Optimal signal timing design for the intersection of Dazhi Street and Hexing Road

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Abstract—The phenomenon of intersection congestion has become a major problem in the city. Based on the intersection of Hexing road and Dazhi street, the delay phenomenon of Urban Road intersection is optimized. The intersection of Hexing road and Dazhi street is seriously delayed. In order to improve the road capacity of the intersection and reduce the delay of the intersection, the traffic characteristics parameters of the intersection during peak period are obtained, and the traffic capacity and intersection service level of the signalized intersection are analyzed and calculated. Based on the study of the basic content and research methods of signal timing at signalized intersections, the microscopic simulation software VISSIM was used to improve the traffic control scheme with serious delays at intersections and low urban road capacity, the simulation optimization is carried out by changing the signal timing and resetting the channelization scheme of intersection. Meanwhile, the signal timing of intersection is optimized. The results show that the traffic capacity of the intersection has been greatly improved by VISSIM simulation.

1. INTRODUCTION
With the development of my country's economy, the urbanization process is getting faster and faster, and the problem of urban congestion has become more and more serious. Traffic congestion at intersections is particularly prominent. Therefore, reasonable and effective organization of traffic flow at intersections has become the key to solving urban traffic problems [1]. There are multiple methods for traffic organization at intersections. Timing optimization of traffic signals is one of the least costly and most effective methods.

Taking Hexing road Dazhi street intersection as an example, this paper expounds the method of signal timing optimization design. The intersection of Hexing road and Dazhi street is an important part of "Ring Road + cross" in Harbin. The traffic flow of Hexing road and Dazhi street is dense, and the intersection of the two roads makes the traffic pressure at the intersection very large, and congestion often occurs. This paper analyzes the existing problems and deficiencies in the current traffic control scheme of the intersection, and improves the traffic capacity through the signal timing of the intersection again. The feasibility of the signal timing is tested by VISSIM simulation.
2. SURVEY AND ANALYSIS OF GEOMETRIC CHARACTERISTICS OF INTERSECTIONS

2.1. Survey of current status of intersections
The intersection of Hexing Road and Dazhi Street is located in Nangang District, Harbin City, Heilongjiang Province, which is one of the more prosperous areas in Harbin. Near the intersection there are shopping malls, hospitals, hotels, etc., which is one of the places where people and vehicles gather.

Hexing Road is the main road of the city, east-west direction, with a central divider, 3 straight lanes, 1 right-turn and straight lane and 2 left lanes on the west entrance; 2 straight lanes and 1 left turn on the east entrance Lane, 1 straight and right-turn lane;

Dazhi Street is the main road of the city, north-south direction, with a central divider, south entrance road has 1 left-turn and straight lane, 1 right-turn and straight lane, 1 left turn Lane; North Entrance Road has 1 straight lane, 1 left turn lane, 1 right turn and straight lane. The width of each lane is about 3.5m. The dimensions and traffic conditions of some geometric facilities at this intersection are shown in Tab. 1.

TABLE I. INTERSECTION GEOMETRY AND TRAFFIC CONDITIONS

| Import Road | Lane type   | Lane width | Number of motor vehicles |
|-------------|-------------|------------|--------------------------|
| West import | Go straight | 3          | 3                        |
|             | Turn left   | 3          | 2                        |
|             | Straight right | 3          | 1                        |
| East Import | Go straight | 3          | 2                        |
|             | Turn left   | 3          | 1                        |
|             | Straight right | 3          | 1                        |
| North Import | Go straight | 3.5        | 1                        |
|             | Turn left   | 3.5        | 1                        |
|             | Straight right | 3.5        | 1                        |
| South Import | Go straight | 3.5        | 1                        |
|             | Turn left   | 3.5        | 1                        |
|             | Straight right | 3.5        | 1                        |

Based on the field investigation of the intersection, the plane sketch map of the intersection is drawn. Because the interchange passes directly above the intersection, and the interchange has no influence on the traffic capacity of the intersection, the interchange situation is not drawn. The plane diagram of the intersection is shown in Fig. 1.

