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USING VEHICLE-TO-INFRASTRUCTURE COMMUNICATION TO REDUCE TRAFFIC EMISSIONS AT SIGNALIZED INTERSECTIONS

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ABSTRACT

This paper presents the first results of a cooperative algorithm for reducing traffic emissions at signalized intersections. The algorithm uses communication between vehicles and traffic signals to obtain information about the traffic signal status. First, the paper compares a vehicle actuated controller with an adaptive controller. The adaptive controller reduces the total emissions by 13%, 15% and 10% for CO_2, NOx and PM_{10} respectively. Second the cooperative algorithm is implemented on top of the actuated controller. This reduces both CO_2 and NOx emissions by about 7.5%, and PM_{10} by 3.9%. In the future, the cooperative algorithm will be implemented on top of the adaptive controller.

KEYWORDS

Traffic emissions, Actuated controller, Adaptive controller, Cooperative systems

INTRODUCTION

Vehicle emissions are known to be the main source of air pollution in urban areas. To reduce these emissions, special attention needs to be paid to vehicular traffic at intersections. This is due to fact that most of the traffic-related characteristics which increase traffic emissions occur frequently at intersections. These include delay, stop-and-go, deceleration, idling and acceleration (Pandian et al., 2009). As such, efficient control mechanisms are required for traffic signal controllers. Traffic signal controllers can be categorized into fixed-time, actuated and adaptive controllers. For fixed time controllers, historical data are used by engineers to develop fixed signal timing plans. Actuated controllers use detectors to sense vehicles approaching and decide whether to extend or terminate a current green phase according to the demand on the active green phase. Adaptive controllers use a traffic model to select the optimal decision based on objectives that take into account the demand on the entire intersection (van Katwijk, 2008).

Fixed controllers can not react to sudden changes in traffic conditions and can suffer from ageing problems if they have not been updated for many years (Hounsell & McDonald, 2001). The main drawback of actuated controllers is that traffic on other approaches is not considered which causes "a tunnel vision" problem. Current adaptive controllers do not consider environmental aspects explicitly. Adaptive controllers, as other traffic signal controllers, focus mainly on improving traffic throughput and reducing delays. Although this can also help in reducing traffic emissions, recent studies have proved that this is not always the case. Kun & Lei (2007) found that the implementation of an exclusive lane for buses improved traffic operation but increased the overall emissions. Generally, adaptive controllers use a queue model to perform optimization based on the evolution of the queues in the network. The current queue models do not consider vehicle characteristics. One reason for this is the limited information provided by traditional detection devices which can only detect vehicle presence, volumes and sometime speeds.

This paper studies the use of vehicle-to-infrastructure (V2I) communication to reduce traffic emissions at signalized intersection. Using V2I communication, traffic signal status can be sent to approaching vehicles to avoid unnecessary hard accelerations/decelerations. First the test site is described including the configuration for actuated and adaptive controllers as well as the cooperative algorithm. Second the modeling framework is presented. Then the first results are discussed. Finally the conclusions and future research are given.

TEST SITE AND SIGNAL CONTROLLERS

The test site consists of a single intersection located at the Bentinckplein in the city of Rotterdam, The Netherlands. The intersection has four legs with the main street (Statenweg) running north-south and the branch street (Bentinckplein) running east-west. Public transportation lines for buses and trams are included together with pedestrian and cyclist crossing facilities.

The test site has an actuated signal controller consisting of two controllers denoted as SC11111 and SC33010. The signal controller SC11111 is responsible for the switch of two trams and includes two signal groups. The signal controller SC33010 is responsible for the whole intersection and has 39 signal groups for motorized, trams and buses as well as cyclists and pedestrians.

The look-ahead adaptive controller developed by van Katwijk (2008) was used. Its main features compared to the actuated controller are:

- The entire intersection is taken into account and not only the currently active green phase
- The decision is based on a long term analysis using information from further upstream i.e. looking to the next 120 sec
- Have a flexible sequence of green times for different signal groups.

The cooperative algorithm uses V2I communication to obtain information about traffic signal status. On the vehicle-side, drivers use this information to decide, in advance, whether they can pass through the intersection or not. For example, a driver who receives information about the remaining green time, knowing that it is not possible to pass through intersection, will start to decelerate earlier. This will reduce the idling time and the number of stops at the intersections.

