A Multi-Class Macroscopic Intersection Model

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1 Introduction

Within dynamic traffic assignment a dynamic network loading model (DNL) is required to propagate traffic over the network. The main components of a DNL are (1) the link model to propagate flow over a road and (2) the node model to connect upstream traffic demand with internal and downstream supply of an intersection. Macroscopic node simulation received increased attention in the last few years. Requirements for realistic node models are presented in [1] and [2] as a generic class of node models. The provided insights show that previous approaches are insufficient. Furthermore, new solution algorithms are available. However, the approach assumes traffic homogeneity, i.e. all vehicles have equal behaviour. This study extends the recent node models with multiple classes and therefore allows traffic heterogeneity[1].

1.1 Developments in macroscopic intersection modelling

Most of the requirements in [1] and [2] are generic in the sense that these are independent of intersection type or driving behaviour; two requirements are elements that exactly define the model to match the intersection type and characteristics. The first element captures the internal node constraints (e.g. turns with limited physical capacity). The second element is the supply constraint interaction rule (SCIR) which describes the way how (downstream and internal) supply should be distributed over competing demands,

[1]Traffic heterogeneity of different types can be captured. Classes can be defined for different vehicle types (e.g. cars, trucks) and/or different driver behaviour paradigms (e.g. aggressive, cautious)

thus, priorities and conflict resolution is captured. It is necessary to define the SCIR (i.e. behaviour on the intersection) in order to distribute demand.

An often violated requirement for intersections is the invariance principle (see [3]). The invariance principle states that if some demand is restricted by supply (i.e. upstream congestion builds up), the flow is invariant to the abundance of demand. In other words, if your model predicts spillback on a link, the model should produce the same result if demand from that link is increased to capacity.

Developing models for different types of intersections (e.g. signalized, roundabout, prioritized) has proven to be problematic[4]. Simple priority constraints can lead to non-unique solutions making it complex to find both realistic and efficient solution procedures.

1.2 Review of existing multi-class intersection models

Typically, the emphasis in multi class modelling has been with the link flow propagation models, while multi class node models have received much less attention. A common way of describing the relations between different classes is by using (speed-dependent) passenger car equivalents (pce) capturing the spatial occupancies. Examples are the Fastlane model [5] and multi class model presented in [6]. However, in the former only diverges and merges are considered, while the latter model does not comply with the invariance principle. Another approach is to assume (independent) class specific free flow speeds, and equal speeds in congestion. This is, for instance, done by Bliemer [7]. The disadvantage here is that this model does not maximize flows on individual level [1].

In this paper the usage of pce is avoided since multiple definitions of it exist, however our results are compatible with each of the previous mentioned models by unit conversion. The aim is to develop a node model as generic as possible.

2 Generic Multi-class Intersection framework

In this section a framework for generic intersections with set I of upstream or incoming links (inlinks) and set J of downstream or outgoing links (outlinks) is presented, afterwards the solution algorithm for an instance of this generic class will be given. Let $C = 1, \ldots, |C|$ be the set of classes. Each inlink releases a certain demand which is divided over the classes, and then a route keeping mechanism or turning fractions will determine directed demands. This three-dimensional (class, inlinks, outlink) demand is denoted with S_{ij}^c in $\frac{\text{veh}}{\text{h}}$ for all $c \in C, i \in I, j \in J$. Denote Q_i in $\frac{\text{veh}}{\text{h}}$ as the actual outflow capacity of inlink $i \in I$, for most multi-class node models this capacity will depend on the class mixture. The outlinks have supply available, since this supply is independent of upstream (i.e. in the intersection) traffic it cannot be assigned to either classes or inlinks. Therefore the supply of each outlink $j \in J$ is a single value denoted with R_j. The flow unit (e.g. $\frac{\text{pce}}{\text{h}}$) must be chosen such that the supply can be fully utilized independent of class mixture. It can be shown that this will be true if inflow capacities of all classes are equal (with this unit) in a single class setting. This can be realized by transforming all classes $c \in C \setminus \{1\}$ to class 1 with respect to capacity. Consequence of these transformations at outlinks are conversion factors for each outlink j and class c mapping $\frac{\text{veh}}{\text{h}}$ tot the new unit, this factor is denoted with Γ_j^c. In Figure 1 the topology of a node is presented. These definitions are compatible with the existing multi-class (link) models.

Adjustments of the requirements in [1] and [2] to this multi-class setting will, in combination with the new requirement that class mixture at inlinks remains constant, determine the generic multi-class intersection framework. The full paper will discuss each requirement in detail.

2.1 Solution Algorithm for Unsignalized Intersections

In the case of an unsignalized intersection with 'turn-taking' behaviour, an efficient solution procedure can be constructed. Supply will be distributed according to directional capacities, which is the division of the inlink capacity proportional to the directed demands. Algorithm 2.1 shows the working of this procedure is pseudocode with additional comments. The full paper will discuss the underlying assumptions and algorithm in detail.

3 Contributions

The contributions of this study include:

- The multi-class extension of the generic class of node models as presented in [1] is given, the proposed requirements are generalized for multiple classes and the conservation of class mixture is added.

