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Self-driven particle model for mixed traffic and other disordered flows

Venkatesan Kanagaraj, Martin Treiber*

Technical University of Dresden, Germany

HIGHLIGHTS

- A fully two-dimensional traffic flow for non-lane based traffic has been proposed.
- The model has been calibrated/validated on video-based trajectory data of mixed traffic in India.
- Limiting case include car-following models, lane-changing models, and the social-force model.
- Applications include bicycle models and models for autonomous vehicles.

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ABSTRACT

Vehicles in developing countries have widely varying dimensions and speeds, and drivers tend to not follow lane discipline. In this flow state called "mixed traffic", the interactions between drivers and the resulting maneuvers resemble more that of general disordered self-driven particle systems than that of the orderly lane-based traffic flow of industrialized countries. We propose a general multi particle model for such self-driven "high-speed particles" and show that it reproduces the observed characteristics of mixed traffic. The main idea is to generalize a conventional acceleration-based car-following model to a two-dimensional force field. For in-line following, the model reverts to the underlying car-following model, for very slow speeds, it reverts to an anisotropic social-force model for pedestrians. With additional floor fields at the position of lane markings, the model reverts to an integrated car-following and lane-changing model with continuous lateral dynamics including cooperative aspects such as zip merging. With an adaptive cruise control (ACC) system as underlying car-following model, it becomes a controller for the acceleration and steering of autonomous vehicles in mixed or lane-based traffic.

1. Introduction

Traffic flow in developing countries is growing disproportionately fast now accounting for 80% of the total road accidents and an estimated economic loss of 1–2% of the GNP [1]. As visualized in Fig. 1, vehicles in developing countries have widely varying dimensions and speeds, and drivers tend to not follow lane discipline. In addition to in-line car following (Fig. 1a), a model for mixed traffic should describe staggered following (Fig. 1b), follow ing between two vehicles (Fig. 1c) and passing (Fig. 1d) [1,2]. Generally, the interactions between drivers and the resulting maneuvers in this flow state, called "mixed traffic", can only be described fully two-dimensionally. In a wider context, mixed traffic becomes also increasingly relevant in industrialized countries: On the one hand, bicycle traffic and its interaction with driving and standing cars and pedestrians

* Corresponding author.
E-mail addresses: vkanagaraj.iitm@gmail.com (V. Kanagaraj), martin@mtreiber.de (M. Treiber).

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Fig. 1. The four driving behavioral patterns of mixed traffic. (a) In-line car following, (b) staggered following, (c) following between two vehicles, and (d) passing.

has the attributes of mixed traffic, particularly on bike lanes allowing several cyclists to drive in parallel while only single-file bicycle traffic has been modeled [3,4]. On the other hand, the concept of "shared space" creates mixed traffic (of motorized vehicles, bicycles, and pedestrians) by design [5].

The core behavioral models such as car-following models [6–9] and lane-changing models [10–15] are designed for lane-based traffic, only. There exist a few models describing staggered car following [16–18], or continuous lane changing based on a constant lateral speed [19]. To our knowledge, there are no models describing the full dynamics of non-lane based traffic. Existing self-driven particle models like the social-force model for pedestrians do not apply because, due to the kinematic constraints of high speeds and the negative consequences of crashes, drivers behave qualitatively differently as pedestrians or point-like particles.

In this contribution, we propose a continuous, fully two-dimensional microscopic model for motorized and non-motorized vehicles in unidirectional traffic and show that it reproduces the observed characteristics of mixed traffic on arterials in an Indian city. The main idea is to generalize conventional acceleration-based car-following models to a two-dimensional force field. Depending on the underlying car-following model, its parameterization, and optional floor fields, it can describe manually driven or autonomous motorized vehicles as well as bicycles driving in lane-based and non-lane-based traffic.

Generally, the proposed model describes the directed flow of high-speed self-driven particles where "high-speed" indicates that collisions are undesirable and kinematic aspects such as braking distance play a significant role. This includes all of the above, and the flow of athletes in running and cross-country ski Marathons, city inline-skating events, and others [14,20].

The paper is organized as follows. In the next two sections, the model is specified and tested for plausibility on some standard situations. In Section 4, the model is calibrated and validated on trajectory data of semi-dense and congested traffic in an Indian city. Section 5 concludes with a discussion.

2. Specification of the Self-Driven-Particle Model

While the Mixed Traffic Flow Model (MTM) proposed in the following is designed to describe general self-driven high-speed particles, we will refer to them as "vehicles", for notational clarity. Assuming that all considered vehicles drive in the same general direction, we separate the motion into a longitudinal part along the local road axis (coordinate x), and