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Timing Optimization of Signalized Intersections Using Shockwave Theory by Genetic Algorithm

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Shockwave,
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Abstract

Signalized intersections act as one of the main elements to control the traffic flow at transportation systems in urban areas. However intersections as nodes impose more delays to vehicles. Creating maximum efficiency in transportation systems in urban areas and maintaining the optimal performance of these intersections always have been the main concern of traffic engineers. Furthermore, recently, the various kinds of programs and techniques are presented to help to traffic engineers to find optimized timing of signalized intersections. In this study, a new method based on kinematic wave theory is used through genetic algorithm technique to optimize the timing of three signalized intersections in the most crowded city in the north of Iran (Rasht city) to minimize travel time, delays and create better performing crossings at a dense transportation systems. The applied algorithm indicated that after the signal timing optimization, the average vehicle delay time can be reduced at the intersection in a.m. peak, noon peak, and p.m. peak by 31, 22 and 22 percent, respectively.

1. Introduction

Overcrowding and congestion in the streets and corridors of cities especially in recent years has been more problematic than before. This is partly due to population growth and consequently using more passenger cars in transportation system. Traffic flows at signalized intersections would stop by signals and keep moving during the green interval. Stopping the movement of vehicles and pedestrians during the red phase creates delay for users. Delay at signalized intersections increases the travel time of the users of the transportation system. Furthermore, this causes performance and efficiency reduction of the transportation network, and also society related issues such as air and noise pollutions.

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Optimization of intersections and using new approaches for traffic control are of the most important methods. So to do, the proper functioning of the traffic signals is important. The efficient timing causes vehicle delay reduction. Admittedly, this leads to reduced drivers' stress and also energy saving in terms of fuel consumption. Moreover, according to Vallyon and Turner [1]'s study conducted at intersections in York, Virginia State, reducing delays at the intersections through optimizing the timing of signals, saved 65,000 dollars for drivers annually.

Over the past two decades, significant progresses have been made in developing methods to reduce vehicle delay and congestion at intersections within urban area. Garber and Hoel in 2002 [2] carried out extensive research to analyze traffic flow dynamics and proposed effective measures that could potentially improve efficiency of intersection capacity utilization.

The kinematic wave theory known as the Lighthill-Whitham-Richards (Lighthill and Whitham (1955) [3] and Richards (1956) [4] (LWR) theory has been investigated in many studies to explain traffic dynamics on a roadway segment or intersection approach with kinematic waves, including queue forming or discharging shockwaves. The shockwave theory was applied to model moving incidents with overtaking in a study conducted by Chandana in 1978 [5]. Furthermore, a real-time signal control strategy for minimizing total intersection delays subject to the constraint of maximum queue length were presented in a comprehensive study conducted by Michalopoulos and Stephanopoulos in 1981 [6]. Recently, Roshandeh et al. (2014) [7] in a most extensive investigation with a sensitivity analysis evaluated the application of an enhanced model to examine the impacts of assigning different weights to vehicle and pedestrian delays on intersection vehicle travel time and delay reductions after signal timing optimization. This study was performed based on the data collected form the Chicago central business district (CBD) area. The experimental findings reveal that after the systemwide signal timing optimization, vehicle delays in the CBD area could reduce by 13% while considering only vehicle delays. However, this decrease reaches to 5% when simultaneously considering vehicle and pedestrian delays.

In the current study, data was collected from three signalized intersections located on main streets (called Mikaeel- Parastar- Hafez) in Rasht and analyzed using shockwave theory to generate new timing plan in order to minimize traffic delay. Shockwave theory is programmed with Genetic Algorithm (GA) optimization technique. The aim of this study is to minimize travel time and delays at a dense transportation system with applying the shockwave theory through GA optimization method. The proposed method is able to simulate area traffic data second by second accurately.

