Adaptive traffic signal control for the fluctuations of the flow using a genetic algorithm

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Abstract

This paper describes adaptive traffic signal control for the fluctuations of flow using a genetic algorithm (GA). The target of signal control parameters for this study is offset that is difficult to optimize because of its variety of combinations. Offset optimization using GAs has been investigated in previous studies. Most of them however, focused on signal control in a condition where the traffic flow was fixed. In a practical scene, the rate of flow changes as time passes, so that offset-optimization considering these fluctuations of flow is required. As a case study, an urban traffic route in a city of the Chubu region in Japan, with twenty-one signalized intersections, was tested. To perform offset-optimization by a GA, offset values were represented in a chromosome having the same number of genes as the signals. Two different conditions of traffic flow, slow monotonous and rapid increase, were chosen for the simulation. The results show that the offset optimization technique used in this study was a valuable one for efficient signal control.

1 Introduction

The traffic signal control has been recognized as an important means of solving various traffic problems such as traffic congestion. Among the various signal control parameters such as cycle length or green split, offset is one of the most important yet most difficult to optimize.

In a practical traffic scene, offset based on a very simple algorithm has
been used for traffic signal control. However, the offset using the present method is not guaranteed to be an optimum parameter. In addition, it takes enormous time to test all offset patterns because of their variety of combinations. To find an optimal offset, a genetic algorithm (GA) (Goldberg [1]), which is a search/optimization algorithm, is valuable technique.

Offset-optimization using GAs has been investigated in previous studies (Park [2], Goto [3]). However, most of them focused on signal control in a condition where the traffic flow was fixed. In a practical scene, the rate of flow changes as time passes, so that offset-optimization considering the fluctuations of flow is required.

In this study, we investigate adaptive offset optimization by a GA-based program designed to take into account the fluctuations of the traffic flow.

2 Target route

As a target for computer simulation, an urban traffic route, with twenty-one signalized intersections in a city of the Chubu region in Japan, was selected. Figure 1 shows the schematic diagram of the target route. The route is 8,305 meters long, and consists of twenty-one signal intersections shown as numbered circles in the Figure. The distance between the 19th and the 20th signals is short, so they are controlled together.
In this study, the parameter of offset is optimized for traffic signal control. The other parameters, cycle length and green split, are fixed. The cycle length for all signals is 130 seconds, and the green splits and the link length between signals are displayed in Table 1.

3 Genetic algorithm-based program

3.1 Concept

In order to find a near-optimal offset, we make a genetic algorithm-based program. The genetic algorithm-based program consists of two main components: a GA optimizer and a traffic simulator. The concept for our GA-based program is shown in Figure 2. The GA optimizer produces randomly a certain number of individuals (offset) as the initial generation. Each individual offset is evaluated by the traffic simulator which then returns a fitness value (average travel time) to the GA optimizer. The GA optimizer will evolve the next generation based on fitness values obtained from the traffic simulator. Evolution is continued until the specified number of generation is achieved.

3.2 Genetic algorithm optimizer

To perform offset-optimization, offset values have to be coded as a gene value of a chromosome. The basics of genetic algorithms use binary strings to represent solutions. In this study, integers from 0 to 99 are used as a gene value to code an offset value that is a percentage of a cycle length. Each chromosome has the same gene value for the offset values of the 19th and the 20th signals for the reason described in the section of the target route. An example of a chromosome representing an offset is shown below:


Table 2 shows the parameters for the GA optimizer. The size of chromosome is the number of signals in the route. A pair of mates is picked from
Table 2: Parameters for the GA optimizer.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of individuals</td>
<td>30</td>
</tr>
<tr>
<td>Size of chromosome</td>
<td>21</td>
</tr>
<tr>
<td>Crossover rate</td>
<td>0.8</td>
</tr>
<tr>
<td>Mutation rate</td>
<td>0.5</td>
</tr>
<tr>
<td>Number of generation</td>
<td>250</td>
</tr>
</tbody>
</table>

Table 3: Parameters for a vehicle.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration [m/s²]</td>
<td>1.4</td>
</tr>
<tr>
<td>Deceleration [m/s²]</td>
<td>1.7</td>
</tr>
<tr>
<td>Maximum speed [km/h]</td>
<td>60</td>
</tr>
</tbody>
</table>

the population by using the roulette wheel selection, and crossover is performed with two-point crossover operation. The number of generations is set at 250 because this is enough for the GA optimizer to find the individual having the best fitness value in an optimization trial.

In this research, we are investigating adaptive offset control for fluctuations of traffic flow. The GA-based program will start when the traffic flow level changes to a different one. Therefore, the population of individuals (offset) at the initial generation contains the optimal offset for the previous traffic flow level. This prevents the GA optimizer from producing more recessive offset than for the previous traffic level. In addition, this suppresses dispersion of the best solution for each optimization trial.

3.3 Traffic simulator

The traffic simulator is a part of the GA-based program for providing fitness values. In the simulator, vehicles are generated at the 1st intersection for an up flow and the 21st intersection for a down. Losses of vehicles turning left or right are not taken into account in this simulator. A traffic flow level can be set as the degree of saturation for an up and down flow separately. The parameters for a vehicle are shown in Table 3.

The fitness value provided from the simulator is a reciprocal number of average travel time, the average of travel time for all vehicles. The travel time for each vehicle includes the number of stops × 30 seconds.
Table 4: Average travel time for five different flow levels.

