Optimizing traffic control signals in a signalized intersection using genetic algorithm – (the case of Iran)

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Abstract: In this paper genetic algorithm is used to minimize the total user delay in a junction by controlling the signal timings. Both pedestrian and vehicular users are considered to be contributing to the total user delay. A model of the problem is explained for both scramble and two-way crossing patterns. The appropriate definition for chromosome is determined to code the information of pattern and timings of crossings. The explained model and optimization algorithm are implemented for determining the optimum timings and crossing pattern in an intersection in the city of Rasht in Iran as a case study. Given that the timing signal traffic at the intersection of the scramble crossing is not considered, recommended that a traffic signal phase timing for this intersection to be considered in order to minimize delays in moving pedestrians.

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1. Introduction

As urban roads experience increasing traffic congestion, efficient management of traffic signal system control becomes an important traffic engineering research area. Traffic congestion wastes a large amount of the national income for fuel, environmental and economic problems caused by traffic. Traffic congestion creates a variety of problems, such as air pollution, wasting a large amount of time of people, noise pollution, economic problems, and slow vehicle movements.

Actually the best conditions one can assume for a road which is thick with traffic, includes green lights appear with regularity, traffic flows smoothly, and lane changing is minimal. [1] It seems that it should not only remain at the level of a dream, but also by using the state-of-the-art technologies and mathematical algorithms, is implemented and exploited.

Generally, the main goal of management of traffic signals is to optimize traffic operation. The statistical nature of this operation and the myriad related parameters add to the difficulty of the problem. To achieve this prime goal, the optimization processes are indispensable. The conventional techniques, such as integer programming, hill-climbing, or descent gradient methods cannot overcome the troubles encountered in this problem. Efficiency and effectiveness of genetic algorithms in solving complex optimization problems which have been demonstrated in many areas including traffic signal

Traffic signals are the most common and critical tools to control traffic flow in urban areas. They assign the right of way to various traffic movements in different time intervals depending on traffic demand level. Control methodologies of traffic signals have gradually improved, along with advancements in technology.

In one approach, we use fixed-time signals (also known as Time of Day control), signal timings are calculated and set based on historic traffic patterns. Needless to say, this approach is suitable for situations with predictable traffic patterns. The most important fault of it is that it cannot recognize short-term fluctuations in traffic arrivals and long-term variations in traffic patterns.

Actually adaptive traffic signal control is the most recent and advanced type of traffic signal control. In this method, traffic congestion could be relieved by continuously adjusting signal timings in response to real-time traffic conditions.

operation, single out this technique for solving our optimization problem. For example, the potential of genetic algorithms to optimize signal timings of a simple network comprising of four signalized intersections demonstrated clearly. By the way, a signal optimization program using a genetic algorithm optimizer to handle oversaturated conditions of signalized intersections is presented successfully.

A number of studies, the balance between pedestrian and vehicle delay at a single intersection in the network have been evaluated. Noland in 1996, timing signal traffic on the cost of travel time for pedestrians and for vehicles with large numbers of single intersection has pedestrian check.

Ishaque et al in 2005, the timing cycle delay vehicle and pedestrian lights on the hypothetical network using micro simulation model VISSIM to analyze. Aimed at minimizing travel costs, travel delay model was multifaceted.

Li et al in 2009, strategies to optimize the traffic signal in the MATLAB programming for minimizing the total time delay for a single intersection, pedestrian and vehicle were developed. Total delay in vehicle pedestrian walking path was calculated according to the order queue.

Intersection case study of one of the important centers in Rasht is CBD, which is facing a large volume of pedestrians. Given that the traffic signal timing for pedestrians at this intersection is not considered a separate phase, this phase of this research has been studied for pedestrians.

2. Methodology for Signal Plan Optimization in a Single Intersection

The objective of this research is to develop an effective procedure to optimize signal timing of an individual intersection by minimizing total user time (cost) which considers both vehicle and pedestrian delay.

Traffic signals generally are used for minimizing average vehicle delay, but pedestrian delay is not taken into account. Although in some area like rural areas or highways, this is a reasonable scenario, but in some areas full of pedestrians walking around, optimizing just vehicle flows would not be suitable because the pedestrian delay is ignored. Consequently, Traffic signal plan optimization should be a trade-off between vehicle delay and pedestrian delay by minimizing travel delay for all the travelers.

In what follows, we explain our cost function (total user time) in details. Further detailed explanation about the calculation of two important variables in the model, average pedestrian and vehicle delay (D_p, D_v), is also included.