2.2. Intersection traffic conditions
The intersection's morning and evening peak traffic hours were investigated, and the traffic flow and road capacity were obtained. Each observation time is 1 hour, the results are shown in Tab. 2.
### TABLE II. INTERSECTION GEOMETRY AND TRAFFIC CONDITIONS

| Import Road | Flow (pcu/h) | Capacity (pcu/h) | Saturation |
|-------------|--------------|------------------|------------|
| West import |              |                  |            |
| Go straight | 1688         | 2249             | 0.75       |
| Turn left   | 876          | 859              | 1.02       |
| Straight right | 341      | 323              | 1.06       |
| total       | 2905         | 3431             | 0.85       |
| East Import |              |                  |            |
| Go straight | 1116         | 1355             | 0.82       |
| Turn left   | 396          | 375              | 1.06       |
| Straight right | 584      | 758              | 0.77       |
| total       | 1916         | 2223             | 0.86       |
| North Import |            |                  |            |
| Go straight | 108          | 168              | 0.64       |
| Turn left   | 516          | 498              | 1.04       |
| Straight right | 840      | 724              | 1.16       |
| total       | 1464         | 1399             | 1.05       |
| South Import |            |                  |            |
| Go straight | 120          | 137              | 0.88       |
| Turn left   | 828          | 870              | 0.95       |
| Straight right | 420      | 401              | 1.05       |
| total       | 1368         | 1408             | 0.97       |

#### 2.3. Intersection signal timing

The intersection adopts four-phase signal control, and the signal period is 182s. The phase sequence scheme and signal timing are shown in Fig. 2 and Fig. 3.

![Figure 2. Current phase diagram of intersection](image)

![Figure 3. Schematic diagram of signal timing at intersection](image)
3. ANALYSIS AND EVALUATION OF THE CURRENT SITUATION OF INTERSECTIONS

3.1. Data analysis
The service level of intersections is an important indicator to evaluate the rationality of intersection design, and delay is an important measure to evaluate the operational efficiency and service level of signalized intersections [2]. To a certain extent, saturation can reflect the operational efficiency and service level of intersections. The intersection has a high degree of saturation in the left-turn direction, and the green light time is difficult to meet the driving requirements of vehicles at each intersection.

According to the calculation of the survey data, the maximum saturation to the intersection is 1.06 of the left turn of the east entrance, and the saturation of each left-turn lane of the entrance is relatively high, resulting in serious delays for the entire intersection. According to the delayed service level rating table of intersections [3], the overall service level of intersections is D-level, and the traffic capacity reaches 10810pcu/h.

| Lane Group | West Import | East Import | North Import | South Import |
|------------|-------------|-------------|--------------|--------------|
|            | Turn left   | Go straight | Turn left    | Go straight  |
|            | 60          | 84          | 38           | 19           |
|            | 662         | 804         | 288          | 517          |
|            | Average delay(s) | Number of parking(vehicle) | Queue length(vehicle) | Service Level |
|            | 29          | 33          | 103          | 103          |
|            | 362         | 313         | 422          | 31           |
|            | 78          | 132         | 54           | 19           |
|            | 88          | 110         | 31           | F            |
|            | 19          | 29          | 19           | E            |

3.2. Current Situation Simulation
VISSIM traffic simulation software is applied to the simulation analysis of the traffic operation status of urban traffic networks (especially intersections) and the optimization and evaluation of traffic schemes. The method has good operability and practicability based on existing survey data [4]. Using VISSIM simulation software for simulation, the current situation of intersection simulation is shown in Fig. 4.

![Figure 4. Schematic diagram of traffic status simulation](image)

3.3. Analysis of current situation

3.3.1. Through a traffic survey on the intersection of Dazhi Street of Hexing Road, although some traffic control measures were taken at this intersection, traffic police will guide traffic in the morning and evening rush hours, but there are still the following problems.

3.3.1.1. Hexing Road Traffic Status: Hexing Road is the main road of the city, and there are many schools and work units beside the road. In the morning and evening peaks, traffic congestion often occurs. There is only one left-turn lane at the east entrance, and the east entrance turns into a large road.
The traffic volume in the direction of Straight Street is relatively large, which often leads to the phenomenon that left-turning vehicles seize a straight lane.

