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Cooperative queue data for adaptive traffic control

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Abstract

One of the challenges of adaptive traffic control is to accurately estimate the state of the queue and arrivals for an intersection. Usually, such predictions are based on signals from inductive loops at intersection approaches. With recent developments in V2X technology, connected vehicles are able to directly broadcast precise information about their position, velocity and direction, by means of Cooperative Awareness Messages (CAM). In this paper, we investigate how adaptive control of traffic lights at intersections can be enhanced by this more detailed data. We adapt the queue model of the commercial traffic light algorithm ImFlow and perform traffic simulations on a model of a real-world intersection. We evaluate the results based on commonly used traffic performance metrics: the delay and the number of stops of vehicles passing the intersection. This shows an improvement of 6% when CAM messages are taken into account.

Keywords:

Traffic control, cooperative detection, queue estimation

Introduction

Traffic light controllers based on adaptive control algorithms can respond to the varying traffic demands and adjust the signal planning accordingly. Various studies [1, 2, 3] have confirmed that adaptive control outperforms traditional controllers based on fixed cycles. There are several commercial adaptive controllers, among them SCOOT [4], ImFlow [5], Utopia [6]. Each of them requires real-time demand models, and their performance relies on the quality of the queue information. Traditionally, the arrival data is deduced from measurements of inductive loops. This data can then be processed by the prediction unit of the traffic light controller to create a queue model, based on which the adaptive intelligence unit can decide on the planning. Queue predictions from loop detection are by far the most widespread; however, this solution has some disadvantages. Even though inductive loops are not expensive, the costs of road works often prohibit large scale deployment. This holds in particular for the entry link detection, as it requires long connecting cables. Moreover, with a limited amount of loops it is impossible to track the exact speed and trajectory information of the approaching vehicles in real time.

With the advent of cooperative technology, alternatives to loop detection are becoming available. In the near future, connected vehicles will be able to accurately identify their position on the road with use of differential GPS [7] and highly automated driving maps [8]. Cooperative Awareness Messages (CAM) can be used to broadcast this information and indicate the vehicle’s lane to roadside units (RSUs) connected to traffic light controllers. This solves the problem of accurate trajectory tracking, as adaptive controllers are provided with exact information about the position and velocity, and can adjust the signal planning accordingly.

The work in [10] already concluded that using CAM information is promising for signal control. However, it assumed either full penetration of C-ITS equipped vehicles, or only had one lane approaching the intersection. A key challenge lies in distributing scarce data among different lanes that correspond to different turn directions. Additionally, due to limited communication range, there is a hand-over moment from regular detection data to CAM data which requires data fusion algorithms.

In this paper we evaluated the impact of cooperative queue detection on adaptive signal control. Our performance metrics are the delay and the number of stops of vehicles. We performed simulations on a model of a real-world intersection on an arterial transit road in the city of Helmond. We used the ImFlow adaptive algorithm to control the status of the traffic lights. The simulation was performed in an open-source microsimulation software SUMO [9].

A case study

Typically, a multi-lane approach to an intersection will consist of several movements that do not necessarily need to be assigned green within the same stage. For instance, consider a stage diagram depicted at Figure 1. A commonly encountered configuration is to assign the right-through movements of the same direction to the same stage, and the left-turn movements of the same direction to a separate stage, as they are in conflict with the through movements, but not with each other. Now let us assume that the intersection is equipped with an adaptive stage planning algorithm, and the demand is detected by inductive loops located at the entry of the approach. Our case study will be the intersection of Europaweg and Hortsedijk, which is generously equipped with inductive loop detection, both at entry links and at stop lines. From now on, we will refer to this intersection as HEL701.

