Efficiency of Adaptive Traffic Signal Control in a Partially Connected Vehicle Environment

Anton Agafonov, Alexander Yumaganov, Vladislav Myasnikov
Samara National Research University
ant.agafonov@gmail.com

САМАРСКИЙ УНИВЕРСИТЕТ
SAMARA UNIVERSITY

The emerging trend in the development of connected and autonomous vehicles provides new opportunities for solving practical problems in a transportation area, in particular, an adaptive traffic signal control problem, which is considered in this paper. The aim of the paper is to evaluate the performance of a traffic signal control algorithm in a partially connected vehicle environment with a mixed traffic flow, including both connected and human-driven vehicles. A control algorithm based on maximizing the weighted flow of vehicles, passing through an intersection in a specified time interval is explored. Experimental studies of the algorithm under various penetration rates of connected vehicles in a real-world traffic simulation scenario confirm the effectiveness of the considered approach.

Introduction

Adaptive traffic signal control at signalized intersections is one of the ways to increase the efficiency of the use of transport infrastructure, reduce the level of traffic congestion and lower the time that transport correspondence takes. In adaptive control, the selection of the next traffic signal phase depends on the current traffic situation at the intersection that allows responding to changes in a traffic state.

Adaptive Control Method

As adaptive control of traffic light phases, a method based on maximizing the predicted weighted flow of vehicles crossing an intersection at a selected traffic light phase is used. The algorithm consists of the following steps:

- The arrival time of each vehicle at the intersection is estimated using a deterministic or a neural network model based on the vehicle's position, speed, acceleration, and other factors.
- The total number of vehicles that will pass the intersection for each traffic signal phase is calculated. This value is "weighted" (i.e. the weighted traffic flow is calculated) using the total waiting time of each vehicle at the intersection.

Formal description

The set of phases of the selected traffic signal is denoted as P, $\tau_{\min}$ is a phase switching interval, t_{cur} is the duration of the current (active) phase $p_{cur} \in P$ of the traffic signal, $p_{out} \in P$ is the selected next (switching) phase. Using these notations, the algorithm in the pseudocode form can be defined as follows.

Algorithm 1: Adaptive Traffic Signal Control Algorithm

Input data: $\tau_{\min}, t_{cur}, p_{cur}, P$
Output data: p_{out}
if $t_{cur} < \tau_{min}$ **then**
  $p_{out} = p_{cur}$;
  $t_{cur} = t_{cur} + 1$;
else
  $p_{out} = \text{argmax}\left(\{PWFlow\left(p\right) \text{ for } p \text{ in } P\}\right)$;
  $t_{cur} = 0$;
end

The main operation of the algorithm is the calculation of the predicted flow by the $PWFlow\left(p\right)$ function for each phase $p \in P$:

$$PWFlow\left(p\right) = \sum_{l \in L_p^{income}} \sum_{c \in C_l^{obs}} \eta\left(c, l\right) I\left(t\left(c\right) < \tau_{min}\right),$$

where L_p^{income} is a set of road lanes of the transport network, movement on which is allowed when the phase $p \in P$ is on, C_l^{obs} is a set of connected vehicles on lane $l \in L_p^{income}$, $t\left(c\right)$ is an estimate of the time that is necessary for the vehicle $c \in C_l^{obs}$ to reach the intersection, $\eta\left(c, l\right)$ is a coefficient taking into account the waiting time of the vehicle c .

Considered vehicle types

To consider a partially connected environment with a mixed traffic flow, we define three types of vehicles that can be distinguished in a traffic flow:

1. Connected vehicles (CV). For this type of vehicle, it is assumed that the route, position, speed, and other real-time vehicle information are known.
2. Observable vehicles (OV). These are human-driven vehicles that move within the range of the CV sensors (cameras, lidars) in front of or behind the CV vehicles. This group also includes vehicles that are in the range of CCTV cameras at intersections. For this type of vehicle, the position and speed are assumed to be known.
3. Non-observable vehicles (NOV). These are vehicles that cannot be detected. As a result, information from these vehicles is not used to estimate the predicted traffic flow at intersections.

These types of vehicles are schematically shown in Figure 1.

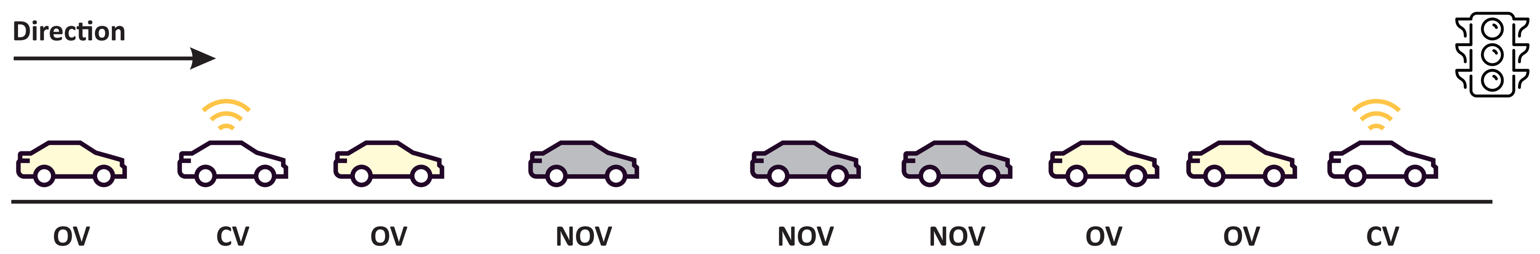

Figure 1: Different types of defined vehicles.

