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Correlation velocities in heterogeneous bidirectional cellular automata traffic flow

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HIGHLIGHTS

- Heterogeneous bidirectional traffic.
- Velocity correlations.
- Strong correlation velocity in short time headway.

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ABSTRACT

Traffic flow behavior and velocity correlation in a bidirectional two lanes road are studied using Cellular Automata (CA) model within a mixture of fast and slow vehicles. The behaviors of the Inter-lane and Intra-lane Velocity Correlation Coefficients (V.C.C.) due to the interactions between vehicles in the same lane and the opposite lane as a function of the density are investigated. It is shown that high densities in one lane lead to large cluster in the second one, which decreases the Intra-lane velocity correlations and thereby form clusters in the opposite lane. Moreover, we have found that there is a critical density over which the Inter-lane V.C.C. occurs, but below which no Inter-lane V.C.C. happens. The spatiotemporal diagrams correspond to those regions are derived numerically. Furthermore, the effect of the overtaking probability in one lane on the Intra-lane V.C.C. in the other lane is also investigated. It is shown that the decrease of the overtaking probability in one lane decreases slightly the Intra-lane V.C.C. at intermediate density regimes in the other lane, which improves the current, as well as the Inter-lane V.C.C. decreases.

1. Introduction

Over the past years, there has been an extensive interest in the properties of vehicular traffic flow. Many traffic models based on the approach of CA have been proposed to capture the essence of traffic phenomena [1–4]. Since the CA model is discrete in the time, space and states, it has been used extensively for modeling single-lane traffic. The most popular CA model for traffic flow using the concept of one-dimensional CA was proposed by Nagel and Schreckenberg [2] (called NaSch model). In this model, the velocity of each vehicle depends on the interaction with vehicle in front of it, in addition to the randomization probability which is the only parameter associated with random process in the NaSch model. Although it is simple, the NaSch model may reproduce some complex traffic phenomena observed in real traffic, such as the occurrence of phantom traffic jams and the realistic flow–density relation that is often called the fundamental diagram. However, the

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model is not able to capture some aspects of traffic dynamics such as the existence of meta-stable states and synchronized flow. Therefore, modifications have been suggested to obtain a more realistic description [5–15].

In single-lane traffic CA model, vehicles always keep their relative order, which means that the interactions between vehicles depend only on the randomization parameter and the headway between vehicles [16]. Often in the real traffic situations, this principle is no longer obeyed due to overtaking maneuvers. In order to simulate real traffic, two-lane models have been proposed. Nagatani [17,18] presented a straightforward two-lane system, based on the deterministic CA-184 model [1]. Rickert et al. [19] investigated a simple extension of the single-lane NaSch model by introducing a set of lane changing rules. Wagner et al. [20] and Nagel et al. [21] have been shown that the details of the lane changing rules may lead to considerable changes in the model results.

In multi-lane traffic it is of particular interest to investigate heterogeneous systems (i.e. with different types of vehicles). Therefore, Chowdhury et al. [22] proposed the first CA two-lane system with slow and fast vehicles. Knospe et al. [23] suggested considering anticipation effects to weaken the effect of slow vehicles.

Furthermore, traffic models have also been developed for bidirectional traffic. Simon and Gutowitz (SG) [24] have introduced a two lane CA model which consists of vehicles moving in opposite directions whereas passing is allowed on one or on both lanes (i.e. home and passing lane), they found that three kinds of traffic jams can appear on a bidirectional road namely; the start-and-stop waves and jams caused by vehicles who try to pass but cannot return to their home lane and the super-jams when an adjacent pair of vehicles try to pass simultaneously. However, in the case where the density of the home lane is great enough, the passing vehicles can provoke a head-on collision with on-coming vehicles [25]. Therefore, the lane changing rules of the SG model were modified in Ref. [25] to reduce the occurrence of wide jams on both lanes as well as the risk of the head-on collision.

In this paper, we propose a straightforward bidirectional traffic model to investigate the effect of the defect particles i.e. vehicles with smaller maximal velocity, on the traffic flow stability as well as on the interactions between vehicles. We have introduced a CA model; based on the model proposed by Ez-Zahraouy et al. [26] where they simulated a periodic single-lane system with slow and fast vehicles, where fast vehicle can overtake the slow one. We have considered two lanes in opposite directions; each lane is composed by two types of vehicles (slow and fast). The interactions between the two lanes are implemented by the process of overtaking i.e. when a fast vehicle is hindered by a slow moving vehicle, the passing may be allowed when the conditions on both lanes are more convenient. In order to quantify this interaction, we have studied the Inter-lane velocity correlation coefficient (Inter-lane $V.C.C.$) as well as the Intra-lane velocity correlation coefficient (Intra-lane $V.C.C.$). We have found that the Inter-lane $V.C.C.$ (resp. Intra-lane $V.C.C.$) depends strongly on the density in the two lanes, in addition to the overtaking probability in the other lane. This finding would be useful to understand the collective behaviors in bidirectional traffic.

This paper is structured as follows. In Section 2 we describe the model, Section 3 is devoted to results and discussions and Section 4 is reserved for the conclusion.

2. Model

Our model is built from two parallel single lanes; each lane is composed of L cells. Every cell can be either empty or occupied by a vehicle with a velocity $V = 1, \dots, V_{\max}$. In this model there are two different values of the maximum velocity $V_{\max}$; $V_{\max F}$ and $V_{\max S}$ corresponding to the fast and the slow vehicles, respectively. We denote by ρ_1 and ρ_2 the densities of the lane 1 and lane 2 respectively. Furthermore, the fraction of the fast and slow vehicles for the lane 1 (lane 2) are defined as $f_{F1}(f_{F2})$ and $f_{S1}(f_{S2})$ respectively; where $f_{F1} + f_{S1} = 1$ $(f_{F2} + f_{S2} = 1)$. Our approach in this model is to search for minimal sets of rules which mimic the effect of the slow vehicles in bidirectional traffic. In this model, vehicles move to the right on lane 1 and to the left on lane 2; two vehicle motion aspects are incorporated in this model, namely the forward movement according to the NaSch rules and the overtaking.

Before introducing the overtaking rules, we briefly recall the update rules of the NaSch model [2]. At each discrete time step $t \to t + 1$, the system update is performed according to the four rules:

Rule 1: Acceleration: $V_n(t + 1/3) \to \mathrm{Min}(V_n(t) + 1, V_{\max})$.
Rule 2: Deceleration: $V_n(t + 2/3) \to \mathrm{Min}(V_n(t + 1/3), g_n)$.
Rule 3: Randomization: $V_n(t + 1) \to \mathrm{Max}(V_n(t + 2/3) - 1, 0)$ with probability P.
Rule 4: Motion: $X_n(t + 1) \to X_n(t) + V_n(t + 1)$.

Let V_n and X_n denote the velocity and position of the vehicle n, respectively. g_n denotes the number of empty cells in front of vehicle n. P is the randomization probability. These set rules control the forward motion of vehicles. In this model, fast vehicles can move forward in parallel according to the NaSch rules or overtake when the conditions are more convenient, according to defined rules.

Let us now define the rules of the overtaking, based on the model proposed by Ez-Zahraouy et al. [26]. We have modified this model to make it adequate for use in bidirectional traffic system. Generally, a pass will only be initiated if the following criteria are fulfilled:

Incentive criteria:

1: Fast vehicle follows slow one.

This means that only fast vehicles are allowed to overtake the slow ones. A fast (slow) vehicle cannot overtake another fast (slow) one because all of them have the same maximum velocity.