2. Proposed Methodology

The kinematic wave model can analyze how a queue is formed and dissipated at a signalized intersection approach. Wave speeds, maximum queue lengths and vehicle delays can be predicted for each intersection approach according to under-saturated or over-saturated traffic stream dynamics and the signal timing design. The analysis can be extended to multiple signalized intersections along a corridor and finally to all signalized intersections within an urban street network. To this end, shockwave theory objective functions are applied through GA optimization technique.

Broadly speaking, genetic algorithm is inspired from evolution of life on earth and it was first proposed by Holland in 1970s [8]. It has three stages in searching space:

Stage 1: Creating an initial population

Stage 2: Evaluating a cost function

Stage 3: Producing a new population

An initial population is made from random generator with each member being evaluated by Cost function. After this, each member is manipulated by GA operators. There are usually two kinds of operators. The first operator is crossover which would select two member of population as parents and produces 2 offspring by swapping on the elements of parents. Participating in crossover depends on value of member's Cost which members with low Cost value participate in crossover more. The second operator is called mutation operator. It is an operator in the background and it is used to increase exploration of the algorithm. Since this operation is completely random and there is no guarantee for good results so probability of its operation is usually assigned very low. At the end a new population will be selected from production of these two operators and these stages will be continued until centralization of all members. Figure 1 shows a flowchart of GA procedure. In this process, existing timing plan of the signalized intersection is initial population and optimized timing plan is the output. According to Roshandeh et al. (2014) [7], the objective functions applied in GA are presented as Eqs. (1) and (2).

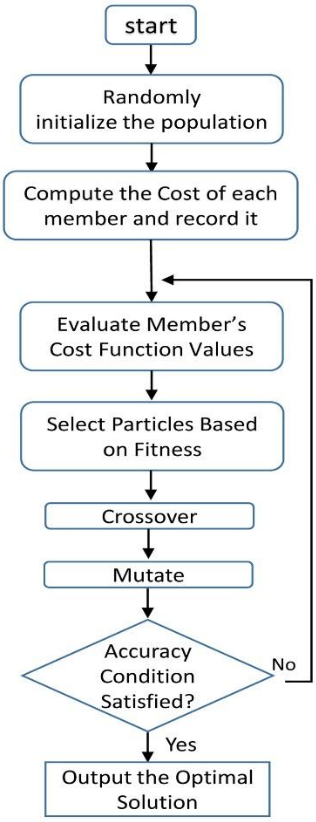

Figure 1. GA processing flowchart

$$DELAYS_{VEH,U} = \left\{ \frac{\left[\frac{L_{bh} \times T_{bh}}{2}\right] + \left[\frac{(L_{Max} + L_{bh})}{2} \times (T_{Max} + T_{R} - T_{bh})\right] - \left[\frac{(L_{Max} \times T_{Max})}{2}\right]}{L_{Max}} \right\} \times \frac{L_{Cell}}{L_{Max}} \tag{1}$$

$$DELAYS_{VEH,O} = \left\{ \frac{\frac{L_{Min} \times T_{Min}}{2} + \left[\frac{(L_{bh} - L_{Min}) \times (T_{R} - T_{Min})}{2}\right] + \left[(T_{R} - T_{Min}) \times L_{Min}\right] + \left[\frac{(L_{Max} + L_{bh}) \times T_{Max}}{2}\right] - \left[\frac{L_{Max} \times T_{Max}}{2}\right]}{L_{Max}} \right\} \times \frac{L_{Cell}}{L_{max}} \tag{2}$$

where DELAYS $_{\text{VEH, U}}$, DELAYS $_{\text{VEH, O}}$ = Average vehicle delays per vehicle per cycle for undersaturated or oversaturated cases, s/veh/cycle; L_{Cell} = the cell length in cell-based simulation model with a model calibration value of 7.5 m. The cell length and maximum queue length, L_{max}, help convert the total vehicle delays to average delays per vehicle. And also, L_{bh}, L_{min}, L_{max}= maximum queue length before the hump, minimum queue length, and maximum queue length, in m; and T_{bh}, T_{max}, T_{min}, in T= time at which traffic hump will start, time at which the queue is fully discharged, time of minimum queue length, and time of maximum queue length.

