Traffic Signal Control of Multi-Forked Road

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***Abstract*:** The traffic jam has become more serious at the multi-forked road intersection, and the conventional pre-timed control is less efficiencies to the congestion problem. In this paper, the new traffic signal control system for multi-forked road is proposed. Firstly, the cellular automaton (CA) model is used to develop a traffic simulator for multi-forked road. Next, the stochastic model of traffic jam is built up. In addition, new traffic signal control algorithm is designed using the optimization technique, Genetic Algorithm (GA). Finally, the effectiveness of the proposed method is shown using the actual traffic data with traffic simulator.

***Keywords*:** Traffic signal control, Multi-Forked, Bayesian Network, Cellular automaton, Urban micro traffic simulator, Genetic algorithm

I. INTRODUTION

In recent years, the traffic congestion has become serious problem with the exponential grown in vehicles. In the urban area, the road networks are not easy to be extended. In this case, the traffic signal control is considered as an effective way to solve the problem. The traffic signal control can be divided into two classes. One is the offline (pre-timed) control, the other is online (adaptive) control. In the pre-timed traffic signal control, Webster's formula is used to calculate green splits and cycle lengths offline using the historical traffic data of road networks. The pre-timed traffic signal control cannot handle any variation of traffic flows. On the other hand, the adaptive traffic signal control can overcome this limitation and this method can adjust the traffic signals online with changing traffic flows.

The various intelligence techniques such as fuzzy concept, reinforcement learning agents, and neural networks [1-3] are used to implement the adaptive traffic signal control. However, as the limitation of these methods, the green time and/or the cycle length are included as the control target. The signal of the right turn exclusive is not included. And then, the road networks were not concerned multi-forked road intersection. Generally, the traffic signal timing of multi-forked road intersections is more complicated than crossroad intersections or t junction intersection. The inappropriate traffic signals timing cause the congestion of a part of the roads at multi-forked road intersection.

In this paper, the stochastic forecasting model [4] and Genetic algorithm (GA) is used to design a real time traffic signal control system for multi-forked road. Firstly, the probabilistic distributions of standing vehicles of roads are predicted using the stochastic forecasting model, and then, GA is used to calculate optimal traffic signal to minimize the probability of the traffic jam. An urban micro traffic simulator is developed by using cellular automaton (CA) model. Through the observation of vehicle movements of traffic simulator, the parameters of the GA are determined.

II. URBEN TRAFFIC SIMULATOR

The micro traffic simulator can model the movement of individual vehicles on road network. CA is usually faster than any other traffic micro simulators, the computational requirements are rather low with respect to both storage and computation time, making it possible to simulate large traffic networks on personal computers [5].

The CA traffic movements are based on the SchCh model (highway traffic model) [6]. The rules of the vehicle movements on the road network are shown as follows.

1) Input to cell: according to comparison of a random number (from 0 to1) with set value, a vehicle will be generated and the direction of travel on the intersection

will be determined.

2) Speed: the vehicle can accelerate up to maximum speed (Maximum speed = move 2 cell; 1cell=7*m*/1 step [1sec]), when there is no obstacle. According to conditions of the road the speed can be changed randomly by probability.

3) Intersection: when traffic signal is green, the vehicle will be allowed to cross the intersection according to direction of travel, and the direction of the travel on next intersection will be reset.

4) Multi lanes: in multi lanes road, a vehicle can move to parallel lanes. If the direction of travel is right turn, the vehicle moves to the right turn exclusive lane.

By above rules, we can move the vehicles on the road network, and the procedure of the simulator is shown in Fig.1.

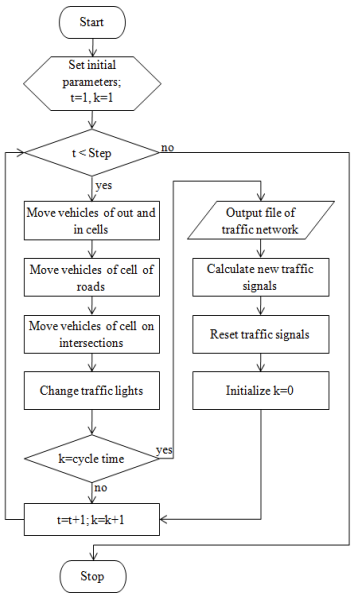

Fig.1. flowchart of simulator

III. STOCHASTIC FOREACASTING MODEL

In previously published paper [4] we described a stochastic forecasting model of traffic jam at crossroads. The stochastic forecasting model is used to predict probabilistic distributions of standing vehicles of multi-forked road.

A multi-forked road is considered as an example shown in Fig.2. The random variables of inflows I_k, outflows O_k, standing vehicles S_k on the road 1 have relationship as following:

$$S_k = S_{k-1} + I_k - O_k. \quad (1)$$

And then, a Bayesian network model is built up using this relationship, and the random variables of the inflows and the outflows of each direction, and the standing vehicles are represented as the nodes.

