological changes to the road system. This makes CCC a feasible next step towards a future with a fully automated road system as CCC is aimed at a system optimum within feasible individual limits.

KEYWORDS

Traffic flow, advisory system, optimization, traffic state prediction, headway, speed, lane-use

INTRODUCTION

Congestion, delays and travel time variability are unwanted phenomena of today's road system. To overcome these problems many attempts to optimize road use have been undertaken that influence various decisions such as mode choice and route choice but also to help with or to take over driving tasks (van Driel 2010, Hegyi et al. 2010). Many current systems such as ramp-metering are road-side systems and fail to influence traffic at individual driver level. Studies into the effects of individual in-vehicle systems focus more on safety (lane departure warning, headway warning) or throughput effects of automated systems (such as Kesting et al. 2010) which cannot be easily applied in current vehicles (retro-fit). For the far future fully-automated systems are foreseen by many traffic researchers that replace/overtake all aspects of the driving task. It is expected that an extensively automated system will greatly improve the efficiency of the road system in terms of lane-use and headways (capacity). Such a system can not be implemented at once and intermediate solutions are required to improve the road system till then. The project Connected Cruise Control (CCC) aims to create not only an intermediate solution for highways, but even the

next possible step for highways towards the future. To this end no aspect of the driving task is taken over. Instead, the system will be advisory and can be retro-fit. The system gives an advice on recommended headway, speed and lane use. It is expected that such an advisory system will be able to improve traffic flow at crucial locations by postponing or preventing breakdowns. These locations are typical areas where congestion is triggered and where human driving behavior is sub-optimal, e.g. more stable traffic can be achieved without significantly sacrificing throughput by obtaining different headways, speeds or lane-use. The main strength of the system is that it is able to look further ahead than humans, typically 1km downstream. Current road-side systems are already able to inform the driver of congestion downstream and present dynamic speed limits on gantries. However, the driver does not know what the optimal action is in terms of headway and lane use. Furthermore, individual speed advice could be more effective than a collective speed limit and could also discriminate between lanes. Also, using the road-side traffic state prediction, breakdowns might be prevented. The traffic state prediction can be done using loop detector data and/or Floating Car Data. Finally, current road-side systems are not located everywhere. With sufficient (few %) penetration rate for Floating Car Data, CCC can work even without loop detectors.

CONNECTED CRUISE CONTROL SYSTEM

In this article we focus on the traffic flow improvement aspect of the CCC system as in figure 1. The available data will be detector data with a delay of about 2-3 minutes and Floating Car Data which at least contains time, position and lane but preferably also speed. The system will advice the driver for relevant situations about 1km downstream as this allows the driver to take action while not being so far away that it is of no interest to the driver. The next section will elaborate on the traffic state prediction required to generate the advice. In the predicted traffic state undesired situations may be present. These can be diagnosed for instance with triggers based on density. Note that the advice is at this stage not vehicle specific. However, the advice is only valid for a certain time range, a certain area and possibly only for certain routes (mainline vs. off-ramp). Whether the advice is relevant for a given driver is determined by the in-vehicle unit where the route is also known. Additionally, the advice may only be given to a percentage of all drivers by means of for instance a random number. This is useful if for instance 10% of vehicles should change lane. There is also an in-vehicle generated advice based on dynamic speed limits and safety constraints by bends and other vehicles.
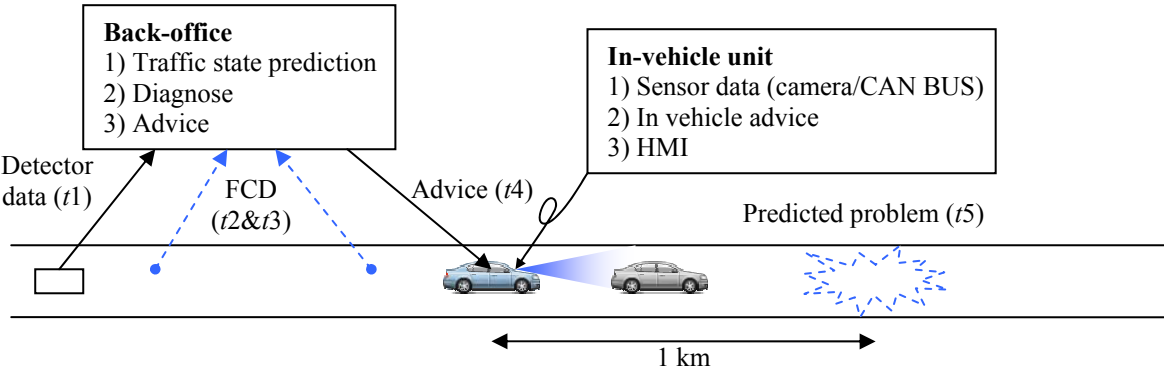

Back-office
1) Traffic state prediction
2) Diagnose
3) Advice

In-vehicle unit
1) Sensor data (camera/CAN BUS)
2) In vehicle advice
3) HMI

Detector data ($t1$)

FCD ($t2$&$t3$)

Advice ($t4$)

Predicted problem ($t5$)

1 km

Figure 1: Connected Cruise Control system overview. At $t1$ the detector transmits data to the back-office. At $t2$ & $t3$ the vehicle transmits Floating Car Data. At $t4$ a traffic state estimation is made based on past data. A problem is predicted that will occur at $t5$ and consequently the vehicle will receive a road-side advice.