3. Location and Data Processing

In order to optimize the signal timing plan, three main signalized intersections (Mikaeel- Parastar-Hafez) are selected in Rasht as a big city in the north of Iran (capital of Guilan province) [9]. Many of signalized intersections in Rasht are in shopping areas and medical centers. Hence, timing optimization of signalized intersections could be considered as one of the critical traffic related points in Rasht. Mikaeel, Parastar and Hafez intersections location is shown in Figure 2.

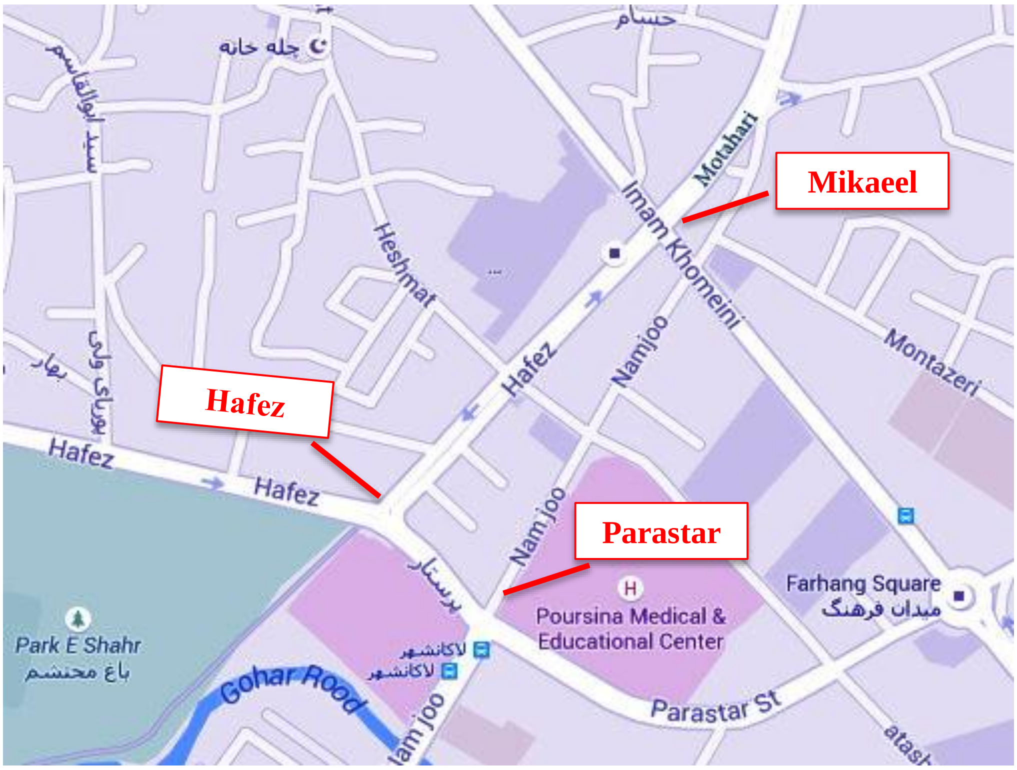

Figure 2. Mikaeel, Parastar and Hafez intersections location

According to the existing condition of intersections and considering peak times, three data sets for morning (7:00AM-9:00AM), noon (11:30AM-1:30PM) and evening (17:00PM-19:00PM) were collected. Table 1 shows timing plan of three intersections before optimization process. Moreover, the number of vehicles in each intersection leg are shown in Table 2.