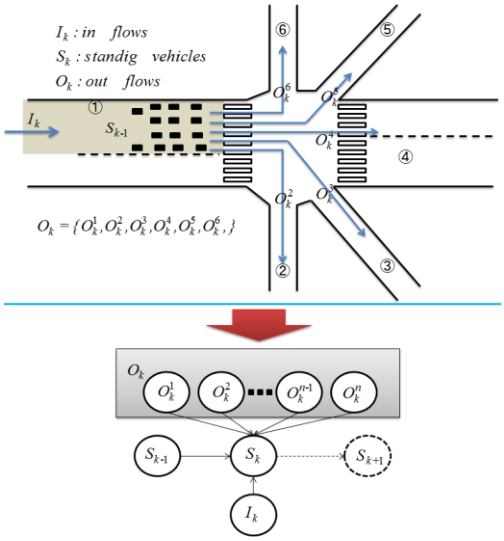

Fig.2. Multi-forked road and BN model

The probabilistic distribution of the standing vehicles at *k th* cycle is obtained by summing over all values of the other variables as following,

$$P(S_k) = \sum_{S_{k-1} I_k O_k} \sum \sum P(S_k, S_{k-1}, I_k, O_k)$$

$$O_k = \{O_k^1, O_k^2 \ldots O_k^{n-1}, O_k^n\} \quad (2)$$

$$n : number\ of\ the\ derection$$

With the chain rule, the joint probabilistic distribution is represented as the product of the conditional probability. And then, according to the d-separation, equation (2) can be represented as

$$P(S_k) = \sum_{S_{k-1} I_k O_k} \sum \sum P(S_{k-1}) \cdot P(I_k) \cdot P(O_k) \quad (3)$$

According to equation (3), the probabilistic distribution of the standing vehicles is predicted. Using this model, the probabilistic distribution of standing vehicles of each road can be predicted.

IV. TRAFFIC SIGNAL CONTROL BY GENETIC ALGORITHM

The objective of the proposed system is to reduce the traffic queue of the congested roads and to maintain the traffic queue of the other roads in a steady range. At first, the stochastic forecasting model is applied to predict the probabilistic distribution of the congested roads. Then, the optimal traffic signal within an adjustable range will be searched according to minimization for the probability of the standing vehicles over a set value S_{max}. (If the standing vehicle is bigger than S_{max}, the road is considered as a traffic jam). In the search process, GA is utilized.

1) Fitness function

For this optimization the fitness function is defined as following;

$$MIN \quad F = \sum_{i=1}^{i=n} w_i \cdot \left(\sum_{S=S_{max}}^{S=\infty} P^i(S_k) \right)$$

$$i = number\ of\ the\ roads$$
$$S = number\ of\ the\ standing\ vehicles \qquad (4)$$
$$S_{max} = set\ value$$
$$w_i = weight\ of\ the\ function$$

and, the $P^i(S_k)$ can be obtained from equation (2). On the other hand, the probabilistic distribution of the inflows and the outflows will be changed by different traffic signal. According to the characteristics of the traffic flows, an estimating equation is defined as following;

$$P(f_k) = P((f_k / t_{old}) \cdot t_{new})$$
$$f_k : the\ traffic\ flows\ of\ k\text{-}th\ cycle$$
$$t_{old} : the\ time\ of\ signals\ of\ k\text{-}th\ cycle \qquad (5)$$
$$t_{new} : new\ time\ of\ signals$$

By equation (4) and (5), the fitness value can be calculated.

2) Chromosome encoding

A chromosome is defined as an example shown in Fig.3. In this multi-forked intersection, the traffic signal can be divided into six parts. In the chromosome, each traffic signal is represented using different color, and consisted of some genes. The meaning of each number is time [sec.].

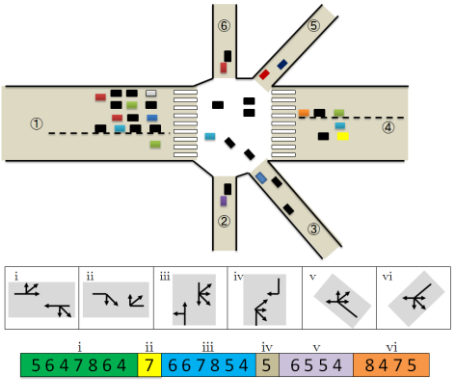

Fig.3. Chromosome encoding

3) Initial population

Chromosomes as an initial population will be generated randomly within adjustable range of the traffic signal.

4) Selection

A truncation and elitism combination is used in this strategy. First, the best chromosome will be cloned to the next generation. The other chromosomes of next generation will be created by crossing 50% of the population.

5) Crossover

Two chromosomes are randomly chosen as a pair of parent chromosome. And then, at four random points, the gene will be interchanged.

6) Mutation

According to a mutation probability, an individual is chosen to be mutated and the changing point will be randomly chosen.

