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Improvement of genetic algorithm and its application in optimal control of intersections

Nan Ji[1]*, Jie Zhang[2], Yingna Zhao[1]

[1]Hebei United University, Tangshan, Hebei Province, (CHINA)

[2]Tangshan Tanggang Expressway Management Office, Tangshan, (CHINA)

ABSTRACT

In this paper, average vehicle delay time is used as objective function to evaluate the performance of intersection signal control. Through the evolution process of dynamic adjustment in the population fitness the value of crossover probability and mutation probability of the maximum individual, then realize the improvement of genetic algorithm, effectively avoid the premature phenomenon. The simulation experiments show that the method is an effective and reliable method.

KEYWORDS

Improvement of genetic algorithm;
Delay time;
Simulation analysis;
Traffic signals.

INTRODUCTION

Genetic algorithms were formally introduced in the United States in the 1970s by John Holland at University of Michigan. The continuing performance improvements of computational systems has made them attractive for some types of optimization. It can solve every optimisation problem which can be described with the chromosome encoding, and it also can solve problems with multiple solutions. In a genetic algorithm, a population of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem is evolved toward better solutions. Each candidate solution has a set of properties (its chromosomes or genotype) which can be mutated and altered; traditionally, solutions are represented in binary as strings of 0s and 1s, but other encodings are also possible.

The evolution usually starts from a population of randomly generated individuals, and is an iterative process, with the population in each iteration called a generation. In each generation, the fitness of every individual in the population is evaluated; the fitness is usually the value of the objective function in the optimization problem being solved. The more fit individuals are stochastically selected from the current population, and each individual's genome is modified (recombined and possibly randomly mutated) to form a new generation. The new generation of candidate solutions is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population.

Genetic algorithms can be found its application in bioinformatics, phylogenetics, computational science, engineering, economics, chemistry, manufacturing, mathematics, physics and other fields. With the development of the industry, in various cities, chronic traffic jam happens and traffic congestions lose billions hours and money, In order to reduce these losses, it is required to create an efficient method to resolve traffic congestion and reduce the delay time. In this article, we will establish four phase intersection model, the average delay time to be shortest as objective function, using the improved genetic algorithm, and then find the intersection traffic signal optimization solutions.

THE FOUR PHASE INTERSECTION GEOMETRY MODEL

A typical four phase model of the intersection is shown in Figure 1. Phase distribution is shown in Figure 2. There are four approaches to the intersection, in which each approach has three traffic (turn left, go straight and turn right). Implementation phase controlling can eliminate straight left traffic flow and traffic conflict, improve the driving safety.

