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Traffic Light Signal Timing Using Simulation

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Abstract

Increasing trend in the number of vehicles and consequently intensifying the traffic volume, traffic lights optimum timing plays a vital role in congestion mitigation in the critical intersections of urban areas. This paper gives an insight into traffic light timing using simulation modeling methods. In fact, this study aims at minimizing the average time that entities (vehicles) spend in the system (intersection). First, real data including vehicles arrive and leave times, and the time spent waiting at a red light etc. is collected through monitoring an intersection in downtown Urmia, Iran. Then, a simulation model is developed using Arena Simulation Software. The most important feature of the proposed model is the replacement a four-stroke traffic light with the current three-stroke one. After model validation, several alternatives are considered for traffic light timing and the one which resulted the minimum average time spent in the system is selected. According to the simulation results, the four-stroke traffic light yielded a better performance compared to the three-stroke one.

Keywords: Traffic light timing, Traffic congestion, Simulation, Intersection.

The rapid increase in the number of vehicles is an undeniable fact that all countries face with it. Moreover, streets and urban areas in third world countries and even in many developed cities are not designed according to the urban planning principals and it is difficult to change their road plans because of the high prices of the famous buildings in downtowns. Therefore, the most feasible solution is to use new technologies to manage the traffic congestions in populated areas [2].

Traffic signals first used in Westminster, London in 1868 and the first three color light signals were installed in 1918 in New York which was controlled by a human. Since then, different types of traffic lights have been developed in which the state of the art technologies are adopted to have better efficiency [2]. In a general classification, there are two main types of traffic lights, including pre-timed traffic lights which work based on constant time intervals and traffic-actuated lights that use cameras and electronic sensors to assess traffic volume and conduct accordingly. Due to the high costs of installing and operating expenses of traffic-actuated systems, pre-timed systems are widely used all around the world.

Traffic light timing has attracted researchers who deal with traffic management problems and who searching for low cost and practical solutions that do not require high-cost changes in infrastructures of urban areas. Several mathematical methods have been applied to obtain an optimized scheduling for a traffic light in different researches, some of which are reviewed in the next section of this paper.

In this study, the traffic flow in an intersection has been analyzed where a three-stroke pre-timed traffic light is applied. The current system suffers from problems like frequent car accidents and vehicles long waiting times. In order to handle these problems, a four-stroke traffic light is suggested. As mentioned earlier, since the pre-timed traffic lights are not capable of adapting their function according to the traffic flow, a simulation model is developed to analyze the behavior of the traffic flow and to find the most appropriate timing for the traffic light.

2 Literature Review

The British transportation researcher, Webster [3] was one of the first researchers who developed several traffic theories and established a new perspective for dealing with traffic control problems in the 1950s. In his famous model, an objective function for cycle time optimization is proposed, taking into account the traffic volume of streets. After that, since the first computer-based traffic lights were installed, their timing optimization has become an attractive area for researchers and different aspects of traffic lights have been discussed in papers.

Developing mathematical models is one of the prevalent approaches employed by researchers in order to reach an optimal timing for a traffic light. Schutter and Moor [4] constructed a model in which the growth of the queue lengths is presented as a function of the time. Their study aims to find an optimal traffic light switching scheme allowing the red-amber-green light cycle time to be variable from one cycle to another. Fouladvand et al. [5] developed a stochastic model for minimization of the total delay in an intersection in which both traffic-actuated and pre-timed lights are operating. In terms of queuing theory, Babicheva [6] proposed the queuing theory methods for traffic light timing optimization considering the Poisson process for traffic flow in lanes.

In order to overcome computational and modeling difficulties in some traffic models, especially in large sizes, a group of researchers benefited from learning and heuristic and meta-heuristic approaches in their solving algorithms. Spall and Chin [1] proposed a new method for signal timing optimization based on neural networks which use current traffic information to solve the traffic problem in the system. The most important feature of this method was that it did not need the previous sophisticated mathematical models. Teo et al. [7] applied a genetic algorithm which resulted in the optimum time for green light, using the current queue length as the input data. In addition, they analyzed the influence of queue length and green time on the traffic system through simulations. Sanchez-Medina et al. [8] proposed a new model for traffic light timing and applied a genetic algorithm for its optimization; they assessed all feasible solutions using cellular automata-

