A Fuzzy Adaptive In-Vehicle Traffic Control Method for Isolated Intersections Using Car-to-Car Communication

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Abstract

Keywords: Intelligent transportation systems, Traffic control, Vehicular ad hoc network (VANET), car-to-car communications, Fuzzy control system.

One of the most important applications of Vehicular Ad-hoc Network (VANET) is the traffic control application. One of these applications is adaptive signal control at the intersections. This paper, using Vehicle to Vehicle (V2V) communication, proposes a virtual (in-vehicle) signal control system. Using Fuzzy control system, it proposes an adaptive signal timing system at isolated intersections without traffic light. After calculating length of cycle and optimum phase setting using Webster equation, this paper uses a fuzzy control system for best decision making for extending green light period in different lanes of intersections. In proposed fuzzy system, in addition to considering the number of stopped and crossing vehicles, intersection emergency state is determined according to the number of emergency vehicles, remaining red light time and emergency coefficient of each vehicle. Simulation results of proposed model clarified the least delay time, queue length and travel duration compared Webster equation.

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1. Introduction

Reduction of the traffic flow is one of the most important issues in vehicular ad hoc network (VANET) which has a great importance today. The main motivation of vehicular systems is safety and prevention of life and property losses in traffics [1]. Now since intersections have a major role in traffic flow trend, in order to control urban traffic, traffic lights are used. Traffic lights react with the increase of traffic flow. The most important progress which has been made yet about traffic lights is the application of sensors and cameras to produce online maps. Many methods have been proposed for traffic control at intersections which apply many methods to collect traffic data [2]. One of the data collection methods is applying a wireless sensor network to determine the setting and the length
of traffic light phases. A sample of these systems has been proposed by B. Zhou and et al [3] for adaptive traffic light control using real traffic data. Also Al-Khateeb et al [4] proposed an algorithm for determining dynamic traffic light using real time, but RFID technology was applied for real time traffic information. The majority of common systems in USA are based on complicated mathematical models which optimize the traffic light variables (time of cycle, green time). These systems consist of SCATS [5] and SCOOT [6] which use sensors in an intersection. These systems cannot produce precise data if car queue increases. Now there are fewer articles which evaluate vehicle networks (V2I and V2V communications) as the resource for real time traffic information. Gradinescu et al present a method which uses vehicle communication messages for collecting real time information. Then there is a simple algorithm which is based on Webster [7] unique explanation for determining cycle period and green light time. Also Maslekar and et al [8] used an analytic solution for adaptive traffic light. So VANET network (which is based on cluster and dispersion technique) was used for collecting traffic density data. Michel Ferreira and et al [9] present a novel method for traffic management at intersections only by using V2V communications. Their proposed algorithm does not need to road side equipments (RSE) or physical traffic light. Above mentioned researches present a simple algorithm for determining traffic light cycle and phase setting. A common method is Webster equation which cannot directly be compatible with adjusted system. Fuzzy logic controllers have the ability to perform real life laws. Like humans, they guess allowable traffic control route in a given intersection. In this proposed plan, only V2V communications are performed to control traffic in isolated signalized intersections. Therefore, in addition to calculation of cycle time and optimum phase setting by Webster formula, Fuzzy rules are used to decide about the best green light time at different lanes of the intersections. In a related proposed Fuzzy system, in addition to the number of green light crossing vehicles and stopped cars, intersection emergency state is determined according to the number of emergency vehicles, the distance between an emergency vehicle and intersection, remaining red light time and emergency coefficient of each vehicle. Consequently, the simulation results of this model show the least delay time, queue length and duration of travel. The remainder of this paper is organized as follows: Section II briefly reviews the VANET. Section III compares adaptive and pre-timed traffic light control, followed by a description of the case study and the proposed algorithm in section IV. Section V, VI describes the simulation environment and presents the experiment results. Section VII concludes the paper.

2. Vehicular Ad-Hoc Network (VANET)

Vehicular ad hoc network (VANET) is a technology in which vehicles are considered as mobile nodes and road side equipment are regarded as fixed communicative infrastructure. In these networks, vehicles are designed in such a way that will be able to interact information with each other according
to the needed band width [10]. VANET systems are divided into three categories according to the kind of relationships between nodes as follow:

A. Inter-vehicles communication systems (IVC):

These systems are totally independent from infrastructure and roadside equipments are not needed for communications. In these systems, vehicles exchange information.