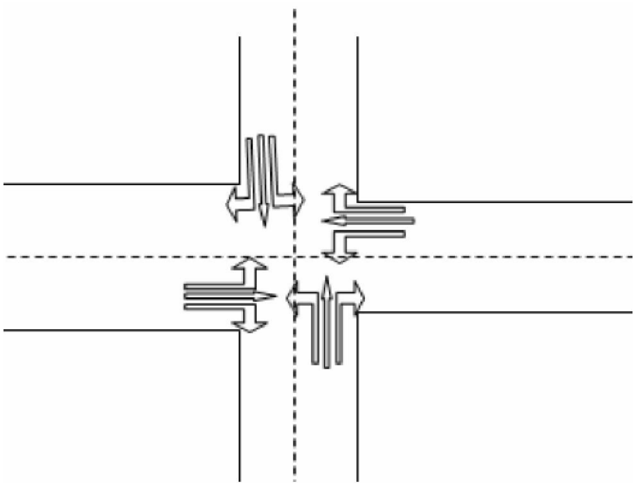

Figure 1 : The four phase intersection geometry model

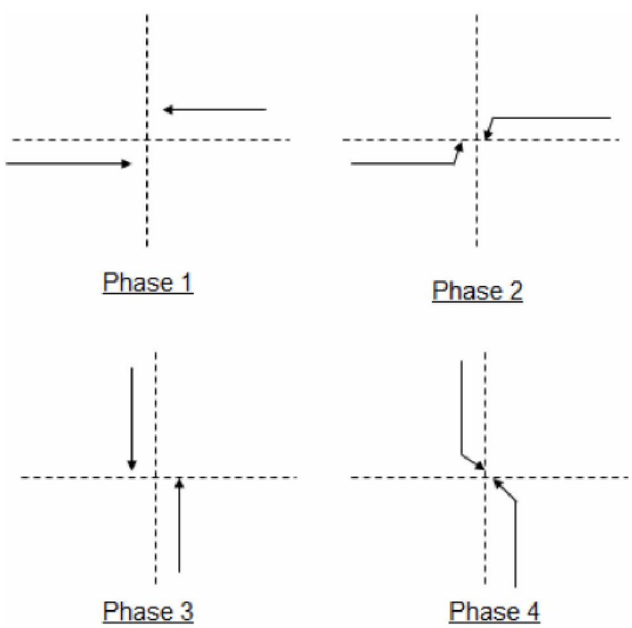

Figure 2 : Intersection phase distribution

Model assumptions

Some detailed factors complicates the setting of the model, so to simples and generalize the model, an ideal traffic condition is given, in which only the main factors are considered.

- ◇ four phase intersection model is chosen as an example
- ◇ the standard vehicle type (small vehicle) as the basic measuring unit while measuring the passing volume
- ◇ only vehicles are considered, pedestrians and non-vehicles can go through the overpass or underground passage

In this paper, four phase intersection geometry model is mainly researched, and later research can be extended.

ESTABLISH AND ANALYSIS OF AVERAGE DELAY MODEL

Delays can theoretically be calculated, according to the intersection signal intersection saturation flow rate of each flow, traffic flow and traffic flow per share distribution of green time. Using Webster delay calculation formula, the average delay of every vehicle in the intersection as following formula (1).

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} \quad (1)$$

Where,

d = Average delay per vehicle on the particular approach of the intersection(s); c = Cycle length (s); q = the arriving rate (veh/s); λ = Proportion of the cycle which is effectively green for the phase under consideration; x = Degree of saturation (volume to capacity ratio)

In formula (1), the first term represents the average delay to the vehicles assuming uniform arrivals, which is called Uniform delay.

$$d_u = \frac{c(1-\lambda)^2}{2(1-\lambda x)} \quad (2)$$

The second term represents the additional delay due to the randomness of vehicle arrivals, which is called Random delay.

$$d_r = \frac{x^2}{2q(1-x)} \quad (3)$$

This additional delay is attributed to the probability that sudden surges in vehicle arrivals may cause the temporary over-saturation of the signal operation. The third term is a semi-empirical adjustment term that was introduced in the model to account for specific field conditions. When the saturation is low, the proportion taken by the second part and the third is small, but with the increase of the saturation, their influence on the formula's result increases. The model is applicable for isolated intersections and the permissible upper limit of traffic flow for the model to provide satisfactory results is slightly less than full saturation.

Based on the real-time collection of traffic flow data, in order to import road intersection each phase at least as the goal, the total delay time target optimization function is established.

$$D = \sum_{j=1}^{2}\sum_{i=1}^{4}\{q_{ij}[\frac{c(1-\lambda_i)^2}{2(1-\lambda_i x_{ij}} + \frac{x_{ij}{}^2}{2q_{ij}(1-x_{ij})}]\} \quad (4)$$

Where,

q_{ij} = the traffic in the i-th phase of the j-th approach (pch/h); x_{ij} = degree of saturation in the i-th phase of the j-th approach; q = the arriving rate (veh/s); λ_i = Proportion of the cycle which is effectively green for the phase under consideration in the i-th phase,

