Optimization of signal control parameters in grid street networks

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Abstract

In this paper, we propose a GA-based method for optimizing three signal control parameters consisting of cycle length, green split and offset in area traffic control of grid street networks to minimize the weighted sum of delay time and stop percentage. Each gene for offset and green split is expressed by three bits, and that for cycle length by six bits. Each individual (a candidate for solution) is evaluated using CORSIM simulator in TSIS traffic integration software. The results of simulation experiments for regular and irregular grid street networks show that optimal solutions obtained by the proposed method are better than approximated ones by a linear model in traffic signal control.

1 Introduction

At present, the number of vehicles is increasing every day in the world. A rapid increase of it generates serious problems such as traffic accidents and congestion. It is considered that appropriate traffic signal control facilitates traffic safety and smooth traffic flow. There are three types of traffic signal control: independent control handling a single signal, coordinated control in which two or more signals on an arterial road work in association with each other, and area traffic control which is a two dimensional version of the coordinated control.

The objective of this study is to improve the performance of the area traffic control. We focus attention on common cycle length, splits, and offsets among the parameters of the area traffic control. The determination of control parameters is considered as a combinatorial problem. If the number of intersections increases, the number of combinations becomes huge. So, any enumerative method has fundamental limitations in a broad search space. Abu-Levdeh and Benekohal [1] examined several genetic algorithms (GAs) applied to the optimization of traffic control parameters. In this paper, we adopt a GA as a heuristic method, and we propose a GA-based method for optimizing control parameters in the area traffic control of grid street networks.

In preceding study, we confirmed the effectiveness of a GA-based method when optimizing traffic signal control parameters of the common cycle length and offsets [2]. In this study, control parameters to be optimized include the split, adding to the common cycle length and offsets, and we deal with green time of main street as the split.

2 Area traffic control

Coordinated control is an approach to manipulating two or more signals on an arterial road in association with each other. Area traffic control (ATC) is a method by which a traffic signal group placed on a street network spreading two-dimensionally is controlled concentratedly. Common cycle length, splits, and offsets are major parameters of ATC. Common cycle length is a total time to complete one cycle in common with all signals. Split is the ratio of effective green time to common cycle length. Offset is the delay from the start of the green time of a reference signal to that of the signal concerned. According to a linear model [3], if round trip time T of a link with length D in overall speed V is multiple integer of cycle length C, that is,

$$T = \frac{2D}{V} = nC, \tag{1}$$

vehicle delay time can be minimal, where a link is a road interval between neighboring signals. In the method adopted by present Japan, a region to be controlled by ATC is manually divided into several blocks based on the amount of traffic flow for every traffic situation considered. The control parameters are decided in every block and they are integrated. For a traffic situation, a set of control parameters corresponding with the situation is chosen from among the several sets of them obtained in advance and applied. However, because the frequent renewal of the several sets of them is difficult in this system, the system can not deal with unexpected traffic situations immediately. And, it is difficult to automate such work. So, we aim at optimizing ATC parameters of all signals in the region of interest by a heuristic method. In this study, we limit street networks to grid ones as the simplest case, and propose an optimization method of the control parameters.

3 GA approach to ATC optimization

In the GA loop, we have to evaluate each individual having a set of control parameters and obtain a fitness value for the individual. For the evaluation we use a micro traffic simulator CORSIM which is a part of T-SIS traffic integration software. Evaluating the results of the simulations, we use the output data of COSIM; Vt (Vehicle Trips : the number of vehicles that have been discharged from the link), Tt (Total Time : total time on the link for all vehicles), Dt (Delay Time : the time that vehicles are delayed if they cannot travel at the free flow speed), Sp (Stop Percentage : the ratio of the number of vehicles that have stopped at least once on the link to the total link trips) where the link means unidirectional one. We calculate a cost index (CI) as follow:

$$CI = \sum_{n=1}^{N} \left\{ \frac{\mathrm{Dt}_n}{\mathrm{Tt}_n} \times \frac{\mathrm{Vt}_n}{\mathrm{Td}} + K \times \mathrm{Sp}_n \times \frac{\mathrm{Vt}_n}{\mathrm{Td}} \right\}, \qquad (2)$$

where K is the weight coefficient of Sp, Td is the simulation time, and N is the number of unidirectional links.

