An Organization Method Research of Simulation-Based Dynamic of Urban Traffic Circle

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***Abstract*—With growing urban traffic, control strategy in traffic circles are needed: signals, stop/yield signs, and traffic lights. In this paper, we create two progressive simulation models, the first macroscopic models are based on Markov chain, and the second simulates traffic by traffic capacity. We find that the number of lanes in the circle are major factors for optimal choice of a control system, and by exam the Bell Tower Circle in Xi'an, our model is accurate suitable. The simulated-based performance of traffic circles with an intellectual period of traffic light operate better than fixed cycle traffic light. However, further research will be done to verify strength and sensitivity of our model, as well as emergency cases to judge its flexibility.**

Keywords- urban traffic; traffic circle; travel time; simulation; sensitivity test; delaying time

I. INTRODUCTION

Traffic circle is used to control traffic flow through an intersection; depending on this goal, a traffic circle may take different forms. A circle can have one or more lanes, one or more arms; and a circle can have a large or small radius; a circle can confront roads containing different amounts of traffic; vehicles that enter a circle can be controlled by a stop sign, a yield sign, or a traffic light. These features affect the congestion that a vehicle confronts as it circles, the cost of the circle to build, the size of the queue of vehicles waiting to enter, and the travel time of a vehicle transit the circle. Each of these variables could be a metric for evaluating the efficacy a traffic circle. In this paper, we take travel time as the parameter.

Modern traffic circles have recently been recognized as safer alternatives to traditional intersections. The most famous traffic circle is Paris's arc DE triomphe circle, other examples of large traffic circles include Columbus Circle in New York City, while small, one-lane traffic circles often exist in residential neighborhoods. Research by Zein, Flannery and Datta using statistical methods has demonstrated that traffic circles bring added safety to the urban environments. Attempts to understand the specific safety and efficiency benefits of traffic circles in urban traffic, the researchers have taken four primary approaches: critical-gap estimation, regression studies, continuous models, and discrete models.

Critical-gap models: build from how drivers empirically gauge gaps in traffic before merging or turning into a traffic flow. However, according to Brilon et al.[1], attempts in the 1980s to model roundabout, the traffic circle named roundabout in Europe, capacity based on gap-acceptance theory were not exceptionally promising; in particular, critical-gap estimation lacked valid procedures as well as general clarity[1]. Recently, more researches applying gap-acceptance models to understanding traffic circles has included Polus et al. [1997] and the modeling of unconventional traffic circles by Bartin et al.[2].

Nevertheless, regression studies on empirical data is the major research fields, and the regression studies on empirical data made much progress. The most beginning research is Kimber in 1980, he studied roundabouts in England and discovered a linear relation relating entry capacity to circulating flow and constants depending on the entry width, lane width, angle of entry, and the traffic circle size[3]. Further regression studies have built extensively on Kimber's work, such as in Polus and Shmueli[4,5], which determined the importance of traffic circle diameter in small-to-medium circles.

Continuous models have included fluid-dynamic models [Helbing 1995; Bellomo et al. 2002; Daganzo 1995; Klar et al. 1996][6]; however those papers model traffic flow in standard traffic environments, not in traffic circles.

Discrete models include cellular automata models [Fouladvand et al. 2004; Klar et al. 1996][7] and discrete stochastic models [Schreckenberg et al. 1995][8]. Discrete models are suitable for small environments such as traffic circles, where individual car-to-car interactions takes priority over traffic flow as a whole. Discretized approaches have attempted to model multilane traffic flows [Nagel et al. 1998]; but to our knowledge, there has been no research in discrete models of multilane traffic circles of varying sizes.

II. THE MACROSCOPIC MODELS

In this paper, the goal is to determine how best to control vehicles traversing a traffic circle, therefore the accurate calculation of traffic capacity in traffic circle is necessary. We take as given the traffic circle capacity, the arrival and departure rates at each of the arms, and the initial number of vehicles circulating in the circle (circulation). We take travel time as the parameter. For a vehicle to traverse the circle efficiently, its time spent in the queue should be minimized. As a result, we try to minimize the queue length by allowing the rate of entry

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from the queue into the circle to vary first. Figure 1 shows an outline of the program flow and design.

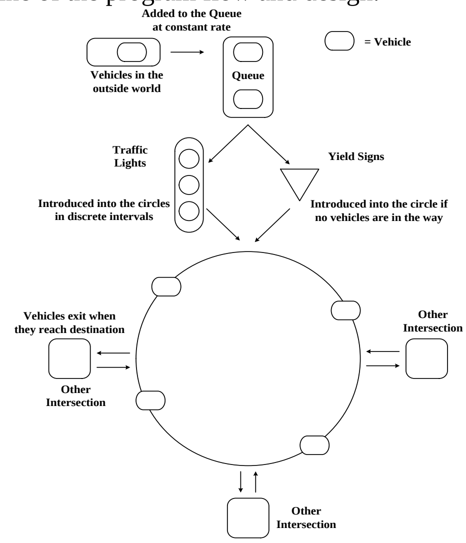

Figure 1. Program flow and design[9]

Each intersection is modeled as a queue of vehicles with a traffic control device. Vehicles are arriving to the queue at a constant rate. For a vehicle to leave the queue and enter the traffic circle, the area in the circle must be clear of other vehicles. Additionally, if the queue has a yield sign or a traffic light, the unit must be active[10].

