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Research on Dynamic Models of Traffic Flow

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Abstract: Road factors significantly influence the safety conditions and driving patterns of individual vehicles, as well as the interactions among vehicles in traffic flow. Therefore, exploring the dynamic variation laws of core characteristic parameters of traffic flow holds important theoretical value. By designing uniform and non-uniform motion scenarios, this study quantifies the dynamic evolution process of density, speed, and intensity, and clarifies the formation conditions of congestion critical points. Through dynamic modeling and simulation, the dynamic coupling mechanism of traffic flow characteristic parameters is revealed, and the variation trends of flow and density under different road conditions are predicted, providing a quantitative basis for optimizing traffic organization, road network design, and control strategies.

Keywords: Traffic Flow; Congestion Critical Points; Simulation

1. INTRODUCTION

The purpose of studying traffic flow is to accurately understand the current traffic situation and its development laws, so as to provide appropriate road construction measures and traffic management methods for future traffic demands. Over the years, it has been widely applied in research fields such as traffic planning, traffic control, and vehicle design. The influence of road factors not only affects the safety conditions and driving patterns of individual vehicles, but also impacts the interactions among vehicles in traffic flow. Therefore, it is necessary to investigate the variation characteristics of the main features of traffic flow—intensity, speed, and density.

Traffic flow refers to the theory that analyzes the movement laws of pedestrians and motor vehicles (mainly automobiles) on roads, either individually or in queues, and explores the relationships among traffic flow, speed, and density. Its objective is to reduce traffic delays and accidents while improving the operational efficiency of road infrastructure. Originating in the 1950s, this theory serves as a foundational and continuously evolving field within traffic engineering.

Traffic intensity refers to the number of vehicles passing through any part or section of a road per unit time, measured in vehicles/hour. Traffic density depends on the number of vehicles per 1 km of lane, with the unit of measurement being vehicles/km. As traffic density increases, the distance between vehicles decreases, driving speed reduces, drivers' work intensity increases, and driving conditions deteriorate. The maximum flow density can be achieved under congested conditions [1]. Speed, a physical quantity, is the ratio of displacement to the time interval during which the movement occurs, typically measured in km/h or m/s. The relationship among these three parameters is that traffic volume is the product of traffic speed and traffic density.

To sum up, all these relationships among the main characteristics of road traffic enable the prediction of changes in the state of traffic flow and throughput when planning measures to improve traffic organization and develop road networks.

2. DYNAMIC MODELS OF TRAFFIC FLOW

Most dynamic models of traffic flow can be conditionally classified into three categories: macroscopic models, kinetic models, and microscopic models.

Macroscopic models are those that describe the average motion of vehicles, such as density and average speed. In such models, traffic flow is analogous to the movement of a liquid, hence they are called hydrodynamic models. Microscopic models, on the other hand, explicitly simulate the movement of each vehicle. Kinetic methods occupy an intermediate position, where traffic flow is described as the density of vehicle distribution in phase space.

Cellular automaton (CA) models occupy a special position in the category of microscopic models because they adopt a highly simplified description of vehicle motion with discrete time and space, thus enabling these models to achieve high computational efficiency.

3. TRAFFIC FLOW SIMULATION SCHEME AND PARAMETER CALIBRATION

Scenario modeling is a type of modeling that takes into account alternative options for model development. It is one of the most effective strategic analysis tools.

A modeling script creates an object designed to generate sequences of simulation variables and upload data to the object after the completion of modeling task calculations.

The preliminary result graph obtained after calculating the intensity according to the formula is as follows.

$$q_{m,i}(k) = p_{m,i}(k) * V_{m,i}(k) * \lambda_m$$

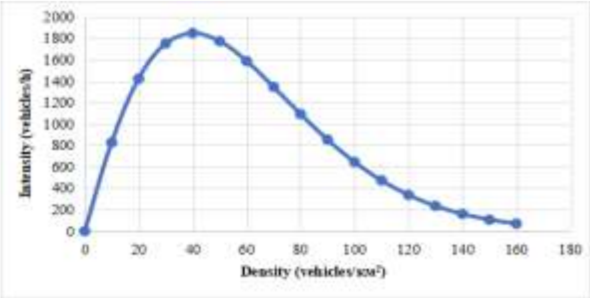

Figure 3.1.1 The Relationship between Intensity and Density

As can be seen from the above figure, the maximum flow density can be achieved under congested conditions. The recorded maximum intensity is 1,850 vehicles per hour, and the minimum is 50 vehicles per hour, and the traffic density on this road section is continuously increasing.

