CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

Traffic light system and traffic flow control are not new ideas as the traffic lights first appearance was on December 1868 in London when they installed gas lanterns in front of the British Houses of Parliament. Until now, many researchers are still proposing new approaches to serve the different needs of the society.

In this chapter, a quick historical review and a general traffic light system description will be written, focusing on the main contributions proposed by other researchers in terms of road data collecting systems, controlling traffic light phase plan systems, and in term of simulating traffic light operations. In addition, this chapter also highlights the latest attempts to enhance the traffic light management systems.

2.1.1 Historical Perspective

The first attempt to control the vehicles' traffic flow was in London, on December 1868, precisely around the area of the British Houses of Parliament. Railway Engineer J. P. Knight was the prototype designer. He used a gas lantern with red and green lamps which were operated manually by a policeman. This prototype did not stay in action for more than two months when a gas leak accident led to a fire which killed or injured the operating policeman [25-26]. Since then, researchers started looking for an electric replacement.

In 1912, an American policeman from Utah, Salt Lake City, has developed the first electric traffic light prototype with also red and green lights [27]. This design with some modifications have been used in many American cities such as the design of the American Traffic Signal Company in Ohio, during 1914, which added a buzzer to provide a phase change warning[28-29]. During the same decade, another design appeared by James Hoge [30], provided the emergency vehicles with a traffic light remote controller. During the 1920-1930, the traffic light employment has expanded over all the famous cities around the United States of America and reached to The United Kingdom [31-32]. In 1922, the idea of Automatic Control of interconnected intersections has been developed in Texas, Houston [31]. While in 1963, a computerized traffic light system with a centralized control which was the first of its kind at that time was developed to cover all Toronto city traffic lights [33].

2.1.2 General Description of Traffic Light Systems

In this thesis, traffic light management system will be looked at as shown in Figure 2.1. It has three main entities; Road's data collector whose duty is to collect inputs from the road and forwards them to the traffic light controller that decides the next phase time and green lights which will be implemented on the Traffic Light Display entity.

As soon as a phase is time out, a trigger will be sent back to the controller requesting a new phase plan to implement. The TLC makes two decisions; the next phase green lights to be, and the next phase time [34]. In this chapter, the system shown in Figure 2.1 will be considered as the prototype for comparison with other researchers' works.

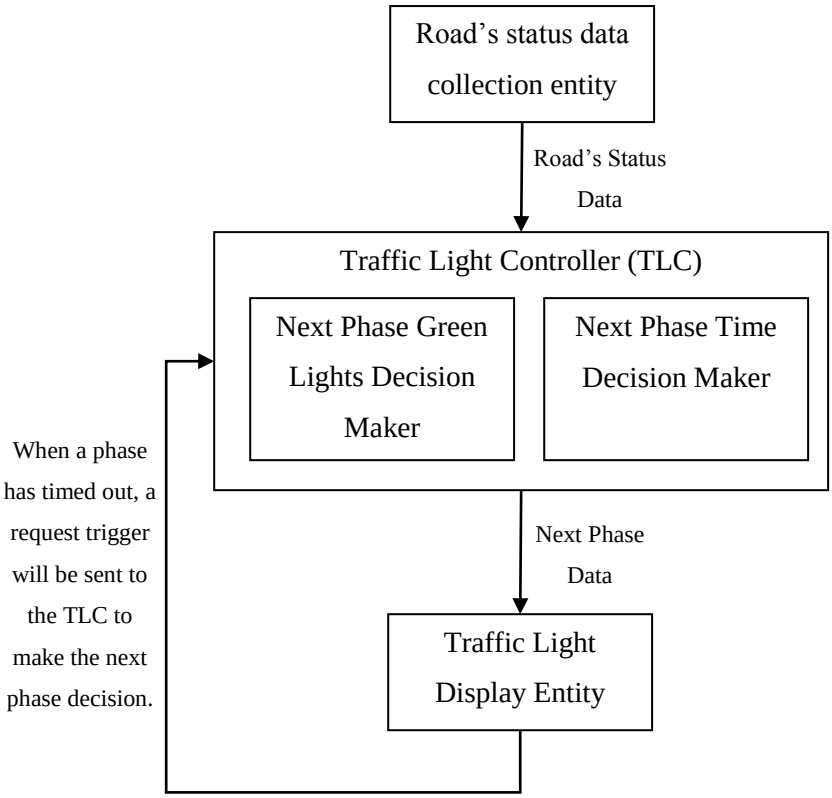

Figure 2.1: Traffic Light System Architecture

A traffic light system can be evaluated through an enormous set of measures. Within the context of this thesis, seven evaluation measures will be used, six of them are standard factors [31]: intersection throughput ratio, maximum queue length, average queue length, maximum waiting time, average waiting time, green time utilization, and a seventh factor (the system stability) those all are defined in Table 2.1.