B. RoadSide-To-Vehicle communication systems (RVC):

In these systems it is supposed that all communications only exist between vehicles and roadside units. In fact, if two vehicles want to connect with each other, this connection is done via roadside unit.

C. Hybrid vehicle communication systems (HVC):

In this system, in the case of lack of connection by one step with roadside unit, it is done through several steps via other vehicles [11].

Vehicular ad hoc network (VANET) is a growing method which is recommended for traffic control by research institutes and industries. The main reason for research about VANET systems is developing safe traffic and using it everywhere. The majority of adaptive traffic lights benefit from collected data to produce online maps by sensors, high processing cameras and sensor loops. To name a few purposes of signal control mechanisms, we can mention some items such as minimizing mean delay time (for vehicles near the intersection), coordination of car groups between intersections, reduction of queue length toward one intersection and even reduction of pollution and fuel costs [1]. VANET is a technology which may take an important role to control the traffic flow.

3. Performance of the Traffic Lights

The main reason for creation of vehicular systems is to provide comfort for drivers and travelers. The first traffic signals for urban areas were made in 1917 in Salt Lake City with 6 intersections which were controlled by a traffic light. Automated control for traffic lights was offered for the first time in Texas in 1992 [12]. These systems were based on the precision of the sensors or computer images. Then the proposed method made use of connected vehicles. Adaptive traffic lights can be divided into 2 steps: First step is related to collection of real traffic data. The second step is the algorithm for processing traffic data which are used for determining cycle time and the green light timing. A traffic light may be defined with three main elements i.e. cycle time, green light timing and phase sequences. Cycle duration is the total duration of red, yellow and green phases which are given to all intersections’ lanes. Therefore, traffic lights can be divided into three categories: pre-determined, active and adaptive traffic lights.
**Pre-timed traffic lights:** These are the most basic and simplest kind of traffic lights. Cycle duration and green light times are determined before the activation of traffic light and they are not sensitive to sudden changes surrounding the traffic light.

**Actuated traffic lights:** These kinds of traffic lights are considered a new version of pre-determined traffic lights. Also in this kind of traffic light, duration and green light times are determined before the activation of traffic light. But traffic lights have the ability to respond to surrounding events and changes and are equipped with sensors and traffic controllers.

**Adaptive traffic lights:** These kinds of traffic lights compute cycle duration and green time according to the controlled traffic data in a real time situation of surrounding environment. Several sub units may be defined on the basis of data collecting techniques and some algorithms were used for computing different parameters of traffic lights. Consequently, red and green light times are determined. This is the main focus of our discussion [13].

**Mathematic model:** Webster formula is a well-used tool for determining optimum cycle duration for a traffic light according to the traffic flow information’s and lost times (red and yellow times). The equation number 1 shows the request levels (presence of vehicles) by a parameter which is named critical flow or saturation flow rate. This parameter is a ratio of recorded current flow rate which is more than road situation flow rate (obtained from exchanged messages):

\[
C_0 = \frac{1.5 \cdot L + 5}{1 - \sum_{i=1}^{n} y_i}
\]

In which, \(C_0\) is optimum cycle duration, \(L\) is lost times, \(y_i\) is critical ratio of group road; I and n stands for the number of roads’ groups. By road part group input traffic flow may access to intersections coincidently. This system may adjust changes in input traffic flow. This algorithm uses transferred information’s of messages. These messages include some information about position, speed, acceleration and etc. since these messages are received in each step of simulation a specified function is needed to end information to a perfect cycle. Equation number 2 may be used to calculate optimum cycle (\(C_0\)) according to estimated frules. Also green times may be calculated according to calculated critical ratios in equation 2 as follow:

\[
g^i = \frac{y^i}{Y} (C_0 - L)
\]

In which \(g^i\) is green time that should be related to the group of the \(i\) part of road. Using this algorithm:
1) Red waiting times are automatically changed into green if there is no request in opposite lane. In the other word, excessive red time is removed. 2) If there is no request in opposite lane, extension for green time is ended. This extension for green time only considers presence of vehicles in current lane and no intelligent decision making is considered in relation to other lanes and the kind of vehicles.

