Smart Cities: Study and Comparison of Traffic Light Optimization in Modern Urban Areas Using Artificial Intelligence

Mustapha Kabrane, Salah-ddine Krit, Lahoucine El Maimouni
Laboratory of Engineering Sciences and Energ, Polydisciplinary Faculty of Ouarzazate, Ibn Zohr University, Morocco
Email- mustaphakabrane@gmail.com, salahddine.krit@gmail.com, la_elmaimouni@yahoo.fr

Abstract—In large cities, the increasing number of vehicles private, society, merchandise, and public transport, has led to traffic congestion. Users spend much of their time in endless traffic congestion. To solve this problem, several solutions can be envisaged. The interest is focused on the system of road signs: The use of a road infrastructure is controlled by a traffic light controller, so it is a matter of knowing how to make the best use of the controls of this system (traffic lights) so as to make traffic more fluid. The values of the commands computed by the controller are determined by an algorithm which is ultimately, only solves a mathematical model representing the problem to be solved. The objective is to make a study and then the comparison on the optimization techniques based on artificial intelligence to intelligently route vehicle traffic. These techniques make it possible to minimize a certain function expressing the congestion of the road network. It can be a function, the length of the queue at intersections, the average waiting time, also the total number of vehicles waiting at the intersection.

Keywords—Smart Cities, Traffic light controller, Optimization, Algorithms, Artificial Intelligence, Average Waiting Time, Length of the queue.

I. INTRODUCTION
Everywhere in the world, traffic congestion continues to be a major problem in most cities, because of the increasing number of vehicles. Among the negative consequences of this phenomenon of congestion (especially in peak hours [1]) on the environment and the users of the road network [2].

In practice, several solutions can be expected such as the construction of new roads, keeping a special track for public transport [3], and improvement of the road signaling system [4-9]. Two solutions are suggested:

- The first one (infrastructure construction) is the more costly and requires a very expensive strategic investment, and sometimes geographical constraints make it impossible to build new roads or modify the infrastructure.

- The second solution which is more sensible relates intelligently relates to the existing infrastructure. Such as the use of traffic signals. The latter play an important role in solving these problems as they control the flow of the city's road network. This traffic control system (traffic lights that are controlled by a light controller) can be:

  ✓ Fixed light plan (Static): State machines that specify the green and red times on each line of lights of an intersection as well as their sequencing. The orders are set only once taking into account traffic forecasts, and they do not change. This method quickly shows its limits when traffic conditions change rapidly. It then becomes necessary to deploy efficient methods, one sees there is the need for more dynamic systems which have been the subject in recent years of particular attention.

  ✓ Real time controllers (Dynamic) : In real-time techniques, the system must be able to adapt immediately (or very briefly) to traffic conditions, and optimize the control of fires. In addition to the algorithms which enable to control traffic, such a system receives information on the state of the traffic which has been sent by the sensors placed on each lane [10,11], which makes it possible to recalculate the duration and the synchronization of the lights in order to minimize the congestion i.e to minimize the time average waiting time at lights, and length of queues. So it is very important to study and analyze algorithms that manage traffic lights in order to optimize them.

II. LITERATURE REVIEWS
Dynamic models of the literature which can be the basis for theoretical studies are represented sometimes by trying as much as possible to reality. Some of these models are quoted: this model is based on the deployment of two sensors by
one or more intersections (Fig. 1). From the collected data, we know the average size of a queue is defined on a track. The green light time is calculated in relation to the size of these queues, thanks to algorithms which are integrated into the traffic light controller.

![Diagram of a 4-way intersection and 4 traffic lights]

**Fig. 1. The literature Model of a 4-way intersection and 4 traffic lights**

A. **Queue theory**

The use of queue theory is a simple and efficient method for modeling queues at intersections. This model is based on the deployment of two sensors by one or more intersections. From the collected data we can know the average size of a queue on a track. The green light time is calculated in relation to the size of these queues, thanks to algorithms which are integrated into the traffic light controller.

- The solution suggested by Tubaihat and all [12], is to rely on a gain system, which corresponds to one track to the number of cars between two sensors.

\[
gain = \begin{cases} 
  x & \text{number of vehicles passed} \\
  0 & \text{reset every } t \text{ cycles}
\end{cases}
\]

So, each possible phase is evaluated by the sum of the gains of its movements. The phase which is the most loaded is therefore selected first, until its number of vehicles passes below another or the maximum fire time is exceeded.