Then the average delay time in a cycle for intersection is as following,

$$E = \frac{\sum_{j=1}^{2}\sum_{i=1}^{4}\{q_{ij}[\frac{c(1-\lambda_i)^2}{2(1-\lambda_i x_{ij}} + \frac{x_{ij}{}^2}{2q_{ij}(1-x_{ij})}]\}}{\sum_{j=1}^{2}\sum_{i=1}^{4} q_{ij}} \quad (5)$$

Assuming that each phase saturation is less than 0.85, in order to make the average vehicle delay of the intersection time reaches the minimum, we get the optimization problem as following

$$\min E = \min \frac{\sum_{j=1}^{2}\sum_{i=1}^{4}\{q_{ij}[\frac{c(1-\lambda_i)^2}{2(1-\lambda_i x_{ij}} + \frac{x_{ij}{}^2}{2q_{ij}(1-x_{ij})}]\}}{\sum_{j=1}^{2}\sum_{i=1}^{4} q_{ij}} \quad (6)$$

$$\text{s.t.} \begin{cases} t_1 + t_2 + t_3 + t_4 = c - L \\ t_i \le c - L - 3\times 20 \\ t_i \ge \dfrac{cy_{i\max}}{0.85} \end{cases} \quad (7)$$

Where,

L = total loss of time(s); $y_{i\max}$ = the maximum value of flow rate ratio in the i-th phase;

SOLVE THE MODEL BASED ON THE IMPROVED GENETIC ALGORITHM

Chromosome encoding and the generation of initial population

Membership function parameters corresponding to the chromosome using real number coding. Length of the coding is the number of the variable, so we choose $t_i (i = 1, 2, 3)$ as the optimization variables. If the Cycle time and total loss of time L are known, we get t_4 as following

$$t_4 = T - L - t_1 - t_2 - t_3 \quad (8)$$

On the one hand, in order to avoid search space is too big to improve the efficiency of search, the population size is not too big. On the other hand, the size of the population selection is also associated with the difficult level of solving the nonlinear problem. For strong nonlinear degree of traffic system, we choose N=100 to keep the population diversity

Fitness function

In the genetic algorithm to optimize the process, according to the fitness value of the size of the genetic manipulations of the chromosome, the objective function is usually the largest value. In this paper, the intersection of the average vehicle delay as a measure of performance evaluation of the control effect, so the intersection average delay of vehicles is the inverse of E as fitness function.

Genetic operations

Three basic genetic operators for genetic operations are selection, crossover and mutation

(1) selection, Implementation of the elite reserve strategy
(2) crossover, Arithmetic crossover
(3) mutation, Uniform mutation

The optimization process

The adaptive adjustment method of crossover probability and mutation probability is adopted. In classical genetic algorithm, the probability of crossover and mutation operations with fixed, according to different optimization problem, requires repeated experiments to determine P_c and P_m, it is hard to find a suitable for the optimal values of each problem. To avoid the "premature" phenomenon, in this paper, we use the improved adaptive crossover and mutation probability adjust algorithm. The calculation flow chart is as follows,