A. Our model for give priority to incoming traffic

Usually, we do not know where each vehicle enters and exits the circle; we only know the number of vehicles coming in and out of each arm, hence we can calculate the average time of vehicles transiting the circle. Meanwhile, macroscopic models, which form a widely used class of models, are characterized by the fact that they are sensitive to small perturbations. So we adopt a macroscopic simulation.

Firstly, we combine the lanes in the sections and arms together and regard them as a one-lane traffic circle. Then we explain how the multilane simulation works. We have a simple analysis of this model, then we consider the rule of this control method is to give priority to the vehicles in the incoming lanes when they crossing through the conflict of the traffic circle. Then we model the following model to assess the traffic circle.

B. The Macroscopic Simulation

1) Assumptions

In order to streamline our model, we make several key assumptions:

a) Vehicles in the same section of traffic circle are distributed uniformly.

b) The largest density of vehicles in the circle is a constant，furthermore, the traffic flow is free movement of the bowels when it comes to the biggest density.

c) The arrival rating at each arm is constant in the period which we can simulated, and the speed of vehicles are unchangeable during the time from arms to section.

d) Simplicity, we consider an ideal round traffic circle (Fig. 2). The macroscopic simulation itself does not depend on the form of the circle.

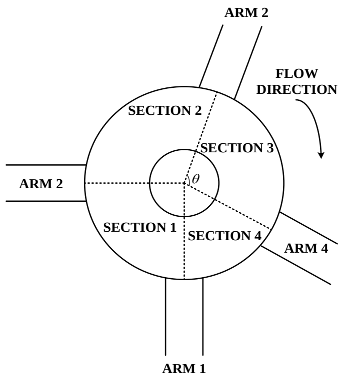

Figure 2. Sample of ideal traffic circle[11]

2) The Markov Process

We divide the traffic area into sections and take vehicles in the same sections as a whole. We label the sections and the arms as Figure 2 shown above. Associate to section *i* are the quantities:

a) Number num_i^t of vehicles in the section at time *t*.

b) Number arm_i^t of vehicles waiting to enter through one arm at time *t*.

c) The maximum number cap_i^t of vehicles that can enter the traffic section through one arm per unit time.

The traffic state at time *t+1* depends only on the traffic state at time t, so traffic is a Markov process. To describe the state of the whole system, only the quantities num_i^t and the arm_i^t are needed. To implement the simulation, we must determine num_i^{t+1} and the arm_i^{t+1}, for *i=1,2,⋯,n.*

In principle, we can calculate the transition probability matrix; but not in our problem. For a traffic circle with four arms/section and each holding up to 10 vehicles, the number of the traffic states is 10^8.

Considering this sobering fact, we use the expectations $\overline{num_i}^t$ and $\overline{arm_i}^t$, instead of the actual distribution of cars ,to denote a state.

3) The Simulation Process

$\overline{num_i}^t \times out_i^t$ vehicles leave the circle from section *i*. The ratio out_i^t drops when $\overline{num_i}^t$ approaches its capacity.

To deal with the junction, there are two streams $\overline{num_i}^t \times \left(1 - out_i\right)$ and cap_i^t trying to flow into the next section. If there is a traffic light, only one of them is allowed. If stop/yield sign is used(at the arm side, for example), then only asmall fraction of cap_i^t can flow it.

This fraction is denoted by the disobey rate α_{stop} or α_{yield}.

An inflow of in_i newly-arrived vehicles runs into arm_i.

4) Results

We use the macroscopic model to simulation a real traffic circle, The Bell Tower Circle in Xi'an, which has four arms and three lanes. For simplicity, we consider only the average time needed for a vehicle to traverse the traffic circle, the value is 25.2s. In practice, we observed for two hours in peak hour, and calculate the average travel time is around 27s.

TABLE I. SENSITIVITY TEST OF SIMULATION MODE[11]

Parameter	Variation	Model
v_{max}	+10%	-2.6%
	-10%	10.5%
l_0	+1%	-19.6%
	-1%	12.3%
r_{out}	+10%	-7.3%
	-10%	1.1%
Traffic flow	+10%	10.6%
	-10%	-3.0%

We analyze sensitivity by running the program with modified parameters, as shown in Table 1. The average passing time is relatively insensitive to all the parameters except l_0. We consider it is reasonable, due to the number of traffic lanes in the circle affects the passing time significantly. Then we consider some more details in the next section.