based simulators. Yanguang and Hao [9] developed a novel dynamic model for traffic light scheduling and applied a hybrid chaotic quantum evolutionary algorithm to solve the problem. Li and Schonfeld [10] presented a combination of simulated annealing (SA) and genetic algorithm (GA) for arterial signal timing optimization in which the optimal green time is assigned taking into account the proportion of the critical lane volumes of each phase. The results show that hybrid SA-GA algorithm has some strength and benefits in comparison to the SA and GA algorithms when adopted independently. Zhao et al. [11] proposed an intelligent traffic light scheduling algorithm which benefits from GA and machine learning algorithm simultaneously to find an optimal timing for phases of each traffic light based on real-time flow rate. In fact, the algorithm developed in this study seeks to minimize the total waiting time of traveling vehicles in the intersection. Sun et al. [12] in a recent study developed a tri-level programming model for combined urban traffic signal control in which the lower level model refers to the intersection delay, the middle-level model concerns about the traffic signal control optimization and the tide lane management is controlled with the upper level of the model. Finally, they solved the model using a heuristic iterative optimization algorithm. Due to the complexity of the model, they gave the expression of the partial derivative and changed the rate of the objective function to deal with the problem. In terms of fuzzy sets, Keyarsalan and Montazer [13] applied fuzzy ontology to control traffic light. The most distinguishing characteristic of this model was considering a module for reusing traffic light control knowledge. The results presented a considerable drop in the average delay time of each car in each cycle.

Although all previous studies adopted effective methods to analyze the vehicular traffic behavior, all characteristics of a real world situation with different scenarios are considered in studies which apply simulation methods. The work done by Schaefer et al. [14] was one of the first studies in traffic flow simulation area. They considered three different scenarios including heavy traffic flow, medium traffic flow and light traffic flow for the freeway and developed a simulation model in order to analyze how lane control signing can affect the freeway congestion. According to the results, only the flow rates between heavy and medium level was sensitive to the lane control. Howell [15] benefited from a smoothed perturbation analysis to simulate and optimize traffic light timing. They intended to minimize the average number of cars waiting at the traffic light at an intersection of two one-way streets. Wen [16] developed a framework for a dynamic and automatic traffic light control system which benefits from a simulation model. This model was simulated using Arena software consisting of six sub-models, so as to minimize the average waiting time of cars at every intersection. D'Ambrogio et al. [17] introduced a new method for traffic simulation models development which equips traffic systems analysts and designers against the difficulties arise from relying solely on experience and intuition in simulation. In other words, they introduced a step by step method to formally specify and build simulation models for traffic intersections. Suh and Hunter [18] developed a Monte Carlo simulation method to minimize intersection delay for a displaced left-turn intersection. In fact, they applied the Monte Carlo simulation in order to approximate the best range for near-optimum parameter selection considering the traffic demands. One of the recent review papers in traffic light timing area is produced by Araghi et al. [19] in which the most outstanding studies related to the traffic signal timing controlling, specifically works focusing on Q-learning, neural network, and fuzzy logic systems are criticized and their performances were compared to each other through different scenarios.

Muting et al. [20] optimized the signal control systems for one of the main intersections in Shenyang taking into account all important factors related to the traffic flow and simulated their impacts. The result was a decline in queue length and an increase in traffic flow average speed and a considerable improvement in service level of the intersection. Recently, Zhao et al. [21] proposed a bi-level programming model and benefitted from dynamic traffic simulation method for intersections scheduling. This model tries to minimize the delays of critical intersections inside of the evacuation zone considering their traffic distributions.

In this study, a simulation model is developed for traffic light timing in an intersection of two two-way streets. The proposed model aims at minimizing the average time that entities (vehicles) spend in the system

(intersection). Different scenarios were considered in the simulation model in order to find the most near-optimum timing for the traffic light.

3 Problem definition

This study aims to minimize the average time that a vehicle spends in an intersection of two two-way streets in which a three-stroke pre-timed traffic signal is installed. It is assumed that there are 3 lanes on each street. Vehicles should stop and wait for the traffic light if they want to turn left or to go straight but they do not need to stop if they want to turn right. It is assumed that the first and second lanes from the left are assigned to the vehicles which want to turn left or to go straight and the third one is the lane for vehicles which want to turn right while entering and leaving the intersection (see Figure 1).