Available data comes from the vehicle CAN BUS (velocity, acceleration, steering angle) and from the camera (headway, velocity difference) which are also part of the CCC system. Together with digital map data an advice can be formed. The road-side advice competes with the in-vehicle advice and is not always presented to the driver. Depending on system penetration, in-vehicle generated advice and compliance rate a certain number of drivers will adhere to the road-side advice, mitigating the undesired situation.

PRECISION OF A LANE-BASED FIRST-ORDER MACROSCOPIC PREDICTION MODEL

The traffic state prediction should be able to predict about 8-9 minutes ahead. This is a combination of 2-3 minutes delay in detector data and a maximum travel time of 5-6 minutes at slow speeds over 1km. As CCC will be designed to optimize traffic flow with lane-specific advice, the traffic state prediction has to be lane-specific. Usually traffic state prediction is performed at link level. Therefore an investigatory experiment has been performed to see whether a first-order macroscopic traffic model is accurate enough at lane level for a period of 8-9 minutes. A first-order model is selected for speed as the traffic state prediction needs to run on-line. In this experiment we use the Cell Transmission Model (Daganzo 1993). Detector data from a 6.6km long section of the A4 between The Hague and Leiden has been collected. Using the Adaptive Smoothing Method (Treiber and Helbing 2003) this data is interpolated to the cell grid of the Cell Transmission Model. An additional data set is generated from the original detector data. Random errors are applied to assess the robustness with respect to measurement errors while the original detector data is perceived in this experiment as being the ground truth. The traffic state prediction is based on the erroneous data where a rolling horizon is used. In general it appeared that shockwaves are correctly predicted for a time span of about 8-9 minutes. It should however be mentioned that 2nd order effects are not included causing some falsely predicted or falsely solved shockwaves. A larger issue in this experiment with respect to correctly predicting congestion and shockwaves is however the assumed inflow and outflow per lane. Three solutions have been used in this experiment to deal with the inflow and outflow:

1. *Buffer region*. A buffer region is a section of the network that is outside of the concerned area. Traffic within this area is however the inflow or may be a constraint on the outflow through congestion for a given time period.
2. *Constant flow*. A constant flow can be assumed that is equal to the flow of the last few minutes.
3. *Split/merge fractions*. At onramps and off ramps these fractions can be determined based on traffic of the last few minutes.

The first solution is the most exact solution. However, the required region can consist of many links. Especially for onramps and off ramps large sections of the underlying road network may influence the highway in a period of 8-9 minutes. For on-ramps a merge fraction would pose a theoretical difficulty as it relates the flow on the highway with flow on the onramp. Especially in case of congestion these flows are largely independent as the highway and on-ramp may be differently affected. Therefore it is more realistic to assume a constant flow for onramps. If flow on the onramp over the last few minutes has been hampered by congestion it is not wise to simply use the average inflow of the last few minutes. Instead inflow should be equal to free flow capacity. The congestion patterns that are present on the highway will limit the inflow to realistic values. In this way the traffic state prediction will continue the congestion patterns. Speed on the onramp can be used to evaluate whether flow has been congested or not. For off ramps a split fraction can be used as the flow on the highway and the off ramp are both related to the flow just upstream of the off ramp.

TRAFFIC FLOW INSTABILITY AND ADVICE

At the current stage of the CCC project the algorithm to generate the road-side advice has not yet been developed. However, an investigation has been performed into situations that may be mitigated using a combination of headway, speed and lane advice. A selection of these situations is based on where congestion often occurs and where human behavior may be sub-optimal. Two possible examples of the CCC system are:

- *High densities*. Higher densities have a larger probability of triggering traffic flow instability. Therefore high densities are an undesired situation. In case of uneven lane use drivers can be advised to change lane. If lane use is more or less even, drivers can be advised to lower their speed resulting in larger time headways. A balance between maximum flow and breakdown probability has to be made.
- *Synchronized flow*. Kerner (2004) distinguishes three traffic phases: free flow, synchronized flow and stop-and-go waves. Highest flow is found in synchronized flow where speeds on different lanes are more or less equal. If there is a reasonable chance of stop-and-go waves, drivers could be advised to adhere to a single speed on all lanes. The benefit of this is 1) that lane changes are less frequent as there is hardly any speed benefit and 2) that lane changes that are performed form a smaller perturbation as there are hardly any speed differences.

CONCLUSIONS

The CCC system is a promising step towards an efficient road system. The advisory nature enables easy integration in the current road system. The largest uncertainty is the compliance rate of the drivers. Therefore the system should not give conflicting advice and needs a high certainty that traffic flow will actually improve when giving advice. The required traffic state prediction at lane level is feasible and available use-cases are good candidates to develop and test the system before actual implementation.

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