DEVELOPMENT SUB-AREA DESIGN AND OFFSET CONTROL METHOD FOCUSED ON FLUCTUATED TRAFFIC FLOW

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ABSTRACT

Traffic signal control systems in Japan improved from a pattern selection control method to an adaptive control method for cycle-length and split control starting in 1995, and such methods have decreased traffic congestion in urban road networks. However, the pattern selection control method was selected for the sub-area and offset control because a real time simulator is required for adaptive offset control and sub-area design, and CPU power was not sufficient to calculate the offset and sub-area data in real time. Since then, CPU power has continued to improve day by day, and up-to-date computers have enough CPU power for Real Time Sub-area and Offset Control (RSOC). On the other hand, the phenomenon of traffic flow fluctuation between two sub-areas controlled by different cycle-lengths should be considered for developing RSOC, because the simulator results stated that fluctuated flow increases delay and stoppages on the street. This flow is referred to here as “fluctuated traffic flow”. This paper reports on the development of RSOC focused on fluctuated traffic flow.

KEYWORDS: Signal Control, Cycle-Length, Split, Offset, Simulator

ISSUES WITH CURRENT OFFSET PATTERN SELECTION APPROACH

We will first explain the current offset control method and sub-area design method.

Pattern Selection Control

Currently, an offset pattern is selected by referencing the saturation degree $\beta_1, \beta_2$ and cycle lengths measured of upstream and downstream-traffic along a specified link within a sub-area unit. Each of the O1 to O7 offset patterns is designed match the respective saturation degree levels of upstream and downstream traffic. They are preloaded on the system. Offset pattern selection approach is shown in Fig.1.

Each offset data (O1 to O7) is designed using off-line offset simulator. And there are rooms for improvement as follows.

1. Re-design is required every few years due to changes in traffic conditions over time.
2. The general offset simulator minimizes delay and stoppages rather than maximizing safety. As such, an offset design that improves both is required.

-1-
Fig. 1. Offset pattern selection approach

**Sub-area Groupings**

In the current sub-area design method, intersections are grouped into sub-area units, and the intersections in the same sub-area unit are controlled by the same cycle-length. If cycle-length difference between adjoining units is below the threshold, these units are married and controlled by the longer of the two cycle-lengths.

However, the result of simulation analysis says that this method does not minimize delay and stoppages in the network. For the decision of marriage or divorce of adjoining units, two conditions should be considered. The positive and negative impacts of two sub-area units being married are described as follows.

1. In a sub-area unit where the cycle-length is lengthened due to marriage, the delay and stoppages at intersections are increased at each intersection. (Negative impact)
2. The border link between two sub-areas that are controlled by different cycle-lengths becomes the cause of fluctuated traffic flow. The fluctuated traffic flow increases delay and stoppages; when two sub-areas become married, however, fluctuation vanishes. (Positive Impact)

**Marriage or Divorce**

![Diagram of Sub-area Groupings](image)

Fig. 2. Sub-area Groupings
REAL TIME SUB-AREA AND OFFSET CONTROL METHOD

To solve the aforementioned problems, a Real Time Sub-area and Offset Control Method (RSOC) was developed. The features of RSOC are as follows.

**Problems of Offset Design Simulators**

Generally, offset design methods such as TRANSYT minimize delay and stoppages (weighted value). However, there is room for improvement as described below:

1. There are cases in which an alternative offset is selected for the link, even if the length is not sufficient. This may cause traffic congestion, because the time in which the signal is simultaneously green for both intersections is not used effectively.
2. If offset is designed such that vehicles arrive at the intersection as the signal changes from green to yellow, the risk of traffic accidents such as rear-end-collision increases, as decisions of whether to stop or continue differ by driver.
3. Even if the traffic volume of upstream and downstream traffic is approximately the same, the TRANSYT system occasionally returns a priority offset for one or the other, as the priority offset is one of many offset patterns that minimize the index value (delay and stoppages) for the street.

**Improvement of Offset Design Simulator**

The functions attached to the simulator to solve these problems are as follows:

1. The simulator regulates the range of offset prior to designing the offset data. Fig.3 is an image of the range of under-saturated traffic. This range is calculated using cycle length, time when the signal is green, travel speed, and link length.