The authors have thus listed different combinations of fire conditions (red, arrow right, left arrow, green, etc.) and have established three plans of fixed lights, with respectively 4, 6 and 8 phases, on which they perform Simulations.
Khalil M. Yousef and all [15] are based on a deployment of two sensors per lane. They define a mechanism for managing fires at a simple intersection by modeling each movement as an M / M / 1 queue [16]. They suggest two algorithms:

- Traffic System Communication Algorithm Description (TSCA) allows communication between all components of the control system (sensor nodes, base station) of the traffic in order to regulate the duration of all traffic signals using the Traffic control.
- Traffic Signal Time Manipulation Algorithm Description (TSTMA) The main objective of the TSTMA is to adjust the duration of the traffic signal in an efficient and dynamic manner in order to minimize the average queue length (AQL) and the average waiting time (AWT) and to calculate The duration of the red / green light as a function of the total number of vehicles, using the Conflict directions matrix.

These algorithms interact between them and with other components of the system for the proper operation of the control system.

- B. Zhou and all proposed in [14], an adaptive traffic light control algorithm that adjusts the sequence and length of traffic signals according to the real-time traffic detected taking into account the traffic flow, waiting time. The objective is to determine the optimum duration of the green light.

This algorithm contains 3 steps:
- Vehicle detection
- Determination of the sequence of the green light
- Duration of green light

- The authors in [18] approach the theory of queues using an intelligent traffic light control system, based on data collected by a wireless sensor network deployed on each lane. This system optimizes the following elements:
  - Minimize average waiting time
  - Maximize Average Service Time.
  - Average number of cars of the same queue not passing from the first time (Minimize).

- S. Faye and all in [19] proposed a distributed algorithm to control traffic lights in urban environments. This proposed solution is flexible in the management of conflicts (one per phase instead of one per cycle). The algorithm calculates the maximum duration of the green light according to the longer queues. Vehicles are detected by the sensors placed before and after the light.

They introduced a new model that avoided the use of a central point (Base Station) to locally manage the intersection. Their algorithm uses a conflict matrix, which describes all possible cases of contradictory movements and results in the creation of phases, in order to manage the traffic light in an optimal and more efficient way. In [20,23] the authors presented and evaluated Distributed and Adaptive Intersections Control Algorithm (DAPIOCA). This algorithm uses a network of wireless sensors, which aims to collect information on vehicles located on the queue in order to calculate the duration of the green light, and to apply a traffic management strategy following the steps of the algorithm (Vehicles logging, Counting, Next phase definition, Information propagation, and Inter-intersection vehicles monitoring), which defines the sequence and duration of green lights in an intelligent transport system in the case of several intersections in order to reduce the time (AWT) of the users. This algorithm uses the data collected by a wireless sensor network. Each intersection of can communicate with its adjacent intersections through this network (be limited to a communication distance to a jump (a neighboring intersection)). The objective is to create a wave sequence of successive green lights, synchronized so that the vehicles do not slow down. It is among the most effective techniques to unload a network because it makes traffic more fluid.

**B. Fuzzy Logic Control**
The approaches in [13,21, 26, 27] used fuzzy logic for traffic signal control. A few of them are summarize below:

- Zou and all. [13] use fuzzy logic to optimize the control of traffic lights: They determine the time of a light according to the number of vehicles present on the line:

  To a number of vehicles corresponds an interval defining a duration of fire. The vehicles are detected by a sensor placed on each line. This allows to establish the duration of the lights according to the number of vehicles per minute (Table 1).
Table 1 Category of traffic flow based on fuzzy theory [13]

<table>
<thead>
<tr>
<th>Number of vehicles</th>
<th>Small</th>
<th>Medium</th>
<th>Great</th>
<th>-tremendous</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less than 5/min</td>
<td>5/min to 10/min</td>
<td>10/min to 15/min</td>
<td>More than 15/min</td>
</tr>
<tr>
<td>Green light time</td>
<td>10s</td>
<td>20s</td>
<td>30s</td>
<td>40s</td>
</tr>
</tbody>
</table>

If the number of vehicles passes is less, for example, five vehicles per minute on one direction, then the corresponding light is set to ten seconds. Therefore the number of vehicles corresponds to an interval defining a duration of fire. This is the principle of fuzzy logic.

- N. Shahsavari For and all in [21] approach a new multi-objective mathematical model to optimize the synchronization of the traffic signal of a simple intersection, which minimizes the length of traffic queue. The fuzzy light controller is used to optimize the control of large traffic flows such as supersaturated load conditions. The authors use the theory of fuzzy logic in the computation. This principle based on a new method of defuzzification (NDM). The authors are interested in calculating the duration of the green time in order to minimize the length of traffic congestion. To do this, wireless sensors must collect traffic data in the intersection (input and output in one lane).

