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The effect of lateral interaction on traffic flow

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HIGHLIGHTS

- An extended cellular automaton model to describe lateral interactions.
- Lateral interactions with defects for different residual widths.
- Lateral interactions between vehicles in a two lane traffic flow.

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ABSTRACT

We propose an extended cellular automaton model for traffic flow, taking into account lateral interactions with defects and between vehicles. The fundamental diagram for a given defects density on the road is studied. It is found that the plateau size increases linearly with the decreasing road width for little defects densities. Furthermore, the capacity increases linearly with the increasing road width. However, for a fixed road width, the capacity decreases exponentially with the increasing defects density. The lateral effects for non-mutual interactions between lanes and for the same maximal velocity is also investigated. It is found that the lateral effects on one lane are meaningful only when the density on the other lane is above the critical density. However, the lateral effects are always present if fast and slow lanes exist. Little differences have been found for the mutual interactions.

1. Introduction

In the last decades, the increasing vehicular traffic volume throughout the world has stimulated an increasing pace of researches. Indeed, the resulting congestion phenomena have harmful effects on the economy, human health and the environment. In that respect, physicists have modeled the traffic flow from different perspectives. Namely, the macroscopic models, in which the traffic is considered as a compressible fluid [1]. The mesoscopic models that consider traffic as a gas of interacting particles [2], and the microscopic models that track the properties of individual particles or vehicles.

In the framework of the microscopic models, researches began by using the car following theory. In this case, vehicle acceleration acts as a response to a stimulus created by the following vehicle [3]. After that, various approaches have been suggested to improve the model [4–6]. However, only the longitudinal interaction between vehicles has been considered.

More recently, Nagel and Schreckenberg developed a cellular automaton model for traffic flow [7]. In this model, only longitudinal interaction between vehicles is considered (the second rule of movement) to move forward avoiding rear end collision.

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Within the framework of cellular automaton model based on longitudinal interaction, researches have succeeded to reproduce some interesting phenomena in traffic flow, like phantom jams, metastability and hysteresis effect [8]. After that, additional rules have been incorporated to simulate phenomena that are more complex. For example, in the case of mixture of fast and slow vehicles, Jetto et al. [9] have modeled the longitudinal interaction by considering both the gaps behind and front of the slow vehicles. New shapes of the fundamental diagrams have been obtained.

Actually, in addition to the longitudinal interaction, vehicles may interact laterally with their environment. The environment can be a reduced lane width on some random locations, or vehicles that circulate in the adjacent lanes in the same direction. This fact has been little studied [10–12]. The first case may correspond to road works, illicit parking, etc. These situations are called defects in the scientific literature. Several works have studied the behavior of traffic in the presence of defects by using cellular automaton model. In such works, the defect causes the vehicle to slow down and takes much more time to cross it. It is found that the defect controls the flow for a certain density range, where a plateau appears in the fundamental diagram [13,14]. This fact is due to the coexistence of two phases the free flow and the congested phases. After that, researches have studied the distribution of defects with a given law of probability [15,16], which gave the same main effect. The case of extended defect in which it occupies a long portion of the road has been also investigated [17].

We believe that the effect of road defect discussed above is the result of lateral interaction. Indeed, defect leads vehicles to decelerate with a rate that depends on the remaining road width.

Moreover, the highway capacity Manual states clearly that the lane width affects the road capacity [18] and the equivalent passenger car [19]. These facts lead us to ask the following questions:

How does the driver interact with his (her) lateral environment?

What are the effects of such lateral interaction on the macroscopic parameters of traffic?

Our aim is to answer these questions in order to contribute on both theory and traffic engineering. In this context, we will propose a cellular automaton model, which takes into account lateral interaction. The following section will be devoted to explain the model. The third section will deal with the simulation results. We conclude by stating some recommendations for optimizing the traffic flow when lateral interaction is noticeable.

2. Model

According to the cellular automaton NaSch model, a vehicle i moves ahead on a one-dimensional chain by following the four steps:

- Acceleration: $v_i = \min(\mathrm{Vmax}, v_i + 1)$.
- Deceleration: $v_i = \min(v_i, d_i)$, $d_i = x_{i+1} - x_i - 1$, it is the gap between the leading and the preceding vehicle.
- Randomization: $v_i > 0$, $v_i \to \max(v_i - 1, 0)$ with the probability P.
- Vehicles motion: vehicles move according to the velocity calculated:

$$x_i \to x_i + v_i.$$

Vmax is the maximum velocity.

We recall that each vehicle occupies one cell of length $L_{ec} = 7.5$ m [8].

To study lateral interactions, let first define some notations:

L_c is the mean width of vehicles. Empirical results state that $Lc = 2.4$ m [18].

L_v represents the width of the one lane road section. Typically $L_v = 3.6$ m [18].

L_{rmax} denotes the maximum remaining space $L_v - L_c$, the above values give $L_{\mathrm{rmax}} = 1.2$ m.

The maximum remaining lateral space L_{rmax} can be empty (Fig. 1(a)), occupied partially (Fig. 1(b)), or fully by defects (Fig. 1(c)).

In these cases, we define the residual width L_r as the free lateral space on the right side of the vehicle. It can vary from $L_r = 0$ (Fig. 1(c)) to $L_r = L_{\mathrm{rmax}}$ (Fig. 1(a)).

Indeed, Fig. 1(c) shows that defects occupy the full lateral space, $L_r = 0$. Thus, the vehicle has no available space to maneuver. It must decelerate with a probability P_d. However, in Fig. 1(a) the vehicle has enough empty space to maneuver $L_r = L_{\mathrm{rmax}}$ and $P_d = 0$.

In most cases, vehicles will decelerate with a probability P_d that depends on the residual width L_r. In other words, we have quantified lateral interaction of the vehicle by a lateral deceleration P_d, which depends on the residual width L_r. This analysis leads us to ask the following question:

How does the lateral deceleration evolve with the residual width?

The answer will be given in the following subsection.

2.1. The law of probability P_d

We extract the law of the lateral deceleration P_d from the formula of capacity adjustment given by HCM [18]. Here we are not taking into account the other parameters like presence of ramps, trucks, grades. Thus:

$$s = s_0 f_w \tag{1}$$

$$f_w = 1 + \frac{W - 3.6}{9} \quad \text{If } W \geq 2.4 \tag{2}$$