An Elegant and Computationally Efficient Approach for Heterogeneous Traffic Modelling using Agent Based Simulation

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Abstract

For developing nations, where mixed traffic conditions prevail, it becomes necessary to develop a heterogeneous traffic flow model which is able to model all vehicle types of different static and dynamic characteristics and equally efficient in computational performance. For this purpose, in this study, an agent based framework is used which uses a queue model in its mobility simulation. In first step, queue model is enhanced by adding different vehicle types with different maximum speeds and sizes. Furthermore, traditional FIFO (First-In-First-Out) approach of queue model is modified to a more realistic modified queue model in which faster vehicles can pass slower vehicles. The enhancements are discussed with their fundamental diagrams for traffic flow and spatio-temporal diagrams.

Keywords: Heterogeneous traffic, Mixed traffic, Passing, Fundamental diagrams for traffic flow, Multiple mode simulation

1. Introduction

Homogeneous traffic flow models are unable to help in engineering the infrastructure that provides better mobility and safe movement in heterogeneous conditions.[17] The problem is especially severe in developing countries: Traffic streams in such nations consist of a wide variety of vehicles, e.g. car, motorbike, bike, bus, truck etc. They all use the same right of way and therefore vehicular interactions between all vehicle types are in abundance. Despite a low share of cars, mixed traffic conditions can cause congestion and conflicts.

Many papers look at mixed traffic. For example, Dey at al.[7], Arsan and Koshy[1], or Hong et al.[9] use highly detailed car following models that even include lateral movement. Lan et al.[12] or Vasic and Ruskin[18] use cellular automata models. Marwah and Singh[14] do not mention their modelling technique in the paper.

In the present paper, however, we do not want to look at detailed modelling of mixed traffic. Rather, we are searching for an approach that allows very fast microscopic network loading simulation. The starting point is the network loading algorithm of MATSim,[2] which is a so-called queue model.[8,16,4] The network loading algorithm is embedded into an iterative algorithm that emulates co-evolutionary day-to-day learning of synthetic travellers, leading to an approximation of a Nash or user equilibrium. Clearly, in order to perform such iterative studies of large scenarios, the network loading algorithm has to be computationally fast. For example, Balmer et al.[2] mention computing times of 10 *min* to simulate 24 *hours* of all of Switzerland with about 7 *million* synthetic persons.

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2. Modelling

MATSim queue model. The MATSim queue model takes, for each link, flow capacity, storage capacity, and free speed link travel time into account. For each vehicle that enters a link, an earlist link exit time is computed based on the link's free speed travel time. Then, the vehicle is added to queue data structure. The queue is served by moving vehicles across the downstream intersection as long as the following criteria are fulfilled: (1) the first vehicle's earliest link exit time is current or lies in the past; (2) the downstream link has space according to its storage capacity and the number of vehicles on it; (3) there is still flow capacity left for the current time step. For details see Cetin et al.[4] The queue model is computationally fast because it touches vehicles only when they enter or when they leave the link. That is, no matter how long the link, the algorithm will never spend time on computing any dynamics along the link.

Multiple congested modes. Until the present study was done, the mobility simulation in MATSim was designed for car traffic as congested mode. MATSim was in fact previously applied to another congested mode, namely pedestrian, by re-scaling speed, flow capacity, and storage capacity.[11] Yet, these are link parameters, which means that the approach only works as long as the moving items are all the same. For the present study, the mobility simulation is extended with the option of associating the congested mode with different *vehicle types*, which have maximum speed and passenger car equivalents as attributes. This lays the foundation for having multiple congested modes.

Changing the queue sorting criterion. Until the present study, the MATSim queue model used a FIFO (first-in first-out) queue, and thus passing was not possible. This seemed an acceptable compromise as long as it was assumed that all vehicles had the same maximum speed. Once vehicles have different maximum speeds, this simplifying assumption seems no longer justified. This will be particularly significant with vehicles of very different speeds, e.g. cars and bikes.