2.1. Total User Time

The detailed user time model (our cost function which should be minimized) is as follows.

$$UT = K.T.\frac{TD_p}{3600} + \sum_{i=1}^{4} V(i).T.\frac{D_v(i)}{3600}.n_v \qquad (1)$$

Where
UT = total user time in the analysis period (h)
T = duration of the analysis period (h)
K = relative time value of a pedestrian compared with a passenger car
TD_p = total pedestrian delay in the analysis period (s)
V(i)= vehicle adjusted volume in lane group i (veh/h)
$D_v(i)$ = average delay per passenger car in lane group i (s)
n_v = average vehicle occupancy per passenger car

If two-way crossing is applied,

$$TD_p = D_p(1).\sum_{j=1,3} p(j) + D_p(2).\sum_{j=2,4} p(j) \qquad (2)$$

If scramble crossing is applied,

$$TD_p = D_p(1).\sum_{j=1}^{4} p(j) \qquad (3)$$

Where
$D_p(m)$ = average delay per pedestrian in pedestrian crossing direction m (s);
For two-way crossing, $D_p(1)$ is for major street direction crossing, $D_p(2)$ is for minor street direction crossing; for scramble crossing, $D_p(1)$ is for crossing of all the directions.
p(j)= pedestrian volume of the pedestrian group j (ped/h)

According to the research of Ishaque, et al., the relative time value of a pedestrian compared with a passenger car (K) could range from 0 to 3 in most cases. Bhattacharya and Virkler recommended K value of 2.0 S, we consider it equals to 2 in this research.
The average vehicle occupancy 1.22 (n_v = 1.22) is used in this study, on the basis of the traffic condition observation by Bhattacharya and Virkler.
Furthermore, the vehicle adjusted volume (V) in the model equals to the hourly volume divided by a peak hour factor (PHF). The PHF is calculated to be 0.9 in the case study.

2.2. Average Pedestrian Delay

The average pedestrian delay model is proposed in Pedestrian Compliance Effects on Signal Delay (Virkler). [7] The model is based on the assumption that all pedestrians arrive randomly, which means pedestrians who arrive in green enter the intersection without any delay and pedestrian flow arrives uniformly in red. It is also assumed in the model that the cycle length is constant and no pedestrian actuation is applied in the intersection. The detailed model is as follows.

$$D_p = \frac{(R + 0.31A)^2}{2C} = \frac{[C - (G + 0.69A)]^2}{2C} \qquad (4)$$

Where

R = duration of DONT WALK or red (s)
G = duration of WALK (s)
A = duration of flashing DONT WALK or clearance (s)
C = cycle length (s)

2.3. Average vehicle delay

The average vehicle delay model is from HCM 2000. The detailed model is as follows.

$$D_v = d_1 + d_2 + d_3 \qquad (5)$$

$$d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8kIX}{cT}}\right] \qquad (6)$$

If $Q_b = 0$,

$$d_2 = PF\frac{0.5C(1 - g/C)^2}{1 - \min(1, X)\, g/C}, d_3 = 0 \qquad (7)$$

$$t = \min\left[T, \frac{Q_b}{c(1-X)}\right],$$

$$u = \max\left[0, 1 - \frac{cT}{Q_b}(1 - X)\right] \qquad (8)$$

If $X < 1, Q_b > 0$

$$d_1 = 0.5(C - g)\frac{t}{T} + PF\frac{0.5C(1 - g/C)^2(T - t)}{(1 - X g/C)T},$$

$$d_3 = \frac{1800Q_b(1 + u)t}{cT} \qquad (9)$$

If $X \geq 1, Q_b > 0, t = T, u = 1$

$$d_1 = 0.5(C - g), \quad d_3 = \frac{3600Q_b}{c} \qquad (10)$$

Where
D_v = average delay per passenger car(s/veh)
Q_b = initial queue at the start of period (veh)
PF = uniform delay progression adjustment factor
g = effective green time for lane group (s)
C = cycle length (s)
c = lane group capacity (veh/h) = s.g/C
s = saturation flow rate (veh/h)
V = passenger car volume (veh/h)
X = V/c ratio = (V □C) /(s □ g)
T = duration of the analysis period (h)
t = duration of unmet demand in T (h)
u = delay parameter
k = incremental delay factor (dependent on controller settings)
I = upstream filtering/metering adjustment factor

3. Genetic Algorithm

Global optimization is one of most important tasks in many engineering problems. There are many problems which include determining some tunable parameters to obtain minimum cost, efficient design and maximum user satisfaction subject to some constraints. Ordinary optimization methods from calculus suffer from falling in local minimums which are not the desired solution of engineering optimization problems. On the other hand many of applicable models are too complex to take the advantage of analytical methods. In order to oppose such difficulties one can utilize evolutionary optimization algorithms such as genetic algorithms (GA). GA is inspired from concepts of evolutionary biology and shown to be a very powerful and applicable method for solving a plethora of engineering problems. In this section basic notions of ordinary GA are introduced.