Experiments

In the experimental study, we evaluate the effectiveness of the adaptive traffic signal control algorithm in a partially connected environment. We compare the algorithm with different available information used to estimate a predicted weighted flow in the function $PWFlow\left(p\right)$:

- "CV only": only real-time information from connected vehicles is used.
- "CV + observed": information from CV and OV is used.

Scenario

Experimental research of the algorithm was carried out in the SUMO modeling system. The part of a real-world urban road network was used in a simulation scenario. The network contains 2928 intersections, of which 316 are signalized. The simulation was performed in the morning rush hours from 7 am to 9 am.

Metrics

- Average travel time (in seconds) that is the travel time that the vehicles take to complete their trips from their initial position to their destination, averaged over the vehicles and episodes.
- Average waiting time at the intersection (in seconds) that shows a standing time of a vehicle at the intersection, averaged over the vehicles and episodes.

Results

The dependence of the average travel time and the average waiting time on the CV market penetration rate are shown in Figure 2 and Figure 3, respectively.

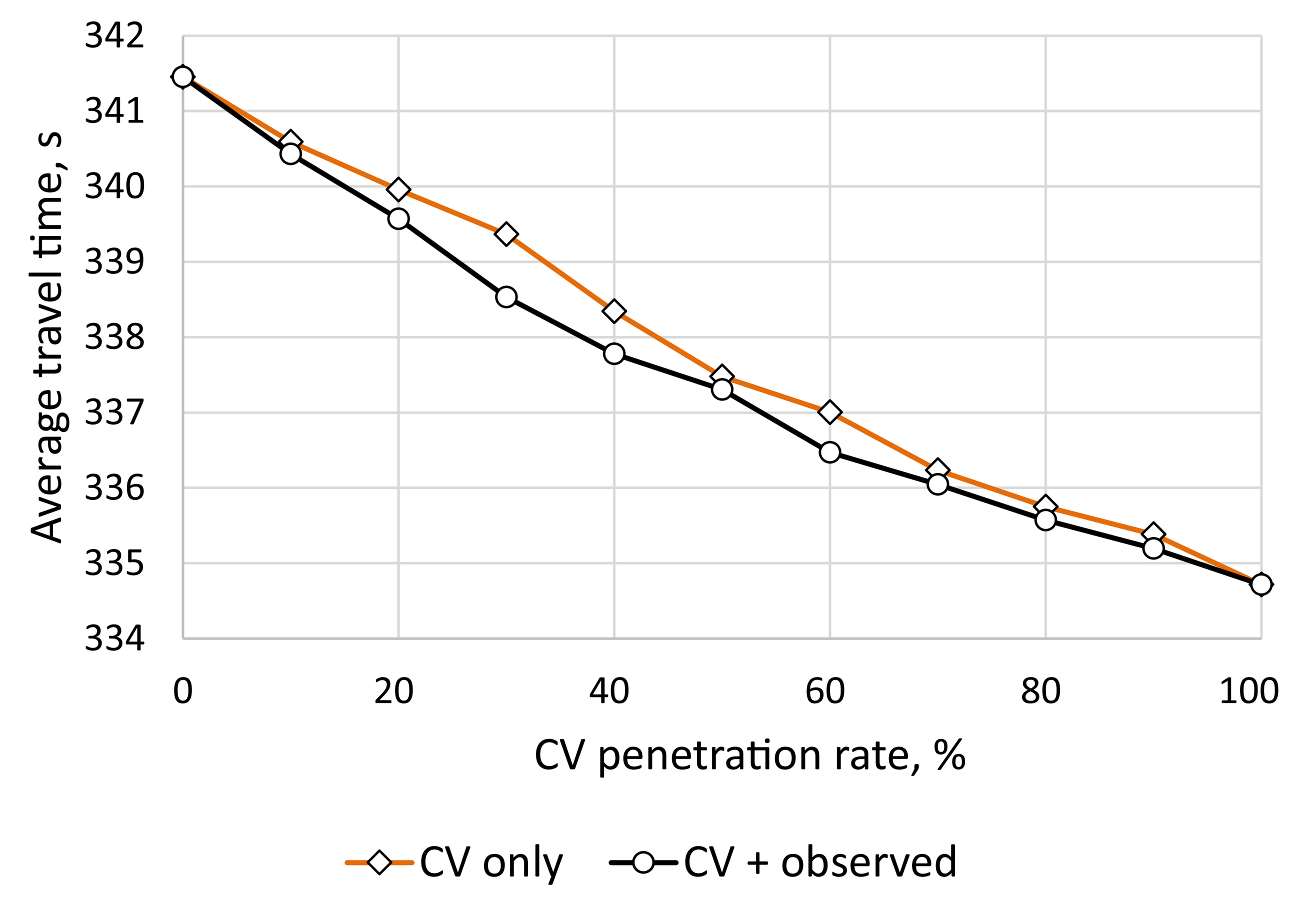

Figure 2: Dependence of the average travel time on the CV market penetration rate.