The new approach now is that the ordering of the vehicles for the link exit is no longer in the sequence in which they entered the link, but in the sequence of their *earliest-link-exit-time*, which is the time by which the vehicle would reach the end of the link if it was only constrained by the maximum speed of the vehicle type and the link. As in FIFO, flow and storage capacity constraints of the link are still observed, and the vehicle type *PCU* are taken into account. It means that now, a sufficiently fast vehicle can pass other vehicles whose earliest link exit times have not yet been reached. Note that the implementation of this is really simple and elegant: The existing queue data structure which sorts by first-in first-out is simply replaced by a queue data structure with the new sorting criterion. This will also have the advantage that it keeps the fast computational performance of the queue model where vehicles are only considered when they enter and leave the link and never in between.

PCU calculation. There are several methods available in the literature to get passenger car units (*PCU*) for different vehicle entities. Some of them find *PCU* depending on the density and thus implicitly on the speed of respective vehicle[10,13,17] and some other depending on the speed and area occupied on the road by respective vehicle explicitly.[5,3] For example, in the latter, a long truck may occupy as much space as three passenger cars when stopped, but that factor will be smaller when moving at 80 km/h. The approach taken here, however, is even simpler and just takes a constant *PCU* value per vehicle type, which is used both for the flow capacity and the storage capacity. Consequently, in the present approach, *PCU* is determined using the ratio of area occupied by a vehicle type to the area of car, as shown in Table 1.

Table 1: PCU calculation

Vehicle type	length	width	effective width	area	*PCU* calc	*PCU* taken
Car	4.1	1.6	2.6	10.66	1	1
motorbike	1.8	0.6	1.4	2.52	0.2364	0.25
bike	1.8	0.5	1.3	2.34	0.2195	0.25

3. Results

Traffic flow theory has three fundamental variables, namely flow q, density ρ, and speed v. Fundamental diagrams (FDs) can display any relation between two of the variables; the following will plot q as a function of ρ. To generate FDs, a test scenario is considered with a simple network in the form of a triangular race track. The race track has 3 links of length 1000 m each. Agents enter the track at one corner and then drive in circles while the observable simulation properties average speed, flow and density are measured. When these quantities have stabilized, the simulation can be terminated. The number of simulated agents is varied, resulting in data points for varying densities. The maximum number of agents on the network is limited by its storage capacity, a property of the queue model, where a vehicle of 1 PCU uses up, by default, 7.5 m of space. This results in a cut-off at around 135 PCU/km. The maximum flow is also a simulation parameter. In this experiment, it is set to 2700 PCU/h. Vehicles of three different types, namely car, motorbike and bike, are put on the network in different combinations. The maximum speeds of car, motorbike and bike are set to 60, 60 and 15 km/h respectively. Motorbike has the same speed as car but is smaller (0.25 PCU), and bike is the same size as motorbike, but slow. In the present study, three cases are considered and their resulting FD plots are discussed: these are "homogeneous traffic", "heterogeneous traffic without passing", and "heterogeneous traffic with passing". Fig. 1 shows the FDs for various experimental simulations.

Homogeneous vehicle fleets. Fig. 1a shows the flow behavior for the three cases with only one vehicle type each. Since in the simulation, car and motorbike differ only in their PCU factor and density and flow are measured in PCU, FDs for both modes look almost identical. The FDs of the queue model have a laminar regime, a capacity regime and a jammed regime.[16] In the laminar regime, flow increases with density, and speed is constant at free speed. In the capacity regime, flow is constant at maximum flow of the link, and speed decreases parabolically with increasing density. Furthermore, in the jammed regime, flow and speed drop nearly vertically with increasing density, finally reaching zero.

It is a peculiarity of the queue model that the jammed regime is unrealistically narrow; this corresponds to the absence of the backwards traveling kinematic wave. (Or more technically: The backwards traveling kinematic wave travels with the speed of one link per simulation time step.) It is well known that this is a shortcoming of the queue model,[16] yet our consistent practical experience is that for large-scale applications this is an acceptable trade-off in order to obtain high computational speeds.

The blue points in Fig. 1a are for the bike only simulation. In this case, flow grows linearly with density, up to a value smaller than the maximum flow capacity of the link, and then abruptly drops. The reason is as follows: Free speed determines the rate of the linear increase in flow in the laminar regime. For a lower free speed, the point of maximum flow is reached only at a higher density. In the case of bikes, free speed is so slow that the maximum flow is not reached before the maximum density, so that the capacity regime does not exist and the laminar regime changes directly into the jammed regime. Similar plots for bike from survey data were obtained in past.[15,6] The latter also state that bike flow rarely reaches high volume conditions.

