Physics Letters A 380 (2016) 992–997

Contents lists available at ScienceDirect

Physics Letters A

www.elsevier.com/locate/pla

Phase diagram of a single lane roundabout

H. Echab, N. Lakouari, H. Ez-Zahraouy *, A. Benyoussef

Laboratoire de Magnétisme et de Physique des Hautes Energies (URAC 12), Département de Physique, B.P. 1014, Faculté des Sciences, Université Mohammed V, Rabat, Morocco

ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form 29 December 2015
Accepted 5 January 2016
Available online 7 January 2016
Communicated by F. Porcelli

Keywords:
Cellular automata
Roundabout
Phase diagram
Density profiles

ABSTRACT

Using the cellular automata model, we numerically study the traffic dynamic in a single lane roundabout system of four entry/exit points. The boundaries are controlled by the injecting rates α_1, α_2 and the extracting rate β. Both the system with and without Splitter Islands of width L_{sp} are considered. The phase diagram in the (α_1, β) space and its variation with the roundabout size, P_{agg} (i.e. the probability of aggressive entry), and P_{exit} (i.e. the probability of preferential exit) are constructed. The results show that the phase diagram in both cases consists of three phases: free flow, congested and jammed. However, as L_{sp} increases the free flow phase enlarges while the congested and jammed ones shrink. On the other hand, the short sized roundabout shows better performance in the free flow phase while the large one is more optimal in the congested phase. The density profiles are also investigated.

1. Introduction

To understand the traffic problems more thoroughly in modern society, many scientists in the fields of statistical physics have carried out many studies with different methods such as fluid-dynamical method, car following, and cellular automaton (CA) [1–7]. The CA model developed by the Nagel and Schreckenberg (NS) is intuitive and it can simulate complicated phenomenon (e.g. congestion, accidents) observed in traffic flow, due to its simplicity, flexibility, and its fast performance in simulations [1–3].

As an important factor in the traffic dynamics in the cities, intersections have attracted the attention of researchers. The intersections include traffic circle, roundabout, T-intersection, Y-intersection, X-intersection [8–18]. Among them, the roundabout in particular has been widely studied [10–17], because it ensures smooth mobility and has a larger capacity. Fouladvand et al. [10] studied the waiting time of traffic caused by a roundabout on both framework of car-following and CA models; Ding-Wei Huang [11] has investigated the emergence of gridlock at a traffic roundabout in the framework of CA model; Wang and Ruskin [12] propose a CA model with Multi-stream Minimum Acceptable Space (MMAS) to examine unsignalized multi-lane urban roundabout. Lakouari et al. [13] studied the characteristics of the traffic flow at single-lane roundabout as well as traffic circle using a CA model. Chen Rui-Xiong et al. [14] studied the traffic dynamics in a roundabout with inner-lane and outer-lane using a CA model.

Usually, roundabouts have Splitter Islands, i.e. a painted or raised area between two successive exit and entry points, used to separate exiting from entering traffic, slow and deflect incoming vehicles, and provide the opportunity for pedestrians crossing the road in two stages, this issue has seldom studied in previous works. In this paper, we investigate the traffic behaviors on roundabout system with Splitter Islands. Furthermore, the effects of the roundabout size, the probability of aggressive entry P_{agg} (i.e. when vehicles ignore the priority rules at the entrance points), and the probability of preferential exit P_{exit} will be studied. The paper is organized as follows: Section 2 we explain the model. Results and discussions are presented in Section 3. The conclusion is given in section 4.

2. Model and method

2.1. Model

We consider one-dimensional closed chain of L cells (circulating lane) with four entry/exit points which are equidistantly located respect to each other. The Splitter Islands of width L_{sp} is designed between two successive exit and entry points. Vehicles enter from odd-numbered points and exit from even numbered ones. In the circulating lane vehicles move orderly and counter clockwise. Fig. 1(a) shows the sketch of the roundabout model. To describe the motion of a vehicle, we use the NS model [1]; where all vehicles are handled in parallel during one time step according to the four rules:

R1: Acceleration: $V_j \to \mathrm{Min}(V_j + 1, V_{max})$

* Corresponding author.
E-mail address: ezahamid@fsr.ac.ma (H. Ez-Zahraouy).

