An Atypical Induction Control with User-Defined Rules

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Abstract. Under traditional induction control methods, phase sequence combination can't be adjusted dynamically by traffic flow characteristics. To solve this problem, this paper put forward an atypical induction control with user-defined rules, which is supported by real-time traffic data such as vehicle presence, queue length, and the number of vehicles in the interval. Under this control, users can define the identification and triggering rules of the traffic state and design the combination rules of the conventional and extended stage chain according to the characteristics of the actual scene. Based on the analysis of the local high-resolution log data of the signal controller at the intersection of Jiaotong Avenue and Tianxian Road in Xiaogan City, it is concluded that the maximum queuing length of the average intersection cycle decreases from 160 m to 95 m after the implementation of the scheme, a decrease up to 40.6%. The results show that the atypical induction control with user-defined rules has good flexibility, controllability, and expansibility and is extremely suitable for traffic scenes with dynamic traffic characteristics.

Keyword: traffic engineering · actuated control · user rules · demand response

1 Instruction

Traffic signals usually operate in either a fixed period or induction control mode in the signalized intersection. All the control parameters of fixed period control are preset offline on the premise that the traffic demand of the time period is determined, which has limited adaptability to the traffic fluctuation in the urban traffic network. However, the period, green signal ratio, and even phase sequence of induction control can be adjusted in real-time by relying on traffic detection data, and its adaptability to traffic fluctuation is stronger than that of fixed period control.

The traditional induction control method is too experiential in determining timing parameters and detector positions, the control strategy is relatively single, and the control effect is also not obvious. Domestic and abroad scholars have done a series of studies on intersection induction control. Shao et al. [5, 7–9] studied the calculation method of unit green light extension time. Jing et al. [1, 4, 10] studied the methods of minimum green time and maximum green time. Han et al. [3, 6] put forward the concept of

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demand degree. Guo et al. [2, 11, 13] delved into the confluence scenario. Yang [12] proposed a real-time signal control method based on queue length and vehicle waiting time. Although the above research has improved the traditional induction control, it still lacks the consideration of determining the requirements of different scenes and flexibly formulating relevant induction control methods.

To address these issues, this paper proposed that according to the characteristics of the scene, the user can define the identification rules of traffic state and abnormal state to design the phase sequence combination and the trigger rule of the atypical induction control method in accordance with the local traffic habits in the conventional stage and the extended stage. It provides a better idea for complex traffic scene governance.

2 Control Strategy

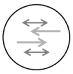
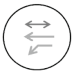
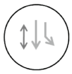
2.1 Stage Design

Based on traffic flow characteristics at intersections, phase sequences of release triggered by conventional conditions and special conditions at intersections are designed, respectively. It is assumed that the traffic flow at an intersection is mainly symmetrical, and occasionally there is more one-way flow. The general and extended stages are shown in Table 1.

2.2 Mutually Exclusive Stage Chain

Around the conventional stage and the extended stage to design the chain of stage release order meeting the requirements of traffic safety, and these stages are mutually exclusive. Taking the east-west flow as an example, the mutually exclusive stage chain of symmetrically overlapped unidirectional or unidirectional overlapped symmetry is designed, as shown in Fig. 1. That is, during the cycle operation, if "(a) east-west go straight" is used in the first stage of east-west flow, the release stage chain of east-west flow in this cycle becomes "(a) east-west go straight - stage X-(b) east-west go left," where stage X can be skipped, or it can be either "(e) east-all release" or "(f) West-all release."

