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Effect of pre-signals in a Manhattan-like urban traffic network

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HIGHLIGHTS

- The implementation of pre-signals in a network system is studied by microscopic simulations based on cellular automaton.
- A reliable method is proposed to provide good timing of pre-signals and intersection traffic lights.
- The optimization of pre-signal area length is discussed by showing that the best length should be determined by the left-turning phase of the traffic lights.
- Effects of the traffic light period, and the loading process in an open boundary condition are also provided.

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ABSTRACT

Pre-signal is an additional traffic light proposed in traffic system to improve the left-turning efficiency of intersections. The efficiency of pre-signals in a networked environment will be affected by the coordination of pre-signals and the intersection traffic lights. In this paper, we study the implementation of pre-signal in a Manhattan-like urban traffic system based on a microscopic cellular automaton model. The pre-signals are located before the normal traffic lights, and have two phases (left-turning phase and through phase) for the aim of segregating left-turning and through vehicles into separate sets of lanes. We propose a reliable method to coordinate the intersection traffic light period and phases with the pre-signal period and phases. Simulation results show that the pre-signals can improve the performance of the system, for both closed and open boundaries. The macroscopic fundamental diagram of the system shows a much higher traffic flow for a wide range of densities. Moreover, the effect of pre-signal area length also needs to be considered in a networked environment. We find that the optimal length of pre-signal area should be determined by the number of vehicles passing the traffic light in a left-turning phase at the intersection. The results can help the implementation and application of pre-signal in real traffic system.

1. Introduction

With the development of economy, traffic congestion has become a global problem faced by most modern cities. In order to mitigate the traffic congestion, various mechanisms and strategies have been proposed, such as perimeter traffic control [1] and congestion pricing [2]. The efficiency of the left-turning lane has been proved to be one of the major hindrances to improve traffic flow [3]. Some strategies are also designed specially for this problem, such as short left-turn

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Bay [4],(turning and through lane sharing at intersection [5]), left-turn waiting area [6], and continuous flow intersection (CFI) [7,8].

One of the effective strategies to increase left-turning flow is the pre-signal [9]. The idea of pre-signals was originally proposed to give priority to buses [10]. Wu et al. [11] and Xuan et al. [9] studied this pre-signal mechanism for buses and bicycles system, respectively. In this strategy, before the normal traffic light, an additional traffic light is added to give a pre-timed traffic signal, i.e., the pre-signal. The pre-signal has two phases: one for left turning only, and the other for the through or right-turning vehicles. Since the pre-signal separates the left turning and through/right-turning vehicles before they reach the intersections, the number of lanes the vehicles can occupy can increase when they pass the pre-signal. In this way, the traffic capacity of the intersection is supposed to be improved.

However, in previous studies, only one road directing to the intersection is considered. As a result, the correlation of the traffic flow of adjacent roads and adjacent intersections in a networked traffic system is not taken into account. However, the network features such as route choice and traffic lights could play a key role [12,13]. This kind of study is missed for pre-signals in real traffic systems. In this paper, we study the implementation of pre-signals in a Manhattan-like urban system, in which the traffic lights and origin–destination trips are both considered. To reflect the route choices behavior, we consider a route guidance strategies based on the real-time information feedback, (such as the geographic shortest path (GSP) and the time shortest path (TSP) [14–16]). This paper compares the performance of traffic networks with and without pre-signal to obtain a good strategy to improve the traffic of urban system. We suggest a reliable method to coordinate the traffic light period and phases with the pre-signal period and phases. Simulation results show that the pre-signals can improve the performance of the system, both for closed and open boundaries. The effect of pre-signal area length was not considered in previous studies. We find that the optimal length of pre-signal area should be equal to the number of vehicles passing the traffic light in a left-turning phase. The results can help the design of pre-signals in real traffic system.

This paper simulates the traffic system using a microscopic simulator based on Nagel–Schreckenberg (NaSch) cellular automaton model [17]. Microscopic models have been proved to be an efficient tool for the simulation of traffic systems [18]. Our model is an extension of previous work, considering multi-lanes in each link. The movement of vehicles in the system is captured in detail. The car-following, lane-changing and the route-choice behaviors are all incorporated in the model. Especially, the traffic lights are simulated in detail, and the traversing behavior of vehicles at the intersections are treated as passing specific turning tracks. Therefore, our microscopic simulator can be used to study the effect of pre-signals.

The paper is organized as follows. In Section 3, our simulation model and the route guidance strategies will be introduced. Sections 4 and 5 describe the simulation results under closed and open boundaries, respectively. Section 6 discusses the result and concludes the paper.

2. Mathematical formulation

A typical road section with pre-signal is illustrated as Fig. 1(a). The vehicles will first enter channelized lanes with a pre-signal at the end. The pre-signal will allow left-turning vehicles and straight vehicles to enter the pre-signal area alternatively. After the left-turning vehicles cross the pre-signal, they can proceed to occupy more lanes in the pre-signal area. Then the vehicles will enter the intersection area according to the intersection traffic light.

We first formulate the functioning of pre-signal area by considering one incoming direction of the intersection. In a traffic light period, denote Q as the total flow, Q_L as the left-turning flow, Q_S as the straight flow, γ as the proportion of left-turning vehicles in the stream. We have:

$$Q_L = Q\gamma, Q_S = Q(1.0 - \gamma). \tag{1}$$

Denote G as the average number of vehicles which can pass in a traffic light period in one lane (G will be proportional to the duration of green phase of traffic light), G_S as the average number of straight vehicles passing in a straight phase in one lane, G_L is the average number of left-turning vehicles passing in a left-turning phase in one lane. We have:

$$G = G_L + G_S. \tag{2}$$

Denote N_L as the number of left-turning lanes, N_S as the number of straight lanes. We have

$$Q_L = G_L N_L, Q_S = G_S N_S. \tag{3}$$

We denote Q_{cross} as the traffic flow at the intersection traffic light (the flow leaving the pre-signal area and entering the intersection area). Combining Eqs. (1)–(3), we have [9]:

$$Q_{cross} = \frac{G}{\frac{\gamma}{N_L} + \frac{1-\gamma}{N_S}}. \tag{4}$$

Before the pre-signal, denote g as the number of vehicles crossing the pre-signal (it is proportional to the duration of green phase of the pre-signal), n_L as the number of left-turning lanes before the pre-signal, n_S as the number of straight lanes before the pre-signal, n as the number of lanes. We have $n = n_L + n_S$. We denote Q_{pre} as the traffic flow leaving the channelized section and entering the pre-signal area:

$$Q_{pre} = \frac{g}{\frac{\gamma}{n_L} + \frac{1-\gamma}{n_S}}. \tag{5}$$