To utilize GA one should define a fitness function related to the model of system which is influenced by the optimization variables and constraints. In GA a set of optimization variables determines a possible solution for the problem and according to constraints the feasibility of the solution is determined. Every possible solution is modeled as a chromosome which is a vector of binary variables as shown in figure 1. For every chromosome (possible solution) a value is assigned due to fitness function. This value is used to determine the quality of chromosome. A population defined as a set of different individuals (chromosomes) and in different iterations of GA the population is updated modeling the change of generations in a biological system. In each iteration, fitness values of all individuals in the population are calculated and the individuals are ranked by their fitness measures. An individual with a higher rank (higher fitness) is more probable to survive through changing the generation and is more probable to contribute in the process of reproduction and creating children chromosomes. In the process of updating the population and going to the next generation three main operations occur in the ordinary GA in each iteration:

1. Elites selection: The most fitting individuals are selected to survive into the next generation directly.

2. Crossover: Some of individuals are selected as parents and contribute in production of new individuals (offsprings) by means of combining their chromosome vectors. The probability for selection of an individual as one of parents is related to its fitness measure. Two parents will combine their chromosome in the way shown in figure 2 in order to create two children. The most fitting individuals among parents and offsprings are selected for attendance in the next generation.

3. Mutation: For some of individuals one or several binary bits in their chromosome may be changed randomly via the process of mutation. This operation could be beneficial for preventing the algorithm to fall and remain in local minimums.

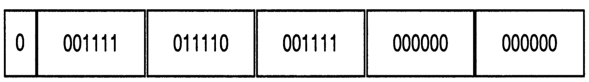

Figure1. A chromosome as a possible solution of the optimization problem

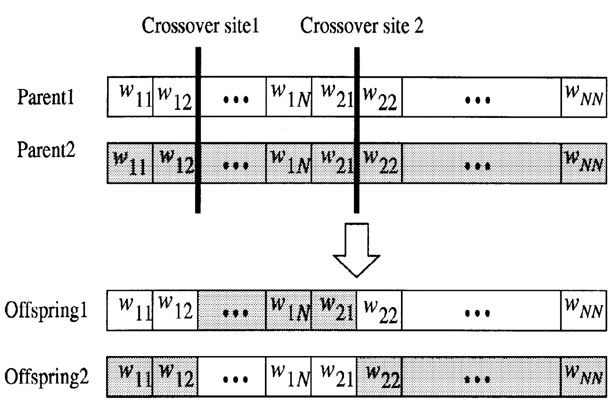

Figure2. The operation of crossover

4. Computational Results

In this study the data for a signalized intersection in the city of Rasht are used as a case study for presented model and algorithm. Vehicle volumes in a period of time are presented in table1.

In this case study no left-turning is considered (Its volume is set to 0). There are 4 independent lane group green time signals g1, g2, g4 and g5 as in the model explained by Yang [12]. Durations of two walk signal are named as G1 and G2. The yellow time is fixed to the value of 3 seconds. Initial queues are chosen as random variables.

To utilize GA in this case study, the chromosome is defined by 31-bit binary vector. First bit defines the pattern of walking, 0 for two-way and 1 for scramble walking pattern. The other 30 bits define green time signals G1, G2, g1, g2, g4 and g5. 5 bits are set for every green time signal. Population size is set to 31 and 50 iterations of GA are considered for every run of algorithm.

The results of several runs of the algorithm are shown in Table 2. These results show that for this case study two-way crossing pattern is more suitable. Parameters of utilized GA are presented in Table 3. With these values for its parameters, GA shows a good convergence pattern for finding the optimum solution. A typical convergence curve is depicted in figure 3.