An intersection with a three-stroke cycle in downtown Urmia, Iran is considered as a case study which is one of the most congested intersections in Urmia and several car accidents are being reported here every day. As it can be seen in Figure 1, the timing of traffic light in this intersection is in a way that firstly, straight movements and left-turning vehicles in Bakeri1 street are allowed (blue arrows in Figure 1), but any other movements for other streets are not permitted. Then, the light becomes green for straight and left-turning movements of vehicles in Bakeri2 Street (green arrows in Figure 1); but it is red for all directions of other streets. Finally, straight and left-turning movements of vehicles in Besat1 and Besat2 streets are permissible simultaneously (red arrows in Figure 1); but it is prohibited for all directions of other streets. And, move to the right is always allowed for all vehicles on all four streets.
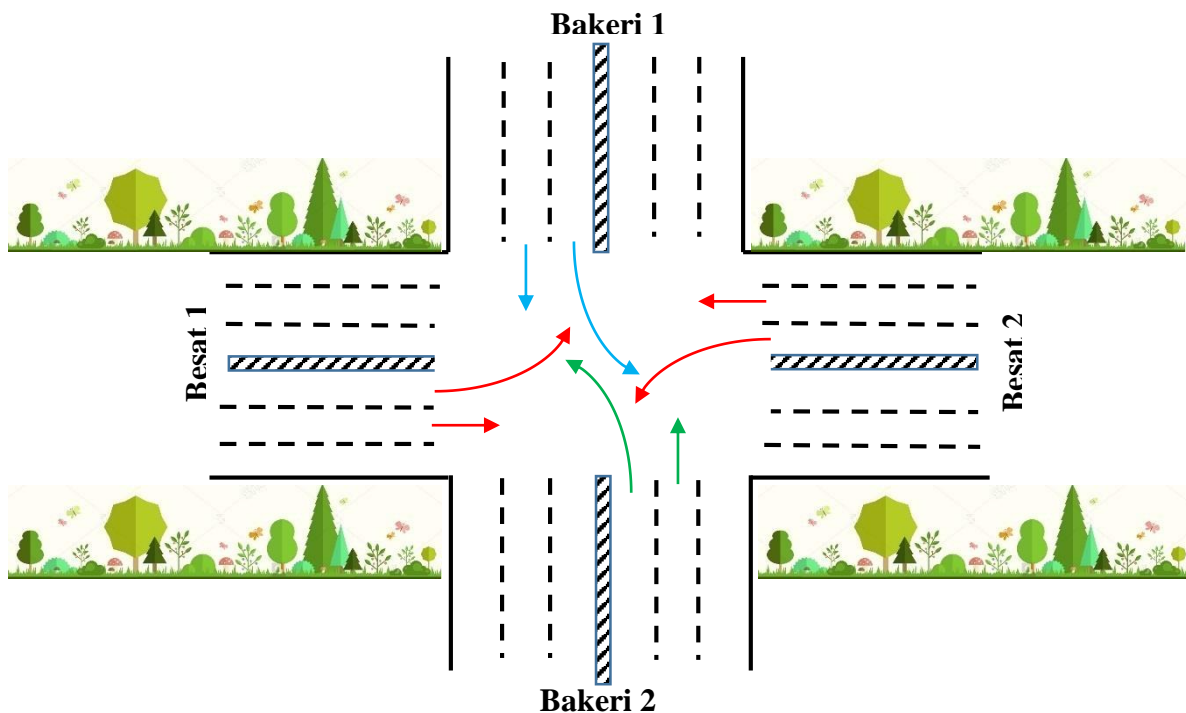

Figure 1: Streets position and allowed movements in the three-stroke cycle in the studied intersection

Empirical real data is collected from the above-mentioned intersection. Input Analyzer Tool is applied to find the behavior (distribution function) which most fits the data. In order to analyze the system in this study, vehicles arrival behavior and the distribution function for when the vehicles crossing the intersection is required. In addition, there is another parameter which presents the time that takes for a vehicle to pass the rows to reach to the front line (first-row vehicles) of the intersection (when there are queues behind the traffic light). This parameter is estimated by simply calculating the average time for vehicles to pass the distance from the row that they are to reach the frontline of the intersection and dividing it by the number of

