The Data-based Analysis of Intersection Delay Research

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Abstract: To analyse the intersection delay, the crossing of Haikou Renmin Avenue and Haidian Five Road is selected as the target of the research. After the field measurements regarding the average delay times at the target intersection, the methodology of data-based analysis is adopted in this article with a full-scale research. What’s more, to enhance the similar intersections’ service level, this article carefully considers relevant delay factors with attempts to explore multi-factorial measures so as to mitigate the concerned delay. Additionally, with the introduction of modern traffic engineering and traffic management, practical methods are proposed to achieve the effective alleviation of intersection delay times as well as improving its operation quality.

1. Introduction
Under all categories of driving delay in urban traffic network, the intersection delay contributes a major part, taking up 80% of the total delays.¹ With increase of the urban population and the acceleration of urbanization, China's urban construction and motor vehicle ownership are under a rapid development stage. Considering the lag of infrastructure construction, the growth of motor vehicles will inevitably aggravate the congestion of urban road network, especially at intersections. Intersection delay, the major issue in the field of traffic engineering, is pending to be solved by scholars all over the world. Due to the inherent complexity of the problem and randomization of delay factors, the research on intersection delay has been continuing as well as the improvement of mitigation measures. This article is based on the research of a typical intersection in Haikou, the crossing of Renmin Avenue and Hadian Five West Road, to ascertain the main factors contributing intersection delay and propose appropriate solutions. It also emphases that, without scientific traffic control and effective organization, the sole reliance on channelization of existing road conditions cannot fully utilize the traffic resources and improve the road network capacity.

2. Basic Concepts

2.1. Planar Intersection
Where the roads meet is called the intersection. Based on the different levels of the crossing roads, the intersection can be categorized into planar intersection and flyover intersection. Generally, the intersections in urban areas are the crossed one, which contains 16 conflict points.

2.2. Traffic Delay
Traffic delay refers to the time loss caused by traffic friction and control, which is measured by ‘s’ or ‘min’.² Intersection delays are described by the delayed time caused by vehicles passing through the
intersections. According to researches on the approach delay, the stopped delay will account for 76% and the queuing delay takes up 97%. Therefore, the approach delay is generally replaced by the queuing delay.[2]

3. Evaluation of Intersection Operation Quality
As a typical intersection, the crossing of Renmin Avenue and Hadian Five West Road is the one without primary or secondary points. Traffic congestion may occur in any direction at any time. In order to evaluate the operation efficiency of the whole intersection, it is necessary to conduct a delay investigation from each entrance. The time of this survey was selected during the flat period (9:00am-11:00am) with normal weather and traffic conditions.

3.1. Survey Data: Summarized analysis of the Intersection

| Entrance | Number of Parking at Intersection | Traffic Volume of Approach at Intersection | Total Traffic Volume of Approach at Intersections |
|----------|----------------------------------|--------------------------------------------|--------------------------------------------------|
|          | Number of Vehicles off the Road | Number of Vehicles on the Road |                                  |
| East     | 1241                             | 300                                       | 77                                              | 377                                              |
| West     | 401                              | 108                                       | 44                                              | 152                                              |
| Subtotal | 1642                             | 408                                       | 121                                             | 529                                              |
| South    | 777                              | 145                                       | 33                                              | 178                                              |
| North    | 430                              | 160                                       | 43                                              | 203                                              |
| Subtotal | 1207                             | 305                                       | 76                                              | 381                                              |

After calculating the delay indicators based on the survey data and analysing the accuracy of the calculated results, the investigated summary is shown below (Table 2).

| Entrance | Total Delay (per vehicle, S) | Average Delay per Stopped Vehicle (S) | Average Delay per Vehicle on the Entrance at the Intersection (S) | Percentage of Vehicles off the Road (%) | Percentage Tolerance (%) |
|----------|-----------------------------|---------------------------------------|---------------------------------------------------------------|----------------------------------------|--------------------------|
| East     | 18615                       | 62.0                                  | 49.4                                                         | 80.0                                   | 5.0                      |
| West     | 6015                        | 55.7                                  | 39.6                                                         | 71.0                                   | 10.0                     |
| South    | 11655                       | 80.4                                  | 65.5                                                         | 82.0                                   | 6.7                      |
| North    | 6285                        | 44.0                                  | 34.5                                                         | 78.6                                   | 5.1                      |

