Including Right-of-Way in a Multi-Modal Large-Scale Traffic Assignment Model Suitable for Bicycle-Dense Areas

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Abstract

Intersections are typically responsible for a substantial share of the total travel time in urban areas, especially with the presence of mixed traffic. Nevertheless, delays caused by yielding for cyclists at intersections are typically not modelled in large-scale traffic assignment models. This study proposes, implements and applies a computationally efficient methodology for modelling delays caused by conflicting movements at multi-modal intersections. Nodes representing the intersections are classified into three node types which process potential movements across nodes differently. A large-scale case study carried out in the greater Copenhagen area simulating more than a million bicycle trips shows reasonable computation times and sensible added travel times for cyclists. Future work before the conference involves a rather straight-forward implementation of traffic signals as well as resolving an issue leading to unrealistic long delays for a small subset of car trips.

Keywords:
Mixed Traffic, Bicycle Traffic, Intersection Modelling, Large-Scale Traffic Assignment, Simulation

1. Introduction

For traffic assignment models it is of uttermost importance to model congestion. Congestion is predominantly considered as a phenomenon occurring on the links, but dating back to Nielsen et al. (1998) delays caused by intersections have often been included in traffic assignment models as well. At least when only considering car traffic.

Such delays at intersections typically constitute a considerable amount of the total travel time in the network. In urban traffic with a high concentration of non-car modes, interactions between various vehicles can be modelled satisfactory in a limited geographical area using microsimulation tools such as AIMSUM (Dandl et al., 2017), SUMO (Alvarez Lopez et al., 2018), and VISSIM (Fellendorf, 1994). The wider consequences that spreads to different parts of the network, on the other hand, are a lot harder to model.

In cities with a large amount of bicycle traffic, particularly many conflicts are present at intersections, as cars and bicycles both have turn movements that require to give way to the other mode. In order to account for the delay

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bicycles cause on car traffic, a range of studies, e.g. Allen et al. (1998); Chen et al. (2007); Xie et al. (2009); Guo et al. (2012); Chen et al. (2014); Prasetijo et al. (2014); Preethi and Ashalatha (2018), have investigated how much the capacity on the car link drops at intersections when bicycle traffic is present. The results of these analyses could potentially be included in a combined assignment of bicycle and car traffic, but no such study seems to have been carried out.

Until recently, only a single example of on-link bicycle congestion modelling (Agarwal et al., 2017) existed, modelling mixed traffic in the Indian city of Patna. Earlier this year using the methodology proposed in Paulsen et al. (2018), a bicycle traffic assignment model incorporating on-link congestion and with sensible feedback mechanisms between demand and supply was applied to a large-scale segregated network in Paulsen and Nagel (2019) for the greater Copenhagen area. However, no studies have applied reasonable intersection modelling capturing advanced right-of-way structures alongside the modelling of on-link bicycle congestion. Doing so is particularly relevant as delays can only be imposed on to other modes of transport at intersections when considering areas with a high level of separation between modes.

The purpose of this study is to model the delays caused by conflicting movements at intersections directly in the mobility simulation of a large-scale traffic assignment model suitable for bicycle-dense areas. Modelling such conflicts is not by any means new in itself, as this is standard features in most micro-simulation software (Fellendorf, 1994; Dandl et al., 2017; Alvarez Lopez et al., 2018). Yet, doing this while simulating the traffic of an entire metropolitan area is normally not feasible, due to the enormous computational demand and the need for extensive calibration. The study will do this by extending the existing open-source agent-based transport simulator MATSim (Horni et al., 2016). As MATSim is already capable of simulating a large geographical area in feasible time, the specific objective is to replace the existing node model of MATSim with a detailed one obeying multi-modal right-of-way at intersections, and apply it on a large-scale scenario.

The remainder of the paper is structured as follows. Section 2 describes how the nodes of network is classified into three different types of nodes, whereas Section 3 presents how vehicles and bicycles are simulated across such nodes. A case study is presented in Section 4 alongside preliminary results. Finally, Section 5 concludes, deals with the limitations of the current implementation, and proposes multiple directions for future work.

2. Node Classification

The node model proposed in this study separates nodes into three types;(i) The *right priority node* which is used when all the links to and from a node have the same capacity; (ii) the *anti priority node* which is used when one or two directions have full stop while the others have priority to the right; and finally (iii) the *directed priority node* which is used when a certain direction from and to a node has priority over other turn movements.

Determining the node type is based on so-called link *bundles*. A bundle is a direction from the node which can consist of up to four unidirectional links, but at most one of each of the following types listed in counterclockwise order: Bicycle out-link, car out-link, car in-link, and bicycle out-link. If there is more than 15° between two consecutive links in a bundle, the bundle is split into multiple bundles.