Table 2.1: Performance Evaluation Measures

Evaluation Measure	**Definition**
Intersection Throughput ratio (Measured)	This measures indicates how many vehicles have been served (given green time) and passed the traffic light stopping line to the total number of vehicles arrived demanding to pass through the intersection within an hour of time.
Maximum Queue Length (Measured)	This factor represents the maximum value recorded as the queue length of all of the intersection's lanes within an hour of time.
Average Queue Length (Measured)	This factor represents the hourly average value of the summation (each five seconds) of the queue lengths of any of the intersection's lanes within an hour of time.
Maximum Waiting Time (Measured)	This factor represents the maximum value recorded as the first vehicles waiting time at any of the intersection's lanes within an hour of time.
Average Waiting Time (Measured)	This factor represents the hourly average value of the summation of the waiting times of each of the intersection's lanes within an hour of time.
Green Time Utilization (Measured)	This factor represents the ratio of how much of the given green time was used by vehicles to pass through the intersection. In other words, it represents the opposite of how much time been wasted.
Stability (Observed)	This factor is the only observed factor which can be indicated from the maximum/average waiting time/queue length. A traffic light system is said to be unstable if it gives long green light time (more than the maximum green light margin) to some lanes, or if it does not give green light for long time for one or more of the intersection's lanes (given red light for more than the maximum decided red light value).

2.1.3 Challenges of Traffic Light Systems

The main concern of all researchers in this field is to reduce the overall wasted time at intersections which can be categorized into two types; Must-to-Waste-Time and Should-Not-Wasted-Time, as shown in Figure 2.2.

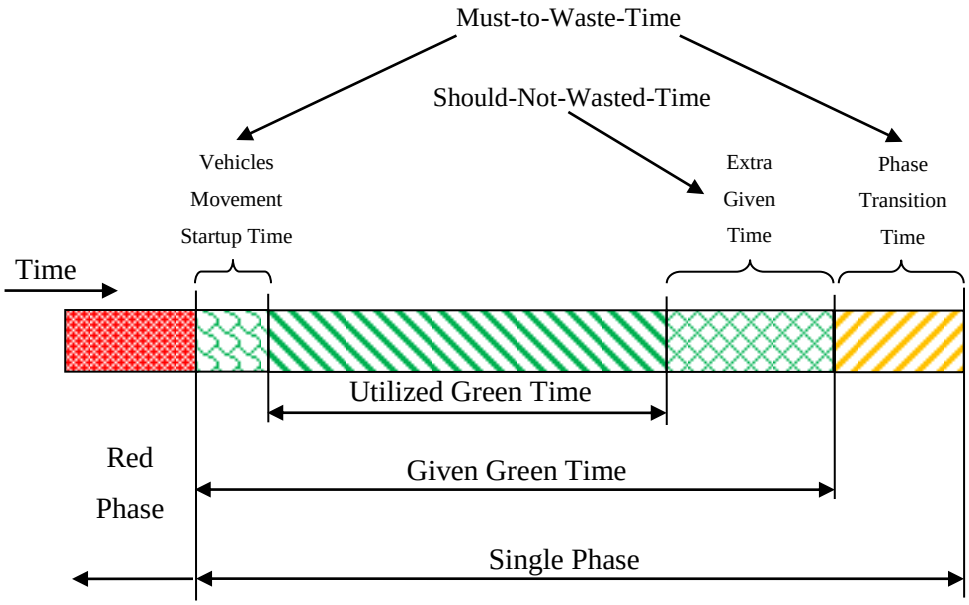

Figure 2.2: Traffic Light Phase Details

The Must-to-Waste-Time will be always wasted (sacrificed) as it is needed for safety and tidiness tasks. The Should-Not-Wasted-Time can be manipulated by the traffic light controllers so that it gets eliminated or at least reduced by making an accurate decision about the amount of the Given Green Time. Accordingly, the traffic light systems face two main challenges [35], those are:

1. Collecting up-to-date roads status data.

2. Optimizing the traffic light phase plan to increase the green time utilization and accuracy with the least negative effect on the whole system stability.