**Intelligent methods:** Traffic control system is a non-linear, Fuzzy and uncertain system, traditional modelling and control are not good methods. With growing trend of computer technology, artificial intelligent methods such as Fuzzy logic, neurotic networks, evaluation algorithms and etc have been developed dramatically. There are two common artificial intelligent techniques for intelligent decision making:

1) FES (Fuzzy expert systems) [14-19]
2) Artificial ANNS [20-25]

In ANNS systems, decision making is performed using experience or collected knowledge. These systems are among the most successful solved samples. ANNS systems use different methods and mathematical models can benefit from computer calculations (beside human calculations). ANNS may be used for calculating complex problems. They have an adaptive property which let each cell (in its network) be changed in response to experience. Then neural network can learn and change by itself. ANNS systems often were used to simulate FES systems. In a FES system, problems are solved using a humanistic intelligent computer [17]. The first Fuzzy controller was presented by Pappis and Mamdani [18] for 2-ways intersections. Fuzzy controller has 3 inputs and one output for single intersection. Each 10 seconds, decision for extension of green time is made 7 seconds after beginning of green time. Nakatsuyama and et al [14] designed a Fuzzy controller which evaluated the capacity of only one way. Chiu [16] presented Fuzzy logic for controlling multiple lanes intersections in a network of 2-ways streets (without round turn). His simulation results show that Fuzzy logic controller may significantly reduce mean delay time. Mohamed Trabia [17] designed a Fuzzy logic controller for responding to real time traffic requests. In such methods, Fuzzy controller use sensor loops to measure route flow and estimate the queues. Sensors only recognize the presence of vehicles and do not have complete information about them. In addition, with increasing length of queue in different lanes of intersection, they cannot produce precise data.

4. Proposed Model

Fuzzy logic is a powerful tool for non-linear problems and uncertain processing and it can offer Fuzzy and qualitative knowledge and simulate human intelligence. A traffic police may conduct traffic effectively and rapidly. In fact, he infers and makes decision using only qualitative knowledge. Inference and decision making process at single intersections may be defined as follows: For each route (lane), more green time is allocated if many vehicles would arrive. Otherwise, less green time is
allocated or next phase should be performed. In other lanes, when phase is changed, evaluation of traffic requests is necessary [19]. Our proposed system is shown in Figure 1. First, traffic data related to near vehicles (which are passing at intersection lanes) are collected. Then, by selecting leader using V2V communications, the optimum cycle length is calculated by formulas (1) and (2). After determining green time and sequence of different phases of intersection, for extension of green time (for input vehicle’s path) presented Fuzzy system will be used. Therefore, Fuzzy controller (intersection’s leader) will determine necessary changes to environment. Proposed solution results in improving the single intersection time setting via combination of mathematic solutions and Fuzzy laws. In addition, application of real traffic information together with complete information of cars’ behaviour such as drivers’ behaviour and kinds of cars is considered.

**Fig. 1: The process of proposed model**

In this system communication is done only through V2V and leader of intersection knows the whole configuration of intersection and creates an optimum timing using proposed algorithm and precise traffic data and acts like a traffic police.

**Intersection Configuration:** For designing supposed single intersections, following characteristics have been considered:

1- Supposed intersection is a single 4-ways with input traffic lanes from north, south, east and west.
2- When vehicles are passing from north way, south and east and west ways should be in stop mode. When vehicles are passing from south way, north and east and west ways should be in stop mode. When vehicles are passing from east way, north and south and west ways should be in stop mode. When vehicles are passing from west way, south and east and north ways should be in stop mode.
3- According to the designed motion model, vehicles at allowed area of intersection are not allowed to change their current lane. Each vehicle is allowed to pass the intersection directly and turning to right and left sides.
Leader selection process: Vehicles are equipped with DSRC and benefit from GPS system and common digital road map. As mentioned before, there is not a physical traffic light in this system. So a Virtual traffic light (VTL) and central station and geographical routing protocol of VANET is needed. Each vehicle has an applied unit including a data base which keeps the intersection’s data and acts as a virtual traffic light. When vehicle arrives into intersection, applied unit is checked to see: is a collision between vehicles possible or not? Or traffic light order should be performed? In this case, traffic light order must be performed. When virtual traffic light is needed, one of the closest vehicles to intersection is selected as a leader and must be stopped with red light at the intersection. The range of leader selection should not be located at a distance more than 30 meters (in relation with center of intersection). The selected leader knows the whole intersection’s Configuration according to messages that receives from other cars. Until the time that leader has been stopped in intersection, it calculates traffic light timing using proposed algorithm and distribute it among all vehicles around itself. Since leader is the nearest vehicle to the intersection and there is Omni- directional communication, as a result other vehicles also follow proposed timing algorithm accordingly.