As can be seen from the above figure, the maximum flow density can be achieved under congested conditions. The recorded maximum intensity is 1,850 vehicles per hour, and the minimum is 50 vehicles per hour, and the traffic density on this road section is continuously increasing.

Under a given traffic volume density, the equilibrium movement speed is determined by the following formula.

$$V(p_{m,i}(k)) = v_{free,m} * exp\left[-\frac{1}{\alpha_m}\left(\frac{p_{m,i}(k)}{p_{crit,i}}\right)^{\alpha_m}\right]$$

Where $v_{free,m}$ represents the speed of free movement in km/h. Here, we specify an example value of 90 km/h.

Where $p_{cirt,m}$ is the critical density of traffic flow, with the unit of vehicles/km². Here, we take 45 vehicles/km² as an example.

Where a_m is a basic parameter, and here we specify an example value of 1867.

According to the formula and the specified relevant data, the relationship between density and speed is calculated as shown in the figure below.

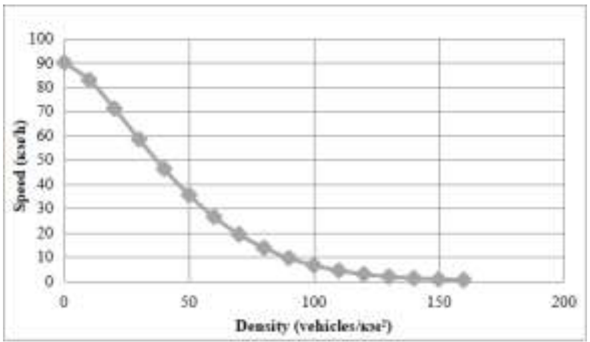

Figure 3.1.2 The Relationship between Density and Speed

As can be seen from the above figure, with the increase of traffic density, the distance between vehicles decreases, and the movement speed decreases accordingly, which increases the driver's work intensity and deteriorates the driving conditions. The maximum flow density is achieved under congested conditions.

4.MODELING SCHEME

4.1 Uniform motion

In the state of uniform motion, the flow density is determined by the following formula.

$$p_{m,i}(k+1) = p_{m,i}(k) + \frac{T}{L_m * \lambda_m} * (q_{m,i-1}(k) - q_{m,i}(k))$$

Where L_m is the distance length and T is the number of simulation steps.

Under a given traffic volume density, the movement speed is determined by the following formula.

$$V(p_{m,i}(k)) = v_{free,m} * exp\left[-\frac{1}{\alpha_m}\left(\frac{p_{m,i}(k)}{p_{crit,m}}\right)^{\alpha_m}\right]$$

The variation diagram is obtained from the traffic flow density formula and the movement speed formula under a given traffic flow intensity, as shown in the figure below.

