A Simple Method of Signal Control for Rotary Interchange

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Abstract. The existing rotary interchange has the problems of heavy traffic and short weaving section. Taking the 2-level rotary interchange as an example, a simple two-phase signal control method is put forward by analyzing traffic conflict and calculating signal timing parameters based on Webster including requirement for the length of red intervals. The applicable road geometry of signal control method is also discussed. Finally, Vissim simulation and evaluation are carried out. Through comparing traffic operation before and after the optimization, the results show that the simple signal control method has a positive influence on rotary interchange traffic.

1. The characteristics and problems of rotary interchange

The rotary interchange developed from at-grade rotary Intersection. The approaching lanes cross the rotary lanes to ensure the artery traffic unobstructed. The artery vehicles use the overpass to pass through, and the turning and secondary vehicles flow on the rotary lanes. If the artery traffic is heavy, the rotary interchange can be built into 3 levels or 4 levels, that is, the upper and lower floors are passing lanes, and the middle levels is a circular road for the turning vehicles to circulate[1].

The rotary interchange has the characteristics and functions of at-grade rotary Intersection, that is, the conflict traffic flow can be transformed into weaving traffic flow, and the efficiency can be improved[2]; on the other hand, the rotary interchange is a kind of interchange in the structure, and the artery vehicles is isolated from other vehicles in space which not only ensures the efficiency of the artery lanes, but also further reduces the traffic conflict at the roundabout.

As the number of urban cars increases, the urban traffic volume is also increasing. The design capacity of original roundabout can no longer meet the growing demand[3]. Such problems also appear on the rotary interchange. Especially in the case of heavy left-turn traffic, conflicts with passing traffic often cause serious congestion at the roundabout; on the other hand, the Specification for design of intersection on urban roads[4-5] requires the minimum weaving length and center island radius for roundabouts. However, most of rotary interchange in China did not meet the standards. Especially when the roads are misaligned or intersected, the short axis will be formed, resulting in short weaving sections between adjacent roads, interspersed conflicts between vehicles, and deadlocks in serious cases, affecting the traffic capacity of the roundabout and becoming accident-prone sections.

Now, the traffic management department sets the signal control for these roundabouts, which are sometimes impossible to change the structural form due to various reasons, to separate the conflicting vehicles in timing and space. The left-turning two-time parking method[6] is a common roundabout signal control mode. This method requires a parking line inside the roundabout. The left turn vehicles need to stop 2 times. Therefore, the rotary lanes are required to have enough length for the parking of left-turn vehicles. If the roads are misaligned, the existence of the short axis makes the left-turn control unsuitable. Based on the conflict characteristics of the 2-level rotary interchange, a simple signal control method was proposed, which makes full use of the parking space in the island and eliminates traffic
conflicts.

2. A simple method of signal control for rotary interchange

2.1 Analysis of 2-level rotary interchange conflicts
The 2-level rotary interchange (figure 1) is a common type of rotary intersection. The straight traffic flows across or under the roundabout, so there are only 6 directions in the roundabout (excluding right turn). Unlike other common intersections which have 8 directions, it is necessary to analyze their conflict characteristics.

![Figure 1. 2-level rotary interchange](image)

The east and west direction is the artery straight traffic flow, passing under the roundabout. Left-turning vehicles in the east and west direction drive into the inner lane of the roundabout through the approach road. The outer lane is for straight-through vehicles. All right-turning vehicles do not enter the roundabout and turn through the approach road. It indicates that although the direct conflict points are reduced in the roundabout, the indirect conflicts are increased (weaving, confluence, and diversion), especially the conflict between the left-turn traffic flowing into the inner lane and the straight traffic on the outer lane. And the conflict between the traffic flow in and out of the weaving sections has the greatest impact on traffic. A1 and A2 respectively represent these two types of conflicts.

