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# The effect of traffic light on accident probability in open and periodic boundaries system

Abdelaziz Mhirech [a,*], Assia Alaoui-Ismaili [b]

[a] Département de Physique, Laboratoire de Magnétisme et de la Physique des Hautes énergies, Université Mohammed V, Faculté des Sciences, B.P. 1014, Rabat, Morocco

[b] Département de mathématiques, Université Mohammed V, Faculté des Sciences, B.P. 1014, Rabat, Morocco

## HIGHLIGHTS

- We model the effect of traffic light on accident probability.
- The system studied is in open and periodic boundaries cases.
- The cycle time light plays an important role in road accidents.
- The study is made in parallel dynamics.

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## ABSTRACT

In this paper we numerically study the dependence of car accident probability $P_{ac}$, *per site* and *per time step* on cycle time $T$ of traffic light, both in open and periodic boundaries system. In this study one traffic light is placed in the middle of the system. This work is based on Nagel and Schreckenberg (NaSch) model (Nagel and Schreckenberg (1992)) in parallel dynamics. The $P_{ac}$ dependence on $T$ and the $(\alpha,\beta)$ phase diagrams are established. $\alpha$ and $\beta$ are the injecting and extracting rates of cars in the traffic lane respectively. The increase of the cycle time light $T$ causes an important decrease of the accident probability $P_{ac}$ both in the open and periodic cases.



## 1. Introduction

Recently, cellular automata (CA) models have been proven to be an excellent tool for studying physical properties concerning the transportation problems [1–5]. Indeed, several studies have been devoted to the traffic of vehicles, ants and pedestrians [6–13]. For a realistic description of traffic on highways, we must quote in particular introduced by Nagel and Schreckenberg [1].

The traffic light is an essential tool for adjusting the urban transportation network. To dispense with traffic officers, urban traffic requires a good set of traffic lights. Indeed, in the case of low traffic, adjusting traffic signals does not require a special strategy, while during rush hours when traffic density increases probably in a side more than the other, a good control of traffic lights is needed. Nowadays, traffic control by light plays a very important role in the lives of people who take daily the road. Consequently, the research in this field is necessary and should be encouraged by leaders. Several interesting models have been developed in recent years [14–18]. They are especially interested in two extreme cases of traffic flow. Namely, the

* Corresponding author.
*E-mail address:* mhirech@fsr.ac.ma (A. Mhirech).

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case of low density where the vehicles can move freely at desired speed and oversaturated one where the queues persist. But the intermediate case, i.e. the transition from undersaturation to oversaturation traffic remains unclear.

In the past few years, some researchers have examined this problem and showed that the saturation current is independent of cycle time $T$ [19,20]. In opposite, others have found that the saturated capacity decreases when $T$ increases [21]. Therefore, the relationship between saturated current or density of vehicles and the cycle time $T$ requires further research to be clarified.

In this paper, we focus on the numerical study of the dependence of car accident probability $P_{ac}$, *per site* and *per time step* on cycle time $T$ of traffic light both in open and periodic boundaries system. We consider the case of a one-dimensional system with open or periodic boundaries. One traffic light is placed at the middle of the study street. This numerical study is made using NaSch model taking into account the braking probability of vehicles. The study is made using parallel cellular automata.

The paper is organized as follows: in Section 2, we describe the used model. In Section 3, the main results obtained in this numerical study are presented with critical discussions. Finally, some conclusions and summary are drawn in Section 4.

## 2. Model

Our main interest in this paper is to numerically study the dependence of car accident probability $P_{ac}$, *per site* and *per time step* on cycle time $T$ of traffic light both in open and periodic boundaries system. In this study one traffic light is placed in the middle of the road. The traffic light is chosen to switch after a fixed time period $T/2$. The duration of red light phase is equal to the duration of the green light phase and the orange light period is ignored.

Let us consider a unidirectional highway lattice of length $L = 1000$. Each lattice site is either empty or occupied by one car of velocity $v = 0, 1, 2, \ldots, V_{\max}$. Hence the state of the system is defined by a set of occupation numbers $\tau_1, \tau_2, \ldots, \tau_L$, while $\tau_i = 1$ (resp. $\tau_i = 0$) means that $i$th site is occupied (resp. empty). We denote by $x(t)$ and $v(t)$ the position and the velocity of the $i$th car at time $t$.

Note that the system update is performed in parallel for all cars, according to the following four rules [1]:

The first rule is acceleration; if the speed of car is lower than $V_{\max}$, the speed is increased by one: $v_i \longrightarrow \min(v_i+1, v_{\max})$.

The second rule is deceleration due to other cars or the traffic light state:

Case 1: The traffic light is green in front of $i$th car: $v_i \longrightarrow \min(v_i, d_i)$.
Case 2: The traffic light is red in front of $i$th car: $v_i \longrightarrow \min(v_i, d_i, S_i)$.

The third rule is randomization; the speed of a moving car is decreased randomly by one unit with a braking probability $p_{ns} : v_i \longrightarrow \max(v_i - 1, 0)$.

The fourth rule is that each car is moved forward according to its new speed determined by the above three rules: $x_i(t+1) \longrightarrow x_i(t) + v_i$.

Here $S_i$ are the empty sites between the $i$th site and the traffic light ahead.

Furthermore, the boundary conditions are defined as follows: cars are injected into the road only on the first site with rate $\alpha$ whereas their extraction is done with rate $\beta$ from the four last sites if there is no vehicle in front of them. Clearly, an $i$th vehicle which occupies the site $L - v_i + 1$ at time $t$ leaves the road at time $t + 1$ with rate $\beta$ if there is no vehicle ahead.

In the basic NaSch model, car accidents will not occur, because the second rule of the update is designed to avoid accidents. The safely distance of driver is respected in the driving scheme. However, in real traffic, car accidents often occur because of careless drivers who have a tendency to drive as fast as possible and increase the safety velocity given in the second rule by one unit with a probability $P_{col}$, which is assumed to be independent of car and time. At the next time it will arrive at the position of the moving car ahead. If the car ahead suddenly stops, the collision between two neighborhood $i$ and $i + 1$ cars occurs. Boccara et al. [22] originally proposed that when three conditions, (1) $d(i, t) \le V_{\max}$, (2) $v(i + 1, t) > 0$, and (3) $v(i + 1, t + 1) = 0$ are satisfied simultaneously, then car $i$ will cause an accident at time $t + 1$ with a probability $P_{col}$ (called $p$ in Ref. [22]).

In our numerical calculations, all steps of the model described above are updated in parallel, i.e. during one update step the new particle position does not influence the rest and only the previous positions have to be taken into account.

We start with random positions and velocities of cars at the initial configurations. Next, we update each car velocity and position in accordance with the NaSch-rules. For each initial configuration, the system runs between $5 \times 10^4$ and $10^6$ time steps to ensure that study state is reached. In order to eliminate the fluctuations, 30 initial configurations were randomly chosen.

## 3. Results and discussion

Let us consider the NaSch model, with $V_{\max} = 5$ corresponding to a typical urban speed limit of 67.5 km/h when one time step corresponds to 2 s in real time. The length of a single cell is set to be 7.5 m. While, the length of the open system considered here is $L = 1000$. One traffic light is placed in the middle of the road.

First, we shall show in Fig. 1 the behavior of the probability, $P_{ac}$, *per site* and *per time step* versus the injecting rate $\alpha$ for various values of extracting rate $\beta$ in open system, without traffic light. The car accident probability $P_{col}$ is taken equal to 0.1. In the absence of light signalization, it is clear that in the low density phase, there is no accident in the system. While,