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A Macroscopic Flow Model for Mixed Bicycle-Car Traffic

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1 Introduction

Total travel time loss is a common indicator for road network performance. Within an urban environment, streets are often shared by multiple user types such as cars, (motor)bikes or pedestrians. Although these entities share the same infrastructure, the experienced delay can differ. To better estimate mode-specific travel times, a model is required that can describe different traffic types.

A model type that meets this requirement is a multi-class macroscopic model. Macroscopic models typically use aggregated variables to describe the traffic situation, which contrasts with microscopic models that describe the movements of individuals. Because of the aggregated approach, a macroscopic model requires less detailed input data and the mathematical equations are typically less complex. Hence, a macroscopic model requires typically less computing time and is easier to calibrate than microscopic models. Such a macroscopic model can be used to describe network loading at computationally low costs, which is required e.g. for demand estimation, network design, or traffic signal optimization.

In this paper we consider mixed traffic in an urban situation where cars and cyclists share the road. An example of this type of road is a so called cycling street in The Netherlands where cars travel along the same roadway as cyclists, and cyclists have the right of way. A cycling street is typically wide enough for cars to overtake cyclists, but cars are forced to slow down when cyclists are present. Furthermore, when the density of cyclists exceeds a certain value, cars cannot overtaking anymore and have to match the speed of the cyclists. When cars are moving slowly in a queue for example to wait for a traffic light, there is enough space for cyclists to carefully pass the queue and create their own queue closer to the intersection. The speed of both traffic types hence depends on the presence of the other type, and both traffic types can be the fastest class depending on the mixed density.

There are multi-class models that meet the requirement of different class-dependent desired speeds but these are subject to the condition that a 'fastest' class exists, i.e. one class always has a faster speed than the other irrespective of prevalent traffic conditions [4]. This limiting assumption should be adjusted for modeling mixed traffic on a cycling street, where the slower class (bikes) can switch to being the faster class e.g. when the car density exceeds the jam density. Including this phenomenon requires a different approach using two-dimensional density-speed relationships.

The main objective of this study is to introduce two-dimensional speed functions in a multi-class macroscopic model, together with the evaluation of the resulting model dynamics. Such a model allows to estimate

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travel times for cars and cyclists by describing their joint traffic dynamics, which in turn can be used to evaluate the overall performance of a mixed traffic road.

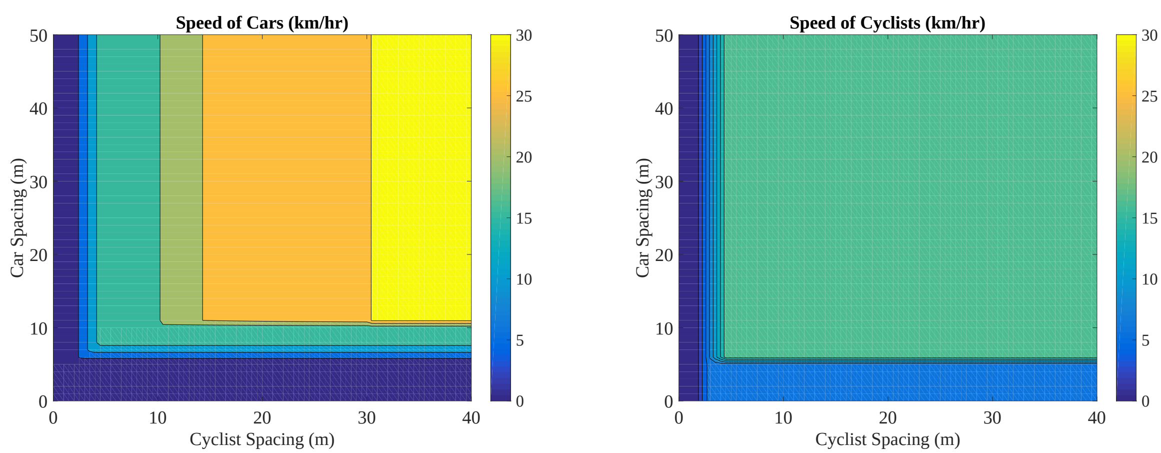
2 Model specification

Macroscopic continuum models assume traffic to behave similar to a fluid. The starting point is the conservation of traffic participants, which can be expressed in Eulerian or Lagrangian coordinates. The Eulerian approach is used traditionally in macroscopic traffic modeling [3] but the disadvantage is that the computation leads to numerical dispersion errors due to the switching between an upwind and downwind discretization. The Lagrangian formulation uses only the upwind method and is therefore less prone to numerical dispersion [2] [5]. Moreover, this approach allows for a description which is more in line with microscopic movements, hence a more intuitive model description would be possible. This study hence pursues a Lagrangian approach, resulting in the class-specific expression for the conservation equation given in Eq. (1). The conservation equation holds for each class u and the variables are class specific. Spacing is main variable and is defined as the average distance between travelers belonging to the same entity. The spacing is inversely proportional to the class-specific density k_u. Furthermore, the equation is expressed in traffic units n which are the total traffic units that have passed a given point in space at a given time.

$$\frac{\partial s_u}{\partial t} + \frac{\partial v_u}{\partial n_u} = 0, \tag{1}$$

stating that the change in spacing s over an infinitesimal time unit t is equal to the change in speed v over infinitesimal traffic unit n.