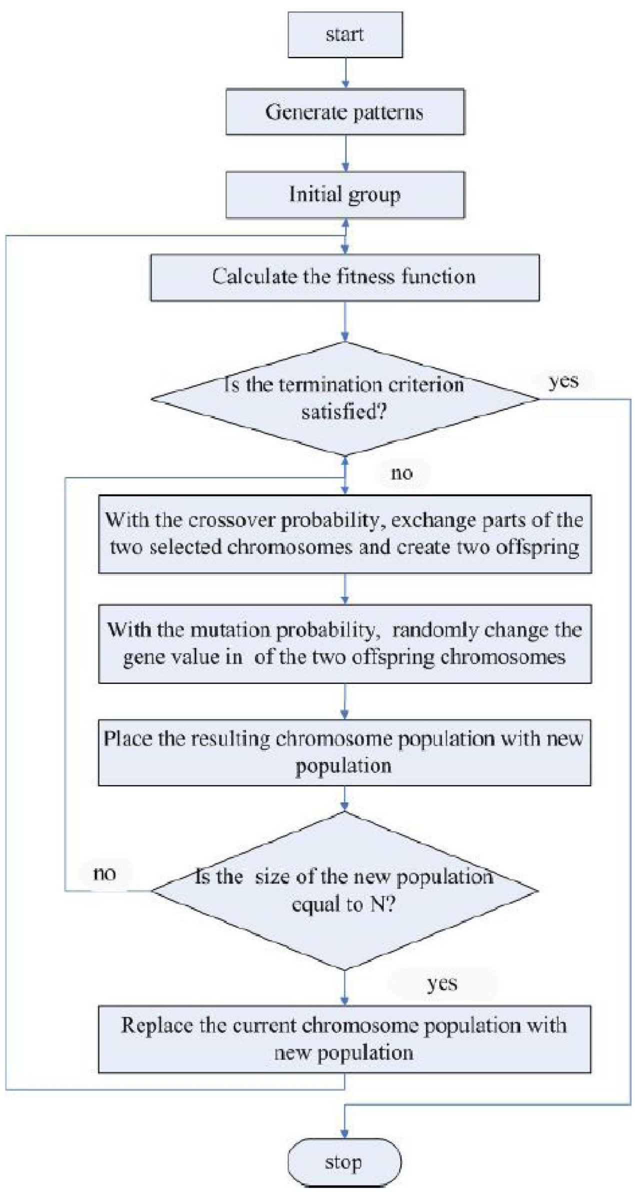

Figure 3 : Calculation flow chart

SIMULATION ANALYSIS

Simulation parameter Settings are as follows

- ◇ Assume intersection in each direction vehicle arrives is random, when traffic is small it obeys Poisson distribution. When traffic is a big, it obeys the Binomial distribution.
- ◇ Saturated flow for phase 1 and 3 is 2000 PCU/h, and phase 1 and 3 is 1000 PCU/h. (see Figure 2)
- ◇ The signal cycle $c = 120s$, total loss of time $L = 10s$
- ◇ minimum green light time of each phase which is obtained by the maximum saturation limit

$$g_{ei} \geq \frac{120 y_{i\max}}{0.85}$$

Intersection traffic parameters is shown in the TABLE 1 as following

When the relevant data generation into the constraint conditions, we get the constraint conditions

$$\begin{cases} t_1 + t_2 + t_3 + t_4 = 110 \\ 23 \leq t_1 \leq 47 \\ 21 \leq t_2 \leq 45 \\ 23 \leq t_3 \leq 47 \\ 19 \leq t_4 \leq 33 \end{cases} \qquad (9)$$

The length of the chromosome is 3, Evolution generations is 100, population is N=100,

- ◇ crossover probability is $P_c = 0.7$, and mutation

TABLE 1 : Intersection traffic parameters

phase	Import direction	Traffic flow	saturation
1	East import	300	2000
	West import	350	2000
2	East import	160	1000
	West import	140	1000
3	South import	350	2000
	North import	300	2000
4	South import	130	1000
	North import	150	1000

TABLE 2 : Comparison results

Effective green light time algorithm	Phase 1	Phase2	Phase3	Phase4	average vehicle delay
Genetic Algorithm	31	26	31	22	14.25
Improved genetic algorithm	33	24	33	20	11.62

probability is $P_m = 0.01$,

Upper and lower limits of the adaptive probability $[P_{d1}, P_{d2}] = [0.9, 0.01]$

Optimization algorithm comparison results is shown in table 2

CONCLUSION

In this paper, we use average vehicle delay time as objective function to evaluate the performance of intersection signal control. Through the evolution process of adjustment probability the maximum individual, realize the improvement of genetic algorithm. The simulation experimental results show that the improved genetic algorithm to calculate the average delay time is shorter than traditional genetic algorithm, which shows that this method is feasible.

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