3.3.1.2. Dazhi Street Traffic Status: The traffic flow of Dazhi street is relatively high, but the number of North and south entrance lanes is small, and there are only three North and south entrance roads respectively. Moreover, there are more vehicles driving into Hexing road in Dazhi Street direction, which results in serious traffic congestion in left turn lane at north-south entrance, which affects the traffic flow speed of the whole intersection and reduces the road capacity.

3.3.1.3. Intersection entrance status: Due to the relatively large traffic flow at the entrance, and the signal timing of the intersection, as well as the unreasonable distribution of the number of entrance lanes in all directions of left, straight, and right, the evacuation speed of the intersection is small and cannot meet the morning and evening peaks. The traffic demand of vehicles during the period leads to severe traffic congestion during peak hours and long queue time.

3.3.1.4. Pedestrian status at intersections: The intersection area is large, and the time for vehicles to pass through the crosswalk in the north-south direction is only 30 seconds, while that in the north-south direction is relatively long. This reduces the utilization rate of green signal, prolongs the crossing time of pedestrians and bicycles, reduces the psychological waiting capacity of pedestrians, and increases the probability of running red light [5].

3.3.1.5. Status of signal cycles at intersections: The right-turn intersection of each entryway at a level intersection is a green light during the signal period of 182s. It often conflicts with the time when pedestrians cross the crosswalk, which is likely to cause harm to pedestrians. In addition, if there is a vehicle in front of the right-turn vehicle, it will occupy the non-motorized lane when turning right, which will affect the non-motorized vehicles on both sides of the road [6].

4. Optimization ideas
To optimize the intersection of the plane signal connecting the main road and the secondary road, not only the smooth flow of motor vehicles should be considered, but more importantly, the point of conflict between pedestrians and motor vehicles should be reduced [7]. The specific optimization plan is reflected in two aspects. The first is to improve the channelization scheme at the intersection, and the second is to re-plan the signal timing. The saturation of left-turn lanes is generally large, and many left-turn vehicles occupy straight lanes, resulting in reduced capacity of intersections. Changing the east entrance near the straight lanes to left-turn lanes can effectively reduce the delay of left-turn lanes to improve traffic capacity [8]; re-planning signal timing can reduce the conflict point between pedestrians and motor vehicles, improve the problem of pedestrians crossing the street, and reduce the occurrence of traffic accidents.

4.1. Improvement of intersection channelization scheme
From the perspective of ensuring safe and smooth traffic flow, the channelization design of intersections should follow the principles of overall design, traffic island design, traffic flow organization and lane design [9]. In view of the large flow of left turning vehicles at the North-South entrance, it is considered to add a straight left turn lane at the North-South entrance, that is, the North-South entrance will be expanded from three lanes to four lanes.

The schematic diagram of the imported lane after the improvement scheme is shown in Fig. 5.
4.2. Some Common Mistakes

There are a lot of pedestrians at the intersection of Hexing road and Dazhi street. Pedestrians often run red lights because of waiting time is too long. Therefore, we need to consider the problem of too many pedestrians in the signal allocation, and optimize the pedestrian crossing.

For signal-controlled single-point intersections, signal timing optimization often plays a vital role in reducing the average delay of vehicle flow and the number of stops, improving the capacity and service level of the intersection [10].

The signal timing optimization considers that the green light time of the first phase display is 30 seconds, and the corresponding minimum green light time is calculated as follows: \( g_{\text{min}} = 7 + L_p / V_p - I \) [11]. In the formula, \( g_{\text{min}} \) is the shortest green light time, s; \( L_p \) is the length of the pedestrian crossing the street, m; \( V_p \) is the pedestrian crossing speed, taking 1.2 m/s; \( I \) is the green light interval time, s. The minimum green light time \( g_{\text{min}} \) calculated by the above formula is 32s, and the actual green light time displayed is 30s, which is less than the shortest green light time 32s, so the signal period should be recalculated [12]. On the basis of the original period, make appropriate extension, select the signal period duration as 187s, keep the original signal timing four phases unchanged, and recalculate the relevant signal timing parameters according to the new intersection channelization scheme, and then use the obtained signal timing. The parameters recalculate the saturation flow correction factor, thereby obtaining the maximum flow ratio of each phase and the total flow ratio, thereby determining the time when the green light is displayed [13]. The calculation results of traffic signal timing design are shown in Tab. 4.