Because the smaller the CI the better the evaluation, fitness F in the GA is defined by the inverse number of CI as

$$F = \frac{1}{CI}. \qquad (3)$$

Grid street networks used here consist of three minor streets and three major streets, and nine intersections are numbered 1 to 9 as shown in Figure 1. A chromosome for the GA consists of 57 bits and is divided into three parts as Figure 1.

The right-most 6-bit string of the chromosome expressed the binary value I_N corresponding to the common cycle length C such as

$$C = C_{min} + \frac{C_{max} - C_{min}}{2^6 - 1} I_N \qquad (4)$$

where C_{min} and C_{max} are the minimal and maximal cycle lengths of 40 and 150 seconds respectively. In the middle part, each 3-bit string expresses each green time of nine intersections. In the left-most part, each 3-bit string expresses each offset of eight intersections, number 2 to 9, while intersection number 1 is considered as a reference one and its offset is fixed to 0. Each 3-bit string of the left-most part represents integer 0 to 7. Actual offset corresponding to it is taken as a center value of one of equally divided 8 intervals between 0 and a common cycle length C obtained from the right-most part as shown in Figure 2. Each actual green time is also calculated from each 3-bit string of the middle part by the same manner.

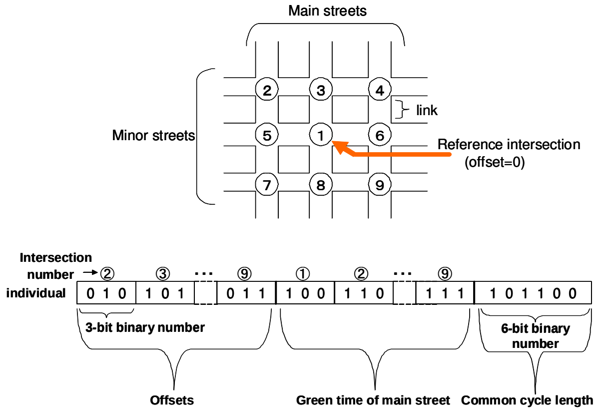

Figure 1: Grid network and coding method of control parameters.

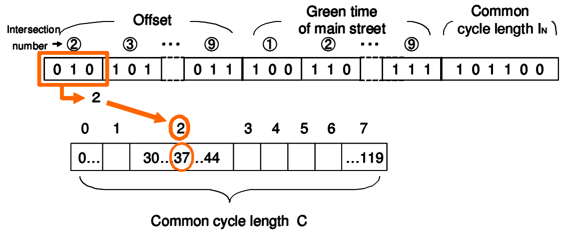

Figure 2: Calculating method of offsets and green time of main streets.

The reason why we use the 3-bit string for the offset and green time is because it enhances the calculation efficiency of the GA. But it decreases the resolution of solution. So, we apply a cease-to-fine approach to raise the resolution as follows. In the first stage of the GA, the interval between 0 and C is coarsely divided into 8 segments, each offset and green time is represented by the segment number 0 to 7 which corresponds to the 3-bit binary number as Figure 2. In the second stage, for each offset and green time, the interval is diminished by one quarter, its center is set to the center of the segment obtained in first stage, and the same procedure as the first stage is carried out. The third stage is also performed as same as the second one. Whereas, the common cycle length C is optimized in the first stage, and it is fixed in the second and third ones.

4 Results of simulation experiments

4.1 Experiment 1 : Regular grid network

First, we compare the solution of a linear model with that of the proposed method under the situation where the actual traffic condition is simplified. Traffic and signal conditions of the simulator CORSIM are set as follows.