Table 1. General stage and extended stage design

Phase properties	Phase combination of phase release			
General stage	 (a) East-west go straight	 (b) East-west turn left	 (c) North-south go straight	 (d) North-south turn left
Extended stage	 (e) East-west all release	 (f) East all release	 (g) North all release	 (h) South all release

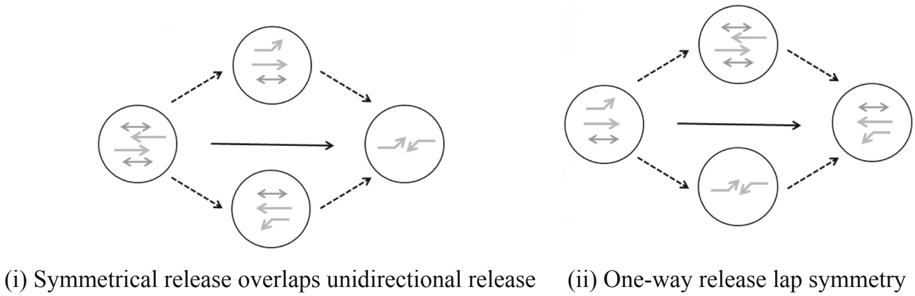


Fig. 1. Mutually exclusive stage chain design

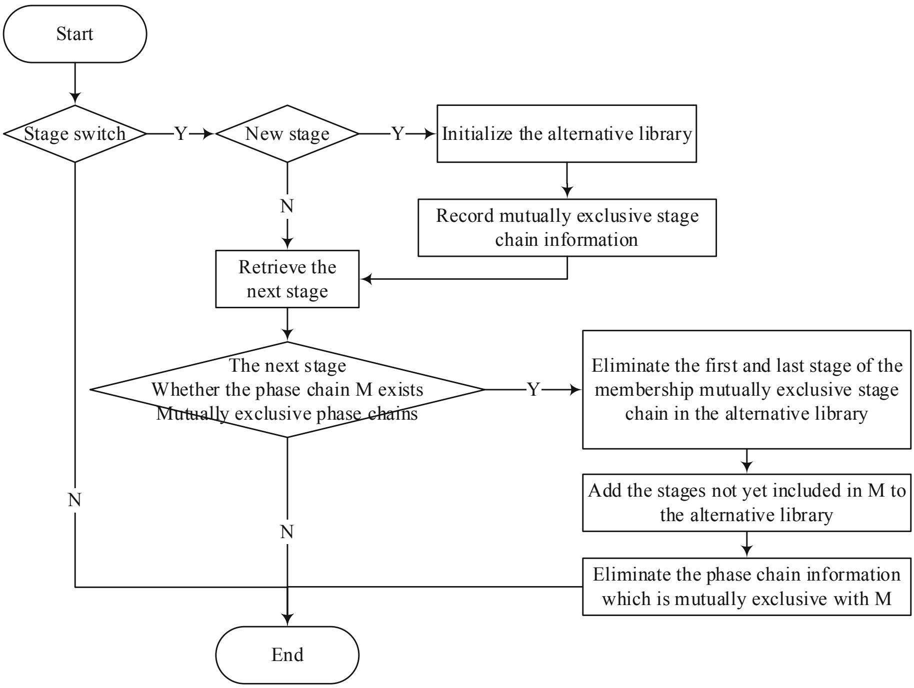


Fig. 2. Atypical induction control decision logic

2.3 Decision Logic

In the process of periodic operation, according to certain decision-making rules of the stage chain, we selected stages conforming to the characteristics of traffic flow and the corresponding stage chain. The decision process is shown in Fig. 2. Under the same conditions, the general stage is preferred by default.

3 User Rules

3.1 Logical Statement Expression

Through the combination of logical variables and logical operators to realize the logical expression of user rules. Logical variables, including constant, detector, lamp group, phase, fault, timer, user variables, etc. Logical operations include and, or, move right, move left, less than, equal to, not equal to, greater than, take large, take small, etc. As Fig. 3 shows, the number of cars passing through detector 27 is more than six, or the queue length is more than 45 m, indicating the appearance of the long queue in phase 1.

3.2 User Logic Design

According to the characteristics of traffic scenes, users define the identification rules of traffic state and abnormal state and provide trigger mechanisms such as stage demand release, neglect and skip, and degradation release.

(1) Traffic status recognition
By using the mapping relationship between detector and phase, multiple traffic data such as vehicle presence, queue length, and the number of vehicles in the interval are logically expressed once or repeatedly, and two or even multiple traffic states, including the negligible and non-negligible number of vehicles with phase, are expressed by output.