Timing algorithm: In the first step of timing, optimum cycle length is calculated by formulas number 1 and 2. Requested capacities for each route of cycle is calculated before the cycle length. After calculating cycle length, individual time of each lane and their Configuration is computed. But regarding determined green time, there is a possibility that no vehicle enter in passing lane but green time still remains, which in this case green time must be ended. Webster Formula cannot be compatible with adaptive system directly and it is possible that the number of passing vehicles are very higher than other lanes which in this case, green time must be increased. It should be considered that existing emergency vehicles in different lanes must be regarded for increasing green time. This results in the fact that no fuzzy change is done and consequently performance measures of intersection including delay time and queue length are reduced. Proposed algorithm combines Fuzzy laws and mathematical solutions and improves timing of the existing vehicles in intersection.

Fuzzy control system: Before ending green time for passing vehicles in intersection, Fuzzy controller checks whether green time should be ended or not. Figure (2) shows proposed Fuzzy system. Another issue is emergency vehicles such as police and medical emergency vehicles in different lanes of intersections. In this situation, green time extension must be controlled. This fact is discussed later.
Fuzzy control system

**Fuzzy inputs and outputs:** Fuzzy Inputs and outputs of green time should reflex the traffic crowd. The number of existing vehicles in lane is named „arrival” and the number of stopped cars is named as „queue” and emergency degree of stopped vehicles at intersection is defined as „compulsive” which is the output of emergency Fuzzy control system. Therefore, according to Fuzzy inputs, extension time is determined by Fuzzy output. Table 1 shows the linguistics variables of Fuzzy inputs and outputs to reflex traffic of vehicles.

<table>
<thead>
<tr>
<th>Input vehicles</th>
<th>Stopped vehicles</th>
<th>compulsiveness</th>
<th>Green time extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>Very low</td>
<td>Zero</td>
<td>Zero</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Very high</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Very high</td>
</tr>
</tbody>
</table>

**Inference rules and engine:** Fuzzy theory defines the Fuzzy operator for Fuzzy sets in simple condition (if-then) using possible states of “AND” rules. Mamadani controller decides about Fuzzy laws using “MIN” and “MAX” operators. Four states have been considered for each Fuzzy input variable and it is possible to consider a combination of $4^3$ inference rules according to number of input variables. Following, two cases of above mentioned laws have been noted.
For example, if the number of passing input vehicles at intersection is high and number of stopped vehicles in other lanes is very low and compulsiveness of intersection is low, then green time will increase into medium. Now if the number of passing input vehicles is very high and stopped cars in other lanes are very low and compulsiveness of intersection is zero, so green time extension is very long. Graphical representations for belonging function of Fuzzy variables are shown in Figure 3.

Traffic data of existing vehicles at intersection’s lanes is collected for Fuzzy input variables and green time extends according to Fuzzy output.

In Fuzzy systems, Number “One” is a complete belonging. For example, as you see in Figure 3 (a), five vehicles are defined as “low”. There is a “high” Fuzzy set with complete belonging i.e “1” at 12 seconds area for Fuzzy output variable and etc. Configuration of these functions is done according to the expert observation of system and environment. But the center and width of belonging functions of these Fuzzy subsets are simply changeable and are adjusted according to different traffic conditions. So rules can be adjusted in Fuzzy controller. These rules act as human intelligence and optimum selection for green time extension will be possible.

The Fuzzy control for emergency state of the intersection: One of the VANET advantages is complete information about existing vehicles on the road. Suppose that many emergency vehicles such as police and medical emergency arrive into intersection and be stopped which in this case, even extension of green time could not offer proper system. In the other hand, vehicles are different depending on their degree of compulsiveness, distance to intersection, remaining red time and their
numbers. So the degree of intersection’s compulsiveness is injected into main system as one of the Fuzzy outputs.