This information is necessary to start the optimization process according to Fig. 2.

![Fig. 2. Scheme of traffic optimization process using data collected from road detectors.](image)

C. Genetic Algorithms
Several authors proposed the technique of the genetic algorithm for the optimization of traffic signals [25].

The authors, K.T.K. Teo and all in [17] have proposed optimizing the cycle time and traffic light traffic phase at an intersection based on a genetic algorithm. Its principle is the following: To obtain an approximate solution to an optimization problem when there is no exact method to solve it within a reasonable time. In the case of application in traffic management, it will determine the phases, the total time of the green light of all traffic lights at the intersections in order to find an optimal solution or the most suitable solution in the objective To make traffic more fluid. The genetic algorithm has succeeded in optimizing the signaling system since the fire controller can react quickly to reduce the number of vehicles in the queue by generating a long green time period for this phase.

Xing Zheng and Will Recker in [22] have proposed an online real-time control algorithm in the form of an optimization procedure that corresponds to the adaptive control algorithm to have the optimal time of the green light. The optimization parameters are based on the 4 points below:

- a) Determining optimal phase sequence
- b) Determining optimal minimum green
- c) Determining optimal unit extension
- d) Determining optimal maximum green
D. Other Solutions

Traffic jams, Congestion, pollution, noise, are many fundamental problems in modern urban areas or the number of vehicles is high. There are more ways to solve these problems. Traffic signal optimization remains an effective solution and plays an important role, because they control the flow of the road network of the city.

However, the authors in [24] have proposed a system that helps the decisions of traffic light controllers to choose the right traffic light algorithm at the real time, and the current traffic situation. It takes the actual traffic conditions and calculates the optimal traffic light plans using bio-inspired techniques and micro-simulations.

In [28] have proposed a dynamic model of optimization of traffic signal synchronization using the BA algorithm. The objective is to find an efficient and optimal time for the green light for each of the four phases of light synchronization in each cycle.

In [29] the authors presented an intelligent control system, called Fuzzy Intelligent Traffic Signal (FITS). Its objective is to optimize the traffic light of an existing infrastructure. This system receives the information obtained from detectors. Here, the vehicle detection information must be processed to know the current traffic status. It is able to make the decision in real time according to its own control logic by communicating with modern light controllers.

III. SYNTHESIS: COMPARISON OF MODELS

The models discussed above can be compared through Table 2. Here the raw results of the solutions are not compared so it is their methods and techniques for optimizing traffic signals are compared.

<table>
<thead>
<tr>
<th>Research group</th>
<th>Date</th>
<th>Optimization Technical of traffic light</th>
<th>Parameter / Principle</th>
<th>Simulator</th>
<th>Remarque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malik Tubaishat and all</td>
<td>2008</td>
<td>Queue theory</td>
<td>• Calculate the queue length (number of vehicles waiting before the traffic light)</td>
<td>GLD (Green Light District)</td>
<td>The distance between the two sensors on the same road lane has no great effect on the traffic flow</td>
</tr>
<tr>
<td>Fuqiang Zou and all</td>
<td>2009</td>
<td>Fuzzy theory</td>
<td>• Determine the time of a traffic light according to the number of vehicles on the lane</td>
<td>Manual calculation in the lane</td>
<td>The performance of traffic light controller (TLC) is determined by calculating the average trip waiting time (ATWT)</td>
</tr>
<tr>
<td>B. Zhou and all</td>
<td>2010</td>
<td>Queue theory</td>
<td>• Time management at traffic lights in real time: Dynamic</td>
<td>iSensNet</td>
<td>2 Sensors / lane</td>
</tr>
<tr>
<td>Khalil M. and all</td>
<td>2010</td>
<td>Queue theory</td>
<td>• Time management at traffic lights: Dynamic</td>
<td>Microsoft Visual C++ 6.0 and MATLAB</td>
<td>2 Sensors / lane</td>
</tr>
<tr>
<td>K.T.K Teo and all</td>
<td></td>
<td>Genetic Algorithm</td>
<td>• Minimize the average length of the queue (AQL) and the average wait time (AWT).</td>
<td>-</td>
<td>The simulation of the genetic algorithm traffic flow control</td>
</tr>
<tr>
<td>Research group</td>
<td>Date</td>
<td>Optimization Technical of traffic light</td>
<td>Parameter / Principle</td>
<td>Simulator</td>
<td>Remarque</td>
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<td>----------</td>
</tr>
<tr>
<td>F.A. Al-Nasser and all [18]</td>
<td>2011</td>
<td>Queue theory</td>
<td>Average waiting time (minimize) that will reduce the queues length, Average service time (maximize), Average number of cars of the same queue not passing from the first time (minimize).</td>
<td>MATLAB R2008b</td>
<td>Intelligent traffic signals control system based on a wireless sensor network (WSN)</td>
</tr>
<tr>
<td>J. Qiao and all [27]</td>
<td>2011</td>
<td>Fuzzy Logic + Genetic Algorithm</td>
<td>Two-stage fuzzy logic control model has been proposed. <strong>Parameter:</strong> Arrival rate AR, Number of detected vehicles NDV, Weighted number of detected vehicles WNDV, Average waiting time AWT, Traffic urgency degree TUD, Extension of green time EGT, Number of passed vehicles NPV, Total delay TD, Average delay AD</td>
<td>Visual C++</td>
<td>Isolated signalized intersection: each direction of the intersection includes three entry lanes (2 Sensors / lane)</td>
</tr>
<tr>
<td>Sébastien Faye and all [19]</td>
<td>2012</td>
<td>Queue theory</td>
<td>Calculate the maximum duration of the green light according to the longer queues</td>
<td>SUMO</td>
<td>A typical 4-lanes intersection with 2 sensors per lane</td>
</tr>
<tr>
<td>Sébastien Faye and all [20]</td>
<td>2012</td>
<td>fuzzy traffic light controller + Genetic Algorithms</td>
<td>Minimize the length of the traffic queue, Traffic optimization process using data collected from road detectors.</td>
<td>Mathematica 1 model</td>
<td>Simple intersection</td>
</tr>
</tbody>
</table>