Many researchers have attempted to handle these challenges to find proper solutions. In the next section, some works will be listed down to be discussed and analyzed.

2.2 Related Work

Many researchers have looked to the traffic congestion problem and produced their own solutions using different techniques and technologies. Each work has its own benefits and shortcomings. In this section, a survey will be done in terms of three aspects; the road's status data collecting systems, traffic light phase control, and the existing traffic lights simulation tools.

2.2.1 Road's Data Collecting Systems

Any real-time responsive traffic control system needs a real-time set of data to process so it can make decision(s) depending upon those data. The real-time data collecting can be done using any of the following detector categories:

a) In-Roadway Sensors.

b) Over-Roadway Sensors.

c) Specialized sensors.

2.2.1.1 In-Road / Over-Road Vehicles Detectors

The main purpose of any road data detector is to detect and survey the vehicles' behavior on a road. By surveying the vehicles' behavior, many parameters can be determined from, such as; vehicles flow speed, vehicles count, vehicles presence, headway, travelling time, etc. [36].

In this thesis, the term road sensor belt can be defined as a set of sensors arranged in a way to achieve the desired detection procedure. There are two categories of vehicle detection sensors, which are In-Roadway Sensors and Over-Roadway Sensors. The In-Roadway sensors are embedded in the sub-grade or in the pavement or attached to the surface of the road, while the Over-Roadway sensors are mounted over the road surface itself or beside the roadway.

Most of the existing traffic light management systems are using In-road sensors for detecting queue lengths [37-38], which is what the developed system using. Most of those systems using the sensor belts to determine the queue lengths of the intersection approaches have a common downside that can be highlighted which is that their queue length determination is limited to a specific and small number of vehicles in a queue, that can be maximally up to 30 vehicles per lane. Whilst, the developed system in this thesis deploys a set of sensor belts to overcome the limitation with the existing systems, as will be illustrated later in chapter 3.

2.2.1.2 Specialized Sensors

There are many different tasks which require special detectors, such as emergency vehicles identification, over-height vehicles detection, pedestrian/vehicles presence/count detection, etc. [39]. Nowadays, in many countries, traffic laws have exceptional actions for emergency vehicles involved such as ambulances, police cars, fire-fighting trucks, etc. The normal vehicles are supposed to go aside of the road and come to a stop until the emergency vehicle has passed. Since the 1940's till today, numerous studies have attempted to create different systems to detect emergency vehicles and/or identify them when they appear to ease their way and prevent accidents when they are rushing to answer emergency calls [40-48].

In [49] and similarly in [50-63], patented solutions suggested that the emergency vehicle must send a direct radio signal to the traffic light which has a radio operated audio and visual warning. These solutions would fail for many reasons such as; the limited communication distance between the emergency vehicle and the traffic light because of the direct radio communication between the vehicle and traffic light. Another reason that led us to believe this system would fail is because there is no traffic light phase control, so when there are more than one emergency case, an accident might happen when both vehicles think that the alarm were turned on for themselves. Another reason for system failure would be because using only audio or visual alarm is not an efficient solution as they might be unnoticed by the drivers due to the noisy surrounding area.

GPS (Global Positioning System) was one of the technologies used by a number of researchers to solve the traffic congestion problem [64-69]. The work in [64] can be considered as an example when GPS is used to detect the on-road vehicles speed and control the traffic light to enhance the traffic flow. Nevertheless, GPS has a limitation in terms of service reception while driving inside a modern city which has a lot of tall buildings. Therefore the GPS might fail to estimate the vehicles' queue length and also fail to detect emergency vehicles if the GPS receiver was inside a tunnel or if there are a lot of clear-sky-view-blocking objects.

