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Comparing lane based and lane-group based models of signalised intersection networks

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Abstract
This paper compares two analytical approaches for modelling signalised intersection networks in relation to the assessment of signal coordination quality as a fundamental element of network performance analysis. These are (i) the traditional model based on using "lane groups" or "links" through aggregation of individual lane conditions, and (ii) a new "lane-based" model of upstream departure and downstream arrival patterns as well as midblock lane changes between upstream and downstream intersections, and the resulting proportions of traffic arriving during the green period at an individual lane level. The latter is part of a lane-based network model that involves blockage of upstream intersection lanes by downstream queues (queue spillback) and capacity constraint applied to oversaturated upstream intersections. The differences between the two models are expected to be particularly important in evaluating closely-spaced intersections with high demand flows where vehicles have limited opportunities for lane changes between intersections. The lane-based model can make use of "special movement classes" for assigning specific movements to separate lanes and separate signal phases, and tracking of their second-by-second platoon patterns through the network separately. The paper presents a staggered T network example to demonstrate important aspects of modelling signal platoon patterns by approach lane use and movement class, and to compare the resulting traffic performance measures (delay, back of queue, level of service) with those estimated using the traditional method based on lane groups or links.

Keywords: traffic signals, intersection, network, lanes, lane groups, signal coordination, platoon, movement class, congestion, queue spillback, delay, queue, stops, level of service

1 Introduction

This paper presents a comparison of two different approaches to analytical modelling of signalised intersection networks. A new lane-based analytical model developed for the SIDRA INTERSECTION software (Akçelik 2015b; Akcelik and Associates 2015) and traditional lane-group (link) based models, for example as used in the US Highway Capacity Manual (TRB 2010) and the TRANSYT software (Robertson 1968, US DOT 1988) are considered for this purpose. Various discussions of the lane-based

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network model, including the discussion of lane blockage (queue spillback) and capacity constraint, have been presented in previous papers (Akçelik 2014a,b, 2015a,b; Nicoli, et al 2015; Yumlu, et al 2015). The two analytical modelling approaches compared in this paper differ from microsimulation modelling fundamentally. It would be useful to extend the lane use and performance comparisons to microsimulation modelling.

This paper discusses the implications of using a lane-based method for the modelling of vehicle platoon patterns in coordinated signal systems as distinct from the traditional lane-group (link) based models. For the lane-based model, the paper discusses the use of Special Movement Classes to assign selected movements to separate lanes as well as the use of unequal lane use specifications to minimize lane changes between closely-spaced intersections with the purpose of increasing the quality of signal coordination model. A staggered T-intersection example is presented to demonstrate important aspects of modelling signal platoon patterns by approach lane use and movement class.

2 Lane-Based Network Model

Unlike traditional network models that use aggregate models of *lane groups* or *links*, the *lane-based* network model can provide information about upstream departure and downstream arrival patterns, queue lengths, lane blockage probabilities, backward spread of queues, proportion of traffic arriving during green, and so on at an individual lane level. These are important in modelling vehicle platoon patterns for estimating performance measures (delay, back of queue, stop rate), and particularly important in evaluating closely-spaced signalised intersections with high demand flows where vehicles have limited opportunities for lane changing between intersections.

The new lane-based network model derives second-by-second downstream arrival patterns in accordance with the above requirements. Modelling of departure patterns at upstream lanes takes into account (i) probabilities of blockage by downstream queues (*queue spillback*) and the resulting capacity reductions at blocked upstream lanes, (ii) capacity constraint at oversaturated upstream lanes resulting in reduced downstream arrival flows, and (iii) lane choices of movements from approach lanes to exit lanes at the upstream intersection (lane movement flow proportions). The modelling of arrival patterns at downstream approach lanes takes into account implied midblock lane changes.

While estimation of individual lane capacities, lane flows and lane queues is important in assessing performance of a single intersection (Akçelik 1980, 1981, 1984, 1989, 1997), this becomes even more important in network modelling. The backward spread of congestion and upstream capacity constraint makes downstream and upstream lane departure and arrival patterns, lane capacities, lane flows and lane queues highly interdependent especially in the case of closely-spaced intersections.

Traditional network models have been concerned more about modelling forward movement of vehicle platoons than backward spread of queues between intersections (queue spillback) and capacity constraint related to oversaturated intersection conditions (Taylor and Abdel-Rahim 1998). Although all these elements are important, the lack of modelling of the capacity-reducing effect of blockage of departures by downstream queues and capacity constraint for oversaturated conditions on a lane-by-lane basis cannot provide a satisfactory network model for the high traffic demand conditions experienced in more recent times.

3 Vehicle Platoon Model for Signalised Intersection Networks

In the lane-based model, the modelling of *arrival patterns* of vehicle platoons at downstream intersection lanes takes into account lane changes due to *exit short lanes* at upstream locations and *approach short lanes* at downstream locations, as well as *midblock lane changes* based on matching of upstream and downstream lane flow rates. The second-by-second upstream departure flow patterns are