![Fig.3. Range of offset](image-url)
2. Accident risk and impartiality indexes are added to the performance index (PI).

\[ PI = \text{Delay} + k_1 \times \text{Stoppage} + k_2 \times \text{Accident risk} + k_3 \times \text{Impartiality} \]

Here in \( k_1, k_2, k_3 \) : coefficients

The accident risk index rises when vehicle arrive at an intersection just before or after the signal changes to red. In Fig.4, the risk is represented by the triangle, the peak of which represents the timing of vehicles arriving as the signal turns red.

![Arriving flow diagram](image)

**Arriving flow**

**Fig.4. Degree of risk**

The impartiality index functions so as to close the PI (delay and stoppages) of upstream and downstream traffic when traffic volumes are similar. Priority offset is calculated when either of them are higher.

**Sub-area Design Focused on the Fluctuated Traffic Flow**

At the border link between two sub-areas that are controlled different cycle-lengths, the traffic flow pattern becomes a fluctuated flow. The traffic arrival pattern then changes dynamically cycle by cycle, even if traffic demand is flat. The negative impact therefore influences all intersections in the both of sub-areas. Simulation results shows that flow becomes a cause of traffic congestion when arriving traffic increases. This impact had not been described on the previous simulators, and they had assumed that traffic flow from the border link was flat. RSOC was developed to solve this problem, and can simulate the phenomenon of fluctuated traffic flow.

**Simulation of the Fluctuated Traffic Flow**

When fluctuated flow is simulated, it is necessary to simulate the length of time of the lowest common multiple of two cycle-lengths. For example, in a case where sub-area unit A is 120 seconds and B is 100 seconds, time length of simulation is 600 seconds. During that time, the offset of the border link changes cycle by cycle as 0, 20, 40, 60, and 80 seconds, and it reverts to the original offset after 600 seconds. In such cases, the origin of the offset should be considered, as if the original offset is 5 seconds, the following offsets change by the same value (e.g. 25, 45, 65, and 85 seconds.)

According to the results of the pre-simulation, the original offset is not sensitive to the performance index (PI). As such, the simulator gives 0 second as the original offset.
**Fig.5. Expression of fluctuated traffic flow**

**Impact of Fluctuated Traffic Flow**

To verify the impact of fluctuated traffic flow, the difference of delay and stoppages between flat rate traffic flow and fluctuated traffic flow on the border link were simulated. The results are shown in Fig.6 (next page).

Under the condition of flat rate traffic flow, delay and stoppages do not change cycle by cycle, and they can be obtained by simple calculation. An example is shown in Fig.6. In a case where traffic volume is 600 (Vehicles / hour), cycle length is 100 seconds and the time when the signal is green is 50 seconds; the total delay and stoppages are 11,250(Vehicles*Sec. / hour) and 450 (Vehicles / hour) respectively.

On the other hand, when simulating the fluctuated traffic flow, these values change cycle by cycle, and during reversal offset most vehicles are blocked at intersection 2, thus increasing delay. The delay increases 17% and stoppages decrease 2%. The results show that it is important to count in the phenomenon of fluctuated traffic flow when offset and sub-areas are designed for urban streets; there are difficulties in obtaining delay and stoppages by calculation if fluctuated traffic flow are considered.

**Relationship between Traffic Volume and Fluctuated Traffic Flow**

The impact of fluctuated traffic flow increases under high traffic volume. Fig.7 (after the next page) shows the relationship between traffic volume and fluctuated traffic flow. Traffic volume conditions are assumed to range from 500(vehicles*second/hour) to 900(vehicles*second/hour). Assuming that the ratio of green to red is 50%, when traffic volume goes over 800 (vehicles*second/hour), the delay and stoppages increase more because the fluctuated traffic flow makes partial over-saturation during reversal offset, even if the average volume is under-saturated.