The work done by Gedawy [70] has combined the ideas of using GPS and controlling all the city traffic lights centrally from an office to detect emergency vehicles and control the traffic lights along an emergency route. Centrally controlling the traffic light phasing by collecting the road traffic information from all around a city then processing it, will not always help solve the congestion problem, for delay would be caused by the huge amount of data to be processed at once. The use of GPS, which has a limitation in terms of service reception while driving inside a modern city, will also make the system less beneficial. Similar work has been introduced before in [71].

Many researchers have argued that an image processing solution would be optimum to solve the congestion problem. (e.g. [72-81], and [63]), they were looking for a solution for traffic congestion problem by applying some image processing methods to detect the amount of congestion on streets by using video or picture cameras. Using a camera to capture the roads in a photograph or a video and then analyzing the captured image or video will not always work as it would fail during the heavy rain, foggy, or sand stormy weather, and at very dark or unlined road [82-83].

2.2.2 Traffic Lights Phase Control

The Traffic-Light phase decision making has been the aim by many researchers from all around the world. For that many of those researchers' works will be illustrated by highlighting their main contributions and downsides. This section will be segmented according to the technologies and techniques used to help in making decision about traffic lights control.

2.2.2.1 Expert Systems

An expert system is defined by a system which uses a set of known rules to make a decision for the next phase action. Two researchers Findler and Stapp have described a group of roads linked by traffic light-based expert systems. The expert systems allow communication with the nearby expert systems to create some kind of synchronization. For the whole road network, a set of rules should be applied to enhance the network performance. No improvement evidences were shown by Findler and Stapp compared to the classic traffic light controllers used that time. [84]

In [85], Wen proposed a dynamic and automatic control system to solve the road congestion problem in a city. Unfortunately, Wen's system has a central server which collects all the data from all around the city and inputs them into a traffic light control simulator built in the server. Centralized controlled has a drawback that its response is slow, thus it might fail the whole city's traffic.

In [86], an intelligent traffic light monitoring expert system was developed to reduce the traffic jam at intersections via image processing. However, using cameras would fail during inclement weather as the taken images might not be clear enough to give accurate data. Similar systems are available, as in [87-88].

2.2.2.2 Prediction-based Optimizing Systems

In [89], a predictive traffic light controller was developed by researchers from the Technical University of Crete in Greece. Simply described, the system detects the number of vehicles on the intersection legs during a cycle then uses those measurements to choose the next phase traffic-lights combination and its green time. The system seems fine in terms of queue length reduction however it would fail at some points as it uses only one input variable (Number of the waiting vehicles).

In [90], a researcher in the University of California and his research team members (2002) have introduced a way to overcome problems by measuring vehicles delay at an intersection. A set of 15 minutes data were used to determine the optimal phase setting for the next cycle. The system performs better than the actuated controllers on the other hand there are some cases it failed at as it is based on predictions made according to the last 15 minutes. Similar work can be found in [91]. Similar work for a network of traffic lights can be seen in [92].

Another example might be the work proposed in [93] would estimate the road average speed by placing two sensors on one part of a road of a given length L, then based on that calculated average speed, the traffic light phase would be determined. The results of such a system will not be accurate as it depends on estimation not detection.

Generally, prediction based systems are not reliable as much as detection based systems. For this reason, the developed system in this thesis bases its decision making upon a set of detected data as will be illustrated in chapter 3.

2.2.2.3 Fuzzy Logic Based Systems

Many researchers looked to fuzzy algorithm as one of the most effective algorithms in traffic control [94-98]. In [96], a multi-intersection traffic light controller was proposed and that would receive information about the previous and the next junctions so it can create what is called a Planned Green Waves. Lee's controller outperformed the fixed controller at most of the road situations. Nevertheless, creating green waves alone will not be able to completely solve the congestion problem or to optimize the intersection's capacity.

A single intersection fuzzy controller was introduced in 1996 by Tan and his research members, [9]. This controller used Fuzzy rules to determine whether the current phase duration should be extended or not. If it should be extended, then for how long would it be extended. Fuzzy controller showed better results than fixed and actuated controllers in terms of reducing the waiting time and traffic flow enhancement. Nevertheless a weakness of fuzzy systems when used in traffic light control is its dependence on preset variable values which would limits the controller's flexibility.