In addition to the conservation equation, a macroscopic model typically requires a fundamental diagram as a state equation, describing the relation between density, speed and flow rate. In the multi-class situation, the class dependent fundamental diagram is based on the spacing distribution of both cars and cyclists. To prevent confusion in abbreviation, the cyclists are referred to as 'b' for bicyclist from this point onward, resulting in v_b for speed of cyclists and v_c for speed of cars. The two fundamental diagrams (FDs) used in this study are shown in Fig. 1. The equations that have created these figures are shown in Eq. (2) and (3), and the characteristic values for jam density ($s_{u,\text{jam}}$), critical density ($s_{u,\text{crit}}$) and free flow speed ($v_{u,\text{f}}$) are presented in Table 1. The FDs used are not limited to this form and different formulations can be explored.



(a) (b)

Figure 1: Speed - Spacing diagrams

Table 1: FD characteristic values

	s_{jam}[m]	s_{crit}[m]	v_{f}[m/s]
cyclists	1.5	4.5	5.0
cars	5.0	10	9.0

$$v_b(s_b, s_c) = \begin{cases} 0 & \text{if} \quad s_b = s_{b,\text{jam}}, \quad s_c > s_{c,\text{jam}} \quad (a1) \\ (s_b - s_{b,\text{jam}})w_b & \text{if} \quad s_{b,\text{jam}} < s_b \leq s_{b,\text{crit}}, \quad s_c > s_{c,\text{jam}} \quad (a2) \\ v_{b,\text{f}} & \text{if} \quad s_b > s_{b,\text{crit}}, \quad s_c > s_{c,\text{jam}} \quad (a3) \\ \min(v_{b,\text{res}}, (s_b - s_{b,\text{jam}})w_b) & \text{if} \quad s_{b,\text{jam}} < s_b \leq s_{b,\text{crit}}, \quad s_c = s_{c,\text{jam}} \quad (a4) \end{cases} \tag{2}$$

$$v_c(s_b, s_c) = \begin{cases} 0 & \text{if} \quad s_c = s_{c,\text{jam}} \quad s_b > s_{b,\text{jam}} \quad (b1) \\ \min(v_b, (s_c - s_{c,\text{jam}})w_c) & \text{if} \quad s_{c,\text{jam}} < s_c \leq s_{c,\text{crit}} \quad s_b > s_{b,\text{jam}} \quad (b2) \\ v_{c,\text{f}} & \text{if} \quad s_c > s_{c,\text{crit}} \quad s_b > a \quad (b3) \\ v_{c,\text{res}} & \text{if} \quad s_c > s_{c,\text{crit}} \quad s_b \leq a \quad (b5) \end{cases} \tag{3}$$

The starting point for the spacing-speed diagrams is the triangular fundamental diagram for single class traffic flow [1], consisting of the cases ($a1$-$a3$) and ($b1$-$b3$). To connect the two classes, additional cases have been introduced while trying to maintain a linear expression as much as possible. For cyclists, condition ($a4$) is added that restricts the speed to $v_{b,\text{res}}$ when cyclists are passing a queue of cars. For cars, there are two additional cases. First, cars cannot overtake when there are too many cyclists on the road so they have to adapt their speed to match the cyclist' speed ($b2$). Second, when cyclists are only sparsely present ($s_b > a$, with $a = 30$m), cars can overtake with reduced speed ($b4$).

3 Preliminary results

First results of the two-class macroscopic model are shown in Fig. 2. Two platoons of five cars and three platoons of five cyclists are followed in space and time. The initial spacing of both classes is 20m, and the cyclists have a head start of 350 m to allow the situation of cars overtaking cyclists. Furthermore, the cars are forced to stop after 190s to allow the cyclists to pass the queue of cars. The color coding is linked to the desired speed of each class, resulting in no color when speed is uninfluenced, and in strongly colored when the speed is reduced for cars (purple) and cyclists (magenta).

Depending on the traffic situation, cars and cyclists experience a delay due to the presence of the other mode. In the first 50 seconds of the simulation, both cars and cyclists are separated in space and can travel at their desired speed. When the cars catch up with the cyclists, the cars have to reduce the speed and but can still overtake the cyclists. As a result of the speed reduction, the car spacing reduces to 13m, which increases again after all cyclists are left behind. The first cars are stopped after 190 s, resulting in a speed reduction of the following platoon of cars and the car spacing reduces to 5m. The cyclists catch up with the cars and pass the queue at a reduced speed, leading to a slight delay for cyclists.