| Lane function          | Number of lanes | Statistics traffic | Saturated flow | Maximum flow ratio | Total flow ratio |
|------------------------|-----------------|--------------------|----------------|--------------------|------------------|
| Straight west          | 3               | 1688               | 2249           |                    |                  |
| West straight right    | 1               | 341                | 323            | 0.2312             |                  |
| Turn west to left      | 2               | 876                | 859            |                    |                  |
| East straight right    | 1               | 584                | 758            | 0.2502             | 0.8343           |
| Turn east to left      | 1               | 396                | 485            |                    |                  |
| Straight east          | 2               | 1016               | 1355           |                    |                  |
| South straight left    | 1               | 120                | 589            | 0.2039             |                  |
| South straight right   | 1               | 420                | 401            |                    |                  |
Turn south to left & 1 & 828 & 870 \\
Straight to the north and right & 1 & 840 & 724 \\
Straight north & 1 & 108 & 725 \\
Turn north to left & 1 & 516 & 498 \\

It can be seen from the calculation that the maximum flow ratio of the east-west straight phase is 0.2312. The east-west left-turn phase maximum flow ratio is 0.2502. The maximum flow ratio of the north-south straight phase is 0.1490. The maximum phase flow ratio of left-to-south left turn is 0.2039. Therefore, the green light time shows that the east-west straight phase is 48s, the east-west left phase is 52s, the north-south straight phase is 32s, and the north-south left phase is 43s. The signal timing is shown in Fig. 6.

5. INTERSECTION OPTIMIZATION SIMULATION

5.1. Intersection optimization simulation

The micro simulation software VISSIM is used to establish the simulation model, and the defined evaluation indexes are simulated and analyzed. Specific process is as follows: Establish an intersection model; Enter traffic volume; Route selection; Signal light setting; Generate evaluation plan.

The simulation diagram of the intersection obtained according to the optimization scheme is shown in Fig. 7.
5.2. Analysis of service level of improvement plan
It can be seen from Tab. 5 that the maximum saturation of the optimized intersection is reduced to 0.80; the average delay per car is relatively reduced, and the delay of all imported cars is more balanced; the total capacity is increased from the current 8461 vehicles/h to 9383 Vehicles/h, an increase of 10.9%; the overall service level of the intersection is Class C; the total number of stops and the length of the queue are reduced from before the optimization, and the traffic condition of the intersection has been effectively improved.

| TABLE V. INTERSECTION CURRENT DATA TABLE |
|------------------------------------------|
| Lane Group | West import | East Import | North Import | South Import |
|            | Turn left | Go straight | Turn left | Go straight | Turn left | Go straight | Turn left | Go straight |
| Average delay(s) | 43 | 56 | 34 | 11 | 23 | 21 | 64 | 35 |
| Number of parking(vehicle) | 467 | 613 | 204 | 254 | 292 | 213 | 376 | 107 |
| Traffic capacity (vehicle / h) | 967 | 2479 | 425 | 1789 | 523 | 237 | 960 | 748 |
| Queue length(vehicle) | 44 | 78 | 21 | 38 | 56 | 89 | 20 | 12 |
| Service Level | C | C | D | B | D | C | C | C |
| Saturation | 0.65 | 0.75 | 0.80 | 0.50 | 0.79 | 0.66 | 0.75 | 0.70 |

6. CONCLUSION
Through the traffic investigation and analysis of the intersection of Hexing Road and Dazhi Street and its surrounding areas, the reason for the reduced capacity of the intersection was found, which can solve the problem of traffic congestion at the intersection to a certain extent. Through the collected data, the signal timing of the intersection is optimized, and the channelization design of the intersection improves the service level of the intersection by one level and improves the road capacity within a certain range. It should be pointed out that the research on the intersection of Dazhi Street and Hexing Road in this article is based on the study of the traffic characteristics of motor vehicles. Obviously, non-motor vehicles and pedestrians also have a greater impact on the road capacity. Due to the small number of non-motor vehicles in Harbin, in this paper, the study of non-motor vehicles is ignored, but when designing intersections, the traffic flow characteristics of non-motor vehicles must be considered. In addition, the research in this paper is mainly for a single intersection. The linkage of multiple intersections has not been studied. In the future, multiple intersections can be considered for coordinated organization optimization [14].

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