http://dx.doi.org/10.1016/j.physleta.2016.01.005
0375-9601/

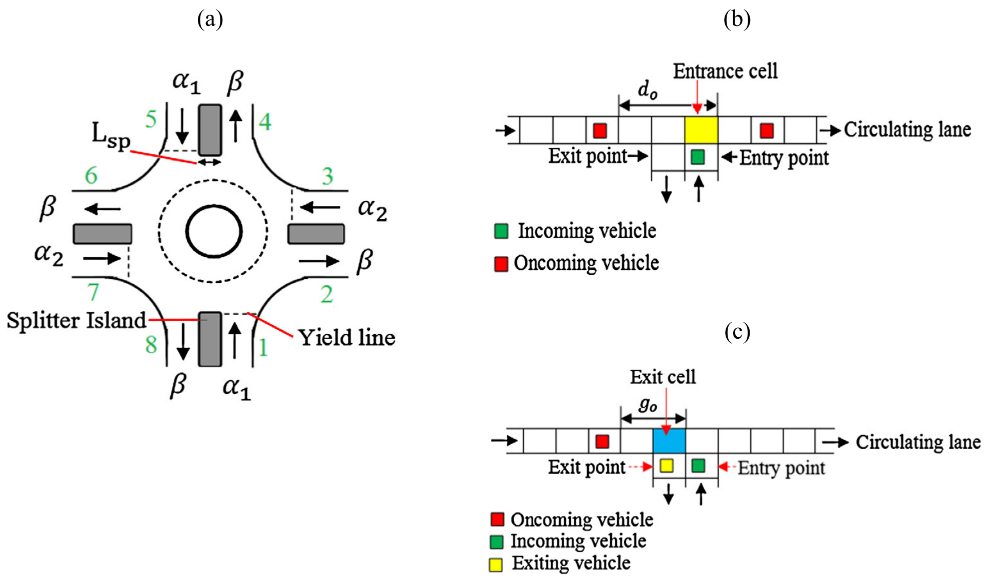

Fig. 1. (a) Sketch of the roundabout, (b) entry rule, (c) exit rule.

R2: Deceleration: $V_j \to \mathrm{Min}(V_j, d_j)$
R3: Randomization: $V_j \to \mathrm{Max}(V_j - 1, 0)$ with the braking probability P_b.
R4: Movement: $x_j \to x_j + V_j$

Where V_j and x_j designate the velocity and position of the vehicle j respectively. The maximum velocity and the headway are denoted as $V_{\max}$ and d_j respectively. In this paper we take $V_{\max} = 2$.

2.2. Priority rules for vehicles entry/exit roundabout

The rules of the roundabout give priority to the circulating flow. To avoid conflict at the entrance, the incoming vehicle (i.e. vehicle on the entry point) should yield to the cars in the circulating lane and reduces its velocity. The incoming vehicle with speed $V_{\text{in}} = 1$ can enter the circulating lane with probability α_1 or α_2; if the entrance cell (i.e. the cell that connects the entry point and the circulating lane Fig. 1(b)) is empty and one of the following conditions is fulfilled:

i. The oncoming vehicle (i.e. the leading vehicle on the circulating lane, in the left of entry point) uses the indicator when it approaches to its desired exit direction.
ii. Otherwise, the incoming vehicle inspects the gap (d_{o}) to the oncoming vehicle; if $d_{\text{o}} > V_{\text{o}} + 1$ vehicle enter the circulating lane.

Here V_{o} designates the velocity of the oncoming vehicle.

Simultaneously, an oncoming vehicle can leave the circulating lane from its aimed exit point with probability β (i.e. there is no other vehicle in the exit point) and if $g_{\text{o}} < V_{\text{o}}$, where g_{o} is the distance between the vehicle and its aimed exit. Otherwise, the oncoming vehicle cannot leave the circulating lane with probability $(1 - \beta)$ (i.e. there is a vehicle in the exit point), here the oncoming vehicle slow down and stop in the exit cell (i.e. the cell that connect the exit point and the circulating lane) waiting to leave as soon as the exit point will be empty (see Fig. 1(c)). The inclusion of the exit probability β can be related to the traffic status in the exit direction.

The exit point is selected for each vehicle with probability P_{exit} (exit = 2, 4, 6, 8) upon entrance to the circulating lane and it remain unchanged.

2.3. Aggressive entry rule

We know that in real traffic aggressive entry commonly exists, which means that there are some incoming vehicles ignore the priority rules to save time. For this purpose, we assume that cars can ignore the entry rules with probability P_{agg} when two conditions are fulfilled: first, the entrance cell is empty and second, $d_{\text{o}} \le V_{\text{o}} + 1$.

3. Results and discussion

In this section, the simulation results are presented. The parameters $L = 40$, $V_{\max} = 2$, $P_b = 0$ are used. The exit points are chosen on an equal probability $P_{\text{exit}} = \frac{1}{4}$. The results are averaged over 40 000 time steps after 5000 time steps for 80 independent runs.

As a preliminary work, we consider the special case that there is no splitter island, this means $L_{\text{sp}} = 0$. Also we assume that $\alpha_1 = \alpha_2$. Based on the current in the circulating lane as an order parameter, the phase diagram in the (α_1, β) plane is presented (see Fig. 2(a)). The results shown that the traffic displays three different phases. In phase I, the free flow state is reached, the vehicles can move freely and the current in the circulating lane increases correspondingly. However, in phase II the congested state is obtained, here the current in the circulating lane decreases because the rotary is dominated by clusters generated at exit points. In phase III, the jams (i.e. the extreme congestion) appear in the entire circulating lane because there are more vehicles than the circulating lane can handle, here the current saturates. Note that both transitions (i.e. from phase I to phase II and from phase II to phase III) are second-order transitions because the current is a continuous function of the injecting rate α_1 for a fixed rate β (see Fig. 2(b)).

It is interesting to point out that the maximum current phase [19,20] cannot be reached due to the size of the system (i.e. shot-sized system $L = 40$) as well the number and the rules of entry/exit (i.e. the incoming vehicle yield to the oncoming one and each exiting vehicle select its destination with probability P_{exit}) make the current on the circulating lane depend of the boundary rates.

In order to get better insights into the traffic dynamics in those different phases, we presented the density profiles of the roundabout with $\alpha_1 = \alpha_2$ (Fig. 3). In the free flow (Fig. 3(a)), the fluctuation is observed, here the interactions among vehicles is extremely