Simulation-based analysis of traffic efficiency at signal intersection

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Abstract Intersection is not only the node of urban road network, but also the key point affecting the operation of the traffic of the whole region. In order to improve the traffic operation efficiency of a signalized intersection, this paper takes Tianjin Dingzigu First Road and Guangrong Road signalized intersection as an example. Based on the present situation, three methods were used to optimize the signal timing of the intersection, including only designing the signal timing of the current intersection, designing the change of the signal timing of the whole line and changing the proportion of different types of drivers. The simulation is carried out by VISSIM software. The results show that the traffic operation efficiency can be improved conspicuously by changing the signal timing at the current intersection. By changing the signal timing of the whole trunk line, the traffic operation efficiency can be improved obviously. By reducing the proportion of conservative drivers and increasing the proportion of progressive drivers, the traffic operation efficiency can be improved.

1. Introduction

Urban road network is composed of intersections and road sections. The intersections are the node of two or more roads in different directions. It is an indispensable part of the entire urban road network [1]. The intersection is also a key point for the gathering, turning and evacuation of vehicles and pedestrians. The unreasonable design of the intersection may lead to decreased efficiency of the intersection and traffic congestion, which will have a serious impact on people's lives and work [2]. There are many ways to improve the efficiency of operations of the intersection. In order to verify its effectiveness, it often takes a long time and a wide range of traffic experiments. With the appearance and application of traffic simulation technology, the original time-consuming and costly design can be carried out under the ideal state of simulation. Although it is a little different from reality, it can explain the feasibility of the scheme to a certain extent.

Currently, VISSIM is the most used simulation software [3-4]. Wang Yupeng analyzed the delay of the new signalized intersection and compared with the HCM2000 calculation results using VISSIM software, and obtained the accuracy, effectiveness and applicability of VISSIM software in the simulation of traffic conditions at actual intersections [5]. Fu Baibai took the intersection of Erhuan East Road and Shanda North Road in Jinan as an example, used the VISSIM software to simulate the traffic flow and reconfigure the timing of the signal. The results showed that the delay and queuing of the intersection are effectively reduced [6].

Based on this, this paper takes Tianjin Dingzigu First Road and Guangrong Road signalized intersection as an example. Based on the present situation, three methods were used to optimize the signal timing of the intersection, including only designing the signal timing of the current intersection, designing the change of the signal timing of the whole line and changing the proportion of different types of drivers. The simulation is carried out by VISSIM software, and we select indicators including
parking time, average queue length and vehicle delay time as evaluation indicators, and the corresponding simulation results are analyzed.

2. Collection of basic traffic data
This paper takes the intersection of Dingziyu First Road and Guangrong Road in Tianjin as the research object. The basic data of the intersection were collected and the schemes were designed and a VISSIM micro-simulation model was established. The traffic efficiency of the signalized intersection is simulated and the simulation results are analyzed. The basic data mainly includes the following three categories.
1. Traffic data: traffic flow, peak hour traffic, traffic composition and so on.
2. Geometric data: lane division of intersection, number of lanes, lane widths and so on.
3. Signal control data: current status signal timing scheme, bus priority principle and so on.

2.1. Traffic status at the intersection
The intersection is an irregularly shaped signal-controlled cross-shaped intersection. By field observation, it was found that the intersection is controlled by a timed countdown signal with a period of 161s, and the specific phase is shown in table 1 below. It is also observed that the traffic lights of each entrance of the intersection are composed of two screens with directional arrows and a countdown screen. The countdown screen can predict the change of the signal light, so that the drivers and the pedestrian can prepare in advance, dodge or start in time, reduce the being delayed at the intersection. In addition, the channelization diagram of the intersection is shown in figure 1.

| Intersection Phase | Release direction | Green light/s | Yellow light/s | Full red/s | Cycle duration/s |
|-------------------|------------------|---------------|----------------|------------|-----------------|
| Dingziyu First road and Guangrong road Phase 1 | East-west straight | 36 | 3 | 16 | |
| Phase 2 | East-west left-turning | 25 | 3 | 2 | 161 |
| Phase 3 | North-south straight | 34 | 3 | 0 | |
| Phase 4 | North-south left-turning | 34 | 3 | 2 | |

Figure 1. Channelization diagram of the intersection.
2.2. Traffic flow at the intersection

By field research, we found that the traffic volume in both directions of the intersection is large, and manual counting methods should be adopted to first arrange people to stand at the intersection for live shooting, and then process those obtained to prevent missing data. Investigate the traffic volume at the intersection in peak hours in working days. After investigation, it was found that there were less large vehicles on the entrance road. The traffic volume was converted according to the standard conversion coefficient table of urban road traffic volume, as shown in table 2.

| Intersection                        | Motor vehicle hourly traffic volume summary (pcu/h) | Intersection traffic flow |
|-------------------------------------|---------------------------------------------------|--------------------------|
| Dangzigu First road and Guangrong road | East: 135, 638, 756, 1529 | 4989                     |
|                                     | West: 240, 1000, 108, 1348                         |                          |
|                                     | South: 219, 455, 338, 1012                         |                          |
|                                     | North: 458, 492, 150, 1100                         |                          |

3. VISSIM simulation

To build the simulation model at last section, three types of basic data are needed. In order to ensure that the results of VISSIM simulation are consistent with the actual situation, the simulation model needs to be tested and corrected when needed.

