MACROSCOPIC INTERSECTION MODELLING IN SIMULATION-BASED DYNAMIC NETWORK LOADING

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ABSTRACT

Node models for macroscopic simulation have attracted relatively little attention in literature. Nevertheless, in dynamic network loading (DNL) models for congested road networks, node models are as important as the extensively studied link models. A formulation defining a generic class of first order macroscopic node models is presented, satisfying a list of requirements necessary to produce node models with realistic, consistent results. Defining a specific node model instance of this class requires the specification of a supply constraint interaction rule and (optionally) node supply constraints. Following, specific macroscopic node model instances for unsignalized and signalized intersections are proposed.

KEYWORDS

Intersection, supply constraint interaction rule, node supply constraints, conflict, oriented capacity proportional

INTRODUCTION

Simulation-based dynamic traffic assignment (DTA) models can be applied for various researches on road traffic (e.g. reliability studies, traffic management, road pricing and network planning). In DTA models, traffic is propagated through the network by a dynamic network loading (DNL) model.

Macroscopic simulation-based dynamic network loading (DNL) models typically propagate traffic flow through a network by handling the flow on links and through intersections (or nodes) in a link model and a node model respectively. Traffic flow theory describing unidirectional flow propagation on links has been extensively studied, and its implementation in various forms (e.g. first and second order) has resulted in adequate state-of-the-art link models, realistically describing shockwave propagation and congestion spillback. On the

other hand, no form of advanced traffic flow theory for intersections (e.g. gap acceptance theory) has found its way into node models for macroscopic DNL. Therefore, the effect of the node model on traffic flow propagation and congestion spillback is currently not satisfactorily modeled, although it is equally important (especially in congested networks) as the influence of the link model.

FUNCTION OF THE NODE MODEL

In first order DNL models the link model provides the demand of incoming links and the supply of outgoing links as constraints to be obeyed in the node model (at a certain time). The function of the node model is then twofold. Firstly, to impose additional constraints on the outflow of each incoming link (limited supply of the node itself or *node supply constraints*); secondly, to seek for a consistent solution (i.e. the flows transferred over the node) regarding all demand and (node) supply constraints.

Constraints imposed by the node - inherent to the presence of traffic lights, conflicts between crossing flows, etc. – arise from traffic flow theory for intersections, defining how flow originating from the incoming links propagates over an intersection. The traditional gap acceptance theory - chapters 8 and 9 in Gartner et al. (2000) summarize earlier work - has a more recent counterpart in the conflict theory of Brilon & Wu (2001) and Brilon & Miltner (2005). Both theories assume an uncongested traffic state downstream, thus ignoring the possibility of congestion spillback over the node, which (among other reasons) renders them not directly compatible with macroscopic node models for DNL applications. As a consequence, node supply constraints are usually not considered in state-of-the-art macroscopic node models.

To find the resulting flows over the intersection in case of active supply constraints of the outgoing links (congestion spillback), a distribution of the available downstream supplies over the incoming links has to be determined. This distribution is not independent of the resulting flows, which severely complicates the problem - even when disregarding the node supply constraints, which are also dependent on the resulting flows. This dependency should be captured by a *supply constraint interaction rule*. Multiple plausible definitions of this rule are conceivable, but it should represent the aggregate driver behavior at a (congested) intersection as realistically as possible. Most existing macroscopic node models do not succeed in correctly accounting for the interdependency of the supply distribution and the solution, hereby rendering the solution itself inconsistent.

A GENERIC CLASS OF FIRST ORDER NODE MODELS

This paper presents a critical review of state-of-the-art node models, highlighting both their contributions and shortcomings. Based on that, a set of requirements for macroscopic node models is compiled, herewith defining a generic class of first order macroscopic node models. This node model class is not only applicable to intersections of vehicular traffic flow. In principle, it is transferrable to any kind of multi-commodity flow as long as the commodities have the propensity to move whenever possible.

Node model instances for specific intersections are obtained by introducing a SCIR and node supply constraints. By doing so, this paper gives the theoretical onset for realistic and consistent macroscopic node model formulations that combine internal node constraints and up- and downstream link boundary constraints within a single generic class. This class

encompasses all types of nodes, ranging from simple merges and diverges to roundabouts, priority and signal controlled intersections.

From this generic class, two specific node model instances (including an efficient solution algorithm) are derived: one for priority junctions and one for signalized intersections. Despite some simplifications, both models are superior to all state-of-the-art node models. For these models, two behavioral rules were postulated. Firstly, vehicles are assumed to always move whenever possible. From this follows that flows over the intersection must be maximized subject to all constraints. Secondly, a supply constraint interaction rule is defined that distributes available supply according to the incoming link capacities and turning fractions (*oriented capacity proportional distribution*). A unique solution to this maximization problem is guaranteed for any combination of demand and supply constraints. These models are simplified in the sense that node supply constraints due to conflicts between crossing flows were not considered.

These models are further extended with such node supply constraints, strongly based on the conflict theory of Brilon & Wu (2001), describing which flows are possible over an intersection considering all conflicts of merging and crossing movements. For this, the two behavioral rules mentioned before are complemented with a third behavioral rule stating that crossing conflicts are subject to strict compliance with the priority rules. The same is assumed for merging conflicts, except in case of congestion spilling back onto the intersection. Different driver behavior is assumed in this case, which is dictated by the supply constraint interaction rule based on oriented capacity proportional distribution of the downstream supply (hereby still considering crossing conflicts). Hereby, downstream supply constraints are introduced into the conflict theory to make it applicable for macroscopic node models in DNL. The resulting flows are obtained from a constrained maximization problem.

The non-linearity of the node supply constraints unavoidably renders this maximization problem non-convex, which means that multiple local maxima are possible in some cases. An important future step is extensive empirical research in order to determine which of these local maxima will prevail (e.g. based on previous history of the traffic states). Also, the proposed behavioral rules need to be validated and possibly fine-tuned or modified. Therefore, detailed data is required on intersection geometry, (shared) turning lane capacities, signal phases, distribution of downstream supply and compliance to priority rules for crossing and merging conflicts.

In conclusion, the proposed theory and node models are an important (theoretical) contribution since they are, to the best of our knowledge, the first to properly combine downstream supply distribution with node supply constraints due to crossing flows.

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