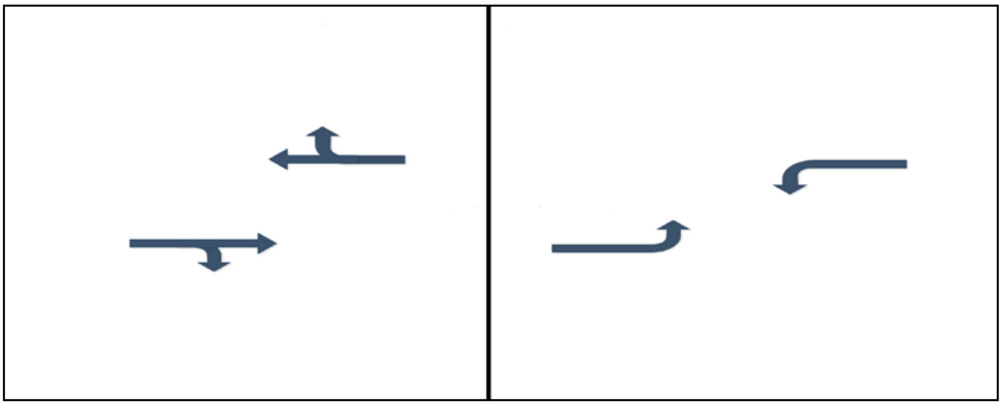


Figure 1 – Phase diagram for the East-West direction at HEL701.

Consider the eastern approach to HEL701, depicted in Figure 2. Vehicles following this link have two lanes at their disposal. The link entry detectors are located at the distance of approximately 400m from the stop line, near the upstream intersection HEL702. At the distance of approximately 150m to the stop line, the link splits into four lanes; with two lanes belonging to through movement, one to right movement and one to left movement.

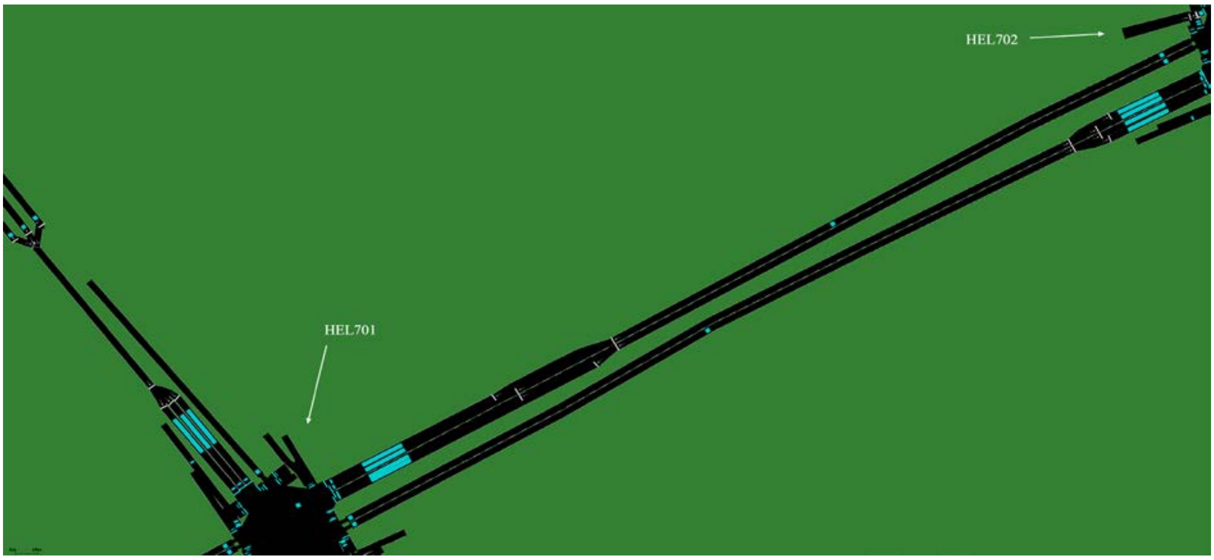


Figure 2 – The approach from HEL702 to HEL701

This configuration poses a challenge to the adaptive traffic light controller equipped solely with inductive loop detection. Let us suppose that a detection event occurs at the entry link. The planning module in adaptive traffic light controller needs to determine, which stage can be given to the detected vehicle, and at what moment, so it is dispatched in a most efficient manner. However, real-time information about the movement direction and the velocity of the vehicle is not available directly from the entry link inductive loop reading. The movement direction can be read from inductive loops usually only when the vehicle leaves the intersection and passes one of the loops positioned at the stop line. The only exception is when the vehicle is the first in a queue, then it is stopped at the induction loop and the algorithm knows there is at least one vehicle waiting. In all other cases, the algorithm has to estimate based on historical turning percentage averages. This introduces inaccuracy and can result in suboptimal stage planning.

