The Influence of Community Opening on Road Capacity Based on Cellular Automata Model

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Abstract. This paper models and analyzes the cellular automata model by exploring the influence of community opening on road traffic capacity in order to make full use of the potential capacity of urban transportation network and alleviate urban traffic contradiction. Firstly, this paper establishes comprehensive evaluation index system of traffic condition by literature review, which can judge the advantages and disadvantages of community opening. And then, this paper establishes the mathematical simulation model based on the cellular automata theory, and gets the data affecting traffic volume around the open plot. Also it establishes the empirical formula of road capacity surrounding the opening area by SPSS multiple regression. Finally, by analyzing the example and discussing six types of communities, this paper gets that whether the community opening can improve road capacity is closely related to community structure, internal road structure, surrounding road structure and traffic flow, and finds it is much better to open the community with surrounding road for multiple lanes.

Introduction

With the development of economy and great growing of cars’ numbers, there are a lot of urban problems appearing in our country. For solving the traffic jam and optimizing road network structure, the state council published the issue, some opinions for further strengthening the city planning construction management, which showed that the government will not construct the closed community in principle, and the residential districts and unit compound that have been built will be opened gradually. This issue made the scholars study on the community opening that weather it can solve the urban traffic problems and cause the dangers or not. Literature [1] analyzes the influence of community opening on surrounding road capacity by the Analysis Hierarchy Process, and gets the conclusion that the community with reticular road structure and many passageways should be opening, while the community with annular road structure should not be. Literature [2] compares the changes before and after the opening of community to judge the community weather should be opening based on the traffic analysis theory and Braess paradox. Literature [3] analyzes eleven indexes of evaluation system by Analysis Hierarchy Process, and aiming at two types of community, compares the operation quality of road network before and after the opening of community by simulation analysis. Literature [4] selects six indexes quantitatively to compose evaluation system to simulate the state of community opening, and establishes the topology probabilistic parsing model in order to analyze the influence of every kind of community opening on road capacity. Literature [5] based on the mathematical model of vehicle traffic and the maximum flow model of multi-source and multi-sinks, gives the evaluation criteria for the improvement of road network capacity, and studies the influence of open closed cell on surrounding road traffic.

To sum up, the domestic and foreign research on this issue is relatively single, and almost has no consideration of the community's own structure on the surrounding road impact. Therefore, based on the cellular automata model\cite{6-7}, this paper simulates the operation state of the surrounding
road traffic flow before and after the opening of community, and quantitatively analyzes the influence of the six types community structures on the road traffic capacity before and after the opening, and provides a theoretical reference for the relevant departments to adopt the decision-making open community for the specific structure.

**Comprehensive Evaluation Index System of traffic condition**

**Space occupancy of the road.** The space occupancy refers to the percentage that the total projected length of the car occupies the length of a unit lane. In the actual measurement, the total length of the vehicle and the percentage is the length of the road are generally measured, which represents the proportion of the road segment occupied by the vehicle at a certain moment, which reflects the load degree of traffic on the observation road. As the following Eq. 1:

\[
R_s = \sum \frac{l_i}{L} \times 100.
\]

Where \(R_s\) is the space occupancy, [%]; \(L\) is the total length of the observe section, [m]; \(l_i\) is the length of car I, [m]; \(n\) are the number of cars in the observe section.

**Road Service Level.** For urban roads, the most important measure of road traffic service level is the saturation of \(V/C\), that is: the actual traffic volume/design capacity of the road segment, as shown in table 1:

<table>
<thead>
<tr>
<th>Road Service Level (V/C)</th>
<th>Grade</th>
<th>The actual situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0.4</td>
<td>A</td>
<td>Traffic flow, basic no delay</td>
</tr>
<tr>
<td>0.4~0.6</td>
<td>B</td>
<td>Steady flow of traffic with minor delays</td>
</tr>
<tr>
<td>0.6~0.75</td>
<td>C</td>
<td>Steady flow of traffic with certain delays</td>
</tr>
<tr>
<td>0.75~0.9</td>
<td>D</td>
<td>Close to unstable traffic, with greater delays</td>
</tr>
<tr>
<td>0.9~1.0</td>
<td>E</td>
<td>Unstable traffic, congestion</td>
</tr>
<tr>
<td>≥1.0</td>
<td>F</td>
<td>Forced traffic, serious congestion, vehicle time off</td>
</tr>
</tbody>
</table>

In terms of the use of the road itself, the level of road service V/C is not the lower the better, because it will lead to inefficient use of the road, therefore, comprehensive consideration, traffic facilities V/C based on 0.6~0.8 will achieve better benefits.