- free flow speed : 27[ml/h]
- traffic flow : (main street) 0.35[vehicles/s]
  (minor street) 0.20[vehicles/s]
- right and left turn : no turn
- yellow time : 3[s]
- all red time : 2[s]

The street network is made to be the regular grid one with 3 columns of main streets and 3 lines of minor ones and having 9 intersections and 24 unidirectional links (12 bidirectional links) of equal length D = 1000[ft]. The data for evaluation are obtained from 12 routes connected to 12 source and sink nodes, adding to 12 bidirectional links mentioned above.

The parameters of the GA are set as follows.

- Initial population at the first stage : 49 individuals are generated randomly and the rest one individual has a chromosome calculated from parameters based on the linear model.
- Initial population at the second and third stages : All individuals are generated randomly.
- Genetic rules : elite, roulette strategy, one-point crossover, and mutation.

In the linear model parameters, the common cycle length is calculated according to the equation (1). Each offset is calculated based on the travel time of the link at free flow speed. Each green time is calculated based on the proportional division of the common cycle length according to the traffic volumes of main and minor streets.

As experimental results, the upper line of Table 1 shows a set of signal control parameters and the fitness value obtained by the proposed method in the regular grid network. Lower line shows the values obtained by the linear model. Offsets and green times are shown like matrix form corresponding to the intersection 1 to 9. Figure 3 is a graphical representation of the offset part in Table 1. One lap of the circle means one cycle of signal. Figure 4 is a graphical representation of the green time part in Table 1. One lap of the circle also means one cycle of signal as same as Figure 3.

4.2 Experiment 2：Irregular grid network

Next, we examine the linear model and the proposed method under a more actual situation than the above. That is, the street network used here is made to be the irregular grid one with 3 columns of main roads, 3 lines of minor ones, and 12 bidirectional links of unequal length as shown in Figure 5. When calculating the signal control parameters based on the linear model, we regard the irregular grid network as a regular grid one with 12 equal-length links whose lengths are equal to the avarage length of all links of the irregular grid one. Their results are shown in Table 2, Figure 6, and 7 in the same manner as **4.1**.

Table 1: Result of experiment 1 (regular grid network).

	cycle (s)	offset (s)	green time of main street(s)	fitness
best solution	57	0 0 26 56 31 30 3 27 0	34 28 35 32 29 29 0 25 0	0.0172
solution based on linear model	50	0 0 25 0 25 25 0 25 0	25 25 25 25 25 25 25 25 25	0.0139

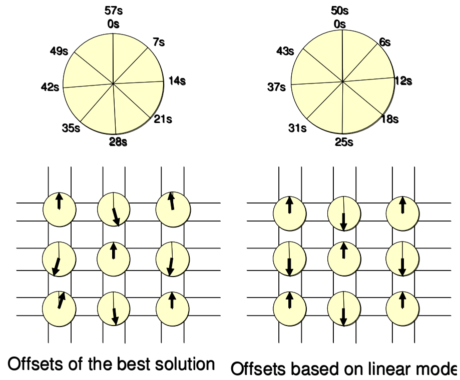

Figure 3: Graphical pie chart representation of offset in Table 1.

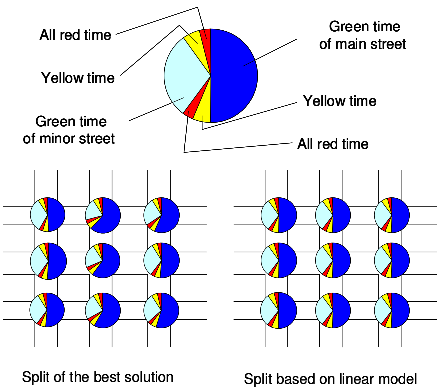

Figure 4: Graphical pie chart representation of green time, yellow time and all red time calculated from Table 1.