Heterogeneous traffic without passing. Fig. 1b shows FDs while car and motorbike are simulated, passing is not allowed, and an equal (by PCU) modal split is used. Since the maximum speed of both vehicle types are same, the FDs for both vehicle types are identical as expected; clearly, for a given overall density the vehicle type's flow is half that of Fig. 1a since they contribute only half of the traffic.[1]

Similarly, Fig. 1c shows the FDs for car and bike simulation with equal (by PCU) modal split. Since passing is not allowed, car are stuck between bikes and thus follow the same FD. Similar FDs (not shown) are obtained when simulating equal share (by PCU) of car, motorbike and bike and passing is not allowed. As soon as a sufficiently slow vehicle type is involved, the capacity regime no longer exists (see Section 3).
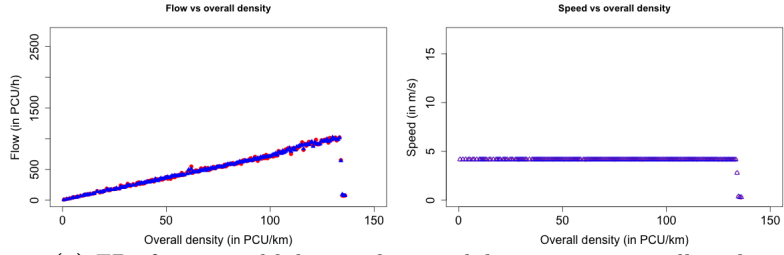
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[1]The slope of the uncongested branch of the flow-density-diagram would get back to what it should be according to the speed if one replaced overall density by vehicle-type-specific density.
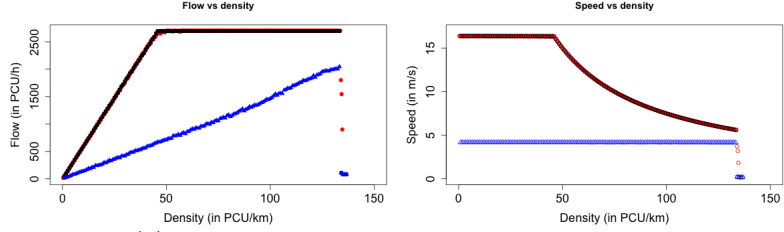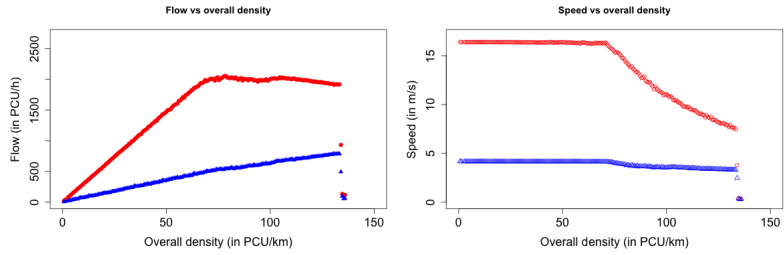
(a) FDs for homogeneous vehicle fleet simulations
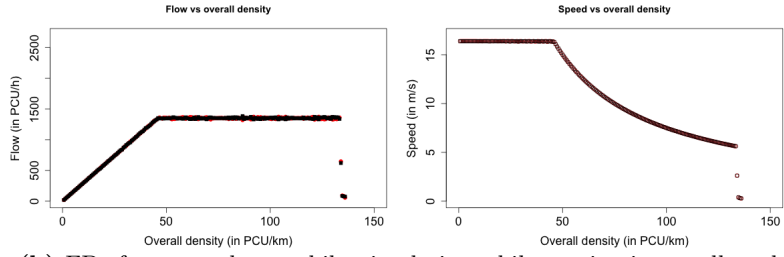
(b) FDs for car and motorbike simulation while passing is not allowed.

(c) FDs for car and bike simulation while passing is not allowed.

(d) Car bike while passing is allowed and equal modal split in PCU is used.