Table 1. Timing plan of intersections before optimization process (seconds)

Intersection		Allowable Entries	A.M. Peak		Noon Peak		P.M. Peak	
			Green	Cycle	Green	Cycle	Green	Cycle
Hafez	37°16'07.2"N 49°35'20.7"E	Park e shahr -Mikaeel	18	77	14	73	38	80
		Mikaeel-Parastar	15		15		15	
		Parastar-Park e shahr	35		35		18	
Parastar	37°16'04.0"N 49°35'24.6"E	Farhang	26	118	28	117	40	147
		Poorsina	26		12		12	
		Namjo	34		27		38	
		Parastar	20		38		45	
Mikaeel	37°16'16.5"N 49°35'31.3"E	Imam Khomeini	40	89	94	169	99	177
		Motahari-Hafez	43		69		72	

Table 2. Number of vehicles in each allowable entries (vehicles per hour)

Intersection	Allowable Entries	A.M. Peak	Noon Peak	P.M. Peak
Hafez	Park e Shahr -Mikaeel	489	535	580
	Park e Shahr - Parastar	680	408	602
	Mikaeel-Parastar	504	510	478
	Mikaeel- Parke Shahr	367	542	508
	Parastar - Mikaeel	739	759	792
	Parastar-Park e Shahr	490	588	667
Parastar	Farhang - Poorsina	104	164	224
	Farhang - Namjo	1053	1153	1253
	Poorsina - Parastar	57	77	117
	Poorsina - Namjo	953	1001	1200
	Namjo - Parastar	1232	1332	1310
	Namjo - Farhang	173	273	301
	Parastar - Farhang	1041	1091	1245
	Parastar - Namjo	236	266	287
	Imam Khomeini - Hafez	229	271	268
	Imam Khomeini - Farhang	1056	1077	947
	Hafez - Motahari	761	789	893
	Hafez - Farhang	173	150	144
Mikaeel	Motahari - Shahrdari	126	146	107
	Motahari-Hafez	985	907	974
	Imam Khomeini - Motahari	114	127	94
	Imam Khomeini - Shahrdari	1090	1046	1106

4. Results and Discussions

The results of optimization process with shockwave theory coded through genetic algorithm for three intersections are presented in Table 3 to Table 4. Table 3 shows new timing plan after optimization process.

Furthermore, the average vehicles delay before optimizing and after optimizing process are shown in Table 4. It has been found that the average delay is reduced and also level of service at each intersection is changed to a better condition. Level of services in this study obtained based on procedure described in Highway Capacity Manual (2010) [10].

Table 3. Timing plan of intersections after optimization process

Intersection	Allowable Entries	A.M. Peak		Noon Peak		P.M. Peak	
		Green	Cycle	Green	Cycle	Green	Cycle
Hafez	Park e shahr -Mikaeel	14	78	12	77	12	65
	Mikaeel-Parastar	17		16		14	
	Parastar-Park e shahr	38		40		30	
Parastar	Farhang	22	110	24	117	42	150
	Poorsina	20		14		12	
	Namjo	38		32		44	
	Parastar	18		35		40	
Mikaeel	Imam Khomeini	42	88	90	156	92	176
	Motahari-Hafez	40		60		78	

Table 4. The average vehicles delay before optimizing and after optimizing process

Time	Not Optimized Cycle		Optimized Cycle	
	Average Delay (Second)	Level of Service	Average Delay (Second)	Level of Service
A.M. Peak	81	F	56	E
Noon Peak	98	F	77	E
P.M. Peak	120	F	94	F

Based on this results, not surprisingly, it is possible to reduce vehicle delay at Mikaeel, Hafez and Parastar intersections just using a new timing plan with a minor changes in this schedule. As shown in Tables 1 and 3, by changing green phase e.g. a.m. peak in Imam Khomeini and Motahari-Hafez from 40 and 43 to 42 and 40, respectively, optimized cycle for a.m. is obtained. More precisely, it is not necessary to increase cycle. As an example, p.m. peak cycle has reduced to achieve the optimized cycle.

5. Conclusions

Based on optimization procedure, using shock wave theory and genetic algorithm, new timing plan for Mikaeel signalized intersection was obtained and decreased vehicle delay in a dense transportation system in urban area.

The contribution of this study is combining shock wave theory with GA. Proposed approach conducted in this paper, with regarding the number of vehicles and their driver behavior has tried to achieve an optimized cycle. In order to minimize traffic delay, one doesn't need to necessarily increase the cycle length, whereas, decreasing the cycle length might be the case.

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