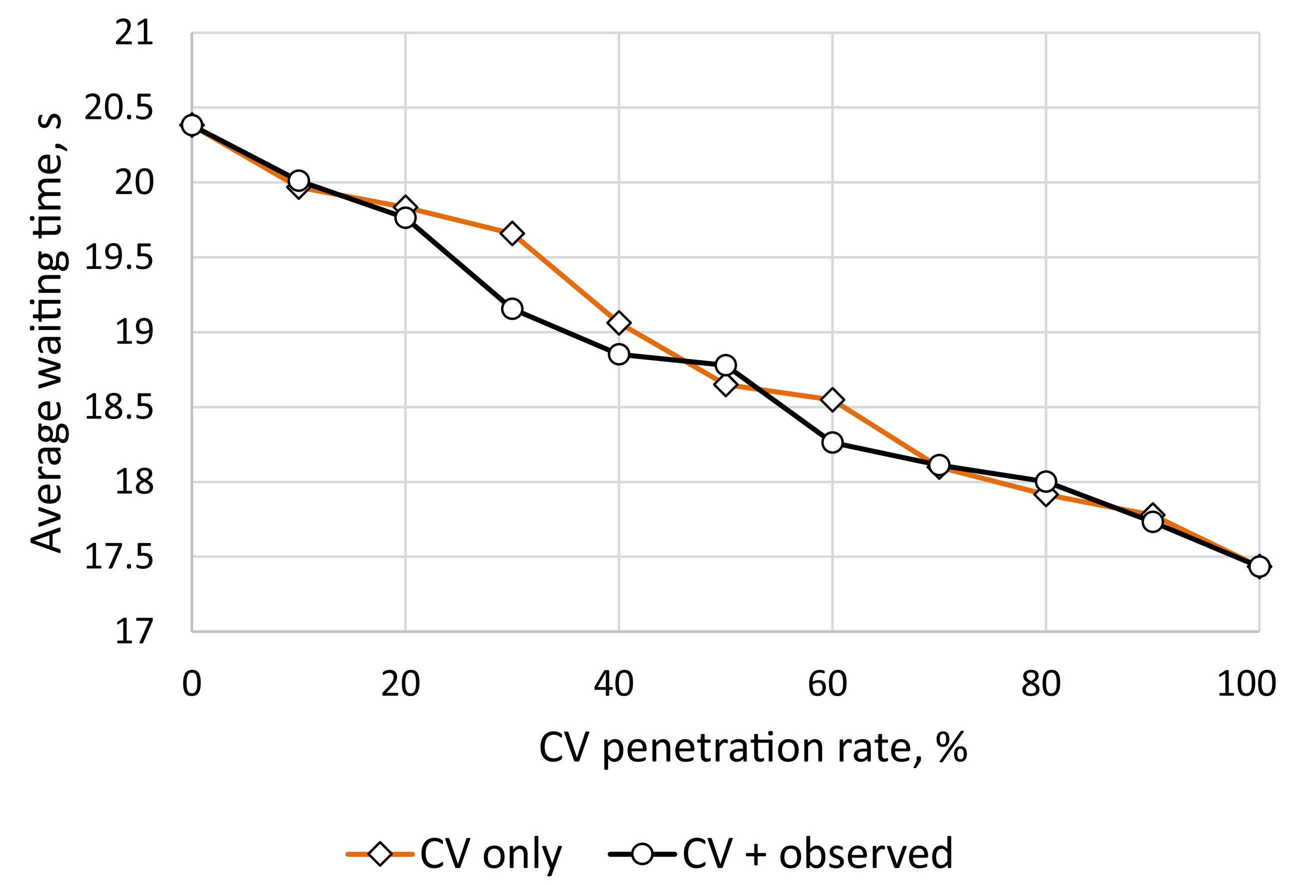

Figure 3: Dependence of the average waiting time on the CV market penetration rate.

Conclusions

In this paper, the effectiveness of a traffic signal control algorithm based on a maximizing of predicted weighted traffic flow is evaluated in a real-world urban traffic scenario in a partially connected environment. In the algorithm, to estimate the traffic flow characteristics used both real-time data from connected vehicles (CV) and information from observed human-driven vehicles that move within the range of the CV sensors or CCTV cameras at intersections.

The experimental results show the effectiveness of the considered approach for different values of CV market penetration rates.

Acknowledgements

The work was supported by the Russian Science Foundation grant No. 21-11-00321, https://rscf.ru/en/project/21-11-00321/