2.2 Signal phase and phase sequence
The conflict analysis indicates that there is no conflict between the south entrance lane and the west entrance lane vehicles. There is no conflict between the north entrance lane and the east entrance lane vehicles, so 2-phase signal control can be used. In order to increase the utilization rate of the lane and reduce the full red time of the signal light, the parking lines (BB’ and CC’) as shown in figure 2 can be set in front of the A1 conflict point, and equipped with roundabout signal control. In the specific signal control process, there are 4 phases in 1 cycle, as shown in figure 2 (phase a is the initial phase, phase d is the same phase b).
Figure 2. Design of signal phase and phase sequence

Figure 2 indicates that there is no conflict inside each phase, and the heavily weaving traffic flow is separated in different phases. The parking line on roundabout acts like an intersection waiting area. Vehicles of next phase drive into the roundabout in advance, but the parking space is limited, as shown by the shaded part in figure 2 a). The length depends on the conflict of the last vehicle of this phase and that of the first vehicle of next phase.

2.3 Parameters of signal control
By dividing the lane function and carrying out signal control, the weaving problems in the loop intersection can be eliminated, and the rotary interchange is simplified into a common at-grade intersection, so the signal timing scheme can be designed using the Webster method.

2.3.1 The capacity constraint of parking space
The queue length of the vehicles on the roundabout can’t exceed the tail of the parking space, otherwise the intersection will be congested. Let the radius of the parking space in the roundabout to be r, the number of lanes in the roundabout to be n, the width to be w, and the angle between the head and the tail of the parking space to be α (figure 2 a)), then the capacity R of a lane of the roundabout is:

\[ R = \frac{n \pi r^2}{180 (r + 0.5w)} / s \]  

(1)

2.3.2 Determination of the length of full red light
The length of full red light refers to that all the signal lights of the entrance lanes are red. In order to improve the efficiency of the roundabout and ensure the safety of the vehicles, the calculation of Ar which refers to the length of full red light should be divided into two parts: ① t1, which refers to the duration of the green light. This time is used to release the vehicles in the roundabout, so that the number of vehicles behind the parking lines is exactly equal to the maximum capacity of the parking space, so that the lane can be used to the maximum; ② t2, which refers to duration of the red light. And the vehicles that have already passed the parking lines can continue to pass, so that it can leave the conflict point before the first car of next phase arrives.

2.4 Requirements of road geometry
The simple signal timing method for rotary interchange is designed for the two-level structure, that is, the straight traffic flow in one direction does not pass through the roundabout, in addition to the following channelization design conditions.

(1) According to the analysis of conflict characteristics, that left-turn and straight vehicles travel separately helps to reduce traffic conflicts. Therefore, the number of lanes in roundabout is at least 2. The ratio of left and straight lanes depends on the traffic volume, but left-turn vehicles need to travel on
the inside, the straight-through vehicle needs to travel on the outside.

(2) In order to correspond to the lane function of the roundabout, the entrance road needs at least one dedicated turning lane for each direction of vehicles, then the entrance road needs at least 2 lanes (the right-turning vehicles can be separated in advance). If not, try to widen it.

(3) The number of exit lanes should match the capacity, and should be coordinated with the number of lanes in each phase that allow traffic from the same exit to the roundabout.

3. Case Analysis.

3.1 Status of rotary interchange of Urumqi’s Northern Station

The roundabout of Urumqi’s Northern Station is a 2-level rotary interchange. The traffic around the island is heavy. The short weaving sections lead to outstanding safety issues. The traffic volume of each entrance road during the morning rush hour is listed in table 1

| Entrance road | Straight | Left | Right |
|---------------|----------|------|-------|
| North         | 612      | 738  | 468   |
| South         | 924      | 237  | 444   |
| East          | 0        | 183  | 882   |
| West          | 0        | 486  | 168   |

3.2 Optimization scheme

The purpose is to minimize the total delay of the entire intersection, and ensure the traffic flow runs smoothly and safely.