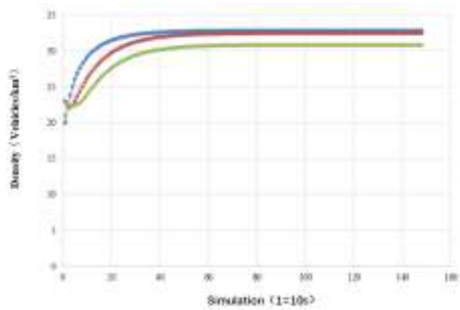

Figure 4.1.1 Density Changes During the Simulation Process

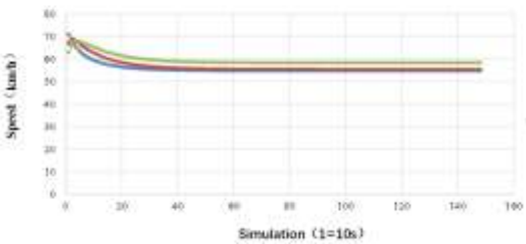

Figure 4.1.2 Speed Changes During the Simulation Process

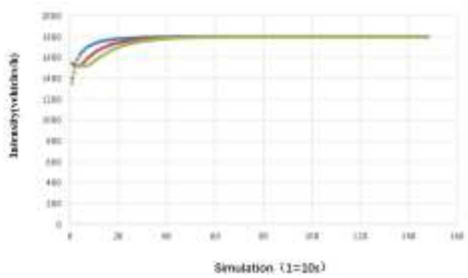

Figure 4.1.3 Intensity Changes During the Simulation Process

4.2 Non-uniform motion

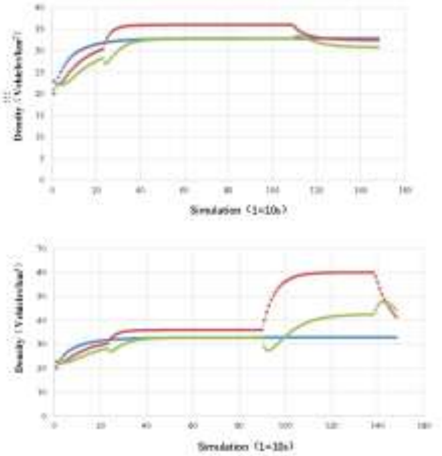

Figure 4.2.1 Density Changes During the Simulation Process

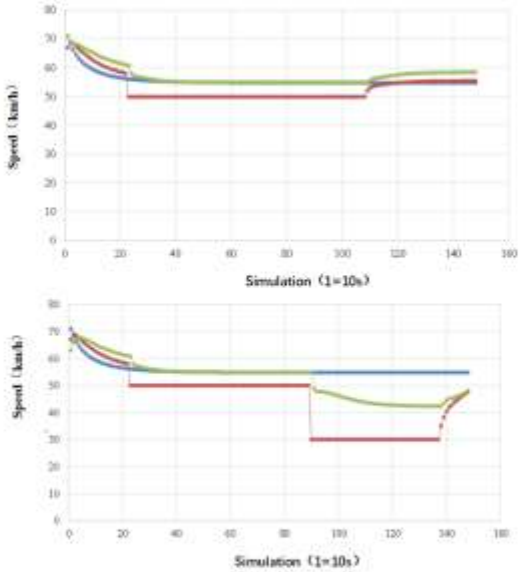

Figure 4.2.2 Speed Changes During the Simulation Process

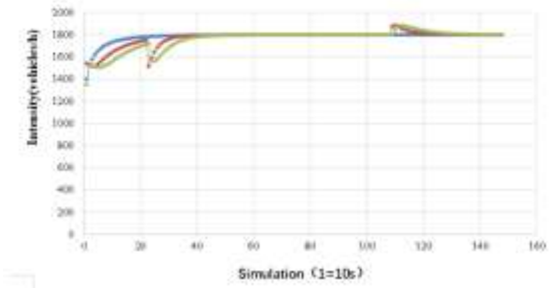

Figure 4.2.3 Intensity Changes During the Simulation Process

5. CONCLUSION

With the increase in traffic density, the distance between vehicles shortens, speed decreases, drivers' work pressure increases, and both traffic conditions and driving conditions deteriorate. Therefore, the maximum density of traffic flow is achieved under delayed conditions, that is, the maximum flow density can be realized in traffic congestion [2]. When there are few vehicles on the road, drivers can choose faster speeds. At this time, the traffic flow rate is higher, but due to the small traffic density, the traffic flow is relatively low.

As the number of vehicles on the road increases, traffic density also rises. Although the speed of vehicles decreases due to the restriction of preceding and following vehicles, traffic intensity increases until speed and density reach certain conditions, where their product (i.e., traffic volume) also meets specific criteria. The maximum value occurs when traffic intensity is at its peak. The speed at this point is called the optimal speed, and the density is called the optimal density. When density is high but speed is low, intensity decreases until density reaches its maximum (currently referred to as congestion density), leading to road blockages. Vehicles cannot move, resulting in zero speed and zero intensity.

All these relationships among the main characteristics of road traffic enable the prediction of state changes in traffic flow and throughput when planning measures to improve traffic organization and develop road networks.

In congested conditions, the maximum flow density can be achieved. The recorded maximum intensity is 1,850 vehicles per hour (v/h), and the minimum is 50 v/h. The traffic density on the road section continues to grow.

6. ACKNOWLEDGMENTS

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