**Connectivity Indices.** The connection index is defined as the ratio of the number of sides adjacent to each node in the network and the number of nodes, such as the Eq. 2.

\[
\beta = \frac{v}{\theta}.
\]

Where \(v\) are the number of sides and \(\theta\) are the number of nodes. The number of nodes in this paper refers to the end of each road or the intersection of the road, and the number of contiguous sides of each node is connected to the number of road edge. The indicator is used to measure the maturity of the road network, the higher connectivity index indicates, the less road network breaks down and the higher the road network maturity, otherwise the lower. When the connection index of the neighborhood roads is lower, it shows that the community open is beneficial to optimize the surrounding road network structure and improve the road traffic capacity.

**Actual Road Capacity.** The actual capacity of urban road sections can be modified according to the theoretical capacity of one lane, such as the Eq. 3.

\[
N_a = N_0 \times \gamma \times \eta \times C \times n.
\]
Where \( N_a \) is actual capacity of urban road; \( N_o \) is the theoretical capacity of a driveway; \( \gamma \) is the bicycle correction factor; \( \eta \) is the lane width effect correction number; \( C \) is the intersection effect correction number; \( n \) is the lane correction factor.

**Average Delay of Vehicles.** The definition of delay is the difference between the actual travel time and the expected time of the driver, in minutes. The cause of the delay is mainly the traffic disturbance and traffic management and control measures, and also is the driver's own response time and vehicle performance differences in the delay, which is negligible. Depending on the cause of the delay, it can be divided into fixed delay, driving delay and control delay.

**Comprehensive Evaluation of Index System.** Firstly, we determine the weight vectors for the five indicators, e.g.

\[
\mathbf{w} = (w_1, w_2, w_3, w_4, w_5).
\]

After determining the weights, a comprehensive evaluation model is established by the linear weighting method, e.g.

\[
y = w_1 \mathbf{B}_1 + w_2 \mathbf{B}_2 + \ldots + w_5 \mathbf{B}_5.
\]

Where \( w_i \) is the weight of the index \( I_i \), \( \mathbf{B}_i \) is the normalized indicator value of the first \( I_i \) (i=1, 2... 5). Finally, the various index data before and after the opening of the community are integrated into the comprehensive evaluation model function, and the comprehensive evaluation score is obtained, and then the degree of the influence of the open area on the surrounding roads can be analyzed by comparing the scores and the degree of difference.

**Mathematical Simulation Model**

**Thoughts of Model Construction.** As an effective model to study complex phenomena, cellular automata can be used to simulate the running state of the surrounding road traffic before and after the open area. By meshing the sections, each grid is treated as an independent cell, and occupied by a vehicle. At this point, the traffic on the road can be transformed into a cellular evolution process, vehicle acceleration, deceleration and stop can be used to describe the speed evolution rules of the cell. As shown in Figures 1 and 2:

![Fig.1 Picture of multi-lane simulation model](image1)

![Fig.2 Picture of single-lane simulation model](image2)

Assuming that the speed of the car from the community is 1, and we have no consideration of the impact of the pedestrian and bicycle and the surrounding parking on the lane. In this paper, a cell for a standard car, the simulation of the length of a total of 100 cells, a cell of the actual length of 5 meters, the actual section length of 500 meters, and limit the maximum speed of the vehicle for 3cell/s. If there is better road after the change of road, you can change the road, right and left the same chance of change.
**Simulation Analysis.** The steps of cellular automata update rule is as following.

Step 1. Generate a random number to determine whether or not to start. If the car departs, a random number is generated to determine the starting lane. And the initial speed of the vehicle is zero.

Step 2. Add one based on speed to the previous speed. Then the speed takes a smaller value between the spacing and the update speed.

Step 3. Generate a random number and then the velocity is randomly reduced by one.

Step 4. If the lane change rule is met, the left and right lanes are randomly swapped.

Step 5. Update location.

Step 6. We should judge whether it is satisfying the loop condition. If loop conditions are not met, return to the last step.