Once the bundles have been formed the priorities can be determined based on the maximum car capacity of each bundle. If two bundles have higher maximum capacities compared to all the other bundles, these two bundles are established as the two priority bundles, and the node is a directed priority node. If more than two, but not all of the bundles, have maximum capacity, the node is a anti-priority node with the maximum capacity bundles being primary links, and the sub-optimal capacity bundles being secondary links. If the car capacities are the same in all bundles, the bicycle capacities (number of lanes) are used instead. If this does still not provide a meaningful directed priority, the node is classified as a right priority node.

3. Simulation at Intersections

3.1. The MATSim Standard Node Model

The mobility simulation in MATSim (Horni et al., 2016) consists of two separate models; a link model and a node model. The link model determines at link entry when a vehicle will be ready for leaving the link again. Once a vehicle is ready to leave the link, it can be drawn across the node by the node model. The node model traditionally selects the processing order of its in-links according to the capacity of the links, as every (remaining) link has a probability proportional to its capacity of being chosen as the next link to be processed. This means, that when going into a node from a link with a low capacity, chances are that other links will be processed first. This is quite relevant because every link in MATSim has an in-flow capacity, which may be exceeded while processing other links, forcing a vehicle from a small capacity link to be delayed at the intersection. Although the existing node model have the potential to add delays on to vehicles, it only happens through the sheer number of vehicles entering a link, not the various turn movements which in reality could be conflicting and directly force a vehicle to wait until there is room to proceed with the turn movement,

3.2. The Right of Way Node Model

The way the node modelling is done in this study differs considerably. Whenever a potential movement is processed it is checked whether any previous movements (potentially from a previous time step) have been temporarily disallowed by a conflicting movement, Each movement m has an associated time t_m (with an initial value of -1) at which that movement is once again allowed to be performed. If the movement is allowed, i.e. if $t > t_m$, then for all movements with equal or lower priority conflicting with m, $c \in C_m$, the earliest time at which the conflicting movement can be performed, t_c, is updated to the current time plus an extra second, $t_c \leftarrow t + 1$. On the other hand, if $t \leq t_m$, the movement is disallowed, and no more vehicles from that queue are processed at that time step.

It is relevant to mention here, that every car-link leading to a directed priority node has a general queue and a separate queue dealing with left turns such that left turns and other movements can be treated separately. This corresponds other movements having the opportunity to overtake left turning vehicles on the right. The combinations of in- and out-links that imply left turns are determined and stored within the node in the pre-processing phase in order to prevent recalculation during the simulation.

Left turning bicycles are handled as a special case in directed priority nodes. Instead of performing the full movement at once, it is separated into sub-turns. The first partial movement takes the cyclist to the front of the first bicycle in-link met when going clockwise from the other-priority bundle. If no such in-link exists or if that link is the cyclist's current link, the in-link of the other priority is used. The in-link to turn to is again determined and stored in the pre-processing phase.

The way to determine the order in which the in-links are processed differ slightly for the three different node types. For the directed priority node the two bundles on which the directed priority is situated forms the set of prioritised bundles, as opposed to the remaining non-prioritised bundles. Potential movements across a directed priority node are processed in the following order:

1. Bicycle movements (left turns performed step-wise) from prioritised bundles.
2. Cars going straight or turning right from prioritised bundles.
3. Cars turning left from prioritised bundles.
4. Bicycle movements (left turns performed step-wise) from non-prioritised bundles.
5. Cars going straight or turning right from non-prioritised bundles.
6. Cars turning left from non-prioritised bundles.

Notice that it does not matter which of the two prioritised bundles that are processed first, as potentially conflicting delays are never processed until it is certain that they can be undertaken without making a conflict. This means that no random number is needed in this case.

Regarding right priority nodes and anti priority nodes, the two node types are handled almost identically. In both cases the first bundle to be processed is chosen randomly from the set of primary bundles offering vehicles, and is afterwards processed in counterclockwise order. For each of the processed bundles the bicycles are handled first where they, as opposed to in the directed priority node case, are allowed to make full left turns immediately. Once the bicycle movements have been processed the car movements are processed.

The procedure is applied once again to the secondary bundles when dealing with anti priority nodes, such that these bundles are only processed once all the primary bundles have been processed. For right priority nodes all bundles are primary bundles.

4. Case Study and Preliminary Results

The node classification and the node model introduced in the two previous sections were implemented into MATSim. Existing methods were used for simulating vehicles on the links. For car traffic the standard MATSim queue simulation consistent with the kinematic wave model (Flötteröd, 2016) was used, whereas bicycles were simulated according to the methodology introduced in Paulsen et al. (2018) shown to be large-scale applicable in MATSim in Paulsen and Nagel (2019).

The model was applied to a case study in the greater Copenhagen area. The network was based on OpenStreetMap, and infers bicycle and car infrastructure directly from that as described in Zilske et al. (2011); Paulsen and Nagel (2019). The demand is based on the Copenhagen Model for Passenger Activity Scheduling (Prato et al., 2013) commonly referred to as COMPAS. In all of the simulations 100% (1,082,958) of all bicycle trips have been included, whereas either no or 10 % of car trips randomly drawn from the total demand profile of 3,050,009 car trips have been. When using 10 % of the car trips the delay such vehicle causes at an intersection was accordingly multiplied by 10 ($t_c \leftarrow t + 10$).