Such situation is depicted in Figure 3. Based on turning percentages, the traffic light controller estimates that the vehicles will follow the arterial road and gives green to the through movement. However, in our situation all vehicles decide to turn left, and in consequence stop at red. A connected vehicle can circumvent this problem by transmitting their movement position right after it enters a turning lane. In Figure 4, a connected vehicle informs the intersection about the lane it is following, and receives green for the left movement.

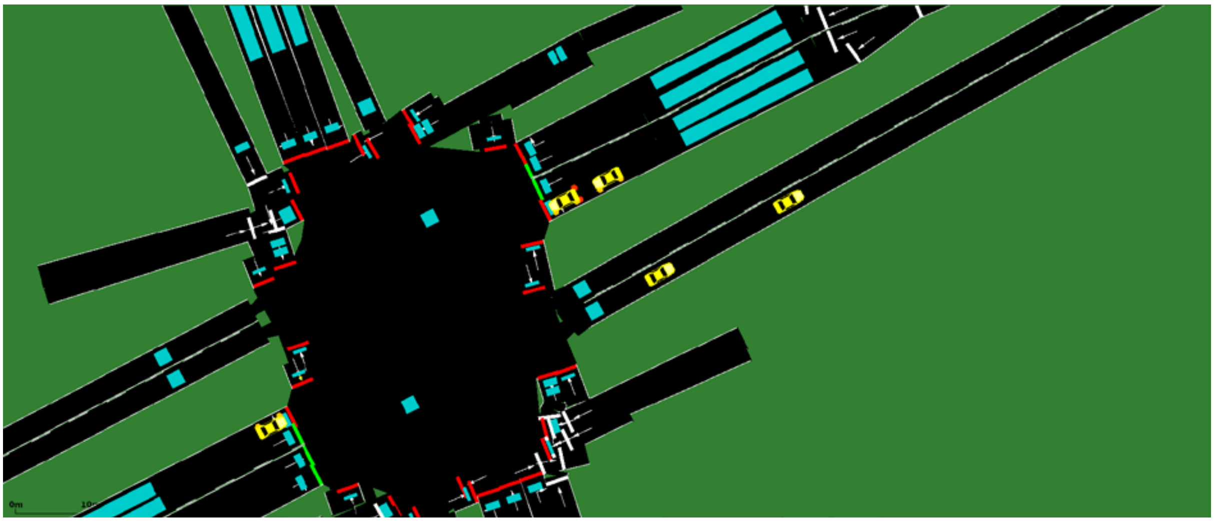


Figure 3 – Non-connected vehicles can arrive at the stop line on a different movement than predicted.