In [97], a research team members added enhancements to the fuzzy controller in [96] to cope with congested traffic flow by increasing the output function resolution. After comparing two results of the two works, a larger traffic flow has been achieved by the enhanced fuzzy traffic light controller in [97] under busy traffic conditions. Nevertheless, the flexibility limitation still there as they have used fuzzy logic as well.

Finally in [98], a research team of three members in Fujian Agriculture and Forestry University in China proposed an advanced real-time fuzzy controller for signalized intersection. Their procedure can be summarized through three simple steps:

1. Detecting the queue lengths waiting at the traffic light at a moment using sensors.

2. Comparing the queue lengths for the lane and finding the maximum two values those would be green next phase.

3. Input the queue lengths for the lanes and the next green phase decision made in (2) to the fuzzy controller to make the green phase time decision.

2.2.2.4 Evolutionary Algorithms

The work in [99] has developed a traffic light controller based on evolutionary algorithms. A traffic light controllers testing and evaluation environment named as FLASH was used to evaluate the proposed approach. Then it was compared its controller performance results with vehicle actuated controller to find that the new controller performs equally or even worse than standard vehicle actuated controller.

2.2.2.5 Intelligent Agents Based Systems

In [100], a dynamic traffic light control was introduced based on VANET using clustering algorithm. In this work, each vehicle acts as a mobile intelligent agent which forwards its existence information to another nearby vehicle through vehicle-to-vehicle communication. While, if there is no other vehicle within the coverage, then it would forward its existence information to a road side unit (stationary intelligent agent) which in turn would pass through the message to a further distance. Based on clustering algorithm to collect data, is unreliable on as the connectivity between vehicles might be lost at some periods of time. No results were presented in this work, although it is expected that this system alone will not be able to make accurate decisions according to the unguaranteed arrival for the set of data being collected from the road.

In [101], a researcher in Delft University in Netherlands proposed intelligent agent architecture to control traffic lights. Two main components; Intelligent Traffic Signaling Agents (ITSAs) and Road Segment Agents (RSAs) meant to work individually to achieve their duties, aiming to reach local optimality. No results were presented however it was claimed to have better results when compared with the existing fixed and actuated methods.

2.2.2.6 Centralized Traffic Management Systems

By looking at the work in [102], it suggested controlling the traffic light phasing in a city from a central office named "Master Controller". Centrally controlling the traffic light phasing by collecting road traffic information from all around a city, and sending them to the Master controller through rented telephone lines then processing it, will not always help solve the congestion problem according to the delay that would be caused by the huge amount of data to be processed at once. In addition, using rented telephone lines would be very costly.

2.2.2.7 Mathematical Algorithms Based Traffic Management Systems

Several studies have found good mathematical solutions for the congestion problem, as in [103-104], nevertheless, their systems might not give accurate results as they depend on few input variables while ignoring important ones. For example, in [104], they have tried to predict the traffic flow depending only on the time and vehicle queue length that might help to solve the problem of traffic congestion and enhance the traffic flow. However it might fail in some cases as they have missed other factors that might help them to make their prediction more accurate, such as the traffic load on the previous traffic light, and the traffic load on the next traffic light.

2.2.3 Traffic Lights Simulators

Many simulation tools are available for evaluating traffic lights designs. Sidra Intersection is one of the most reliable software packages as it is used by many civil engineers to analyze the performance of their intersection (junction) design, endorsed by Austroads[105-106] and is recognized in by the US Highway Capacity Manual[107] and many other transport engineering guides.

Sidra Intersection is a traffic evaluation tool that uses lane-by-lane and vehicle drive cycle model provided in [108]. Sidra Intersections has provides the ability to compare individual signalized intersections or networks of signalized intersections. The user of Sidra Intersections simulator can choose one of the traffic light controllers

provided within the software package; fixed-time/pre-timed and actuated control [109-110] which will be referred to within the text of this thesis as BM1 and BM2 respectively.

Sidra Intersection delivers a long list of performance evaluation measures, such as; vehicles delay, lanes queue lengths, number of stops, alternative level of service measures, and many other measures to help with the environmental impacts and economic analysis.

As in this research, an intelligent traffic light controller is being developed and a performance evaluation is required. Sidra Intersection, does not allow for the users to customize the traffic light controller, which urged the need for the creation of a customized simulation tool, as will be illustrated in Chapter 3.