The assignment model was been run for 100 iterations using a logit choice model for choosing between the routes in the choice set of each agent. Choice sets had a maximum size of five, and had a 20% probability of being updated in every iteration. When adding a route to the choice set, a best guess shortest path was performed in a network using travel times based on the previous iterations with congested travel time being penalised 50 % more than free flow travel time as in Paulsen and Nagel (2019). All scenarios were run on a high performance computer with two 2.8GHz deca-core processors and 120GB of RAM.

Regarding computation times, it is seen in Table 1, that the new right-of-way (RoW) node model implementation is somewhat slower compared to the existing one with a performance drop ranging from 18-35 %. This is still an acceptable performance proving that the introduced methodology is in fact computationally large-scale applicable.

Table 1: Average travel times and congested travel times for bicycles given various setups.

Node Model	Std.	RoW	Std.	RoW	Std.	RoW
Bicycle Population	100%	100%	100%	100%	None	None
Car Population	None	None	10%	10%	10%	10%
Avg. Travel Time Per Bicycle Trip [min.]	16.67	16.76	16.67	17.20	-	-
Avg. Congested Time Per Bicycle Trip [min.]	0.12	0.22	0.12	0.61	-	-
Avg. Travel Time per Car Trip [min.]	-	-	15.51	*72.63	15.51	*72.72
Avg. Congested Time per Car Trip [min.]	-	-	0.04	*54.10	0.04	*54.19
Computation Time Per Iteration [min.]	14.92	17.63	29.97	40.38	9.05	7.89

* *Caused by extreme irregularities of a few trips.*

Table 1 also, and more importantly, shows the modelled travel times and the amount of congested time per bicycle trip using the various setups. It is seen that when using the RoW node model and only modelling cyclists, the congested travel time per trip roughly doubles. It still only constitutes a very small portion of the total travel time. When adding cars onto the network as well, the congested travel time almost triples, and the average travel time is now 3.2% larger than when not modelling intersections. Notice that adding cars obviously does not impact the travel times of bicycles when using the standard node model.

For car trips, the proposed node model currently produces unrealistically long average travel times. A preliminary, disaggregate analysis have however revealed that it is a problem caused by rather few car trips being extremely delayed with some trips having a travel time to free flow travel time ratio exceeding 100. The median ratio, on the other hand, is 1.16 which seems more likely. In comparison, the average numbers correspond to a ratio of 3.92 which is only exceeded by 2.2% of the trips. I.e. more realistic values are expected as soon as the underlying cause of these few trips achieving so long delays are identified and eliminated. Due to the extreme anomalies of a rather small portion of trips, the average values for car travel time currently found in Table 1 are clearly off. More reasonable values will be achieved as soon as the underlying cause has been found.

5. Conclusions, Limitations, and Future Work

This study proposed a method for simulating cars and bicycles separately along links while modelling at great detail the delays caused by their conflicts at intersections. A case study on the greater Copenhagen area showed that, despite increasing the computation time, the suggested node modelling methodology still allows large-scale scenarios to be simulated within feasible time.

The analyses conducted have demonstrated that bicycles do get delayed more when right-of-way is used, and even more when cars are added to the simulation. The numbers are still relatively low though, which probably has to do with traffic signals not being included in the model at the moment. This is especially important for directed priority nodes with signals, where the links of non-prioritised bundles are obviously punished too hard in the current implementation. Conversely, vehicles from prioritised bundles can only be delayed if they turn left in the current implementation, as they will always have priority. As bicycles tend to travel along main corridors which generally have priority, the inclusion of traffic signals will most likely add a substantial amount of travel time for cyclists.

Including traffic signals requires additional data which possibly can be converted from other data sources such as the Danish National Transport Model. The network, however, still needs to be adapted by collapsing nodes as many signalised intersections are actually too detailed in OpenStreetMap to be properly simulated in the proposed framework. The methodological implementation of traffic lights is relatively straightforward, though, as it can be done by simply updating t_m of links facing a red light.

An important issue to address is that some car trips seems to be almost incapable of travelling across nodes with the current right of way node model implementation. The added travel time of these few extreme trips is unrealistic, and as such the model must be adjusted in some way, so that these numbers will drop to a more reasonable level. Resolving this issue is undergoing and will be finished well in advance of the conference.

Another relevant direction for future research is to improve the shortest path search done between each iteration. It is currently performed using node-to-node travel times from the previous iteration where delays at an intersection are parsed on to the in-link the delayed vehicle came from – no matter which link it continues onto. A better approach would be to use a link-to-link travel time network where the delay only counts on the specific in-link out-link combination. This would potentially lead to more realistic paths being included into the choice sets of each agent, and as such, eventually lower travel times.

In general, it is of course also relevant to look more into the disaggregate results of the model. For instance, analyses could explore in which areas of the network the delays most frequently occur or how the congested time is distributed across trips and persons.

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