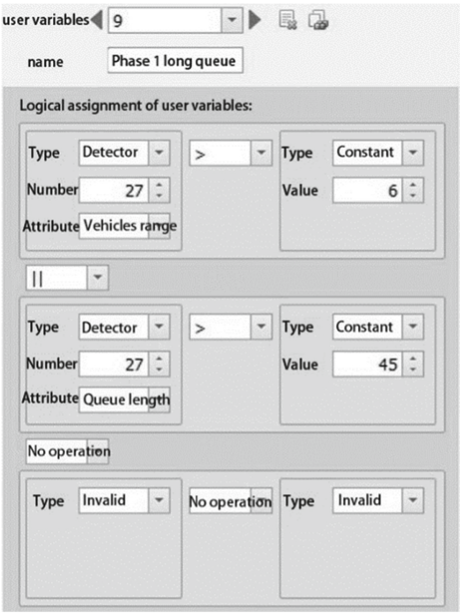


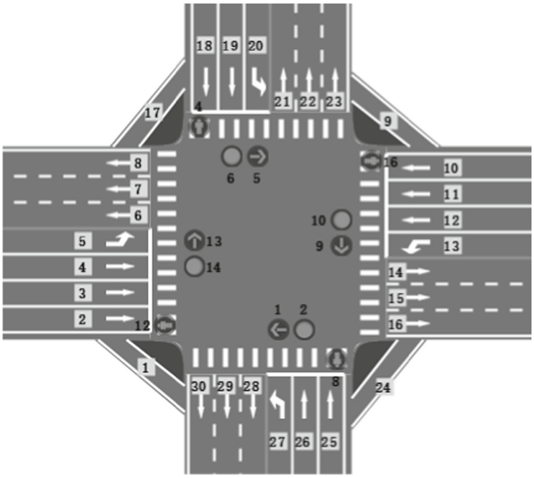
Fig. 3. Logical representation of user rules

(2) Identification of abnormal state
Using the DFM detection mechanism (detector data constant 0, constant 1 or data untrusted anomaly identification), combined with a timer and simple logical expression, the abnormal phase state is obtained.
(3) Trigger mechanism design
Using stage and phase mapping, design stage requirements, ellipsis, and relegation trigger the rule. The trigger condition of the extension stage is more stringent than that of the normal stage, that is, ensure that the extension stage can only trigger under a specific scenario, and the normal stage does not trigger at this time.

4 The Instance Application

4.1 Status Analysis

The selected places are Xiaogan City traffic avenue and Tianxian road intersection, east-west for the city's main road, and north-south branch. Usually, intersection traffic distribution is symmetrical, and the timing scheme uses a symmetric release plan. However, in some periods of time, there is asymmetric flow, and some phase green lights will be empty, and some phase time is insufficient. Intersection channelization and detector deployment information, just as Fig. 4 shows.



*Box-less numbers indicate phase numbers: 1: Left phase from south to north; 2: Straight from south to north phase; 4: Pedestrian phase on the north side; 5: Left phase from north-south; 6: Straight phase from north to south; 8: Pedestrian phase on the south side; 9: East phase from east to west left; 10: Straight phase from east to west; 12: Pedestrian phase on the west side; 13: Left phase from west to east left; 14: Straight phase from west to east; 16: Pedestrian phase on the east side;
*Box number indicates the detection channel number: 1: Turn right detection from west to east; 2~4: Straight detection from west to east; 5: Turn left detection from west to east; 6~8: West exit detection; 9: Turn right detection from east to west; 10~12 Straight detection from east to west; 13: Turn left detection from east to west; 14~16: East exit detection; 17: Turn right detection from north to south; 18~19: Straight detection from north to south; 20: Turn left detection from north to south; 21~23: North exit detection; 24: Turn right detection from south to north; 25~26: Straight detection from south to north; 27: Turn left detection from south to north; 28~30: South exit detection.

