Research on Traffic Condition Discriminant Technology of Urban Intersections Under Intelligent Lighting System Based on Fuzzy Comprehensive Evaluation

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Abstract. Firstly, the basic traffic data collection methods based on intelligent lighting system are introduced, including RTMS data collection and video data collection. Then, based on the fuzzy comprehensive evaluation, a traffic condition discrimination model of urban intersections under the intelligent lighting system is established. The average speed, stop delay and queue length detected by the intelligent lamp post collection equipment are selected as evaluation factors, and the traffic status of signalized intersections is defined as smooth traffic, normal congestion and severe congestion. The research results have realized the fine discrimination of urban intersection traffic operating condition under the intelligent lighting system.

1. Introduction

There are some defects in the traditional traffic information collection and release system, which are mainly manifested in the insufficient number of hardware facilities, low efficiency, poor rationality and systematism of Settings, no real network coverage, especially the lack of mining and processing of acquired information. Combination with the construction of the current wisdom city and traffic demand, in view of the outdoor lighting has been widely used in urban road, the system of distribution network and coverage has unique advantages, but also has its own perfect power supply, communication, light pole and basic conditions, but for wisdom and wisdom urban transportation hardware system construction provides a good platform for the expansion. At the same time, the intelligent lighting system integrates various types of comprehensive services such as lighting, monitoring and forecasting, avoiding the repeated implementation of municipal civil engineering facilities and saving space cost, construction cost and later maintenance cost.

At present, scholars’ research on intelligent lighting system mainly focuses on theoretical system construction and device design. Hongzheng Z [1] combined the construction of smart city with the construction of urban road lighting, and summarized the construction elements of smart road lighting, such as: safety and disaster prevention, traffic management, urban space development, intelligent community construction, landscaping and other aspects. According to the characteristics of road lighting construction elements of smart city, the urban road lighting system under the construction of smart city was constructed. Rui W [2] proposed a complete system architecture consisting of wireless connection server, data analysis software, management and operation hardware platform, lighting controller and energy-saving lamps. Junnan Y [3] carried out a study on the morphological design evaluation method...
of urban intelligent lighting integrated devices from the perspective of value co-creation. Qian Z [4], Zeming Y [5], Du C [6] and others have also designed intelligent lighting system. Based on the intelligent lighting system, this study studies the traffic condition discriminant technology of urban intersections based on the fuzzy comprehensive evaluation model. The research results can provide support for traffic control decisions and provide more efficient, convenient and comprehensive travel services for road users.

2. Urban intersection traffic data collection based on intelligent lighting system
As the main component of the intelligent lighting system, the intelligent lamp post (as shown in Figure 1) assumes the task of supporting the suspension of basic data acquisition equipment in the traffic management and control technology. Because of the vertical height advantage of the intelligent lamp pole, the data collector attached to the smart lamp pole has a wider field of vision and a larger collection area. All these characteristics make the data acquisition equipment based on intelligent lamp pole have more advantages than the traditional equipment. In this study, traffic data collectors, including RTMS data collectors and video data collectors, were laid out on the basis of intelligent lamp posts to collect traffic state parameters at urban intersections.

2.1. RTMS data acquisition based on intelligent lighting system
RTMS stands for Remote Traffic Microwave Sensor. The working principle of RTMS (as shown in Figure 2) is as follows: the microwave principle is used to receive the echoes in the projection area. When there are objects, the background threshold will be formed. When the intensity of the echo signal is higher than the background threshold at the microwave level, it indicates the presence of vehicles. The RTMS detector installed on the intelligent lamp post can collect real-time traffic data and export in the form of Access, including: sensor ID, data time, lane number, speed, occupancy and volume.

2.2. Video data acquisition based on intelligent lighting system
A large number of traffic data can be collected by the video detector on the intelligent lamp post. Through processing, vehicle driving trajectory, queue length, travel time and stopping time can be obtained. The video equipment on the intelligent lamp post is debugged to facilitate the subsequent video shooting and video data extraction. At the same time, check whether the video detector of the intelligent lamp post works normally in advance to ensure that the camera power and memory card space are sufficient. The camera mode is progressive scan (50P). To ensure the synchronization of time and date between multiple devices, the camera clock is adjusted to the local standard time according to the region.

3. Judgment of urban intersection traffic operating condition
3.1. Urban intersection traffic operation judgment process
In the process of evaluating the state of the intersection, the influence of various parameters can not be reflected objectively in proportion, nor can it be represented by accurate mathematical expressions. The fuzzy comprehensive evaluation model can simulate the uncertain situation and concept. For example, it is impossible to use a number to define the boundary between unblocked and congested concepts, but
this study can simulate the difference between unblocked and congested roads through the fuzzy comprehensive evaluation model.