- Supply constraint specifications cannot depend on class mixture since the outflow

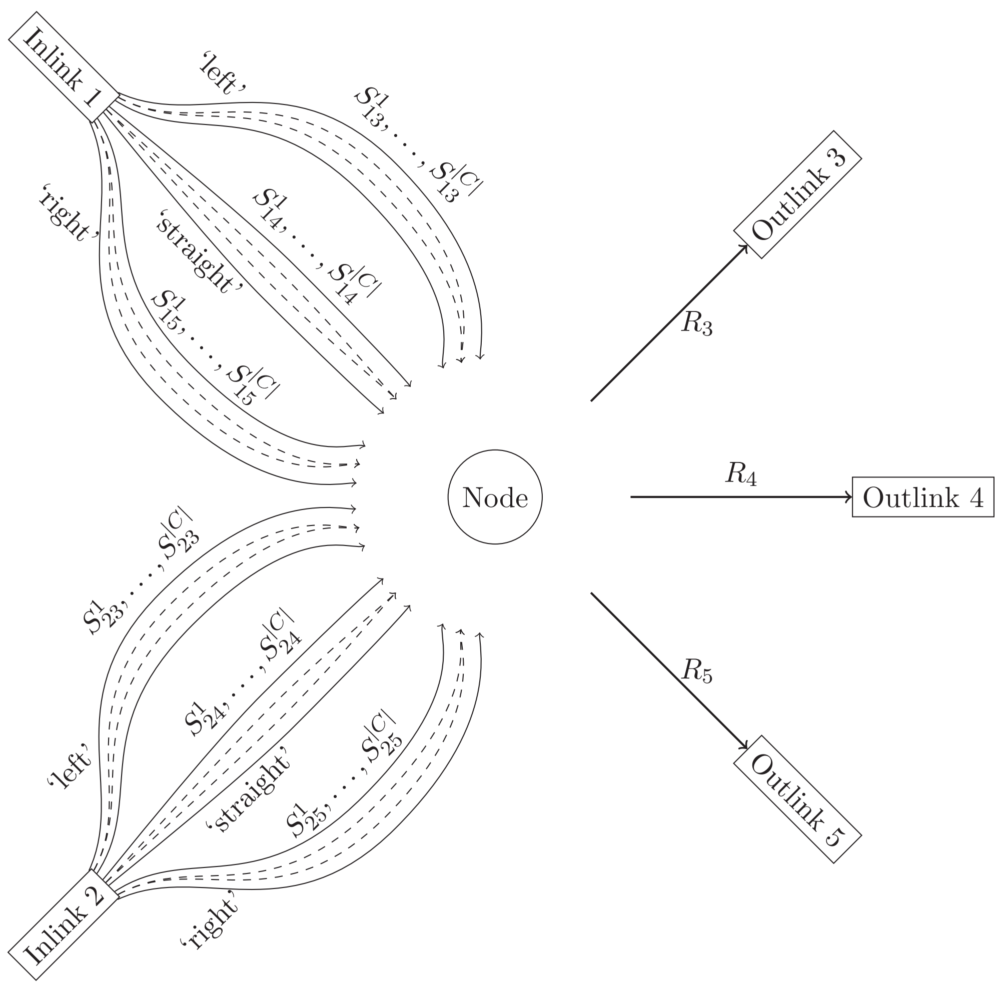

Figure 1: Node topology and variables for a node with two incoming links and three outgoing links

Algorithm 1 Multi-class Intersection

for all $i \in I, j \in J, c \in C$ **do**

  $Q_{ij}^c \leftarrow \frac{S_{ij}^c}{\sum_{j \in J} \sum_{c \in C} S_{ij}^c} Q_i$ # Determine directed capacities

end for

while $I \neq \emptyset$ **do**

  for all $j \in J$ **do**

    $\alpha_j \leftarrow \frac{R_j}{\sum_{i \in I} \sum_{c \in C} \Gamma_j^c Q_{ij}^c}$ # Determine outlink restriction factor

  end for

  $j^* \leftarrow \arg\min_{j \in J} \alpha_j$

  $\hat{I} \leftarrow \left\{ i : i \in I \wedge [\exists j \in J, c \in C \text{ s.t. } \alpha_{j^*} Q_{ij}^c > S_{ij}^c] \right\}$

  # $\hat{I}$ is the set of all inlinks that exceed demand if restricted by j^*

  if $\hat{I} \neq \emptyset$ **then**

    for all $i \in \hat{I}$ **do**

      for all $j \in J, c \in C$ **do**

        $f_{ij}^c \leftarrow S_{ij}^c$ # Set flows equal to demand

        $R_j \leftarrow R_j - \Gamma_j^c f_{ij}^c$ # Update supply by subtracting flow

      end for

      $I \leftarrow I \setminus \{i\}$ # i will not be considered anymore

    end for

  else

    $I^* \leftarrow \left\{ i : i \in I \wedge [\exists c \in C \text{ s.t. } Q_{ij^*}^c > 0] \right\}$

    # I^* is the set of all inlinks that compete for j^*

    for all $i \in I^*$ **do**

      for all $j \in J, c \in C$ **do**

        $f_{ij}^c \leftarrow \alpha_{j^*} Q_{ij}^c$ # Set flows s.t. they are restricted by j^*

        $R_j \leftarrow R_j - \Gamma_j^c f_{ij}^c$ # Update supply by subtracting flow

      end for

      $I \leftarrow I \setminus \{i\}$ # i will not be considered anymore

    end for

    $J \leftarrow J \setminus \{j^*\}$ # j^* will not be considered anymore

  end if

end while

class mixture is not available beforehand. This issue is solved with a transformation on each outlink. This will allow for different class specifications on each link (e.g. unequal pce definitions)

- An efficient solution procedure for unsignalized intersections is presented.
- The presented intersection model does not depend on how multiple classes are modelled on links. The model is compatible with available link models[2]

The algorithm is implemented in a DNL model, in the full paper examples of nodes with different setup and class mixtures are presented.

References

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