This theory can be applied to real traffic flow as follows:

1. Low traffic conditions such as nighttime. In order to minimize the weighting time of vehicles from cross road and pedestrians; each sub-area unit is controlled by suitable cycle-length respectively.
2. High traffic condition such as daytime. In order to prevent traffic congestion; sub-areas are connected and controlled with same cycle-length. (They are then adjusted to the maximum cycle-length in the group.)
Delay and Stop at Intersection-2

<table>
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<th>Flat rate traffic flow</th>
<th>Fluctuated traffic flow simulation</th>
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</thead>
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<tr>
<td>Delay</td>
<td>11,250 (Vehicles*Sec. / hour)</td>
<td>13,110 (Vehicles*Sec. / hour)</td>
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<tr>
<td>Stoppages</td>
<td>450 (Vehicles / hour)</td>
<td>439 (Vehicles / hour)</td>
</tr>
</tbody>
</table>

Traffic volume 600(Vehicle/hour)

Gc=Vol*Red/(Sf - Vol)
25 =600*50/(1800-600)

Delay =(Vol*Red*(Red+Gc)/2)/Cy
11,250=(600*50*(50+25)/2)/100

Stoppages =(Vol*(Red+Gc))/Cy
450 =(600*(50+25))/100

Fig. 6. Impact of fluctuated traffic flow
<table>
<thead>
<tr>
<th>Traffic volume</th>
<th>Index</th>
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<th>Fluctuated traffic flow simulation (B)</th>
<th>B/A</th>
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<td>13,110</td>
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<td></td>
<td>Stoppages</td>
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<td>1.26</td>
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</table>

Unit: Traffic volume (Vehicles / hour)
Delay (Vehicles*Seconds / hour)
Stoppages (Vehicles / hour)

Fig. 7. Relation between traffic volume and impact of fluctuated traffic flow
**Impact of Fluctuated Traffic Flow on the Street**

The impact of fluctuated traffic flow influences the delay and stoppages at all intersections on the downstream sub-area unit. Fig. 8 shows an example of the impact on a street. In the example, the cycle-length of sub-area unit-A is 120 seconds and sub-area unit-B is 100 seconds. The critical intersection in unit-B is given 50 seconds of time with the signal being green and other intersections are given 65 seconds of time with the signal being green. The impact of fluctuated traffic flow is large at border intersections and at the critical intersection. On the other hand, there is less of an impact on the intersections that are downstream from the critical intersection. These results mean that the impact is felt mainly at the critical intersection.

![Diagram of fluctuated traffic flow](image)

**Fig. 8. Absorption of fluctuated traffic flow**
Flow of Sub-area Groupings

As previously mentioned, the aim of sub-area design is to minimize the total delay and stoppages on a main street and cross roads at intersections.

Generally, however, non-critical intersections do not have vehicle detectors at cross roads. In such cases, traffic volumes are estimated according to time spent with the signal being green. Fig.9 shows traffic volume on the main street and cross roads. The traffic volume of cross roads are given by formula 2, and traffic volume of the main street is obtained from detector data.

![Diagram of traffic flow]

- **Main Street: Collected traffic volume**
- **Vehicle detector**
- **Cross Road: Assumed traffic volume by formula 2)**

Fig.9. Absorption of fluctuated traffic flow

**Volume of Cross Road =** Green time/Cycle length * Saturation flow rate * 0.8  \[2\]

There are 4 steps for sub-area design of 2 sub-area units as follows.

1. Offset design of sub-area unit-A (Cycle length 120 seconds)
2. Offset design of sub-area unit-B (Cycle length 100 seconds)
3. Impact estimation at of sub-area unit-A and unit-B (PI-1)
   (Fluctuated traffic Flow simulation)
4. Offset design of sub-area C (Cycle length 120 seconds) and delay and stoppage estimation (PI-2)

PI-1 and PI-2 are compared, and the smaller one is selected. If PI-1 is selected, unit-A and Unit-B are controlled with different cycle lengths.

![Diagram of cycle length]

**Sub-area C (Married)**

Fig.10. Step of Sub-area Groupings
CONCLUSION

Former simulators could not simulate the impact of fluctuated traffic flow. Accordingly traffic flow on border links was assumed as flat rate traffic flow. However, RSOC, which can simulate fluctuated traffic flow, showed that the impact should be considered for offset control and sub-area design.

When we focused on alleviation of traffic congestion at critical intersections, the offset control and sub-area design might contribute less than split control. However, they are effective to decrease delay and stoppages on a street and to improve street safety.

RSOC started the offset control on Ome-Kaido street in Tokyo in April 2007, and average delay time collected by Up-link data from VICS car units was improved 5.7% on the street, and according to simulation results, the ratio vehicles arriving as the signal changes decreased 40%. RSOC has controlled for more than a year, and as such the accident ratio is currently being researched.

REFERENCES


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