Fig. 4. Channelization and detector deployment diagram at the intersection of Jiaotong Avenue and Tianxian Road

4.2 Policy Implementation

Trunk road direction using symmetric lap one-way and one-way lap two mutually exclusive stage chain design, and regional direction was given to maintain symmetry design, and the stage transition diagram is shown in Fig. 5.

The identification rules of traffic state in the east-west phase are shown in Table 2.

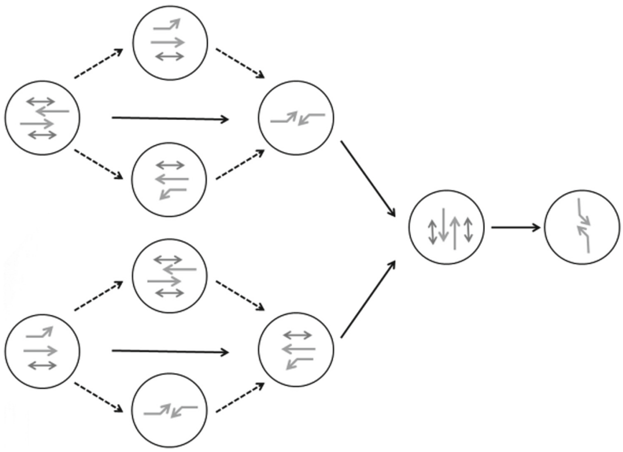


Fig. 5. Transition diagram of atypical induction control stage at the intersection of Jiaotong Avenue and Tianxian Road

Table 2. Key phase traffic state identification rules

User variable name		Logic assignment
Long queue	phase9	(detector 13: Car numbers of district > 6) || (detector 13: Queue length > 45)
	phase10	(detector 10: Car numbers of district > 8) || (detector 11: Car numbers of district > 8) || (detector11: Queue length > 59)
	phase13	(detector 5: Car numbers of district > 6) || (detector 5: Queue length > 45)
	phase14	(detector 2: Car numbers of district > 8) || (detector 3: Car numbers of district > 8) || (detector3: Queue length > 59)
Fewer vehicles	phase9	(detector 13: Car numbers of district < 2) && (detector13: Queue length < 8)
	phase10	(detector 10: Car numbers of district < 2) && (detector11: Car numbers of district < 2) && (detector11: Queue length < 8)
	phase13	(detector 5: Car numbers of district < 2) && (detector5: Queue length < 8)
	phase14	(detector 2: Car numbers of district < 2) && (detector3: Car numbers of district < 2) && (detector3: Queue length < 8)

Table 3. Stage trigger rules

<table>
<tr><th colspan="3">User variable name</th><th>Logic assignment</th></tr>
<tr><td rowspan="4">General stage</td><td rowspan="2">Demand</td><td>West-east straight</td><td>(detector 10: Vehicle condition||detector 11: Vehicle condition) || (detector 2: Vehicle condition||detector 3: Vehicle condition) || (detector 11: Queue length||detector 3: Queue length)</td></tr>
<tr><td>West-east turn left</td><td>(detector 13: Vehicle condition||detector 5: Vehicle condition) || (detector13: Queue length||detector 5: Queue length)</td></tr>
<tr><td rowspan="2">Omit</td><td>West-east straight</td><td>(user variables 20 & user variables 24)</td></tr>
<tr><td>West-east turn</td><td>(user variables 18 & user variables 22)</td></tr>
<tr><td rowspan="2">Extension stage</td><td rowspan="2">demand</td><td>West all release</td><td>(user variables 17 & user variables 19) & (user variables 22 & user variables 24)</td></tr>
<tr><td>East all release</td><td>(user variables 21 & user variables 23) & (user variables 18 & user variables 20)</td></tr>
</table>

Notes:
1. User variables 17 and 21 indicate that there are more vehicles turning left from east to west and turning left from west to east (number of vehicles > 6).
2. User variables 18 and 22 indicate that the vehicles are sparse from east to west and from west to east (number of vehicles < 2).
3. User variables 19 and 23 indicate that there are more vehicles going straight from east to west and west to east (number of vehicles > 8).
4. User variables 20 and 24 indicate that the vehicles are sparse from east to west and west to east (number of vehicles < 2).

