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Sustainability assessments of cooperative vehicle intersection control at an urban corridor

Joyoung Lee [a,*], Byungkyu (Brian) Park [a], Kristin Malakorn [b], Jaehyun (Jason) So [a]

[a] Department of Civil and Environmental Engineering, University of Virginia, 351 McCormic Road, Charlottesville, VA, USA
[b] Vanasse Hangen Brustlin (VHB) Inc., 101 Walnut Street, Watertown, MA, USA

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ABSTRACT

Connected Vehicle (CV) technology, formerly known as IntelliDrive, has emerged and is expected to provide unprecedented improvements in mobility. A recent study developed a cooperative vehicle intersection control (CVIC) algorithm for an urban intersection that does not require a stop-and-go style traffic signal and demonstrated significant mobility improvements over an actuated traffic signal control. This paper expanded the algorithm and implemented it to a corridor consisting of multiple intersections. In addition, this paper investigated sustainability aspects of the CVIC system for an urban traffic control system by applying surrogate safety assessment model (SSAM) and VT-Micro model to measure safety and environmental impacts, respectively. A simulation-based case study was performed on a hypothetical arterial consisting of four intersections with eight traffic congestion cases covering low to high volume conditions. When compared to the coordinated actuated control, the CVIC system dramatically reduced the total delay times for the volume cases considered (i.e., from 82% to 100% delay time savings observed). The CVIC system also reduced the number of rear-end crash events by 30–87% for the volume cases considered, indicating that safer driving conditions would be achieved with the CVIC system. Finally, the CVIC system contributed to improving the air quality (i.e., 12–36% CO_2 emission reduction) and saving fuel consumptions (11–37% of gas saving).

1. Introduction

With the US Department of Transportation's connected vehicle technology initiative (USDOT, 2011), the transportation system is expected to face a new paradigm shift from an existing reactive/proactive control to possibly a fully cooperative vehicle and infrastructure control. The existing control, which is mostly based on fixed point sensors still requires significant operations and maintenance costs and it is generally understood that such control would not able to cope up with ever-increasing transportation demands. Furthermore, the existing control would not be able to adequately address issues related to crashes, fuel consumption and greenhouse gas emissions in the transportation sector. Given the primary goals of US DOT are to improve mobility, safety, energy and the environment, the effect of the cooperative vehicle and infrastructure control on these key measurements should be well evaluated such that policy goals and connected vehicle technology deployment decisions can be properly established.

As is widely known, the transportation system is one of the critical sectors responsible for greenhouse gas emissions (affecting climate change), oil consumption (contributing to energy crises), and fatalities due to crashes (resulting in a lead-

* Corresponding author.
E-mail addresses: jl9hc@virginia.edu (J. Lee), bpark@virginia.edu (Byungkyu (Brian) Park), kjm8pc@virginia.edu (K. Malakorn), js9pb@virginia.edu (Jaehyun (Jason) So).

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ing cause of death for young adults). It is highly expected that several control algorithms relying on fully cooperative controls based on the connected vehicle technology will be developed and evaluated through simulations and eventually implemented in the real world.

In fact, a recent research developed a fully cooperative vehicle intersection control (CVIC) algorithm and evaluated its mobility improvements over the existing actuated control using an isolated intersection (Lee and Park, 2012). In order to consider multiple intersections along the corridor in urban transportation systems and to explicitly assess sustainability measures including fuel consumption, emissions and crashes, earlier research had to be significantly expanded. The purpose of this paper is to examine the sustainability impact of the CVIC system by expanding the algorithm to be implemented at multiple intersections along the corridor.

The remainder of this paper is organized into four sections. The literature review section summarizes the state-of-the-art of cooperative intersection controls for autonomous vehicles and presents the previous research on simulation-based safety, energy and environment evaluations. The methodology section provides the expanded CVIC algorithm in detail and addresses the overall integrated simulation framework to assess the mobility, safety, energy, and environmental impact of the CVIC algorithm. The case study section presents the design of simulation experiments and the results on the mobility, safety, energy and environment measures. Finally, conclusions and recommendations for future research are provided in the concluding remarks section.

2. Literature review

2.1. Cooperative intersection control

With the recent advancement of cutting-edge vehicular wireless communications technologies, cooperative intersection controls have gained increased attention in the research community. This section presents a summary of some of the research efforts to date.

Dresner and Stone (2008) proposed a multi-agent based intersection management algorithm by utilizing an intersection reservation system for autonomous vehicles within a cooperative vehicle and infrastructure system (CVIS) environment. Assuming a hypothetical four-way isolated intersection with three lanes for each approach in which the maximum volume was 750 vph and varying autonomous vehicle ratios such as 100%, 99%, 95%, and 90%, the proposed algorithm showed 99%, 94%, 78%, and 7% of delay time savings, respectively, compared to a pre-timed traffic control system.

de La Fortelle (2010) also proposed an intersection reservation algorithm for fully autonomous vehicles, assuming the perfect CVIS environment. Thus, the author assumed that the intersection in the research not only collects individual vehicles' driving information such as speed and location, but also provides the best reservation solutions for each vehicle such that it can keep crossing the intersection without potential collision risks at the intersection. The author did not include any explicit results in the paper but demonstrated the actual implementation of the proposed algorithm in the field through a video clip (Laraimara, 2010).

Lee (2010) and Lee and Park (2012) proposed an algorithm for a cooperative vehicle intersection control (CVIC) environment and assessed its potential benefits on a hypothetical isolated intersection. The proposed algorithm examined the predictive trajectories of vehicles that would be at risk for coming into conflict with one another at an intersection area. When multiple vehicles on conflicting approaches are projected to cross the intersection area at the same time, with a safe gap constraint between two consecutive vehicles, the algorithm optimizes their trajectories in search of optimal speeds and accelerations that will prevent the occurrence of trajectory overlaps. Comprehensive microscopic traffic simulation-based experiments covering various traffic congestion conditions were performed on a hypothetical isolated intersection. Statistically significant benefits were observed: for mobility 99% and 33% of improvements on stop delays and travel time, respectively, were estimated and about 34% of both CO_2 emission reductions and fuel savings were also reported.

Agbolosu-Amison et al. (2012) quantified the potential benefits of a dynamic gap-out feature for an actuated signal control within the connected vehicle technology. Knowing the arrival time of each vehicle approaching to an intersection, the gap-out was dynamically implemented based on the arrival time of each vehicle. This resulted in efficiency improvements at the actuated control intersections. Assuming 100% market penetration rate of connected vehicle technology deployment, the authors examined the performance of the dynamic gap-out feature on a hypothetical intersection using a simulation-based test-bed and demonstrated approximately 5–20% of benefits can be obtained even for congested conditions.

2.2. Simulation-based safety estimations

It is generally understood that transportation safety is challenging to evaluate, especially where no post crash data is available because new treatments were never deployed. The most straightforward way to evaluate safety would be through surrogate measures. There have been a few research efforts utilizing surrogate safety measures based on individual vehicular data to relate them actual crash data to develop crash prediction models (Son et al., 2011) and to examine the relationships between crashes and surrogate measures (Park et al., 2011). However, obtaining such archived data would either require tremendous effort or be practically impossible. Addressing this challenge, simulation-based safety assessment has gained great