Table 2: Result of experiment 2 (irregular grid network).

	cycle (s)	offsets (s)	green time of main street(s)	fitness
best solution	66	0 1 30 4 28 31 11 38 41	33 31 40 37 39 44 38 41 36	0.0128
solution based on linear model	61	0 0 27 0 27 27 0 27 0	32 32 32 32 32 32 32 32 32	0.0114

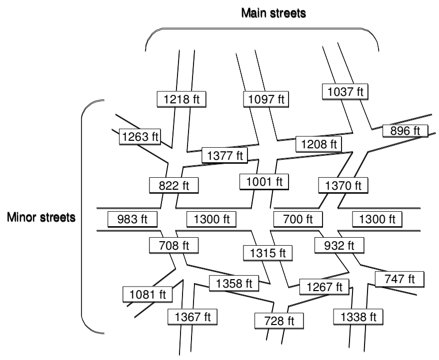

Figure 5: Link lengths of irregular grid network in experiment 2.

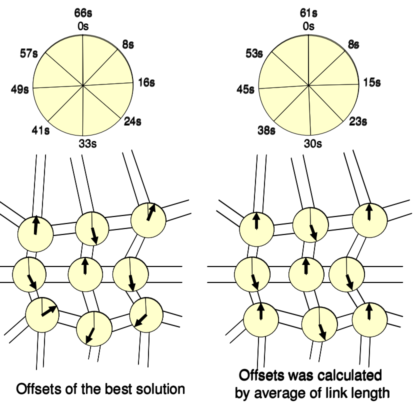

Figure 6: Graphical pie chart representation of offset in Table 2.

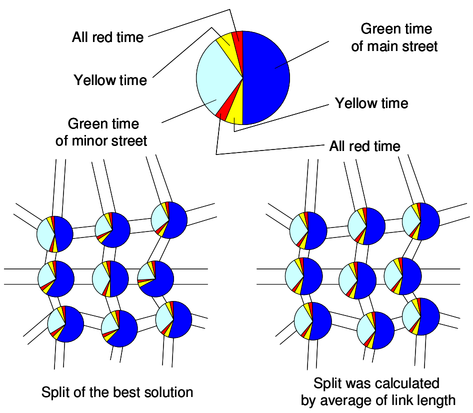

Figure 7: Graphical pie chart representation of green time, yellow time and all red time calculated from Table 2.

5 Discussion

5.1 Experiment 1：Regular grid network

In the comparison of the proposed method with the linear model, Table 1 and Figure 3 to 4 show the displacement of each value of signal control parameters. Since the fitness value by the proposed method is higher than the linear model, the fine adjustment of control parameter values can be realized by the proposed method.

5.2 Experiment 2：Irregular grid network

In the comparison of the proposed method with the linear model, Table 2 and Figure 6 to 7 show the displacement of each value of signal control parameters. Since the fitness value by the proposed method is higher than the linear model, the fine adjustment of control parameter values also can be realized by the proposed method in the irregular grid network.

In the offset of the lower right intersection number 9 in Figure 6, there is large difference between the value by the proposed method and that by the linear model. The offset value by the linear model is calculated based on the regular grid network whose link lengths are equal to the average link length of the irregular ones. So, in an intersection connecting to the link whose length differs widely from the average, the difference of the offset values is also large.

6 Conclusion

In this paper, we propose an optimization method for common cycle length, splits and offsets of signal control parameters in area traffic control of a grid street network using a GA. The results of simulation experiments for regular and irregular grid street networks show that the optimal solutions obtained by the proposed method are better than approximated ones by a linear model in traffic signal control. As future works, the proposed method should be examined under more realistic conditions such as making traffic volume larger or including right and left turns of vehicles. The reduction of execution time is needed for practical use.

References

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[3] Japan Society of Traffic Engineers et al., Manual on Traffic Signal Control, Japan Society of Traffic Engineers, 1994 (in Japanese).