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Characterising Green Light Optimal Speed Advisory trajectories for platoon-based optimisation ☆,☆☆

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ABSTRACT

Conceptually, a Green Light Optimal Speed Advisory (GLOSA) system suggests speeds to vehicles, allowing them to pass through an intersection during the green interval. In previous papers, a single speed is computed for each vehicle in a range between acceptable minimum and maximum values (for example between standstill and the speed limit). This speed is assumed to be constant until the beginning of the green interval, and sent as advice to the vehicle. The goal is to optimise for a particular objective, whether it be minimisation of emissions (for environmental reasons), fuel usage or delay. This paper generalises the advice given to a vehicle, by optimising for delay over the entire trajectory instead of suggesting an individual speed, regardless of initial conditions – time until green, distance to intersection and initial speed. This may require multiple acceleration manoeuvres, so the advice is sent as a suggested acceleration at each time step. Such advice also takes into account a suitable safety constraint, ensuring that vehicles are always able to stop before the intersection during a red interval, thus safeguarding against last-minute signal control schedule changes. While the algorithms developed primarily minimise delay, they also help to reduce fuel usage and emissions by conserving kinetic energy. Since vehicles travel in platoons, the effectiveness of a GLOSA system is heavily reliant on correctly identifying the leading vehicle that is the first to be given trajectory advice for each cycle. Vehicles naturally form a platoon behind this leading vehicle. A *time loop* technique is proposed which allows accurate identification of the leader even when there are complex interactions between preceding vehicles. The developed algorithms are ideal for connected autonomous vehicle environments, because computer control allows vehicles' trajectories to be managed with greater accuracy and ease. However, the advice algorithms can also be used in conjunction with manual control provided Vehicle-to-Infrastructure (V2I) communication is available.

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1. Introduction

Despite having been in existence for decades, current intersection control systems are not as efficient as they could be. By means of modern and upcoming technology it is possible to improve their performance. Differing metrics can be used to measure the performance of traffic control systems. In particular, these metrics are delay, throughput, stoppage time, fuel usage and emissions. Specifically, this paper explains how delay (or equivalently travel time) experienced by vehicles can be minimised by giving acceleration advice to them as they approach the intersection.

Green Light Optimal Speed Advisory (GLOSA) systems have been proposed to take advantage of upcoming Intelligent Transport Systems technology. They allow drivers to be given advice, via Infrastructure-to-Vehicle (I2V) communication, about what speed to drive at in order to catch the next green light at an upcoming intersection. This requires vehicles to send their current movement data, including their positions and speeds via V2I communication to the signalling system using a predefined protocol that communicates this information. For example, SAE J2735 (Dedicated Short Range Communications Technical Committee, 2016) includes specification of a Basic Safety Message intended for this purpose. The round-trip time required for communication between the vehicle and infrastructure is assumed to be negligible over the short distance between vehicles and the infrastructure, that is, a few hundred metres at most. This implies that latency is not a significant issue.

Many GLOSA systems described in the literature attempt to find a speed in an acceptable range for each vehicle approaching an intersection. This speed is assumed to be constant until the start of the next green interval. Some authors take a slightly more complex approach by also allowing a single acceleration or deceleration for a vehicle's trajectory.[1] Adjustments to the trajectory are achievable through judicial acceleration and braking according to Newton's laws of motion. Therefore, it makes more sense to advise drivers what their acceleration/braking rate should be at any given time, rather than their speeds, since they have more direct control over their acceleration and braking rates. In only a few papers is a more general approach taken which considers trajectories with more than one acceleration or deceleration.

Mandava et al. (2009) sought to minimise the rate of a single acceleration before cruising at constant speed. Acceleration was constrained by the engine power available. Using a stochastic simulation technique, velocity profiles were compared along a 10-intersection signalised corridor using the Comprehensive Modal Emissions Model (CMEM) (Barth et al., 2000).

Tielert et al. (2010) considered the effect of gear choice and communication distance on fuel consumption. The Passenger car and Heavy duty Emission Model (PHEM) (Hausberger, 2003) was used to study emissions. In their simulations it was found that an inefficient gear choice may void the benefits of speed adaptation.

Katsaros et al. (2011) were of the first to use the term GLOSA. They used an integrated approach – modelling vehicle traffic in SUMO (Behrisch et al., 2011), modelling communication with a tool called Fraunhofer VSimRTI, as well as modelling driver behaviour. Average stopped time and fuel consumption were measured for differing technology penetration rates.

Rakha and Kamalanathsharma (2011) optimised a vehicle's trajectory by explicitly minimising fuel consumption and emissions using the VT-Micro emissions model (Ahn et al., 2002). In the upstream portion, prior to the intersection, the vehicle is assumed to decelerate at a constant rate, before cruising at a constant speed. Downstream of the intersection, a constant throttle amount is assumed, and the throttle proportion resulting in optimal fuel usage is selected. A single vehicle, rather than a platoon, was modelled.

Kamalanathsharma and Rakha (2013) used the A* search algorithm to find an optimal trajectory, optimising fuel usage. They assume the vehicle will decelerate first, before coasting at a constant speed. Again, the trajectory was broken into an upstream and downstream portion. They also used a car-following model to examine the effect of speed advice for two consecutive vehicles approaching an intersection.

The authors, Li et al. (2014), used a genetic algorithm to find the vehicle's trajectory with optimal fuel usage. They assumed the trajectory will be composed of two intervals of constant acceleration and that the final speed, when the vehicle enters the intersection, will be the free flow speed. The VT-Micro model (Ahn et al., 2002) was used to track fuel consumption. Speed advice is given to each vehicle individually, but a car-following model determines if one vehicle is too close to the preceding vehicle. If so, the following vehicle's behaviour is governed by the car-following model instead of the speed advice.

The effect of different trajectories was considered by Gabriel and van Katwijk (2015). An early deceleration followed by constant speed, and constant speed followed by late acceleration were compared for fuel usage. These was combined with model-predictive traffic control to reduce emissions and delays even further. The EnViVer emissions model, based on VERSIT + (Ligterink et al., 2008) was used to measure CO_2 levels.

Stevanovic et al. (2013) showed that GLOSA was not a reliable means to improve traffic performance for actuated–coordinated traffic control. This is the case because vehicles may not receive trajectory advice early enough before the start of the next green interval. However, Stebbins et al. (2017) showed that GLOSA can be effectively applied to a dynamic traffic control scheme when signal timing is known far enough in advance.

[1] A vehicle's *trajectory* is defined as its location with respect to time over a particular length of road. Its trajectory can be derived from its speed profile over time and its initial location.