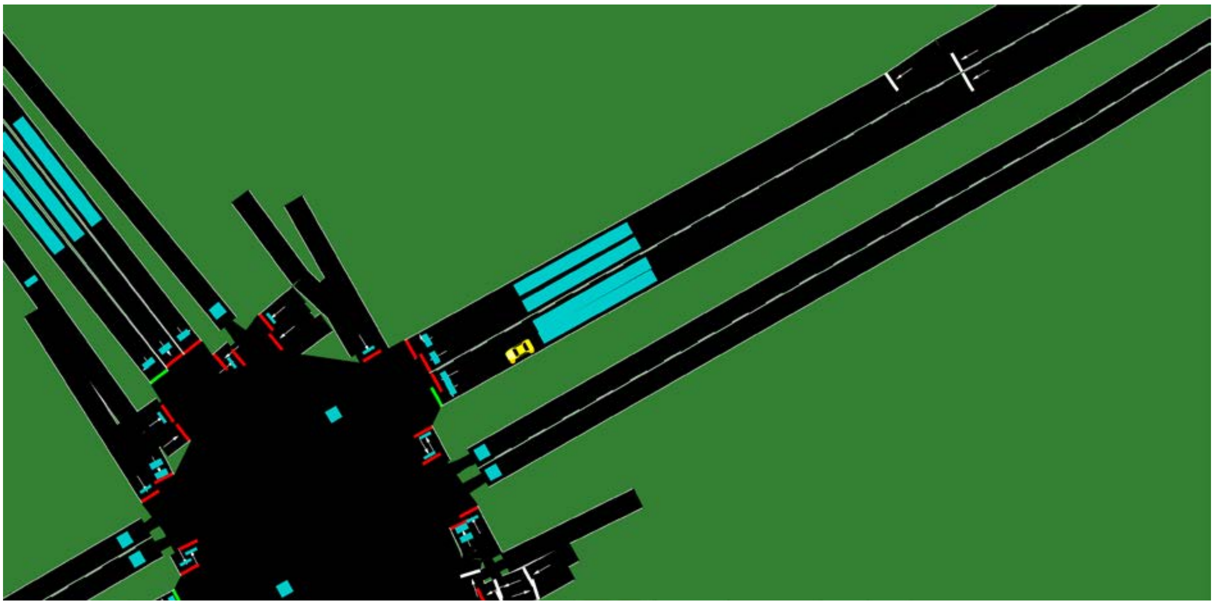


Figure 4 – A connected vehicle transmits its lane information and receives green in advance.

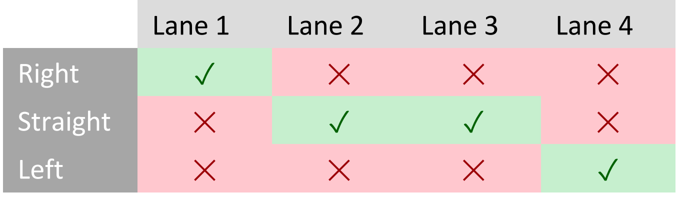
Similar challenges arise when estimating the velocity of the vehicles. The speed limit for the link is often a good approximation. However, certain special or heavy-duty vehicles in urban conditions will not be able to reach this speed. A wrong prediction in their arrival time can result in wasted green time and an unnecessary stop. Vehicles equipped with cooperative transmission systems can communicate their position and velocity values to the controller, so a late arrival can be predicted and taken into account during signal planning.

The simulation network

To evaluate the impact of the improved detection, we have performed traffic simulations on a network representing a part of the arterial road N270 passing through Helmond. The network consisted of seven consecutive intersections controlled by the adaptive algorithm ImFlow, one of them being HEL701, an intersection, which was already described in the previous section. It is worth noting that the same algorithm is deployed to control the intersections in reality. A standard mode of operation of the control system is to predict queues based on inductive loop detection. We compared it with the custom version enabled with queue detection based on real-time probe vehicle data, collected at 1Hz frequency.

We tested three configurations. In the baseline scenario, we assumed that all detection is based on inductive loops, and that all vehicle approaches are equipped with entry loop detectors. In the first cooperative scenario, the RSU was configured to receive probe vehicle data on the approach from HEL702 to HEL701. This scenario can represent a situation where a link approach is dedicated to connected and automated vehicles (CAV). In the second cooperative scenario, probe vehicle data was transmitted on all approaches to HEL701. Messages were assumed contain the information about the reference position, the lane position and the velocity of the vehicle, available in CAM according to the most recent ETSI specification [11]. Our architecture required us to match the lane information to the movement information. For deployment, this translation can be done at the receiving side of RSU, and in the case of the last part of the HEL702->HEL701 link it is depicted in Table 1 (lanes counted from the right).