**TABLE 3. COMPARISON OF MODELS PRESENTED IN SECTION 2**

- B.P. Gokulan and all [26]  
- Geometric fuzzy multi-agent system (GFMAS)  
- Queue  
- Flow(veh/lane/hr)  
- Green time  
- Traffic data  
- Road traffic network with six intersections
<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Optimization Method</th>
<th>Parameters</th>
<th>Software</th>
<th>Description</th>
</tr>
</thead>
</table>
| N. Shahsavari Pour and all    | 2013 | Dynamically recursive optimization procedure: The proposed adaptive control algorithm | • Determining optimal phase sequence  
• Determining optimal minimum green  
• Determining optimal unit extension  
• Determining optimal maximum green | The scalable, high-performance microscopic simulation package | • Data Processing,  
• Flow Prediction,  
• Parameter Optimization  
• and Signal Control. |
| Zheng and all [22]            | 2014 | Optimization of traffic signal synchronization using the bat algorithm BA            | • Minimization of the average spoilage time including vehicular queue length and waiting time per car for each traffic light timing cycle | SUMO                                          | Phase/ Cycle                                                                |
| Jintamuttha, Konlapat and all  | 2016 | Fuzzy Intelligent Traffic Signal (FTTS) fuzzy logic                                 | • The system is implemented on a single board computing device capable of applying its own control logic and taking over the decision by communicating with modern traffic signal controllers | SUMO (Simulation of Urban MObility)          | The controller uses fuzzy logic for the decision making associated with signal timing. |
| Jin, Junchen and all [29]     | 2017 | • fuzzy traffic light controller  
• Genetic Algorithms | • Minimize the length of the traffic queue  
• Traffic optimization process using data collected from road detectors. | Mathematica l model                           | Simple intersection                                                                 |

As noted, each model based on one of the methods of artificial intelligence or sometimes on a mathematical calculation as indicated above. In addition, a common set of researchers worked on the same parameters: using wireless sensor networks, reducing the length of waiting queue, minimizing the average waiting time. Finally, each one uses his model and details an aspect without addressing the whole problem (The communication between the sensors and the fire controller, the routing of information, the algorithm that manage the traffic light, etc.)

IV. CONCLUSION AND PERSPECTIVE

A comparative study of optimization models of a traffic light was conducted, in order to solve the problem of congestion and reduce the waiting time for users, in general the management of road traffic and in particular the case of algorithms of light controllers.

Setting a comparison (ref. Tables 2 and 3) obviously leads to a clear advantage for researchers [19], [20] who have used the queue theory. In addition, they tested their models on a simple intersection as well as multiple intersections, so as to create green wave (synchronizing successive lights), which will have well on a positive point to reduce the length of the waiting queue and minimize the average waiting time. They simulated their model with SUMO, which is much more realistic and richer than the others.

In a future work, this comparative study will lead to a prospective approach to learn more about real-time signaling light controllers by the algorithm based on neural networks. This system must be able to adapt immediately to traffic conditions, and to optimize the control of fires, taking into account the routes of public transport.

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