The macroscopic model in this work is specified for the cycling street situation. However, the situation can be adjusted to any other combination of modes, such as pedestrians and cyclists, or cars and pedestrians. The only requirement is that the class-dependent fundamental diagrams are altered.

Future work before the conference involves the estimation of mode dependent travel times for shared street situations, further tuning of the spacing-speed relationships, and improving the numerical implementation of the model. Ultimately, the model will be compared with empirical data of mode-dependent travel times, and extended to mixed traffic situations with more than 2 modes.

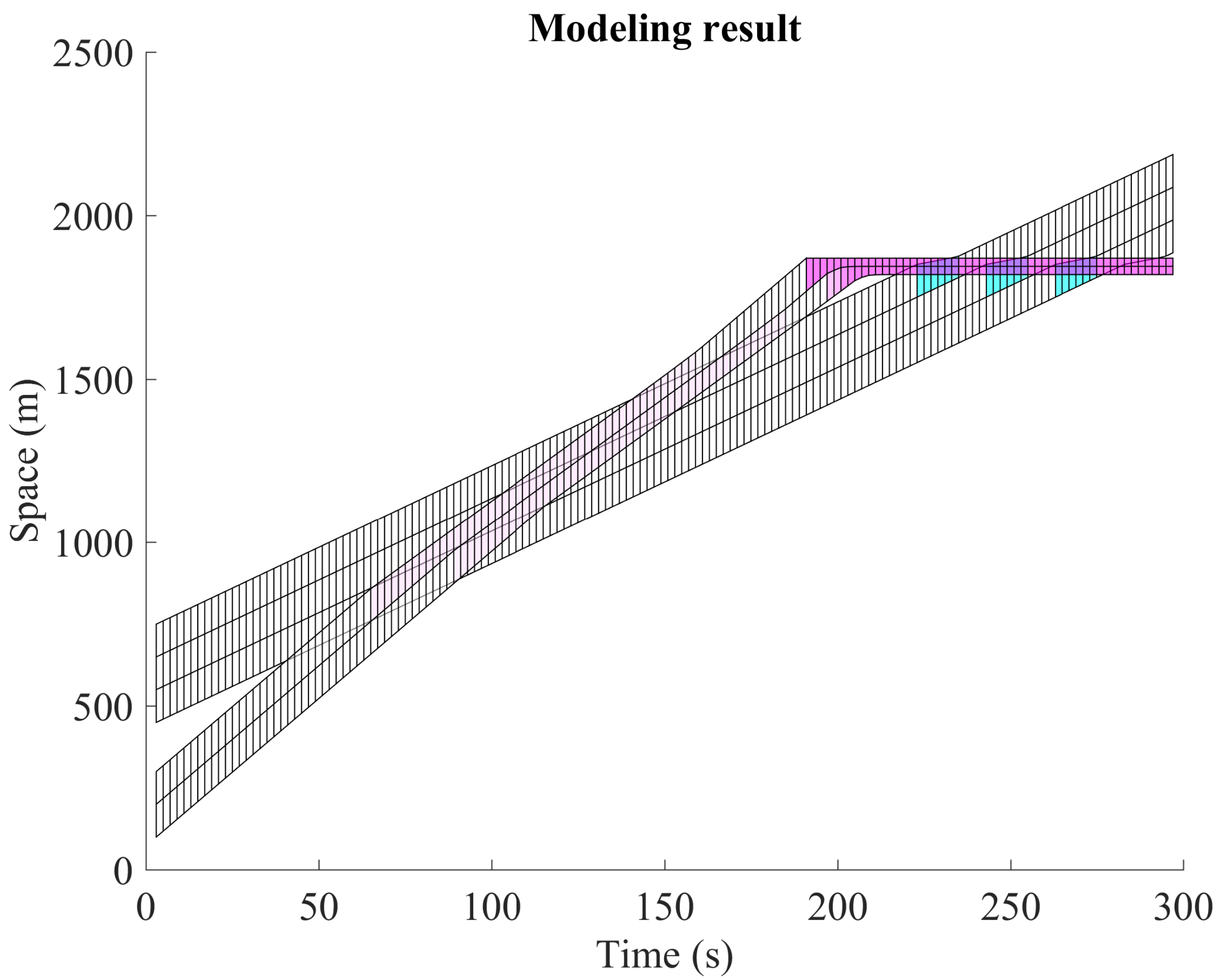


Figure 2: Simulation of the cycling street with a 350m head start for cyclists. The color represents the reduction of speed for cars (purple) and cyclists (magenta).

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