passed rows (Figure 2). This parameter is computed separately for each street. The time that vehicles spend in the system from their entrance until they pass the intersection after the light becomes green (waiting time, the time is required to move from row i to the front line and the time is required to cross the intersection) is hereinafter called *vehicles cycle time*.
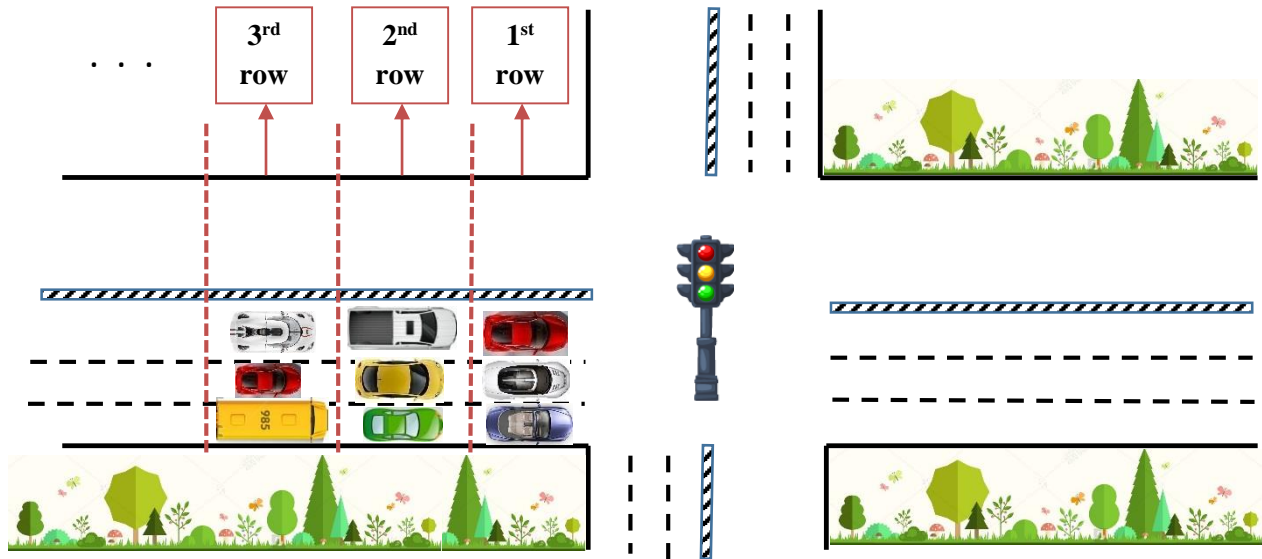

Figure 2: Rows of the vehicles waiting at the traffic light

Some fitting tests like Kolmogorov-Smirnov and Square Error along with factors like P-value are applied to analyze the goodness of fit for estimated distributions. Table 1 presents the distribution functions which most fits with data obtained from four streets along with related parameters and estimation errors resulted from Input Analyzer software.

Table 1: The distribution function for data collected from the studied intersection

Street	Distribution function	
	vehicles entrance	vehicles crossing the intersection
Bakeri1	- 0.5 + 22×Beta (0.971, 2.04) Square Error: 0.008 p-Value: 0.104	Poisson (8.21) Square Error: 0.008 p-Value: 0.188
Bakeri2	- 0.5 + 41×Beta (0.968, 3.44) Square Error: 0.008 p-Value: 0.009	Normal (5.66, 2.08) Square Error: 0.005 p-Value: 0.016
Besat1	- 0.5 + 23×Beta (0.634, 1.61) Square Error: 0.015 p-Value: 0.005	2.5 + Lognormal (7.65, 6.42) Square Error: 0.006 p-Value: 0.189
Besat2	- 0.5 + 24×Beta (0.963, 1.99) Square Error: 0.004 p-Value: 0.724	2.5 + Erlang (2.82, 3) Square Error: 0.007 p-Value: 0.311

4 Simulation

Simulation methods make it possible to assume different sequences of traffic lights for the system and consider animations to show that how the system behaves. Moreover, simulation is less expensive and less time-consuming compared to the other mentioned methods. Finally, because of the probabilistic nature of

the traffic flow in the intersection (entities arrival, time spent in the system, length of the queue), simulation would be an appropriate method for traffic light system evaluation.

4.1. Simulation Modeling

In this research, Arena simulation software is applied for system modeling. As it was mentioned before, the current traffic system is a three-stroke cycle light; Due to the large and dense bustle of the cars and pedestrians, the current system suffers from various problems like tight spacing, slow vehicle movements, frequent car accidents, vehicles long waiting times, passengers delay, more fuel consumption, air and noise pollution, etc. According to the characteristics of this intersection, it seems that one of the main causes of confusion and chaos is the three-stroke cycle traffic light. In this regard, a simulation model is developed and validated according to the current system. After that, a four-stroke cycle is designed and considered in the simulation model in order to make a comparison for system performance by taking into account both types of traffic lights. Assumptions considered in the model are as bellow:

- There are four types of vehicles (with different numbers) including buses, cars, vans and pickups (different vehicles choose different routes with different chances).
- The direction of all the vehicles (to left, straight or right) are determined exactly once they are generated and logged to the system
- There considered three lanes in each street: the first lane from the left is called lane1, the middle one is lane2, and another one is lane3.
- Any vehicle arrives the system, chooses the lane which has the minimum queue (unfortunately this is what happens in reality) and in the situation where lanes have the same number of vehicles, they choose the lane nearest to the direction that they want to go (i.e. vehicles want to go straight or turn left will stop in lane1 or lane2 and vehicles with intent to turn right, will go through lane3. It seems that this category of vehicles does not need to wait for the traffic light but the vehicle of the other two categories (especially the ones who intended to go straight) blocks their way to the right).
- For a given vehicle in row i, the time takes to reach to the frontline of the intersection could be calculated as below (see Table 2):
  $(i-1) \times$ (estimated average time needed to pass one row)

Table 2: Estimated Average time takes for vehicles to move from row i to row i-1 (seconds)

Street	Bakeri1	Bakeri2	Besat1	Besat2
Estimated Average Time	2.675	2.4666	2.6818	2.3243

According to the above descriptions and assumptions, the four-stroke cycle simulation model is represented in Figure 3.
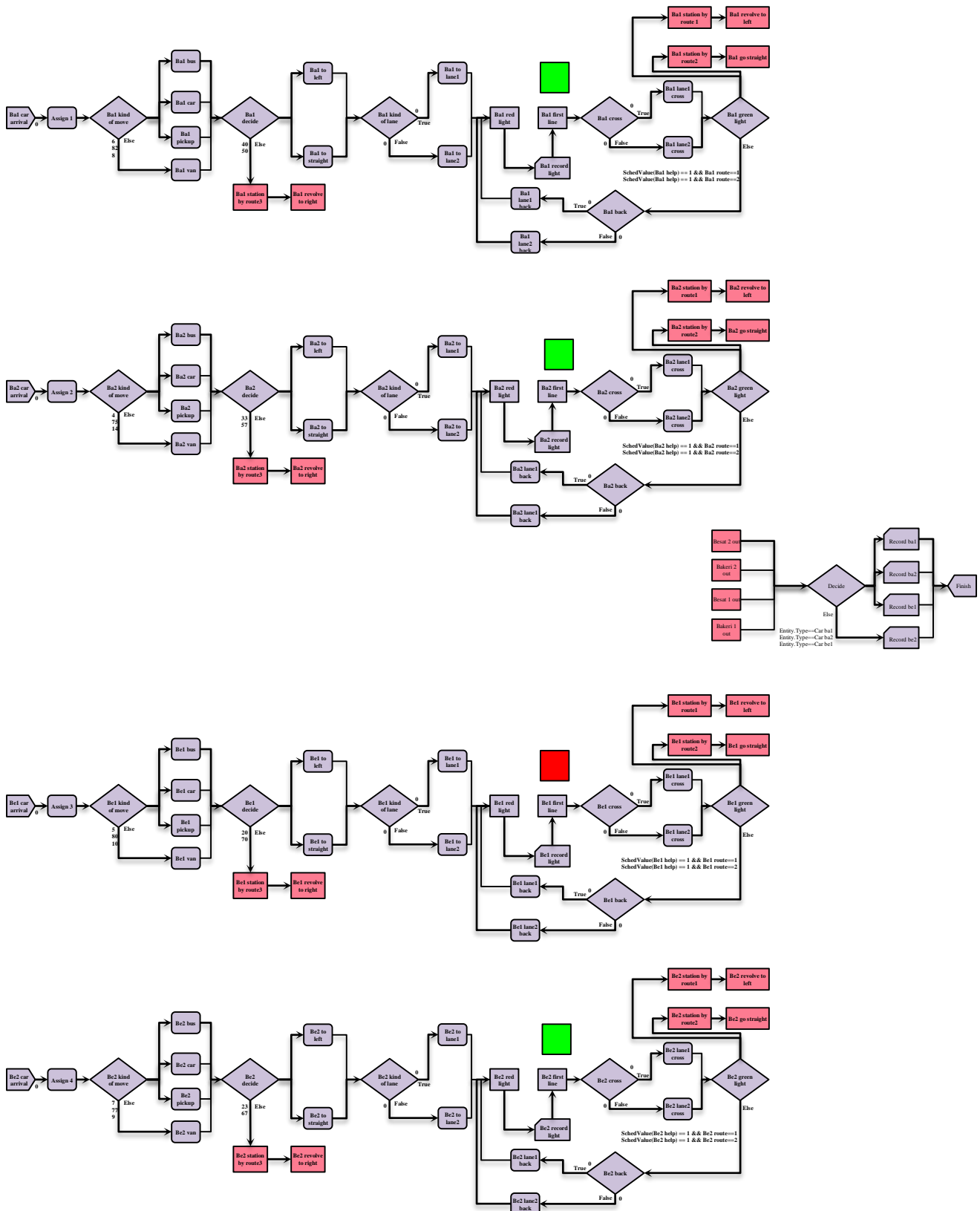
Figure 3: The proposed simulation model

