ATLANTIS PRESS
Advances in Social Science, Education and Humanities Research (ASSEHR), volume 300
2018 International Workshop on Education Reform and Social Sciences (ERSS 2018)

Evaluation Model of Open Community Road Network based on Network Flow

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Abstract. At present, various types of closed-type communities are prevalent in China. The internal road systems of some closed-type communities are dense and perfect, and they have the ability to access external road networks and relieve urban traffic pressure. The existence of these closed communities has destroyed the road network structure of the city and, to a certain extent, caused waste of internal road resources. This paper proposes to establish a multi-end maximum flow model of road network from three aspects: road network multi-end maximum flow, community internal road diversion ratio and road network reliability. Then, the multi-terminal maximum flow problem is transformed into the single-ended maximum flow problem, and the multi-end maximum flow of the outgoing network is solved, thereby evaluating the influence of the internal roads in the open community on the surrounding road traffic conditions.

Keywords: closed-type communities; multi-end maximum flow; reliability.

1. Introduction

At present, various types of closed-type communities are prevalent in China. The internal road systems of some closed-type communities are dense and perfect, and they have the ability to access external road networks and relieve urban traffic pressure. The existence of these closed communities has destroyed the road network structure of the city and, to a certain extent, caused waste of internal road resources. This paper proposes to establish a multi-end maximum flow model of road network from three aspects: road network multi-end maximum flow, community internal road diversion ratio and road network reliability. Then, the multi-terminal maximum flow problem is transformed into the single-ended maximum flow problem, and the multi-end maximum flow of the outgoing network is solved, thereby evaluating the influence of the internal roads in the open community on the surrounding road traffic conditions.

2. Solution of the Problem

For the problem of the impact of community opening on the road, this paper mainly considers three aspects, namely, the multi-terminal maximum traffic volume of the residential network, the traffic volume of each section of the community and the reliability of the road traffic network.

2.1 Maximum Traffic Flow of the Road Network.

The definition of the maximum traffic volume of a road network is to select a point outside the community and all points in the community as a starting point, and two points outside the community serve as a meeting point to form a multi-terminal network. The maximum traffic of the community network is the maximum flow of the multi-end network.

In the classical maximum flow algorithm, there is only one starting point and a meeting point, that is, a single-ended network. In the community scenario, because the traffic flow is not only from outside the community, but also from within the community, there are multiple departure points and convergence points, that is, multi-terminal networks. Therefore, this paper transforms the maximum flow problem of multi-end network G1 into single-ended network G2. To this end, this paper makes the following structure:

(1) Suppose a total point x in the network G1, and connect x to each of the points xi (i = 1, 2, 3, ..., k) in the network G1 with an arc of $+\infty$;

(2) Suppose a total collection point y in the network G1, and connect y to each of the collection points yi (i = 1, 2, 3, ..., n) in the network G1 with an arc of the capacity $+\infty$;

(3) The specified total point of transmission x and the total point of collection y are respectively the origin and the point of collection of G2.

If f1 is a feasible flow in the multi-end network G1, then

$$f_2(a) = \begin{cases} f_1(a) & a \text{ is the arc of } G_1 \\ f_1^+(x_i) - f_1^-(x_i) & a = (x, x_i) \\ f_1^-(y_i) - f_1^+(y_i) & a = (y_i, y) \end{cases} \tag{1}$$

Wherein, the defined function f2 is a feasible flow of the single-ended network G2, and Valf2=Valf1.

The limit f1 of the feasible flow f2 in G2 on the arc set of G1 is a feasible flow in G1, and Valf1=Valf2.

The maximum flow problem of a multi-end network can be transformed into an equivalent single-ended network maximum flow problem by the method constructed above.

The algorithm for the maximum flow problem of a single-ended network is through, given a directed graph G = (V (G), A (G)), the source vertex s and the sink vertex t, and for each directed edge i,j∈A (G) the finite stream capacity uij, setting the current stream to zero: fc←0;

(1) Find a directed path from s to t in the current graph. If there is no such path, stop, the maximum flow from s to t in G is fc;

(2) Calculate umin, the minimum capacity of all directed edges of the directed path in the current graph;

(3) Updating the remaining capacity uij←uij-umin in the current graph for each directed edge i,j in the directed path;

(4) Let fc←fc+umin and return to the first step.

2.2 Traffic Flow in Each Section.

The traffic volume of each section is defined as the traffic volume of each section in the community.

By comparing the traffic volume of each section before and after the opening of the community, it can be known whether the opening of the community serves as a diversion function, and the main roads share the pressure. In this paper, the road is analogous to the circuit, and the various effects of vehicles, pedestrians, bicycles, etc. on the road are considered as road resistance, and it is assumed that the driver will choose to take the fastest road traffic between adjacent road sections.