3.1. Verification and correction of the model

A schematic diagram of the intersection of Dangzigu First Road and Guangrong Road was set up in VISSIM, VISSIM simulation on the basic data such as the intersection geometry, signal timing, and characteristics of traffic flow were performed, and the obtained results of the simulation are compared with the results of the manual investigation. Commonly used evaluation indicators in simulation include vehicle travel time, average queue length, number of stops, and delays. Since the manual investigation is difficult to accurately grasp the travel time and delay of the vehicle, the average queue length comparison is selected. The results are shown in table 3.

| Import direction | Average queue length | Manual investigation /m | Simulation /m | Error % |
|------------------|----------------------|-------------------------|----------------|---------|
| East             |                      | 21                      | 20             | 5       |
| West             |                      | 30                      | 29.5           | 1.7     |
| South            |                      | 24                      | 3.6            | 1.7     |
| North            |                      | 29                      | 27             | 6.9     |

As shown in the table 3, the average error is only about 3.0%, which is consistent with the reality. Therefore, the simulation results are considered to have higher credibility, so the VISSIM simulation can be used to improve the scheme. Current simulation data of intersection is shown in table 4.

| Import Direction | Average delay time /s | Average queue length /m | Maximum queue length /m |
|------------------|-----------------------|-------------------------|-------------------------|
| Right-turning    | 11.2                  | 10.5                    | 36.3                    |
| East             | 25.8                  | 31.8                    | 73.6                    |
| Left-turning     | 36.5                  | 17.6                    | 30.4                    |
| Right-turning    | 4.5                   | 0.9                     | 2.3                     |
3.2. Simulation experiment of changing signal timing at single intersection

Whether the timing of the signal is reasonable or not has an important influence on the traffic efficiency of the intersection. In order to make the intersection as efficient as possible, it is necessary to ensure that the green light time is allocated in the direction of large traffic volume, the queuing time is reduced, or even the secondary queuing, and the relatively small direction is all passed at a green time. In order to make the intersection as efficient as possible, it is necessary to ensure that the green time is allocated in the direction of large traffic volume, the queuing time is reduced, or even the secondary queuing, and the relatively small direction is all passed at a green time. As far as the intersection is concerned, the survey found that the queue length and vehicle delay in the east-west direction are greater than the north-south direction. Therefore, we should increase the left-turning green time in the north-south direction and reduce the north-south straight time. We should increase the north-south turn time to 40s, and reduce the straight-through time to 28s. The simulation results are shown in table 5.

| Import | Direction  | Parking time /s | Average delay time /s | Average queue length /m | Maximum queue length /m |
|--------|------------|-----------------|-----------------------|------------------------|-------------------------|
| East   | Right-turning | 10.8            | 42.2                  | 9.9                    | 35.9                    |
|        | Straight    | 24.5            | 44.1                  | 30.8                   | 71.4                    |
|        | Left-turning | 35.5            | 64.9                  | 17.5                   | 30.1                    |
|        | Right-turning | 4.5             | 18.6                  | 0.9                    | 2.3                     |
| West   | Straight    | 44.3            | 50.7                  | 61.1                   | 99.5                    |
|        | Left-turning | 43.7            | 81.6                  | 23.8                   | 35.7                    |
|        | Right-turning | 14.2            | 48.8                  | 15.1                   | 32.1                    |
| South  | Straight    | 22.2            | 36.6                  | 39.1                   | 60.1                    |
|        | Left-turning | 29.4            | 46.1                  | 16.9                   | 23.1                    |
|        | Right-turning | 6.5             | 19.3                  | 1.6                    | 5.7                     |
| North  | Straight    | 23.1            | 34.1                  | 32.8                   | 51.8                    |
|        | Left-turning | 46.7            | 75.3                  | 26.2                   | 50.6                    |
| All    |             | 25.5            | 46.9                  | 23                     | 41.5                    |

By comparing the simulation results of changing the signal timing and the current simulation results, it is found that the average delay time, parking time and average queue length of the intersection after changing the signal timing are significantly reduced, and the traffic efficiency is improved obviously.

3.3. Simulation experiment of changing the timing scheme in trunk signals

It can be seen from the above that optimizing the intersection signal timing can effectively improve the intersection efficiency. However, under actual traffic conditions, the efficiency of traffic at a single intersection should be combined with the efficiency of the trunk line and regional road network. For this
study, the Dingzigu First road was selected as the main road, and the Webster algorithm (TRRL algorithm) was adopted to calculate the optimal signal period and coordinate the trunk signal. The results of simulation experiment are shown in table 6.