Based on the fuzzy comprehensive evaluation model, this study carries out the traffic status discrimination of urban intersections based on the intelligent lighting system. It can be divided into the following two steps:

Firstly, according to the status quo and characteristics of the traffic operation of urban intersections, relevant parameters are extracted by combining the data detected by the intelligent lamp post acquisition equipment.

Then, the weighted average model of fuzzy evaluation theory is used to analyse the intersection state, and the traffic state is evaluated according to the principal factors and the principle of maximum membership degree.

3.2. Division of urban intersection traffic operation
This study divides the traffic operational condition of signalized intersections into the following three levels: Smooth traffic, general congestion and severe congestion. From front to back, the operation status of signalized intersections gradually deteriorated from good to bad.

Smooth traffic: it is a state of health in the traffic state. Each vehicle is basically not affected by other vehicles in the traffic flow, and the degree of freedom to choose the desired speed is very high. The upper limit is free flow, and the lower limit is that each vehicle should begin to pay attention to the effects of other users in the traffic flow on it.

General congestion: this state includes two state types, one is the slow state, the other is the congestion state. Under the general state of congestion, the traffic flow has an unstable trend, and the flow velocity drops, and even queues are generated at intersections. The driver's speed and comfort are reduced to different degrees.

Serious congestion: this state has already produced traffic congestion, vehicles have long queue. The driver's experience is very poor, and the road condition is unstable, and even secondary queuing is needed.

3.3. The evaluation factors selection of fuzzy comprehensive evaluation
The selection of evaluation factors directly affects the stability and validity of road traffic status discrimination. Therefore, the selection of evaluation factors should be able to accurately reflect the changes of traffic conditions, and it is relatively easy to obtain in practice, and the number of parameters should be reasonable. In this study, relevant factors, such as average speed, stop delay, queue length, were obtained based on the traffic data acquisition equipment of the intelligent lamp post. These parameters are easy for people to understand and can intuitively obtain the change of road traffic status.

- **Average speed**
  The average speed is the average speed of all vehicles on a section of road. The average speed of the road section will change with the change of the traffic condition of the urban road section. The higher the vehicle speed is on the specific road section, the smoother the traffic flow will be, and the traffic condition is good. On the contrary, the lower the driving speed, the more serious the vehicle is blocked, the more congested the road and the worse the traffic condition.

- **Stop delay**
  Stop delay is the average of the total delay of all vehicles on a section of road. Stop delay is a reference standard that can reflect the running state of road traffic. It can not only reflect the time it takes for vehicles to pass the road section, but also reflect the overall running state of traffic flow in the current area.

- **Queue length**
  Queue length refers to the maximum queuing length of vehicles at each entrance of an intersection within a certain period of time. Queue length, as an important index to evaluate the operation efficiency of signalized intersections, can effectively reflect the traffic operating condition of intersections.
3.4. Evaluation of Urban intersection traffic operation condition based on fuzzy comprehensive evaluation

3.4.1. Establish factor set and evaluation set

• Factor set U:
  Factor set is composed of factors affecting the evaluation object, denoted as \( U = \{ u_1, u_2, \ldots, u_n \} \), where \( u_i \) represents the \( i \)-th factor affecting the evaluation object. In order to identify the urban road traffic operating condition more accurately, the average speed, stop delay and queue length detected by the intelligent lamp post collection equipment were selected as evaluation factors.

• Evaluation set F:
  Evaluation set is a set of evaluation results, denoted as \( F = \{ f_1, f_2, \ldots, f_n \} \). Where \( f_i \) represents the \( i \)-th evaluation result of the evaluation object, and \( n \) represents the total number of evaluation grades. The final comprehensive evaluation result is an evaluation grade of the corresponding evaluation set. The traffic status of signalized intersections is defined as three categories: smooth traffic, general congestion and severe congestion.

3.4.2. Establish the membership function of evaluation factors

In this study, trapezoidal function is selected as the function model, and membership functions of three fuzzy sets, namely average speed, queue length and stop delay, are constructed. By referring to the manual of "Urban Road Traffic Management Evaluation Index System" and related materials issued by relevant authorities in China, the membership degree function of each factor is determined.