Table 1 – Lane to movement translation table for the HEL702->HEL701 link



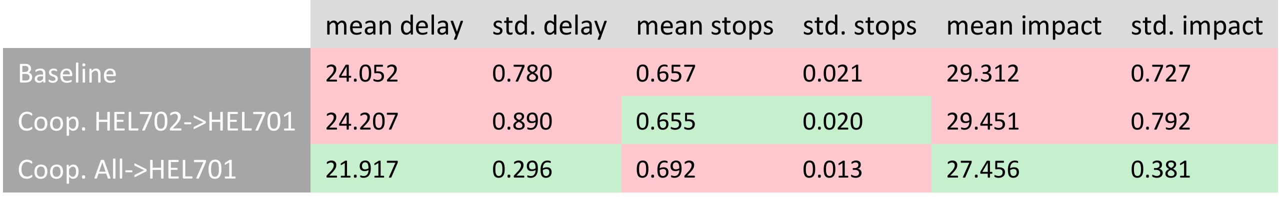
	Lane 1	Lane 2	Lane 3	Lane 4
Right	✓	✗	✗	✗
Straight	✗	✓	✓	✗
Left	✗	✗	✗	✓

For all three CAV penetration rate scenarios, the total traffic volume was based on actual demand data provided by the municipality of Helmond for a typical evening peak hour. The approach HEL702->HEL701 was a part of the arterial road, which had approximately 5 to 10 times higher demand than the demand on the side roads.

Traffic control improvements: results and evaluation methodology

The results were evaluated using the method implemented and described in [12]. After 10 simulation runs of 2 hours each, we compared the average delay (in seconds) and the average number of stops per road user at the intersection 701, and aggregated both of these numbers in a single indicator value *impact* of dimension seconds. Originally, the metric of impact was defined in [10] as the average number of stops of road users at a single intersection passage multiplied by 8 and summed up with the average wait time. We applied the Bessel’s correction to calculate the standard deviations. The results are summarized in Table 2 below.

Table 2 – Traffic performance results



	mean delay	std. delay	mean stops	std. stops	mean impact	std. impact
Baseline	24.052	0.780	0.657	0.021	29.312	0.727
Coop. HEL702->HEL701	24.207	0.890	0.655	0.020	29.451	0.792
Coop. All->HEL701	21.917	0.296	0.692	0.013	27.456	0.381

Taking into account the standard deviations, we did not observe noticeable differences between a baseline scenario, and the scenario where additional detection is enabled at a single approach. However, with cooperative detection enabled for all vehicle links the improvement becomes apparent. Compared to the baseline, the delay time was reduced by approximately 9% and the impact by approximately 6%.

An increase in the number of stops of about 5% was observed, this was likely due to the TLC optimizer forfeiting rewards in stops in favour of rewards for the optimization objective of combined delay and stops. The calibration of the algorithm was deliberately not adjusted with respect to the baseline to allow for a fair comparison. However, due to inaccurate information certain measures had to be taken in the calibration to be more robust against queue length estimation errors. The relatively low importance of stops is the most important here. It is inefficient for the controller to extend the green light for a potential vehicle that may arrive, but may also arrive in a different lane for another turn direction that is not green. With better information the optimizer is more effective at optimizing for delay, which is at the cost of stops, because it has a lower importance than in the evaluation metric.

Conclusion

We have presented a method of enhancing loop-based adaptive intersection control with floating car data from CAM messages. We have performed a case study by simulating a real traffic network of seven intersections in Helmond. Despite the fact that the baseline scenario was already equipped with generous entry link detection, we have shown that the CAM-enhanced data improved the performance in a high demand traffic scenario. For the improvement to be observable at a large-scale level, it is important that cooperative detection is configured for all approaches leading towards the intersection.

These findings show high potential for improving traffic control performance with the increasing share of C-ITS equipped vehicles on the road. The network tested was equipped with the most complete detection field in the current state-of-the-art and already showed 6% improved performance. For intersections currently operating in vehicle actuated mode or with highly fluctuating traffic demand will show even bigger improvement. In situations where a queue has to stay under a certain length, for example at the end of a motorway exit, or a situation with short turning lanes, the extra information should also prove valuable.

Acknowledgement

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