Table 6. Simulation experiment results of changing the timing scheme in trunk signals.

| Import | Direction | Parking time /s | Average delay time /s | Average queue length /m | Maximum queue length /m |
|--------|-----------|-----------------|-----------------------|-------------------------|-------------------------|
| East   | Right-turning | 10.9            | 42.1                  | 10.5                    | 36.3                    |
|        | Straight    | 25.1            | 44.9                  | 30.7                    | 72.9                    |
|        | Left-turning | 35.8            | 64.7                  | 17.2                    | 28.4                    |
|        | Right-turning | 4.2             | 17.1                  | 0.8                     | 2.3                     |
| West   | Straight    | 43.1            | 50.9                  | 59.2                    | 99                      |
|        | Left-turning | 40.2            | 80.3                  | 24.4                    | 35.6                    |
|        | Right-turning | 12.6            | 44.1                  | 12.5                    | 29.2                    |
| South  | Straight    | 18.3            | 27.6                  | 32.8                    | 50.1                    |
|        | Left-turning | 40.3            | 75.4                  | 24.5                    | 34.3                    |
|        | Right-turning | 6.2             | 18.3                  | 1.5                     | 5.4                     |
| North  | Straight    | 17.9            | 24                    | 29.2                    | 45.2                    |
|        | Left-turning | 79.8            | 121.8                 | 45.3                    | 100                     |
| All    |             | 27.9            | 50.9                  | 24.1                    | 44.9                    |

By comparing the simulation results of changing the timing scheme of trunk signals and the current simulation results, it can be found that the average delay time, parking time and average queue length of the intersection after changing the timing scheme of trunk signals are significantly reduced, and the traffic efficiency is conspicuously improved. However, compared with changing the signal timing scheme of a single intersection, the improvement effect is not obvious.

3.4. Simulation experiment of changing the proportion of different types of drivers

Different types of drivers have different driving habits. According to different driving behaviors, drivers are mainly divided into conservative drivers and radical drivers. Conservative drivers drive the vehicle at a relatively slow speed and the acceleration is small. They rarely brake on the brakes or refuel in the driving process, and the overall situation is relatively stable; while the aggressive drivers drive the vehicle at a relatively fast speed and the acceleration is big. They brake suddenly in the driving process and the driving is very unstable. For this intersection, increase the aggressive drivers by 10% and reduce the proportion of the conservative drivers by 10%, and results are obtained in table 7.

Table 7. Simulation experiment results for changing the proportion of different types of drivers.

| Import | Direction | Parking time /s | Average delay time /s | Average queue length /m | Maximum queue length /m |
|--------|-----------|-----------------|-----------------------|-------------------------|-------------------------|
| East   | Right-turning | 10.9            | 42.1                  | 10.5                    | 36.3                    |
|        | Straight    | 25.1            | 44.9                  | 30.7                    | 72.9                    |
|        | Left-turning | 35.8            | 64.7                  | 17.2                    | 28.4                    |
|        | Right-turning | 4.2             | 17.1                  | 0.8                     | 2.3                     |
| West   | Straight    | 43.1            | 50.9                  | 59.2                    | 99                      |
|        | Left-turning | 40.2            | 80.3                  | 24.4                    | 35.6                    |
|        | Right-turning | 12.6            | 44.1                  | 12.5                    | 29.2                    |
| South  | Straight    | 18.3            | 27.6                  | 32.8                    | 50.1                    |
|        | Left-turning | 40.3            | 75.4                  | 24.5                    | 34.3                    |
| North  | Right-turning | 6.2             | 18.3                  | 1.5                     | 5.4                     |
Comparing the current simulation results and the simulation results of changing the proportion of different types of drivers, and the following conclusions are drawn. By increasing the proportion of aggressive drivers and reducing the proportion of conservative drivers, the average delay time, parking time and average queue length at intersections increase significantly, and traffic efficiency decreases, which suggests that we can increase the punishment of aggressive drivers, which will improve the traffic efficiency of intersections and is beneficial for the security at intersections.

4. Conclusions
This paper takes the signal intersection of Dingzigu First road and Guangrong road in Tianjin as an example, and proposes three schemes. Based on VISSIM traffic software, the traffic efficiency of the signalized intersection is simulated. The following conclusions are obtained.

(1) Increasing the length of green time of the large traffic volume direction can significantly improve the efficiency at the intersection, which indicates that optimizing signal timing of the current intersection is an effective way to improve the efficiency of signalized intersections.

(2) After using the coordinated control of whole line, the traffic efficiency of the intersection can be improved. Compared with the first scheme, the improvement is not obvious, but the efficiency of the whole trunk can be improved significantly.

(3) By increasing the proportion of aggressive drivers at the intersection and reducing the proportion of conservative drivers, the traffic efficiency at the intersection reduced. The simulation result shows that reducing the number of aggressive drivers helps to improve the traffic efficiency at the intersection.

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