V. SIMULATION

To prove the effectiveness of the proposed system, a simulation was carried out based on the actual data at Fukuoka-city of Japan with the micro traffic simulator. The multi-forked road intersection is shown in Fig.4. In this intersection, the traffic signals of the direction 1 and 4 are same, and direction 2 and 6 are same. Therefore, the congested roads 2, 4 and roads 3, 5 are selected to predict the probabilistic distribution of the standing vehicles, and to optimize the traffic signals using GA.

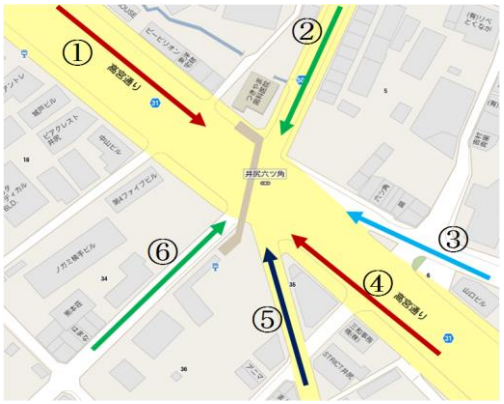

Fig.4. Multi-forked road intersection

The table 1 presents parameters of the fitness function. The parameters are empirical value by simulation with the simulator. In the GA, the number of generations set to 30; population size set to 31; and the mutation probability is 0.04. During the calculating time of GA, the traffic signal will be updated at every 5cycle (15 minutes).

Table 1. Parameters of fitness function

	Road 2	Road 3	Road 4	Road 5
S_{max}	35	35	110	35
w_i	1	0.7	0.9	0.5

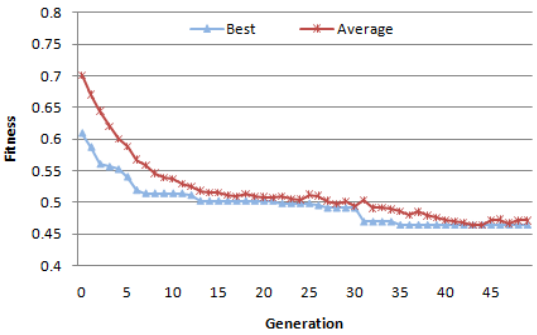

Fig.5 Progress of the fitness function

The progress of the fitness function shows the minimization by the GA illustrated in Fig.5. The traffic signals by the proposed method are shown in Fig.6. The traffic signals of the pre-timed are fixed, but the traffic signals by the new method are updated with the changing traffic flows.

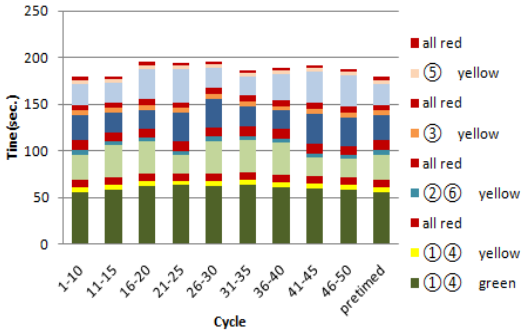

Fig.6 New traffic signals

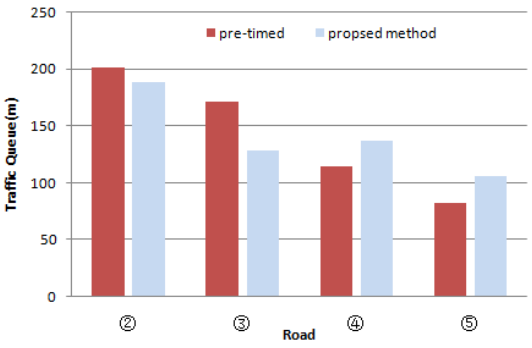

Fig.7 Traffic queue of the roads

Fig.7 represents the traffic queue of the each road. In the congested roads 2 and 3, the traffic queue is reduced by the proposed method. In the road 2 and 3, the average of traffic queue is decreased by 13m and 40 m, respectively. On the other hand, for the road 4 and 5, the traffic queue is maintained in a steady range.

By the proposed method, the average delay time is decreased compare with by the pre-timed, and the results are shown in Fig.8.

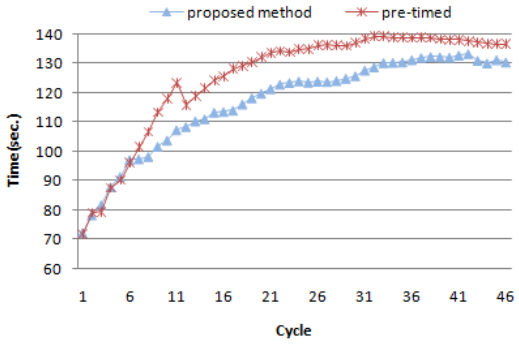

Fig.8 Average delay time of each cycle

The total number of the passing vehicles from the intersection is increased from 8,242[cars] to 8,586[cars].

VI. CONCLUSIONS

In this paper, the optimization of the traffic signal timing by GA and the simulator based on the stochastic forecasting model were proposed. Through the simulation with the multi-forked road intersection of an urban area, the effectiveness of the proposed method is shown.

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