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An Adaptive Neuro-Fuzzy Inference System for estimating the number of vehicles for queue management at signalized intersections

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ABSTRACT

Queue management is a valuable but underutilized technique which could be used to minimize the negative impacts of queues during oversaturated traffic conditions. One of the main obstacles of applying queue management techniques along signalized arterials is the unavailability of a robust and sufficiently accurate method for measuring the number of vehicles approaching a signalized intersection. The method based on counting vehicles as they enter and exit a specific detection zone with check-in and check-out detectors is unreliable because of the likely systematic under or over counting and the resulting cumulative errors. This paper describes the application of the Adaptive Neuro-Fuzzy Inference System (ANFIS) in the development of a new fuzzy logic-based approach for estimating the Number of Vehicles in a Detection Zone (NVDZ) by using detector time-occupancy data (instead of detector counts). Microscopic simulation results are used to evaluate the accuracy of the NVDZ estimates. Tests were carried out to determine the transferability of a tuned Fuzzy Inference System (FIS) and to check the sensitivity of the calibrated FIS to detection coverage, the location of the detection zone relative to the signalized (bottleneck) intersection, the length of the detection zone, and different signal timings at the bottleneck intersection. Results show that the NVDZ estimation based on fuzzy logic seems to be a feasible approach. Although the primary objective of developing the NVDZ estimation technique has been queue management, other applications such as ramp metering and incident detection could potentially use the same technique.

1. Introduction

As congestion increases in most urban areas, queue management techniques will likely have more prominent role in traffic management along signalized arterials. The negative impact of congestion on bus transit as well as other road users can be reduced by moving queues to pre-defined locations where they have the least impact. One of the reasons why queue management is rarely used is the lack of a robust, real-time, and cost-effective technique to determine the length of a queue. In this paper, the term 'Number of Vehicles in a Detection Zone' (NDVZ) has been used instead of queue length because the speed of traffic is irrelevant in the queue management algorithms developed as the continuation of this research. A similar term to NVDZ used in the literature is 'vehicle-count within signalized link' (Vigos et al., 2008).

Fig. 1 shows one example of queue management combined with a transit queue jump. Intersection B represents the capacity bottleneck thus the queue forms upstream from B. Assume that an additional lane cannot be constructed between

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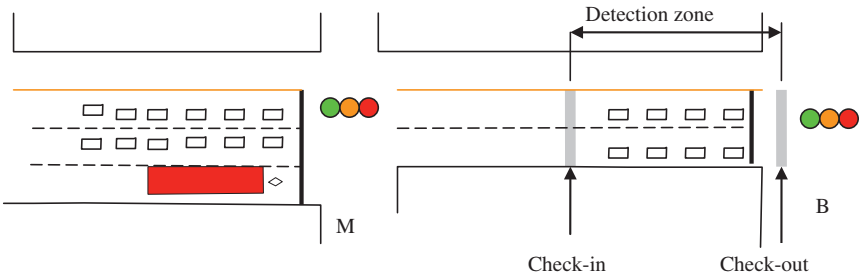

Fig. 1. Traffic control with queue management and transit queue jump.

intersections B and the metering intersection (M) due to the lack of sufficient right of-way, but it could be constructed upstream from M. The new transit lane eliminates congestion delay to transit vehicles upstream from M but with traditional control (i.e. no queue management) transit vehicles would be delayed by congestion between M and B.

To minimize total person delay and maximize vehicular capacity during congested conditions, the bottleneck intersection must always have sufficient number of vehicles on its approach during the green signal to maximize its capacity (i.e. it is never starved), but at the same time the queue of vehicles at B must be as short as possible to minimize transit delay. To achieve this type of optimized control, the green time at intersection M must be continuously adjusted based on NVDZ. Signal timing at the bottleneck intersection B is typically set to maximize capacity and the queue management algorithm modifies the signal timing at the metering intersection M. More discussion on queue management algorithms can be found in Oakes and Metzger (1995) and Mucsi (2009).

There are a number of techniques dealing with queue length measurement/estimation. One of the conceptually simplest methods, based on the difference between the cumulative traffic input and output, has been described by Webster (1958). This simple counting approach has been used in queue management algorithms (e.g. Oakes and Metzger, 1995). However, its widespread real-world implementation is limited, especially on multi-lane intersection approaches, due to the potential for erroneous vehicle counts and the accumulation of errors.

Various sensing technologies exist for vehicle detection, which have different error margins, implementation and maintenance challenges. Sensing technologies can be grouped into pavement invasive and non-pavement invasive detectors. The first group includes inductive loops, magnetometers, and magnet-based technologies and the second group includes microwave radar, active and passive infrared-based equipment, ultrasonic and acoustic detectors, and video image processing (FHWA, 2006). Inductive loop detection is generally considered to be the most accurate with over 99% accuracy when used in a single lane.

Most traffic engineering applications can tolerate some detection inaccuracies but when vehicle counts between two detection points are required, even small but systematic over or under counting is a serious problem due to the potential error accumulation. The identification of malfunctioning detectors is not always simple. If a detector is totally un-operational and provides no counts at all, identification is straightforward, but the identification of intermittent malfunctioning is problematic. It has been demonstrated (Mucsi, 2009) that even in a microsimulation environment, special care is required to minimize and correct for over or undercounting detectors. One of the main reasons for double counting or missing vehicles is lane change at the vicinity of the detectors. As vehicles cross lanes they could be missed or be detected by both detectors depending on the lateral distance between the two detectors, the length and width of the detectors, the width of the vehicle, and its trajectory.

Sharma et al. (2007) presented two techniques for estimating queue lengths at signalized intersections. Both techniques are based on the difference between the arrival and departure traffic flow profiles. The first method, the input-output method, is using the difference between the arrival profile, determined by an advance detector and special algorithm, and the departure profile calculated by an analytical formula. The second method, the hybrid technique, differs by using a detector for determining the output profile as well. To minimize the potential of error accumulation, both techniques apply an error correcting algorithm, which limits queue estimates to values between zero and a site specific maximum. Both techniques are based on a number of assumptions, including no lane changes (thus no double counting or missed vehicles due to lane change at the vicinity of detection points) and constant parameters such as saturation headway and start-up lost time.

The foundations of a conceptually different queue estimation technique have been developed by Papageorgiou and Vigos, 2008 who investigated the relationship between time-occupancy, space-occupancy, and link vehicle-counts for both uninterrupted and interrupted flow. They found that in the case of uninterrupted flow, both occupancy types are roughly proportional to traffic density. However, in case of signalized roadways, they found that the relationship was much more complex. Vigos et al. (2008) built on the findings of the previous paper and employed Kalman-Filter to produce estimates of vehicle counts for signalized links based on three loop detectors. The link volume estimator was tested in a simulation environment and favorable results were reported. However, very limited details about the simulation platform or the modeled example were reported in the paper.