Delays at intersections are usually calculated using the average delay of intersections. The calculation expression for the average delay is:

$$d_1 = \frac{0.5T\left(1-\frac{t_g}{T}\right)}{1-[\min(1,x).\frac{t_g}{T}]} \tag{2}$$

In the formula:

T—the length of the signal period, s;

Tg—the effective time of the green light, s;

x—Drive group V/C or saturation, V/C refers to the ratio of maximum service traffic to basic capacity under ideal conditions.

By reviewing the relevant books, the US Federal Highway Administration's road resistance function (BPR function) was decided when calculating the road resistance. Taking into account the influence of other factors such as pedestrians and bicycles on the vehicle, the influence coefficient of the vehicle is obtained based on the previous research, and an improved BPR model is established.

The unmodified BPR impedance function is:

$$t_{ij} = \alpha_{ij} + \beta_{ij} f_{ij} \tag{3}$$

In the formula:
ij—from section i to section j;
t_{ij} —travel time on road segment ij, s;
α_{ijj}—the travel time of the free stream on the ijth road segment, s;
β_{ij}—delay parameter on the ijth road segment, $\beta_{ij} = \delta(\frac{V_{ij}}{C_{ij}})^{\gamma}\alpha_{ij}$, δ=0.15, γ=4;
f_{ij}—the traffic on the road segment ij, veh/h.

New roads are at the branch level, and traffic is often disrupted by bicycles, opposite vehicles, and pedestrians. When the bicycle traffic volume does not exceed the capacity, the coefficient is 0.8, and when the traffic capacity is exceeded, the final interference coefficient is calculated by the available pedestrian interference correction coefficient and the bicycle traffic on the road.

Table 1. Recommended pedestrian interference coefficient value

Degree of Interference	Very Serious	More Serious	Serious	General	Very Small	None
η	0.5	0.6	0.7	0.8	0.9	1.0

$$\eta_1 = 0.8 - (\frac{q_{bike}}{Q_{bike}} + 0.5 - W_2)/W_1 \tag{4}$$

In the formula:
η_1—the interference coefficient of the bicycle to the motor vehicle;
q_{bike}—the amount of bicycle traffic actually measured on the road;
Q_{bike}—the ability to pass bicycles per meter of non-motorized vehicle lanes;
W_1, W_2 — the width of a one-way non-motor vehicle, the width of a one-way motor vehicle lane.

In summary, the improved BPR function model is:

$$D = \begin{cases} \alpha_{ij} + \delta.\left(\frac{V_{ij}}{\eta \cdot \eta_1 \cdot C_{ij}}\right)^{\gamma} \cdot f_{ij} + d_1 & 0 \le \eta_1 \le 1 \\ \alpha_{ij} + \delta.\left(\frac{V_{ij}}{\eta \cdot C_{ij}}\right)^{\gamma} \cdot f_{ij} + d_1 & \eta_1 \ge 1 \end{cases} \tag{5}$$

2.3 Road Network Reliability.

With a given level of tolerance, the probability that the traveler successfully reaches the end point from the starting point under the specified time conditions and the desired service level is defined as the reliability of the road network.

The reliability of the road network is calculated by establishing a TRC model. For any road unit, its TRC is a probability that the ratio of T_φ and T_α can be kept within the tolerable level γ, and the formula is:

$$TRC_i(\alpha, \gamma) = \Pr\left\{\frac{T_\varphi}{T_\alpha} \le \gamma \middle| T_\varphi = \frac{T_0(1-\rho x)}{1-x}, T_\alpha = \frac{T_0(1-\rho x)}{1-\alpha}\right\} \tag{6}$$

In the formula:
x—the actual level of service, expressed in terms of saturation at the actual service level, x=v/c;
α —The level of expected service, expressed in terms of saturation at the desired service level, $\alpha = v_\alpha / c$.

Reliability reflects the level that road users can accept when there is a problem with the road network. The value can be determined by relevant statistical surveys or calculated as expected. In this topic, it is assumed that the road reliability is 60%, that is, the probability that the traveler reaches the end point from the starting point under the expectation is 60%. At the same time, with the change of road conditions before and after the opening of the road, the reliability of the road will also change dynamically.

According to the above analysis, the maximum traffic volume of the cell network, the traffic volume of each segment, and the reliability of the road network can be used to judge the impact on the surrounding roads after the cell is opened.

2.4 Advantages of the Model.

The model comprehensively establishes the evaluation criteria for the road traffic network, and analyzes the road network through three aspects: the maximum flow nature of the road network topology, the flow calculation of each section of the traffic flow, and the reliability of the use value of the traffic network. Not only has a large coverage, but also a reference value.

2.5 Disadvantages of the Model.

Due to the nature of the road, such as the width of the road, the level of road service, etc., the road sections are not exactly the same. The calculation is large and the specific data is not easy to count, which will cause certain errors.

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