III. THE SIMULATION-BASED OPTIMIZED MACROSCOPIC CONTROL MODEL

A. The Poisson Distribution and Binomial Distribution

The number of the vehicle arriving on the road meets Poisson-Distribution[11,12]. When the flow of traffic is unobstructed and the observing cycle is short, the influence among vehicles is weak, neglecting the other factors around. In other words, the number of the vehicle arriving on the road is random. The possibility of car arriving on the road per second:

$$p_k = \frac{(\lambda t)^k}{k!} e^{-\lambda t}, \tag{1}$$

where p_k is the possibility of k cars arriving on the road during spacing of counting, λ is vehicle average arriving possibility, t is the time of every spacing of counting.

Binomial distribution can meet the certain vehicle flow which makes the traffic quite congested and the vehicles cannot be drove freely[13,14]. The calculating formula:

$$P_k = C_n^k \left(\frac{\lambda t}{n}\right)^k \left(1-\frac{\lambda t}{n}\right)^{n-k} \quad (k = 0,1,2\ldots n), \tag{2}$$

where P_k is the possibility of k cars arriving on the road during spacing of counting, λ is average vehicle arriving possibility, t is the time of every spacing of counting, and $p = \frac{\lambda t}{n}$ is a distribution parameter.

Then we can use real data to reflect initial conditions to determine the traffic light time.

B. Model Design

The program design thought are as follows:100 meters away from the stop line planting coil group, whenever a vehicle signals will be passed to the sensor, and then through the line of its transmission to the traffic police command center of the main system. The main system analyzes the receipt data getting from the junctions to obtain the final passage time of need, that is, the green time, achieving the intelligent allocation of lights time, improving utilization and reducing congestion.

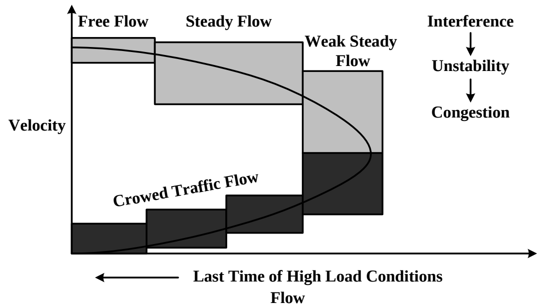

Figure 3. The Relation Curves of Speed and Flow[15]

C. Analysis And Results

Signal timing cycle and the actual green light time of the intelligent traffic control methods changes based on the flow. The basic idea, by comparing the number of waiting vehicles in the queue of the non-right-of-way (red light) traffic flow with the number of vehicles entering into the circle in the queue of right-of-way (green light) the traffic flow, to determine whether to extend the green time of the phase or switch to the next phase, as shown in Fig. 3. Therefore, we can get the two main control parameters as followed.

1) The number of waiting vehicles in the queue of the non-right-of-way (red light) traffic flow.
2) The number of vehicles entering into the circle in the queue of right-of-way (green light) the traffic flow.

Firstly, we assume some initial values of the model, $t_{\max} = 120s$. Because $t_{\min}$ is changeable, it is assumed $t_{\min} \in [5,120], t \in N$ .And the speed of the vehicles is defined under 120km/h. So λ can take 3 cars/s, the sample interval is 30 seconds or 60 seconds or other proper data. The total time of losing time t_0=5s. We create a computer simulation in Matla to account for variables to use in the mathematical model. And calculate from t_1 to t_6, but the result is not very good, for example, when $\lambda t = 90cars$, $t_1 = 30s,\ t_2 = t_3 = t_4 = t_5 = t_6 = 1$.

The change of the traffic lights time length is proposed in the case of the summit of the flow in duty or off duty. However, the traffic flow meets the Poisson distribution in normal. The Poisson-Distribution is used in the situation of small traffic flow, so our initial assumption is not very reasonable. When green lights on, the vehicles entering into the circle, the speed of which become small, the density of vehicles, meeting the Poisson distribution, is also small. The density of the vehicles in the position of the detector far away from the circle is very large and the lanes are very congested, so it should meet binomial distribution.

Based on the assumptions above, we can let N=1,000，p=0.15,at the same time, the other parameters remain the same. Then the result presented as the follow table is reasonable.

TABLE II. THE AVERAGE WAITING TIME

t_i	Average waiting time					
t_1	5	10	15	20	25	30
t_2	24	26	29	31	32	34
t_3	34	36	38	39	40	42
t_4	42	43	45	46	47	49
t_5	NaN	NaN	NaN	NaN	NaN	NaN
t_6	NaN	NaN	NaN	NaN	NaN	NaN

Note: NaN donates that the method using the changeable circulation of traffic lights to control the lights comes to an end, translate regular control method again.

This seems better than before, because the initial values have a big influence on the solution, by changing the initial values, we can obtain some useful results probably[16].

IV. CONCLUSION

To estimate the traffic capacity performance of a traffic circle with a general vehicle flow, we develop two progressive simulation models. The first uses a Markov process to consider the entire traffic flow, and the second devotes its attention to the delaying time.

We offer an optimization model to select traffic units and determine the traffic-light period when it is used. The flexibility of these solutions is proved when confronted with accidents. In addition, the in-depth study of parameters such as traffic-light period and position will be researched in further studies.

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