2.3 Discussion

The main concerns of this research are the methodologies of; collecting the data from the roads, processing the data within the controller to make decisions about the traffic light's next phase plan, and the evaluation of the decisions made by the controller based on the collected data.

As for the road status data collecting system, evidently, most of the specialized sensors used to detect special vehicles and manage the traffic light phasing have downsides. With the latest inventions in wireless technologies, automobile manufacturers are about to take an enormous step to enhance driving safety and comfort by allowing vehicles to communicate with each other and with the roadside equipment infrastructure, that type of networking named Vehicular Ad-hoc Networks or VANET [16-21] and [111]. For that, many projects are in progress aiming to override existing technologies to provide safer and easier road flows. According to the mentioned downsides in specialized sensors, the researcher of this research have suggested to use VANET for collecting the road status data (including the emergency vehicles detection/identification) and delivering them to the traffic light controller to

optimize the intersection performance according to the need, as will be illustrated later in chapter 3.

After completing the literature review, it was found that most of the used technologies and techniques have drawbacks those would lead the system to make inaccurate decisions and failure at some points. By studying the work in [98], it is found that a great improvement has been claimed by the research team when comparing with the traditional timed controlled traffic light. However, according to our observation, this method will not be very accurate as it only depends on the queue lengths without considering how long the lanes been waiting as part of its decision. As a result of ignoring the waiting time variable, when the intersection situation is very busy at three approaches while the forth side is semi idle, Lurong's system would fall into a dead-lock among the three busy sides while forgetting the forth side. In other words, the approach's decision making inaccurate algorithm would lead the system to lose its stability. This method is very much related to our proposed approach. In this thesis it will be referred to as NM1.

Another work in [112] is very much related to the proposed method in this thesis. It aims to optimize the intersection's capacity by using the queue length and the waiting time as the inputs to a fuzzy based decision maker. This work has many drawbacks. One of them is when determining the lanes priority, they use the queue length only as the input, which makes it unstable if there is at least one direction with a very high demand while the others have very low number of vehicles queuing, as two lanes will keep having the green time shared among them while neglecting the others. In determining the phase time they used both of the queue length and the waiting time which is good in a way nevertheless the system can detect a maximum queue length of 50 vehicles per two lanes, which means maximum 25 vehicles per lane. This is another drawback which leads the system to be inaccurate at the very high levels of demand situations. In this thesis it will be referred to as NM2.

Both of NM1 and NM2 are the latest related works to the proposed approach in this thesis. This is why they were chosen to compare the developed approach performance with. In addition, both of BM1 and BM2 will be anticipating in the

comparison as the bench mark methods as they are the most common methods used in the cities.

For evaluating the developed controller, a customized simulation tool is needed to be developed because of the limitation of Sidra Intersection simulator in evaluating a customized traffic light controller. As illustrated in chapter 3.

2.4 Summary

In this chapter, the traffic light life line was drawn since its first appearance in London in 1868 until 2010. Furthermore, many research works and shown their weaknesses were illustrated. The main downsides highlighted were the lack for a real-time road status data collecting system that can cover the whole road, collecting the wrong or insufficient amount of factors to represent the road status, applying some instable techniques or algorithms to control the traffic flow at intersections. All these factors would lead the system to lose its accuracy and stability.

Two of the most related and the latest works were chosen to compare their performances with the developed approach in this thesis. Those are [98] and [112]. In this thesis, the abbreviations NM1 and NM2 will be used to refer to [98] and [112] respectively. Both of NM1 and NM2 aim to optimize the intersection capacity by creating traffic light controlling algorithms. The downsides of the NM1 and NM2 are the inaccuracy in decision making and the system instability at the very high demand level situation as they depend on the wrong type of parameters, inappropriate algorithms with insufficient input factors. In our approach a step-forward was taken to face the challenge of optimizing the decision making by creating an algorithm to overcome the above systems downsides.

For the benchmark methods, two have been chosen; fixed/pre-timed phase plan control [4] and fully-actuated phase plan control [5] which will be named as BM1 and BM2 respectively. These two methods have been chosen because they are the most used nowadays on our roads.