Table 1. Vehicle volume data for Michael junction, city of Rasht

	Sampling time	Entrance	Entrance name	Time interval	15 min volume			
					Right turning	direct	Left turning	Total
1	18:00	Entry 1	Imam Khomeini Ave.	1	34	299	0	333
2	18:15			2	38	254	0	292
3	18:30			3	37	258	0	295
4	18:45			4	37	290	0	327
5	19:00			5	35	292	0	327
6	19:15			6	34	270	0	304
7	18:00	Entry2	Motahhari Ave.	1	39	245	0	284
8	18:15			2	41	279	0	320
9	18:30			3	40	273	0	313
10	18:45			4	42	266	0	308
11	19:00			5	38	278	0	316
12	19:15			6	38	263	0	301
13	18:00	Entry3	Imam Khomeini Ave.	1	60	273	0	333
14	18:15			2	52	295	0	311
15	18:30			3	52	262	0	314
16	18:45			4	55	270	0	325
17	19:00			5	54	268	0	322
18	19:15			6	53	273	0	326
19	18:00	Entry4	Hafez Ave.	1	45	208	0	253
20	18:15			2	44	195	0	239
21	18:30			3	49	204	0	253
22	18:45			4	47	200	0	247
23	19:00			5	52	202	0	254
24	19:15			6	40	211	0	251

Table2. Results of several runs of algorithm

Crossing Pattern	G_1	G_2	g_1	g_2	g_4	g_5	C	Total user time	Pedestrians time	Vehicles time
Two-way	4	4	6	14	6	16	54	36.78	18.81	17.97
Two-way	4	4	6	18	6	16	54	36.43	18.81	17.62
Two-way	4	4	6	20	6	11	54	36.63	18.81	17.82

Two-way	4	4	6	20	6	10	54	36.70	18.81	17.89
scramble	31	-	6	10	6	10	85	36.88	13.29	23.59
scramble	34	-	6	10	6	10	88	36.90	12.84	24.06
Two-way	4	4	6	20	6	15	54	36.33	18.81	17.52

To check the dependence of total user time to the pedestrian population, the pedestrian population is increased from 0 to 2000 in steps of value 100. In each step the total user time is calculated. The plot of total user time versus pedestrian population is depicted in figure 4.

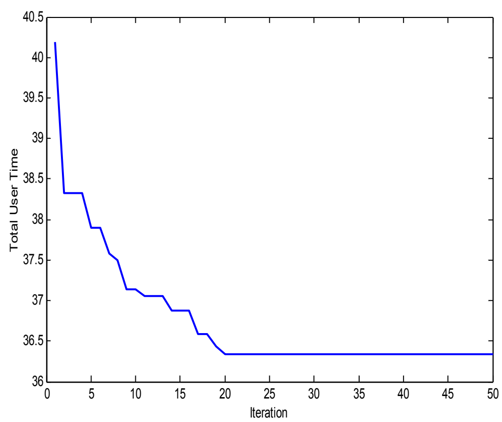

Figure 3. A typical convergence curve of GA

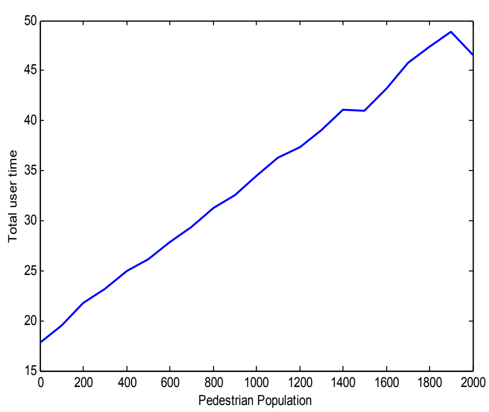

Figure 4. Total user time versus pedestrian population

In another part the same is done for vehicle population (in a constant pedestrian population), the plot of the result is shown in figure 5.

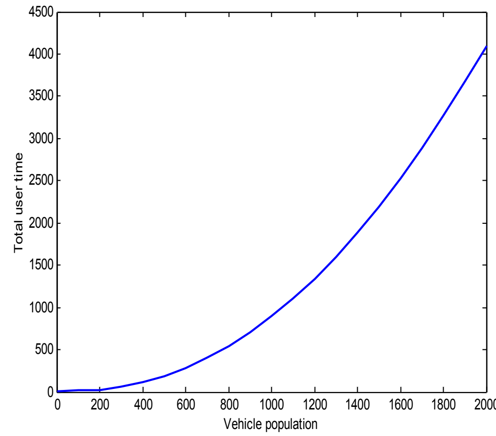

Figure 5. Total user time versus vehicles population

5. Conclusion

The method of genetic algorithm is used to optimize signaling in a junction in the city of Rasht. The model considers total user delay time as a cost function which is sum of total pedestrian delay and vehicular delay times. Computational results show that two-way pattern is more efficient with the optimum timing described in Table 2. According to the model results with the correct timing of the intersection of different approaches to creating long lines at the intersection and reduce delays due to the good part was created and 7.2 percent of the desired intersection to reduce queue length.

Given that the timing signal traffic at the intersection of the scramble crossing is not considered, according to results of a phase with consideration for pedestrians, pedestrians move to delay the rate of 22.4 percent decrease.

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