4.2. Simulation numerical results

Table 3 represents the average time that vehicles spend in the system (average cycle time), according to real data gathered from the intersection in the current situation (three-stroke cycle traffic light).

Table 3: Lights cycle and vehicles average cycle time in the current system

		Bakeri1	Bakeri2	Besat1	Besat2	Average
Lights cycle	Green	40	35	50		−
	Red	85	90	75		−
Vehicles average cycle time		69.19	64.24	58.14	67.11	64.67

A preliminary four-stroke cycle with the cycle time 125 seconds is designed and tested in the developed model. The results obtained from the model shows a slight improvement in the vehicles average cycle time (Table 4 scenario 1). This improvement becomes an incentive to design and assess some other scenarios. In this regard, in order to find high quality and near optimal solutions, several lights cycle options for the traffic light is designed and tested according to the traffic volume for each street and entities average time spent in the system is calculated. Table 4 shows six other proposed alternatives (with different cycle times of 115, 120, 125 and 130 seconds) for traffic light timing along with their respective results and system performance obtained from the simulation model. Each scenario is run 50 iterations.

Table 4: Lights cycle and vehicles average cycle time in different scenarios

			Bakeri1	Bakeri2	Besat1	Besat2	Average
Current state	Lights cycle	Green	40	35	50		−
		Red	85	90	75		−
	Vehicles average cycle time		69.19	64.24	58.14	67.11	64.67
Scenario 1	Lights cycle	Green	40	35	25	25	−
		Red	75	90	100	100	−
	Vehicles average cycle time		57.02	55.76	63.38	63.21	59.84
Scenario 2	Lights cycle	Green	35	35	25	25	−
		Red	85	85	95	95	−
	Vehicles average cycle time		55.29	47.33	61.33	59.81	55.94
Scenario 3	Lights cycle	Green	40	30	25	25	
		Red	80	90	95	95	
	Vehicles average cycle time		52.27	54.04	59.27	51.81	54.34
Scenario 4	Lights cycle	Green	40	35	30	25	−
		Red	90	95	100	105	−
	Vehicles average cycle time		58.01	54.85	60.1	64.08	59.26
Scenario 5	Lights cycle	Green	40	35	25	30	−
		Red	90	95	105	100	−
	Vehicles average cycle time		57.5	53.07	61.69	57.98	57.56
Scenario 6	Lights cycle	Green	35	30	25	25	−
		Red	80	85	90	90	−
	Vehicles average cycle time		57.16	51.46	61.04	53.23	55.72
Scenario 7	Lights cycle	Green	30	25	30	30	−
		Red	85	90	85	85	−
	Vehicles average cycle time		55.12	53.55	55.53	51.4	53.9

According to the results, the timing proposed in Scenario 7 has the minimum average time that vehicles spend in the intersection and therefore, leads to a better timing than the other alternatives and the current situation (with a three-stroke cycle light).

5 Conclusion

   Traffic light timing is one of the most practical and cheapest solutions to deal with congestion problem of intersections in crowded urban areas. Different methods have been introduced in several types of research for traffic light timing. In this paper, a simulation model is developed with a four-stroke traffic light for an intersection in which a three-stroke traffic light is being used currently. The proposed model aims to minimize the average time that entities (vehicles) spend in the system (intersection). In this regard, different scenarios are designed and tested in the proposed model and the one with the best response in average time spent in the system is selected. The simulation results demonstrated the effectiveness of the four-stroke traffic light timing.

As for directions of future researches, optimization methods should be used in order to obtain better solutions according to cycle time and lights cycle time. Also, issues like the implementation of meta-heuristic and learning algorithms in obtaining better traffic scheduling, studying the problem under a dynamic and online condition with a network structure, etc. should be surveyed in such problems. But before offering varied solutions with scientific approaches, promote a culture of driving, and more importantly, pedestrians should be placed on the agenda of decision makers.

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