The trigger rules for the normal stage and extended stage are shown in Table 3.

4.3 Data Analysis

Collect run log data from 2022-3-8 to 2022-3-14, traditional typical induction control was adopted in the first four days, and atypical induction control based on user-defined rules was adopted in the last three days (Fig. 6).

Having extracted queue length data representing three typical periods of morning peak, flat peak, and evening peak, respectively, 07:45–08:45, 10:15–1:15, 17:45–18:45, as Table 4 shows. The largest decrease of the maximum queue length in the average cycle occurred in the morning peak, with a decrease of 40.6%, followed by 38.7% in the evening peak and a smaller decrease of 6.7% in the flat peak.

4.4 Running Effect

During the morning and evening rush hours, there is a characteristic transition from symmetrical traffic flow to tidal traffic flow to symmetrical traffic flow at the intersection. At this time, the effect of atypical induction control with user-defined rules is far better than

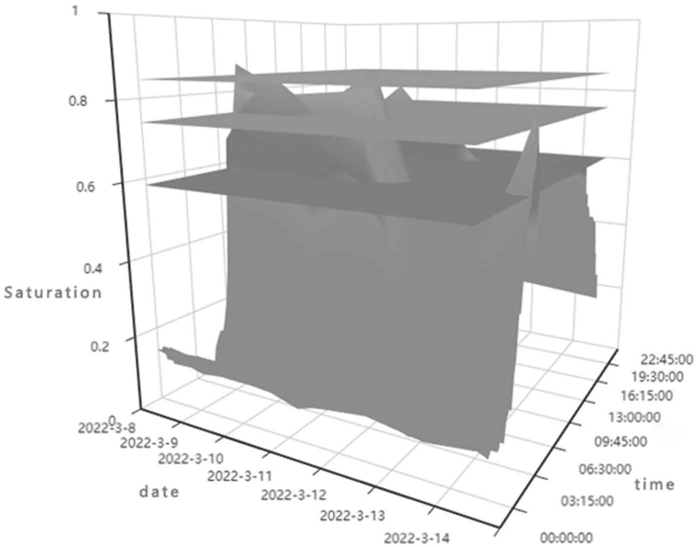


Fig. 6. Jiao Tong Avenue and Tianxian Road intersection saturation from 2022-3-8 to 2022-3-14

Table 4. Comparison of the maximum queue length of three typical periods

	Average cycle maximum queue length		
	Conventional induction control	Atypical induction control	Rate of decline
07:45–08:45	160 m	95 m	40.6%
10:15–11:15	45 m	42 m	6.7%
17:45–18:45	124 m	76 m	38.7%

that of traditional induction control. The specific reason is that the traditional induction control using a symmetrical release strategy alone cannot adapt to the change of traffic flow characteristics in this scene, while the atypical induction control can automatically adjust the release scheme based on unilateral release when the tidal characteristics are triggered, and then automatically execute the symmetrical release scheme when the features recover.

During the flat peak period, although the overall traffic flow at the intersection is small and has little change, the effect of atypical induction control with user-defined rules is still slightly improved compared with traditional induction control.

5 Conclusion

The atypical induction control method of user-defined rules proposed in this paper can customize the control strategy in line with the traffic characteristics for different traffic scenes, select appropriate traffic data, and require conventional and expansion stages. The identification of traffic state, abnormal state, and trigger rules of the control strategy is designed using logic user-defined expression to achieve safe, ordered, and smooth traffic in complex traffic scenes. The successful implementation of the intersection of Jiaotong Avenue and Tianxian Road in Xiaogan city shows that the atypical induction control with user-defined rules is flexible and controllable, not only has good expansibility, but also is extremely suitable for the traffic scene with dynamic change of flow characteristics.

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