• Membership function of average speed
  The membership function of the average speed is shown in Equation 1 and Figure 3. In the formula, \( u_1(v) \) is the membership degree of the average speed, \( v \) is the average speed in kilometres per hour.

\[
\begin{align*}
  u_1^1(v) &= \begin{cases}
    0 & v \leq 20 \\
    v - 20 & 20 < v \leq 21 \\
    1 & v > 21
  \end{cases} \\
  u_1^2(v) &= \begin{cases}
    0 & v \leq 16 \text{ or } v > 21 \\
    21 - v & 20 < v \leq 21 \\
    v - 16 & 16 < v \leq 17 \\
    1 & 17 < v \leq 20
  \end{cases} \\
  u_1^3(v) &= \begin{cases}
    0 & v > 17 \\
    17 - v & 16 < v \leq 17 \\
    1 & v \leq 16
  \end{cases}
\end{align*}
\]

Figure 3. Membership function of average speed

• Membership function of stop delay
  The membership function of the stop delay is shown in Equation 2 and Figure 4. In the formula, \( u_2(t) \) is the membership degree of the stop delay, \( t \) is the stop delay in seconds per kilometer.

\[
\begin{align*}
  u_2^1(t) &= \begin{cases}
    1 & t \leq 30 \\
    4 - \frac{1}{10} t & 30 < t \leq 40 \\
    0 & v > 40
  \end{cases} \\
  u_2^2(t) &= \begin{cases}
    0 & t > 60 \text{ or } t \leq 30 \\
    6 - \frac{1}{10} t & 50 < t \leq 60 \\
    \frac{1}{10} t - 3 & 30 < t \leq 40 \\
    1 & 40 < t \leq 50
  \end{cases} \\
  u_2^3(t) &= \begin{cases}
    \frac{1}{10} t - 5 & 50 < t \leq 60 \\
    1 & 60 < t
  \end{cases}
\end{align*}
\]
The membership function of the queue length is shown in Equation 3 and Figure 5. In the formula, \( u(t) \) is the membership degree of the queue length, \( t \) is the queue length in meters.

\[
\begin{align*}
    u^1(l) &= \begin{cases} 
    1 & l \leq 30 \\
    4 - \frac{1}{10}l & 30 < l \leq 40 \\
    0 & l > 40 
    \end{cases} \\
    u^2(l) &= \begin{cases} 
    0 & l > 70 \text{ or } l \leq 30 \\
    7 - \frac{1}{10}l & 60 < l \leq 70 \\
    \frac{1}{10}l - 3 & 30 < t \leq 40 \\
    1 & 40 < t \leq 60 
    \end{cases} \\
    u^3(l) &= \begin{cases} 
    0 & l \leq 60 \\
    \frac{1}{10}l - 6 & 60 < l \leq 70 \\
    1 & 70 < l 
    \end{cases}
\end{align*}
\]

(3)

3.4.3. Establish multifactor weight set

In the process of evaluation, various factors have different influences on the evaluation results, and different evaluators have different degrees of emphasis on the factors, and the evaluation results will also have different changes. Therefore, different weights of each parameter need to be defined, and the allocation and ranking of each evaluation factor should be made according to the importance of each evaluation factor.

Define a weight set, denoted as \( A = \{a_1, a_2, \ldots, a_n\} \), where \( a_i \) represents the tacit response degree of each evaluation factor in the comprehensive evaluation, satisfying \( 0 < a_i < 1 \) and \( \sum a_i = 1 \).

When determining the weights, we can choose the expert survey method to find several authoritative experts and scholars in the field of intelligent transportation to evaluate the weights of the above three corresponding parameters. After statistics and calculation, we can calculate the average weights of the experts, and get the weights \( w_1, w_2, w_3 \) of the running speed, stop delay and queue length.
3.4.4. Multi-factor fuzzy comprehensive evaluation of intersection traffic operating condition

The weighted sum of the weight value of each parameter and the corresponding membership value can be obtained to obtain the state value $u$ of the inlet road in a certain direction at the intersection, and its calculation formula is as follows:

$$u = w_1 \times u_1(v) + w_2 \times u_2(t) + w_3 \times u_3(l)$$

(4)

In the formula, $w_1$ is the weight of average speed, $w_2$ is the weight of stop delay, $w_3$ is the weight of queue length.

The value of running state value $u$ reflects the quality of traffic state. When $u \in [0,1]$, the traffic operating condition is smooth; when $u \in (1,2]$, the traffic operating condition is general congestion; and when $u \in (2,3]$, the traffic operating condition is severe congestion.

4. Conclusion

Based on the intelligent lighting system, this study studies the traffic condition discriminant technology of urban intersections based on the fuzzy comprehensive evaluation model. This paper introduces the basic traffic data collection methods based on intelligent lighting system, including RTMS data collection and video data collection. Based on fuzzy comprehensive evaluation, a traffic condition discrimination model for urban intersections under intelligent lighting system is established. According to the status and characteristics of urban intersection traffic, combined with the data detected by the intelligent lamp post collection equipment, the average speed, stop delay and queue length are selected as evaluation factors. The weighted average model of fuzzy evaluation theory is used to analyze traffic operating condition of intersections, and the traffic operating condition is evaluated according to the principal factors and the principle of maximum membership degree. This study realizes the fine discrimination of the traffic operating condition at urban intersections under the intelligent lighting system. The research results can provide support for traffic control decisions and provide more efficient, convenient and comprehensive travel services for road users.

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