<table>
<thead>
<tr>
<th></th>
<th>U10D5</th>
<th>U15D5</th>
<th>U20D5</th>
<th>U25D5</th>
<th>U30D5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average [s]</td>
<td>548.2</td>
<td>547.3</td>
<td>554.8</td>
<td>556.2</td>
<td>575.5</td>
</tr>
<tr>
<td>Previous [s]</td>
<td>553.4</td>
<td>547.9</td>
<td>563.8</td>
<td>566.2</td>
<td>601.7</td>
</tr>
</tbody>
</table>

4 Adaptive offset control

To evaluate adaptive offset control for fluctuations of traffic flow, two different conditions of flow were tested. These were slow monotonous, and rapid increase in flows.

4.1 Slow monotonous increase in flows

4.1.1 Offset optimization

For the first condition of a flow, five different flow levels were selected. The degree of saturation for a down flow was fixed to 5% for all flow levels. The degree of saturation for an up flow increases from 10% to 30% in 5% stages. Thus, the five different flow levels are U10D5(up 10%, down 5%), U15D5, U20D5, U25D5 and U30D5.

Ten optimization trials by the GA-based program were carried out for each flow level in order to find the best offset. To perform optimization for each flow level, the population of individuals at the initial generation contained the best solution of the previous flow level. In the case of U10D5, the previous flow level was U5D5. The results of optimization for five flow levels are displayed in Table 4. 'Average' means the average of average travel times (ATTs) for ten trials. 'Previous' indicates the ATT obtained by using the best offset for the previous flow level. For example, Previous 563.8 [s] for the flow level U20D5 is the ATT under the condition of U20D5 by using the best offset for the previous flow level U15D5. The results show that Average and difference between Average and Previous increase with the rise of traffic flow levels.

4.1.2 Evaluation

To evaluate the offset control using the offsets optimized the GA-based program, the effect of changing or unchanging offset with the rise of a traffic flow was examined by a traffic simulator. The effect is measured by the transition of 'moving average travel time' (MATT), which is the average of travel times for vehicles that started in the past six cycles (780 [s]).

Figure 3 shows the typical transitions of MATT for four different conditions of flows. The first flow level lasts for fifteen cycles, then the second flow level continues for thirty cycles (e.g. U10D5 → U15D5). In the case of changing offset, the new offset for the second flow is set with the rise of a traffic flow. In the low flow levels, the loss of MATT occurs only for
changing offset (Figure 3(a)), and as the flow level becomes higher, the gain of MATT increases (Figure 3(b)-3(d)).

4.2 Rapid increase in flows

4.2.1 Offset optimization

For the second condition of a flow, rapid increase in flows was tested. A traffic flow level rises rapidly from U5D5 to U25D5. Because a loss can be expected with the change of an offset, reduction of the loss should be considered. To find an optimal offset without change of the loss, a distance between new and previous offsets was incorporated into a fitness value provided from the traffic simulator. The distance between the offsets can be a parameter to represent ease of changing offset. The distance between the
Table 5: Typical results for different $c_d$ values.

<table>
<thead>
<tr>
<th>$c_d$</th>
<th>0.0</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATT</td>
<td>559.5</td>
<td>562.0</td>
<td>571.5</td>
<td>578.5</td>
</tr>
<tr>
<td>$D_{offsets}$</td>
<td>100.51</td>
<td>13.45</td>
<td>8.66</td>
<td>6.86</td>
</tr>
</tbody>
</table>

The fitness value for the GA-based program is now given by the following equation:

$$Fitness = \frac{1}{ATT + c_d \times D_{offsets}}$$

where

$$D_{offsets} = \sqrt{\sum (o_{i_{\text{Prev}}}^{\text{Prev}} - o_{i_{\text{New}}}^{\text{New}})^2}$$

4.2.2 Evaluation

The effect of changing or unchanging offset was examined with the optimized offsets providing the results in Table 5. The procedure for evaluation was the same as for slow monotonous increase in flows described in 4.1.2. Figure 4 shows the transition of MATT for the offsets with different $D_{offsets}$. Although the MATT for changing offset grows slightly, the offset with small $D_{offsets}$ values gives the more efficient control.
5 Discussion and Conclusions

In a practical scene of traffic flow conditions, the rate of flow changes as time passes. Therefore, it is important that an optimized offset considering these fluctuations of flow can be found within a useful time. In this study, we have investigated adaptive offset control for two different conditions of flows, slow monotonous, and rapid increase. The results presented in this article indicate that offset-optimization by a genetic algorithm (GA) gives valuable solutions for efficient offset changing.

In a condition where the traffic flow increased slowly, the optimized offsets found by the GA for the new flow gave shorter average travel time than did offsets for the previous flow, without serious loss occurring with offset changing. However, in the low flow level where the average travel time for offset changing was greatly close to one for offset unchanging, only the loss with offset changing was observed. This suggests that in the low
flow level, imprudent change of offset should be avoided.

On the other hand in a condition where the traffic flow increased rapidly, although the optimized offsets found by the GA gave good average travel time, the loss occurring with offset changing was serious. This problem could be solved by incorporating a parameter of the distance between new and previous offsets into a fitness value for the GA. The offset with an appropriate small distance value gave efficient control without serious loss.

The results in this study are for the target route with twenty-one signalized intersections under the typical conditions of traffic flow. More research should be done to investigate other routes having different networks and various conditions of traffic flow.

References