**Fuzzy inputs and outputs:** Fuzzy output and input variables define the compulsiveness of the intersection. As a result, having the Fuzzy laws with Fuzzy inputs including: the number of emergency vehicles (countcomp), the distance between emergency vehicles into intersection (intervalcomp), remaining red light time (redlightcomp) and compulsiveness coefficient of each vehicle (coefcomp) it will be possible to access the desired Fuzzy output (which is the compulsiveness of intersection). The linguistics variables of inputs and outputs have been presented in Table 2.

**Inference Rules and Inference Engine:** For each fuzzy input variable, 4 modes have been considered and regarding input variables it may be possible to consider 43 inference rules.

| Table 2: Fuzzy inputs and output for compulsiveness of intersection and linguistic variables |
|---------------------------------|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Compulsiveness of intersection  | Redlightcomp                    | Coefcomp        | Intervalcomp    | Countcomp       |
| Zero                            | low                             | Very low        | Low             | Very low        |
| Low                             | medium                          | Low             | Medium          | Low             |
| Medium                          | high                            | Medium          | High            | Medium          |
| High                            | Very high                       | High            | Very High       | High            |

Two samples of above mentioned rules were discussed below:

If (countcomp is very small) and (Intervalcomp is small) and (Redlightcomp is small) and (coefcomp is very small) then (compulsive is zero)

If (countcomp is small) and (Intervalcomp is long) and (Redlightcomp is long) and (coefcomp is medium) then (compulsive is small)

For example, if stopped cars at different lanes of intersection are very low, the mean interval to the beginning of the intersection is low, compulsive coefficient of vehicles is very low and remaining red time is low, then compulsiveness of intersection is zero. The graphical representation of belonging functions of Fuzzy variables has been shown in Figure 4. Vertical axis is the degree of belonging for each Fuzzy variable. For Fuzzy input variables, traffic data are collected using existing vehicles on intersection lanes and the compulsiveness of intersection is determined according to Fuzzy output. In fuzzy sets, number ,one’ is complete belonging. For example in figure 4 (a) the number of 30 vehicles is considered medium. For Fuzzy output variable, a high Fuzzy set is in sixth part and etc. The configuration of these functions is based on the observation of expert from environment and system.
5. Analyze and Simulation

The main goal of adaptive control at single intersections is minimizing delay and total trips of input vehicles. The arrival of vehicles in software are totally randomly. The vehicles enter from 4 lanes and exit from other 4 lanes randomly. The timing of simulation is presented with 3 different densities including low, medium and high. This causes that presented algorithm is evaluated at different traffic conditions. In this simulation, an intersection with 25 meters width and mean speed of 15 Km/h has been considered. The simulator designs vehicles motions for input cars into intersection. There is a random distribution of allowed lanes for each vehicle. Each vehicle may communicate with other cars in a 300 meters distance and save its neighbors’ information.

Table 3: simulation properties

<table>
<thead>
<tr>
<th>Simulation Scenario</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation duration</td>
<td>60 Seconds</td>
</tr>
<tr>
<td>Intersection width</td>
<td>25 Meters</td>
</tr>
<tr>
<td>Length of vehicle</td>
<td>6 Meters</td>
</tr>
<tr>
<td>Limit of transmission</td>
<td>300 Meters</td>
</tr>
<tr>
<td>Number of vehicles(per minute)</td>
<td>30-70</td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>15 Km/h</td>
</tr>
</tbody>
</table>
Simulation of our proposed work has been done using C# program writing language. In addition, Fuzzy library and Pappis and Mamdani method were utilized for simulation. In this simulation, a single 4-ways with random input and different densities were designed. Our work covers vehicles motion on the basis of micro wave motion model. Traffic light and other parameters including drivers’ behavior (such as limitations of speed and acceleration) were applied. In this simulation, vehicles are designed in a way that is able to connect with each other according to DSRC standard and communication protocol of 802.11 in a 300 meters range. So we suppose that each vehicle can be equipped with wireless communication and GPS receiver. Each vehicle has an individual code and arrival time and position of each vehicle will be recorded. Also it is supposed that there is not any lost messages. Adaptive algorithm will be compared according to Webster equation and our proposed algorithm. Fuzzy inputs and outputs were calculated in the proposed algorithm. Green time extension cause lack of phase change and better performance of intersection.