MODELING FRAMEWORK

In this study we applied a modeling framework of a traffic model and an emission model. For traffic modeling we used the microscopic traffic simulation model VISSIM to simulate individual vehicle movements (PTV, 2007). For emission modeling we used the EnViVer model (Ligterink et al., 2008). Only the morning peak hour (7:00-8:00) was modeled.

RESULTS AND DISCUSSION

Actuated vs. adaptive

The actuated controller was compared to the adaptive controller in terms of total emissions as well as emissions' per vehicles types (see Table 1). Travel times per each signal group were also measured. It was found that the adaptive controller reduced the total emissions as well as emissions per vehicles' types for all the pollutants. Travel times were reduced for all motorized signal groups, but increased for pedestrian and cyclists especially those who cross the main street. This is because the adaptive controller gives less priority for pedestrian and cyclists.

Table 1: Traffic emissions: Adaptive vs. Actuated controller

Scenario/Pollutants		*CO_2 (g)*	*NOx (g)*	*PM_{10} (g)*
Actuated controller	*Total*	536794.9	1934.3	102.3
	LDV	363525.5	815.4	62.6
	HDV	163963.7	1040.9	36.1
	Bus	9305.6	68	3.7
Adaptive controller	*Total*	- 13.2%	- 15.6%	- 10.4%
	LDV	- 12.1%	- 15.8%	- 10.6%
	HDV	- 15.3%	- 17.2%	- 10%

Actuated vs. Actuated Cooperative

For the cooperative algorithm it was assumed that during red phases, vehicles will decelerate smoothly (using a deceleration rate of - 0.45 m/s^2) to reduce the idling time and the number of stops at the intersections. During green phases, vehicles will decelerate smoothly if their travel times to the stop line are greater than maximum green time. The External Driver Model in VISSIM was used to change the behavior of approaching vehicles. The speed/acceleration-time profiles for a vehicle with and without receiving information about red phase are shown in Figure 1. It is clear that, a vehicle with information about red phase starts decelerating earlier and hence has smoother deceleration profile and shorter idling time at the stop line.

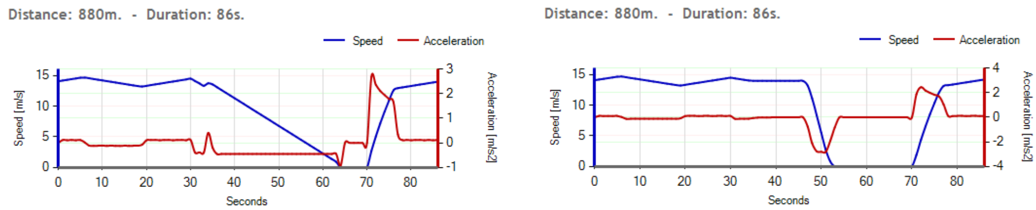

Figure 1: Speed/acceleration-time profile for vehicle with/without receiving information

The total emissions changes as well as change per vehicle type appear in Table 2.

Table 2: Total emissions change and change per vehicle type

Scenario/Pollutants		*CO_2 (g)*	*NOx (g)*	*PM_{10} (g)*
Actuated controller	*Total*	537325.1	1936.1	102.4
	LDV	363745.7	851.6	62.6
	HDV	164440.6	1017.6	36.2
	Bus	9143.729	66.8	3.6
Actuated cooperative controller	*Total*	- 7.4%	- 7.7%	- 3.9%
	LDV	- 6.7%	- 8.1%	- 4.4%
	HDV	- 9.5%	- 8.1%	- 3.7%

The cooperative algorithm reduces CO_2, NOx and PM_{10} emissions by 7.4%, 7.7% and 3.9% respectively.

CONCLUSIONS

Using V2I communication, information about traffic signal status can be sent to approaching vehicles at signalized intersection. This information will help drivers to avoid unnecessary hard accelerations/decelerations and hence reduce emissions and fuel consumption. In this study the first results of a cooperative algorithm were presented. The algorithm was compared with an actuated controller, where both CO_2 and NOx emissions were reduced by about 7.5%. However, PM_{10} emissions were only reduced by 3.9%. For future work the cooperative algorithm will be implemented on top of the adaptive controller.

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