After the channelization of the North Station rotary interchange, according to the signal timing method above, the values of each parameter are shown in table 2.

| Parameter                     | Start loss time. | Duration of yellow light | Green light interval | Cycle | Signal phase 1 | Signal phase 2 |
|-------------------------------|------------------|--------------------------|----------------------|-------|----------------|----------------|
| Value/s                       | 2                | 3                        | 8                    | 100   | 33             | 51             |

3.3 Evaluation of optimization scheme

3.3.1 Evaluation of traffic operation

The service level of an intersection should be evaluated in two aspects: traffic safety and traffic efficiency. Traffic safety indicators mainly include traffic accident rate and total number of conflicts; traffic efficiency indicators mainly include average vehicle delay. Simple signal timing method separates the conflicting traffic flow in time. Therefore, three indicators of vehicle delay, service level, average queue length and maximum queue length are selected to evaluate the operational efficiency of the intersection. The Vissim model was used according to the current road conditions and traffic volume. The results are shown in table 3.

| Entrance road | Direction | Delay/s | Average queue length/m | Maximum queue length/m |
|---------------|-----------|---------|------------------------|------------------------|
| North         | Left      | 102.2   | 37.4                   | 59.6                   |
|               | Straight  | 70.2    | 37.4                   | 59.6                   |
| South         | Left      | 115.6   | 30.2                   | 50.5                   |
|               | Straight  | 84.9    | 30.2                   | 50.5                   |
| East          | Left      | 17.5    | 6.3                    | 8.2                    |
| West          | Left      | 59.6    | 41.3                   | 90.1                   |

Generally speaking, the Vissim simulation indicates that the service level of the whole roundabout...
is E, which has reached the stage of congestion. In terms of direction, except for the stable operation of the vehicles on the east entrance road, the traffic congestion in the north and south entrance roads is the most serious, especially the left-turn vehicles, and the delay has reached more than 100s.

### 3.3.2 Evaluation of optimized traffic

The evaluation of optimized traffic condition is shown in table 4.

| Entrance road | Direction | Delay/s Value | Optimized difference | Average queue length/m Value | Optimized difference | Maximum queue length/m Value | Optimized difference |
|---------------|-----------|---------------|----------------------|------------------------------|----------------------|------------------------------|----------------------|
| North         | Left      | 96.8          | 5.4                  | 32.5                         | 4.9                  | 50.8                         | 8.8                  |
|               | Straight  | 60.1          | 10.1                 | 30.2                         | 7.2                  | 46.9                         | 12.7                 |
| South         | Left      | 45.4          | 70.2                 | 10.2                         | 20.0                 | 19.2                         | 31.3                 |
|               | Straight  | 34.4          | 50.5                 | 27.1                         | 3.1                  | 44.3                         | 6.2                  |
| East          | Left      | 28.6          | -11.1                | 7.4                          | -1.1                 | 10.1                         | -1.9                 |
| West          | Left      | 32.7          | 26.9                 | 10.3                         | 31.0                 | 23.4                         | 66.7                 |

It can be seen from table 4 that the numerical values of the three indicators are greatly reduced, which indicates that the efficiency of the two-phase signal controlled rotary interchange has been significantly improved, and the service level obtained by the node evaluation is upgraded to the D level. Among the traffic flows in all directions, the most significant improvement was the south entrance road. The delays in left-turn and straight traffic were reduced by 70s and 50s respectively. Due to the influence of signal control, the continuous traffic flow of the east entrance road has become a discontinuous flow. The delays and queue lengths of the vehicles are slightly increased, but the overall efficiency of the intersection is not affected.

### 4. Conclusion

Compared with the left-turning two-time parking method, the simple signal control method for rotary interchange is simple and easy to carry out. The two phases are alternated to eliminate the conflict points and severely weaving sections. After verification by examples, the improvement effect is obvious and has certain practical value. However, the adaptation of this signal control method to traffic conditions is not discussed in this paper. This part needs to be improved.

### References

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