6. Simulation results

In this scenario, Webster adaptive and our proposed algorithms were compared. Gradinescu and et al showed that using Webster adaptive algorithm is much better than pre-timing algorithm. This simulation was arranged for 60 minutes which in first 20 minutes low density of vehicles have been considered with 400 vehicles per kilometer per hour. For second 20 minutes, medium densities of vehicles have been considered with 700 vehicles per kilometer per hour. Also for last 20 minutes, high densities of vehicles have been considered with 150000 vehicles per kilometer per hour. Therefore, our simulation results show that proposed algorithm gives more acceptable results at different densities. A sample of work has been presented in figure (5).
The inputs and outputs of Fuzzy system algorithm have been shown in table (4). Obtained results are categorized in 3 times i.e. first, second and third 20 minutes. The total number of vehicles and green time at the end of each 20 minutes, and also mean values for compulsiveness of vehicles were calculated. Emergency (compulsive) vehicles were shown with green color. The more their compulsiveness, the more their colors change into yellow color. Therefore, in proportion to the number of input vehicles from green light and stopped vehicles at intersection and compulsiveness of intersection, green Fuzzy time will be increased.

For example, in first 20 minutes, extension of green time may increase more according to the number of stopped cars and compulsiveness of intersection. At third 20 minutes, as vehicle density rise and number of stopped cars increase, compulsiveness of intersection may increase and green time is reduced. In next parts, we will show that how these values improve simulation measures for intersection enhancement. Input flow of vehicles into intersection has been presented in figure (6). This input flow of vehicles has been presented according to adaptive timing algorithm and Fuzzy adaptive algorithm.

<table>
<thead>
<tr>
<th>Simulation duration</th>
<th>Input vehicles</th>
<th>Stopped vehicles</th>
<th>Compulsive vehicles</th>
<th>Compulsive coefficient of cars</th>
<th>Interval for emergency vehicles</th>
<th>Remaining red time</th>
<th>Compulsiveness of intersection</th>
<th>Fuzzy green time extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>First 20 minutes</td>
<td>102</td>
<td>846</td>
<td>288</td>
<td>0.28</td>
<td>9</td>
<td>4</td>
<td>0.13</td>
<td>125</td>
</tr>
<tr>
<td>Second 20 minutes</td>
<td>182</td>
<td>1456</td>
<td>308</td>
<td>0.38</td>
<td>7</td>
<td>5</td>
<td>0.15</td>
<td>164</td>
</tr>
<tr>
<td>third 20 minutes</td>
<td>335</td>
<td>2681</td>
<td>364</td>
<td>0.39</td>
<td>7</td>
<td>4</td>
<td>0.12</td>
<td>119</td>
</tr>
</tbody>
</table>

Fig. 6: Input flow of vehicles

One of the reasons that the proposed algorithm can enhance system performance is that in each time step and regarding different densities, better timing is offered and more vehicles may pass at
intersection. Performance measures of intersections are mean trip time for vehicles at different lanes. Each vehicle, at the time of arrival into intersection till the time of exit from intersection, travels some part of the lane with its individual speed. Therefore, as it is presented in Figure 7, the less this mean time, timing is improved and more vehicles can pass. One of the most important measures of performance of intersections is the delay control and queue length. Delay control for each passing vehicle is calculated.

![Fig 7: delay time average for vehicles](image)

This is equal to the time that each vehicle spends at red light (when it is stopped). Figure 8 compares the mean delay time for vehicles at intersection. It shows that in all three scenarios of vehicle's density, proposed algorithm leads to improvement. If algorithm is implemented with more optimum timing, the delay can be reduced and consequently shorter queue length may be created in different lanes of intersection.

![Fig (8): delay time average for vehicles](image)
7. Conclusion and Future work

In the proposed design at first step, Webster mathematical solution was used for calculating optimum cycle length. The majority of performed works using connected vehicles technology, have applied above mentioned algorithm to control intersections. This algorithm may not be compatible with adaptive system directly. So by using Fuzzy laws which reflex human wisdom and intelligence, we may measure different situations of lanes such as high density of traffic. Therefore, green time extension or reduction is adapted. According to the simulation results, our proposed algorithm caused an improvement in traffic flow at single intersections in different traffic situations. In the proposed system, pedestrian passing time has not been adapted according to minimum green time. In addition, proposed system may be used for connected multi lanes intersections. The future study need to be conducted to maximize number of passing pedestrians in a traffic light by minimizing optimum cycle length.

References