3.2. Indicator: Services Level of Intersections
The operation quality of every planar intersection can be quantified by indicators such as how long it takes the pedestrians or vehicles passing through this intersection, the delay time, the waiting time, the number of waiting and the extent of people's anxieties. These indicators can be obtained by conducting a delay survey at the intersection. Among these indicators, the delay time is more sensitive to the change of intersection’s conditions and easier to obtain, which is often used to evaluate the service level of signalized intersections all over the world. And the service levels of Chinese signalized intersections could be reconciled with the ones demonstrated in American Highway Capacity Manual.[3]

3.3. Evaluation: Service Level of the Intersection
Combining the survey data with the standard listed in Table 3 and Table 4, the evaluation of the targeted intersection can be carried out. For the east and south entrances, the service levels are considered as ‘F’ given each vehicle’s average delay (62.0s and 80.4s respectively), which is
equivalent to the Grade III intersection under standard in China. The service levels for the west and north entrances are rated as ‘E’, equivalent to Grade II intersection due to their average delay times as 55.7s and 44.0s.

Accordingly, a clear conclusion could be drawn that the targeted intersection only provides a low-level service: its traffic flow is generally with the state of being forced or unstable. Under this circumstance, a slight increase or disturbance on the traffic flow may trigger serious operational problems, such as the discontinuous traffic flow and endless queueing of vehicles. Based on the spot observation, a great number of cars are lined up during red light and this problem cannot be easily eliminated by current signal control, which affects the freedoms of driving, as well as its comfort and convenience. It should be noted that the performance of the targeted intersection makes a heavy impact on the main traffic arteries through the south and north direction in Haikou, influencing the traffic flow through Renmin Avenue and Century Bridge as well as limiting the traffic efficiency of this city. Therefore, it is necessary to improve the targeted intersection’s service level by optimized transformation and comprehensive treatment, to elevate the overall traffic efficiency of the main urban area.

4. Analysis of Delay Reasons
Intersections delay is mainly affected by three factors: traffic conditions, traffic control mode and road conditions.

4.1. Traffic Conditions
Traffic condition refers to the composition of traffic flows, traffic volumes of available lanes, traffic distributions and directions of different traffic flow. Table 3 and Table 4 illustrated below present the distribution of different models in each entrance as well as the traffic volumes of all directions among every entrance. The conversion coefficients of different models such as battery carts, light-duty vehicles and oversized ones are respectively 1.0, 1.0 and 1.5.[6]

| Entrance | Oversized Vehicle (%) | Light-duty Vehicle (%) | Oversized Vehicle’s Proportion of Motor Vehicle (%) | Light-duty Vehicle’s Proportion of Motor Vehicle (%) | Battery Cart (%) |
|----------|------------------------|------------------------|----------------------------------------------------|---------------------------------------------------|-----------------|
| East     | 2.79                   | 48.18                  | 5.47                                               | 94.53                                             | 49.03           |
| South    | 4.67                   | 38.09                  | 10.91                                              | 89.09                                             | 57.24           |
| West     | 6.24                   | 73.62                  | 7.79                                               | 92.21                                             | 20.14           |
| North    | 2.33                   | 40.8                   | 5.39                                               | 94.61                                             | 56.87           |

| Entrance | Turn Left | Go Straight | Turn Right | U-turn | Battery Cart | Total (Motor Vehicle) | Total (Motor Vehicle and Battery Cart) |
|----------|-----------|-------------|------------|--------|--------------|-----------------------|----------------------------------------|
| East     | 153       | 893         | 271        | 0      | 1267         | 1317                  | 2584                                   |
| South    | 841       | 280         | 115        | 0      | 1656         | 1237                  | 2893                                   |
| West     | 171       | 501         | 749        | 286    | 431          | 1708                  | 2139                                   |
| North    | 442       | 413         | 174        | 0      | 1358         | 1029                  | 2387                                   |

From Table 3 and Table 4, the highest traffic volume comes from the south entrance. With the top proportions taking up by motor vehicles (oversized and light-duty vehicles) and battery carts, the south entrance encounters the severest delay among all directions. It is followed by the east with the second-highest traffic volume and proportions of investigated conveyances (oversized vehicles, light duty vehicles and battery carts), which results in a relatively serious traffic delay. Comparing with these
two entrances, although the west one confronts the largest quantities in motor vehicles, due to its lowest battery carts' volume and efficient channelization, it performs the best with lowest delay time. However, the entrance on the north shows a comparatively worse delay performance given its insufficient channelization with a rather small volumes in motor vehicles and large in battery carts.

The above research indicates that the participation of non-motor vehicles at the intersection increases the conflict points by 5.5 times. It results in a mismatch between the capacity of this intersection and its actual necessities, which causes a rather low efficiency in its operation. The number of conflict points at the intersection increased from 16 to 88 with the participation of non-motor vehicles.[5]

Through the above analysis regarding the traffic conditions at the targeted intersection, it can be concluded that, with certain road circumstances and traffic controls, the traffic volumes of motor and non-motor vehicles play a decisive role in the intersection delay, as well as the interference of oversized vehicles and non-motor vehicles.

4.2. Mode of Traffic Control

The targeted intersection is under the control of the four-phase single-point signal system during the flat period. Under the peak time, the length of such phase is controlled by the traffic police and adjusted accordingly with the on-site traffic volumes. This article is focused on the research during the flat period due to its more than 90% composition of the traffic in a day, which causes a significant impact on the targeted intersection.

Figure 1 below illustrates the targeted intersection’s timing scheme of different phases during the flat period, which is obtained by on-spot investigation with phase cycle as T=110s. Under appropriated traffic conditions, each entrance’s delay times are of great relevance with the time allocation of different signals. Any unreasonable time allocation will aggravate the delay. After a thorough research regarding the relevant traffic data of the targeted intersection, it could be discovered that, during the flat period, current time allocation scheme does not coincide with the intersection’s traffic flow and volumes, which requires an immediate adjustment.

Meanwhile, after analysing the survey data, it also shows that, the over 50% electric vehicles from east, south and north entrances have engendered an enormous disturbance to the normal operation of other motor vehicles. The mere designated non-motor vehicle lane or the specific passing time allocated to non-motor vehicles and pedestrians cannot satisfy the operation of electric vehicles. It is necessary to distribute more time to these battery carts through the traffic signal.

| Phase 1       | Phase 2       | Phase 3       | Phase 4       |
|---------------|---------------|---------------|---------------|
| Go straight and turn left at the north entrance of Renmin Avenue | Go straight and turn left at the east entrance of Haidian Five Road | Go straight and turn left at the west entrance of Haidian Five Road | Go straight to the south entrance of Renmin Avenue and turn left |

| G: 27s | G: 24s | G: 21s | G: 26s |
| Y: 3s  | Y: 3s  | Y: 3s  | Y: 3s  |
| R: 80s | R: 80s | R: 86s | R: 81s |

Figure 1. Proposal of Signal Timing Distribution in Non-peak Period
Notes: G: Phase Time of Traffic Signal in Green   Y: Phase Time of Traffic Signal in Yellow   R: Phase Time of Traffic Signal in Red
4.3. Road Conditions
Road conditions include the different forms of intersection as well as the traffic lanes including their numbers, widths and various functions. The four entrances of the targeted intersection were of three lanes before channelization, which are increased into four or five afterwards.

Although all the entrances are channelized with provision of exclusive right-turn lane, it could be observed from the analysed data that the south entrance encounters the most serious delay while the west one bear the heaviest traffic volumes. The reason for the better road capacity on the west is because of the more optimal channelization: with clear guide boards at the entrance and precise road marks for motor vehicles. However, deficiencies are still found in other entrances. Taking the south one as an example, the disturbance from the non-motor vehicles, though with the highest volumes among all entrances, has not been caught enough attention which leads to the serious delay. Other problems such as lack of clear signages, blurred road lines and insufficient maintenance are awaited to be solved.

The lengths of the pedestrian crossings at the four entrances are 37 meters (east), 47 meters (west), 27 meters (south) and 27 meters (north), with respective time lengths of green light as 26 seconds, 27 seconds, 24 seconds and 21 seconds during the flat period. According to the researches from American scholars, the average walking speed of a normal person is between 1.03 m/s and 1.28 m/s. Given the casual purposes for most people coming across this intersection, the lower value, 1.03m/s, is therefore selected as the appropriate speed under this research. And the average time lengths to cross each entrance are calculated as 38 seconds, 48 seconds, 28 seconds and 28 seconds accordingly. However, it is observed that the allocated green-light time lengths are generally less than what are required, especially the east and west entrances.

The targeted intersection is an important traffic node in Haikou, connecting the city’s main roads. On the west, it connects the Century Bridge, the north-south traffic arteries of the city. Another main traffic stem, the Renmin Avenue, is connected on its south. And its east entrance connects the Haidian Five Central Road. What’s more, surrounded with large-scale residential zones, farm produce markets, schools, hospitals and parks etc., this intersection encounters a comparatively high densities of population and vehicles, which forms the complicated traffic circumstances all times during the day. Although the channelization to some extent has mitigated the traffic pressure, more comprehensive measures are awaited to be adopted based on the data analysed in the preceding section.

5. Delay Mitigation Measures
According to the previous analysis, typical problems of intersections in the urban area still exist. To solve these issues, the following measures are proposed to reduce the intersection delay and improve the operation quality.

5.1. Control of Traffic Flow
During the flat period, it is necessary to control the intersection’s traffic volumes from its source when its service level is rather low. As observed from the survey data, the east and south entrances only reach the third level, while the west and north achieves the second. However, the traffic flows at east and south entrances are much higher than their actual capacities.

According to the previous analysis, two measures are recommended to mitigate the targeted intersection’s congestion. The first one is to ban all the left-turn vehicles. It means that vehicles from south to north are only allowed to drive straight or turn right. As for the cars intended to turn left, they have to go reach the next intersection before turning around. Similarly, for the trans-meridional vehicles, they are prohibited to turn left until arriving at the next crossing. The second method is to prohibit the access of all oversized vehicles, excluding public transportations, to go through this intersection during the daytime. But further investigations are required for the exact timeslot for such prohibition.
5.2. Improvement of Geometry

Regarding the current channelization situation of the intersection, its geometric structure needs improvements including the increasing of right of ways without negative influence on the traffic flow of electric vehicles. For example, given the high volumes of battery carts from the south and north entrances, which causes disturbances to the motor vehicles’ normal operation, it is recommended to move back the stop lines in front of these two entrances’ through-traffic lanes for 5 meters, as well as demarcating the area between the through-traffic lanes and pedestrian crossings as the left-turn waiting zones for non-motor vehicles. These measures could effectively control the growth of the conflict points caused by non-motor vehicles at the intersection by equalizing the rights of way between all left-turn vehicles from same entrances. What’s more, considering a relatively longer period for pedestrians to cross the targeted intersection, a safety island could be set up in the middle of the road, creating a two-step crossing and allowing longer time for people to cross. Such as the east and west entrances as observed, safety islands are recommended to be founded, to resolve the originally insufficient time for pedestrians to go through these two entrances.

5.3. Adjustment of Traffic Control Mode

If a rather obvious delay is observed during the flat period at the intersection, it could be predicted that a more serious congestion will happen in the peak time, which indicates certain unreasonableness for traffic control settings of the targeted intersection.

As illustrated by on-site data of this intersection, serious traffic delays are observed during the flat period. And more control phases, although guarantee a safer operation, will generally render a shorter time period which could be effectively distributed to pass through entrances. In the preceding analysis regarding the changes of traffic flow and its current status, certain adjustments could made for the targeted intersection, such as introducing a three-phase control and forbidding the vehicles’ left-turn from east and west directions.

5.4. Enhancement of Safety Facilities

Traffic safety means the non-occurrence of any incident during the whole traffic process. People, vehicles and roads are the directly related elements, which are tightly connected in every intersection. Therefore, the enhancements of safety facilities at intersections are of particular importance. In a typical intersection in urban areas, the safety measures for pedestrians and non-motor vehicles generally include the designated zones for non-motor vehicle, as well as the provision of safety island, zebra crossing, etc. For the motor vehicles, safety facilities mainly refer to clear traffic signs, specific signals, obstacles warnings once falling into the driver’s sight triangle.

As for the targeted intersection, several safety facilities could be used such as clearer traffic signs, road markers and specific signals with regular maintenance. Provision of barrier outside the pedestrian crossing and setting up of safety island could also be considered, which could mitigate the passers-by’s disturbances on the intersection. Additionally, the reduction of all vehicles’ co-existence can enhance the traffic safety as well, for example, to draw specific driving lines or to use the reflective pyramid or cone to segregate the specific driving areas for all left-turn vehicles at the west entrance of the target intersection.

6. Conclusion

The crossing of Renmin Avenue and Haidian Five Road in Haikou is selected as the target in this article, which adopts the quantitative and qualitative methods to carry out a full-scale research on the intersection delay based on the spot data. After taking the average delay time as the index to evaluate the targeted intersection’s service level, this article aims to ascertain the multi-factorial solutions to mitigate the intersection delay by considering various on-site data, such as the traffic volumes of motor and non-motor vehicles from entrances, the proportions of oversized and light-duty cars, the time scheme of traffic signals, the crossing time of pedestrians as well as the current provision of traffic safety facilities and etc. To analyse from the modern traffic engineering and traffic management,
comprehensive solutions are proposed to reduce the intersection delay, such as controlling the traffic volume from its source, improving the geometric structure of entrances, adjusting the traffic control mode and enhancing the traffic safety facilities. Not only could these measures improve the service level and traffic abilities of such typical intersections, but also provide practical and comprehensive solutions to fortify road capacities and utilization of resources among urban traffic network.

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