• car flow   ■ motorbike flow   ▲ bike flow   ○ car speed   □ motorbike speed   △ bike speed

Figure 1: Fundamental diagrams (FDs) for experiments on the triangular test track
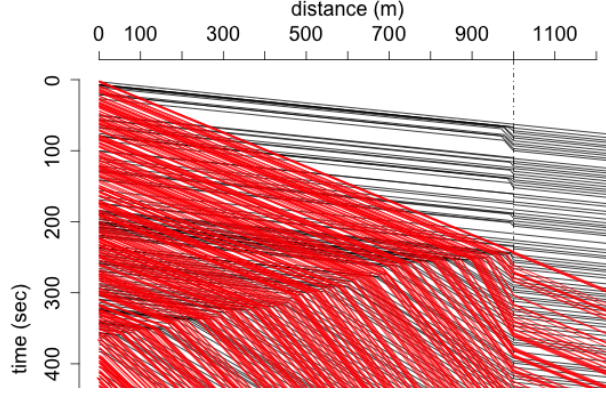
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Figure 2: Space time trajectories for car (black) and bike (red) when passing is allowed.

Heterogeneous traffic with passing. FDs in Fig. 1d are obtained with car and bike simulation with equal modal split in PCU while passing is allowed, according to the alternative queue sorting criterion described in Sec. 2. The maximum flow reaches about 2000 PCU/h for car at an overall density around 60 PCU/km, and about 700 PCU/h for bike at an overall density around 130 PCU/km. The reason for different flows is the difference in the speed of vehicles (see Fig. 1d right); the faster vehicle type (car) is now allowed to pass the slower vehicle type (bike).

One clearly notes that in the free speed regime (up to the overall density of about 60 PCU/km), all vehicles can approximately maintain their respective free speeds. At higher densities, the speeds of the fast vehicles are reduced by congestion, while bikes are not much affected. Recall that these are FDs for the queue model, and thus there is no backwards propagating kinematic wave.

The overall density where the cars reach maximum flow is shifted from about 45 PCU to about 60 PCU. When cars are not stuck behind bikes, they essentially use up the remaining flow capacity left by the bikes until all flow capacity is used.

FDs for car/motorbike/bike when passing is allowed (not shown) show similar characteristics as FDs for car/bike in Fig. 1d. FDs for car/motorbike when passing is allowed (not shown) look like car/motorbike when passing is not allowed (Fig. 1b) because both modes have identical speeds.

Spatio-temporal plots. Since the queue model has defined positions for vehicles only when they enter or leave links, intermediate vehicle positions $x(t)$ are not available. Such positions can only be reconstructed by making certain assumptions. When making these assumptions, it should be kept in mind that those assumptions are made for the purpose of visualization; the true dynamics is entirely given by the abstract model. These visual trajectories (cf. Fig. 2) are constructed according to the following principles: (1) When a vehicle enters a link, it will move according to its free speed until it reaches the end of the queue. (2) The queue is composed of all vehicles whose "earliest link exit time" is in the past, *plus* all vehicles who would have moved beyond the upstream end of the queue according to item (1) and are thus already in the queue although their earlist link exit time has not yet been reached. A consequence of this approach is that vehicles do not join the queue in the same sequence in which they leave the link: For example, a bike which leaves a link *after* a car might still be *in front* of it when it joins the queue.

Fig. 2 shows a resulting space-time plot. Cars (in black) and bikes (in red) enter from the left with constant rate. The plot shows the first link, and a part of the second. Around time step 280, a queue starts, noticeable by a change of velocities both of cars and of bikes, growing against the direction of the traffic. The queue starts at the downstream rather than at the upstream end of the link because the model places the flow capacity constraint at the downstream end of the link.

Note that car trajectories are still faster than bike trajectories even "inside" the queue; this is due to the effect explained earlier that they do not join the queue in the same sequence in which they leave the link. This is presumably a bit unrealistic; one would rather assume that bikes are able to be faster than cars in heavily congested situations. Again, we consider this an acceptable compromise in order to keep

the fast computing speed of the network loading model, justifiable in particular in conjunction with the speed-density FD for the bikes, Fig. 1d, showing that bike speed is nearly unaffected by the overall density until very high densities.

4. Conclusion and outlook

This work provides a way to simulate mixed traffic in a simple and computationally fast queue model. Technically, this is achieved by inserting vehicles with different maximum speeds and different space consumption into the queue. Based on the requirements, the queue may replace the use of first-in-first-out approach by an approach where vehicles at the end of a link are sorted by their free speed link exit times, which effectively enables fast vehicles passing slower vehicles. The approach shows plausible results as long as it can be assumed that the different vehicles cannot pass each other any more once they are queued.

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