According to an empirical formula obtained from the literature [6], the traffic flow of the surrounding roads around the opening area can be calculated, e.g.

\[ V_S = a_1 x + a_2 V_a + a_3 V_x + a_4. \]  

Where \( a_1, a_2, a_3, a_4 \) are the uncelebrated parameters; \( V_S \) are the traffic flow around the road; \( x \) are the distance between community road and the surrounding road intersection to traffic flow confluence; \( V_a \) are the upstream traffic flow around the road; \( V_x \) are the traffic flow of the community to the surrounding roads. According to the cellular automata model, we can get the traffic quantity of different cell in different road position, and use SPSS to carry on the multivariate function linear regression, and thus get the value of the parameter to be calibrated, so the empirical formula may be determined as:

\[ V_S = 0.934 x + 0.304 V_a + 1.171 V_x + 312.838 \]

**The Example Analysis**

The type of community in China can be divided into pieces, axes and radial inflow. In this paper, according to the actual situation of the inner road structure and the surrounding road structure, the plot type is subdivided into A~F six types as shown in Figure 4 and table 2:

![Types of community](image)

**Table 2 Types of community**

<table>
<thead>
<tr>
<th>Surrounding road</th>
<th>Community’s type and internal road</th>
<th>Pieces</th>
<th>Axes</th>
<th>Radial inflow Unidirectional lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single lane with small flow</td>
<td>A</td>
<td></td>
<td>C</td>
<td>E</td>
</tr>
<tr>
<td>Multi-lane with large flow</td>
<td>B</td>
<td>D</td>
<td></td>
<td>F</td>
</tr>
</tbody>
</table>

Based on the cellular automata model, the following data can be obtained, as shown in table3:
Table 3 Simulation data

<table>
<thead>
<tr>
<th>Community</th>
<th>Community closed</th>
<th>Four lanes around the road</th>
<th>Single lane around the road</th>
<th>Community opening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Velocity</td>
<td>1.839</td>
<td>1.8012</td>
<td>1.761</td>
<td>1.7248</td>
</tr>
<tr>
<td>Actual Flow</td>
<td>1.94E+03</td>
<td>2.06E+03</td>
<td>471.5</td>
<td>1864</td>
</tr>
<tr>
<td>Space Occupancy</td>
<td>0.3182</td>
<td>0.3896</td>
<td>0.394</td>
<td>0.29884</td>
</tr>
<tr>
<td>Service Level</td>
<td>0.7713</td>
<td>0.816353275</td>
<td>0.836</td>
<td>0.7402</td>
</tr>
<tr>
<td>Average Delay</td>
<td>18.15</td>
<td>23.34</td>
<td>26.73</td>
<td>12.94</td>
</tr>
</tbody>
</table>

From above simulation data and entropy weight of the idea, we can get the final comprehensive evaluation score, as shown in table 4:

Table 4 Score of comprehensive evaluation

<table>
<thead>
<tr>
<th>Entropy Weight Score</th>
<th>Community closed</th>
<th>Four lanes around the road</th>
<th>Single lane around the road</th>
<th>Community opening</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.4059</td>
<td>0.3617</td>
<td>0.3874</td>
<td>0.4168</td>
</tr>
</tbody>
</table>

From above analysis of six kinds of cell structure, we can get the comprehensive evaluation analysis, such as table 5:

Table 5 Simulation data

<table>
<thead>
<tr>
<th>Types of community</th>
<th>Number of passageway</th>
<th>Intra-cell conflict points</th>
<th>Number of road lanes connected</th>
<th>Comprehensive evaluation score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>0.7937</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>0.9008</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>0.7295</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>0.7311</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>0.624</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>0.6224</td>
</tr>
</tbody>
</table>

In summary, the B-type community scored the highest 0.9008, and the F-type community scored the lowest 0.6224. Because of the structure of the B-type community, it can greatly enhance the capacity of the surrounding roads, relieve traffic pressure.

Conclusions

According to the model simulation data, firstly, it can be seen that the block-type community has rich internal road resources and the network structure features and functions are more suitable for road opening. So the community opening can reduce the traffic pressure around the road and improve capacity. The positive influence of the open-axis cell on the surrounding road is slightly weaker, and the centripetal cell is not suitable to set the road open.

Secondly, it can be seen from the model simulation that: when the road around the opening area is single lane, the vehicle in the small area will directly affect the original driving speed of the vehicle on the single lane, and interfere with the traffic flow. If the road around the opening area is multi-lane, the traffic on the surrounding road can be used to ensure its original driving condition. Therefore, the effect of community opening with surrounding area for multi-lane opening is better.

Finally, when the number of community cars is large, the main trunk road interference is also relatively large, and even will increase nearly half of the value. Therefore, when it is the holiday peak or rush hour, we can take or do not take the community opening policy.

References:


