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Traffic control system techniques: A review

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Abstract

Controlling and managing traffic signals at road intersections is a demanding task in the transportation system to ensure vehicular traffic safety and a consistent flow of traffic. Because of the significant increase in the number of vehicles on a daily basis, reducing road congestion has become a major concern in recent years. The urban transportation system requires effective solution techniques to cope with current traffic conditions and meet the ever-increasing demand for traffic. Changes to urban infrastructure will take years, and in some cases may not be feasible. As a result, optimizing traffic signal time (TST) is one of the quickest and most cost-effective strategies to reduce congestion at intersections and improve traffic flow in the metropolitan network. To improve TST, researchers have been working on a number of ways as well as the use of technology. This paper aims to analyze recent literature published between 2014 and 2022 for various traffic signal management systems that have been developed to improve real-time traffic flow at junctions by optimizing TST and Traffic Signal Control (TSC) systems and to provide insights, research gaps, and possible directions for future work for researchers interested in the field.

Keywords: Traffic light, Intersection, Traffic signal control, Traffic signal timing optimization, Computer vision
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1 Introduction

Traffic signal control and management at road intersections is a difficult task in the transportation system to guaranteeing vehicular traffic safety and a steady flow of traffic. Intersections are the points at which two or more routes intersect. At crossroads, people, automobiles, and bicycles change directions at intersections. Because of the enormous number of vehicles commuting from one location to another, intersections operate as an impediment or barrier to resist smooth traffic flow inside urban regions. This causes traffic disruption, congestion, and inadequate traffic control and management [31, 35]. The intersection delay has an impact on the signal control logic as well as road users' travel efficiency [16]. According to one study, fixed traffic signal delays account for more than 10% of all traffic delays worldwide. At major U.S. highway crossings, traffic delays totaled over 295 million hours [11]. As a result, the exact estimations of time-dependent delays are very required at urban roadway intersections for traffic signal control and management. Intelligent Transportation Systems (ITS) address the challenging problem of effective traffic control and management at intersections. It is important to have a good mix of safe and effective traffic control at intersections so that most cars can pass while still keeping people safe [9]. Currently, traffic-light signaling is utilized to govern traffic at critical junctions/crossings by distributing the same green light timings to all

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routes [43]. The complex architecture of traffic systems does not coordinate/link the timings of traffic signals with average daily road traffic, resulting in intersection congestion. Therefore, the city's transportation system is in need of innovative solutions because the Urban infrastructure changes will take years, and may not even be feasible at all. The optimization of traffic signal time (TST) is one of the most effective methods for reducing congestion at junctions and increasing traffic flow throughout the metropolitan network. Numerous techniques to improve the TST have already been investigated by researchers. The issue of TST or traffic system control (TSC) settings has been the subject of a number of high-quality reviews [3, 20]. There are two survey articles that were published in 2015 that cover a wide range of methods used in this field up until 2014 [20]. The rest of the paper is organized as follows. Research methodology is described in Section 2, with TST's background and classification of TST optimization methodologies and brief analysis of the related approaches. Section 3 presents a discussion and analysis of methodologies. The promising proposals for future study possibilities concluding in the last section.

2 Methodology

This paper examines the most recent literature for the optimization methods for TST and TSC, which have been published from 2014 to 2022 in terms of journal papers and conference proceedings. The growth of technology is one of the key reasons why the most recent research is being covered. Following a thorough search of databases such as Scopus, ScienceDirect, IEEE Xplore, and Google Scholar.

2.1 The Traffic Signal Timing

TST and the controllers' settings and evaluation are based on the concepts outlined in this section. The following section provides an overview of TST's most essential parameters, explains the structural layout of TSC and their common and unique features are explained.

Parameters for Traffic Signal Timing:

One of the primary functions of TST settings is to direct traffic through an intersection in a safe and efficient manner by assigning the right-of-way. Some TST configuration parameters should be able to adjust to changes in traffic demand, while others should be regulated by the traffic management authority. These control parameters are as follows [33]:

Green Time: The amount of time, in seconds, that a traffic flow at a signalized intersection moves at a saturation flow rate.

Cycle Length: A signal's cycle time measured by seconds.

Phase Sequence: The sequence of signal phases throughout a signal cycle.

Change Interval: Also called the clearing interval, it's a technical term. An intersection's clearance time is the time between the yellow and red phases of traffic signals, when no conflicting traffic is present.

Offset: The time interval between two or more synchronized phases.

Increasing and decreasing the green phase timing for a certain movement can reduce the number of stalled vehicles and the resulting delay. An increase in a traffic movement's green time frequently comes at the expense of longer delays and more stopped vehicles in other traffic flows. This is why signal timing plans that prioritize traffic performance, such as minimizing average wait times, are the most effective.

2.2 Traffic Signal Control Structure

Traffic signal control design comes in the following schema: Fixed-time, adaptive, and actuated. Traffic signal control (TSC) techniques have been categorized in [34, 44]. The data and algorithms used to optimize traffic are the primary reasons behind this classification.

Fixed-time TSC techniques are most appropriate for traffic signals and are most typically employed in major cities throughout the world when traffic flow is generally stable and consistent. Based on prior traffic data, these methods culminate with a cycle duration and split setting plan. This technique's main purpose is to reduce average delay, which is the foundation for fixed-time traffic control methods [29, 40]. Because the traffic system in cities is so dynamic, even slight disruptions like traffic collisions or construction can substantially alter traffic flows, rendering a planned traffic signal design unacceptable. Conversely, the goal of adaptive control is to constantly adjust the TST plan based on current traffic conditions. As a result, the usage of sensor technology was introduced. Vehicles are detected when they crossed the sensor's field of view. Later on, visual systems became widely used. Sensors are also used in actuated control schemes, and the cycle length is determined by the actuated controller based on previous information. Adaptive methods, on the other hand, are a modified type of actuated control that uses current data to forecast the cycle length of real-time traffic circumstances. These sensors are installed on every road inside the signalized network's boundaries. However, because they must quickly manage traffic signal layouts, these strategies cannot undertake as deep an analysis as fixed time technique [22].

2.3 Traditional Traffic Signal Timing Control Methods

Traffic signal control is one of the most efficient and safe urban traffic management methods. Inadequate transportation infrastructure, rising vehicle numbers, bad weather, and traffic network structure are all potential obstacles. Even if only one of these factors occurs, it can cause network congestion at any time. Overall, traffic congestion caused by these factors is challenging, complex, and stochastic to cope with [44]. Working on intelligent traffic monitoring and control systems has long been known to reduce junction delays dramatically. SCOOT [6], SCATS [36], OPAC [13], RHODES [30], PRODYN [17], and MOTION [7] are examples of adaptive traffic control systems applied in recent decades [17]. For isolated junctions, the Webster approach [21] was used. This is performed using Webster's equation. Traffic Response Urban Control (TUC) can be used to remove static signal control sequences, leading to better results than the original TUC. The issue is that this method is exceedingly complex.

2.4 Vision-Based Traffic Control Methods

The following are some articles in which researchers use cameras to determine a vehicle's state. Furthermore, it is possible to recognize and track approaching cars using feature-based techniques [15] and neural networks [2]. Occlusion-resistant features are easier to track using feature-based approaches. This technique was ineffective for real-time TSC because of its low precision and hefty storage needs. To recognize automobiles, these feature-based algorithms include binarization and rule-based reasoning, as well as cameras and road conditions. Video camera data was used by Indu et al. [18] to provide equal green light timings and then adequate time was allocated using a fair weight and optimal weight calculation technique. This system was simple but expensive.

In [1] by Amogh et al, the proposed system dynamically alters the time settings of the traffic synchronization system in order to improve its efficiency. This is done via traffic cameras and the OpenCV library. This system calculates the vehicle density at each intersection and sends the data to a dedicated server.

In [23] an intelligent traffic control system was designed. The concept of the system is based on the traffic control theory, which combines the use of a microcomputer single chip and ultrasonic technology. The system's core control is MCS - 51, which is capable of monitoring real-time traffic conditions through the use of sensors (ultra-sonic sensors) for road vehicles. The system's duration time set for traffic signal can autonomously be set according to the number of vehicles and the priority of traffic. In other words, based on traffic demand.

To accurately anticipate real-time traffic, the dynamic Bayesian networks approach and a video camera are used in [8]. Before using dynamic Bayesian to create predictions, the Gaussian mixture model (GMM) is used to classify the distribution of spatially and temporally interesting locations.

Since traffic jams are most evident in densely populated urban areas, the focus of [14] is on signal control by machine learning (ML). Reinforcement Learning (RL) is the most commonly utilized machine learning technique for traffic light control (TSC). This method (RL) is widely used because of its simple algorithmic structure, which is based on real-time "trial and error" experiments in which the errors are used to generate quality estimates for each trial. According to the trials specified as state–action pairings, these quality estimations are calculated and stored in table-like data structures. This approach supports online learning, which is essential for self-adaptation to the constant change in traffic demand and does not require extensive previous datasets.

In [27] traffic cameras are used in order to determine a vehicle's state. This is done by taking pictures of intersecting roadways and then using a computer to create an accurate spatial information matrix for each car. Utilizing reinforcement learning (RL), specifically the PPO algorithm, which is based on the policy gradient, is used to train the traffic light control policy approach as an intelligent agent for traffic signal optimization.

Other strategies, the arrival and departure of cars at a junction can be tracked using a variety of other methods, including detectors [10], on-board GPS, and big data technology [26, 37]. Sensors and traffic servers are also employed to keep track on regional traffic. Cars' GPS data is sent to the traffic monitoring system using GSM/GPRS embedded technology [25]. The expense of implementing this kind of approaches is really high.

2.5 Connected-Vehicles-Based Traffic Control Method

The following are some articles in which researchers use Connected-vehicles-based approach to determine the traffic state. At first, Wang et al. [38] proposed a data fusion approach that collects the data on the speed, position, and direction of the vehicles approaching junctions with the help of GPS sensors in vehicles. This method only improves the traffic flow on a road network; it does not control the traffic signal timing.

Using multiagent systems, MingtaoXu et al. [42] describes a traffic management and signal control system comprised of two interconnected components. The traffic operation system's hierarchal multi-agent system (HMAS) allows these two components to communicate with each other. Signal control requirements information such as vehicle speed, journey time, location, and traffic volume will be gathered by HMAS and used to optimize signal timing plans.

An IoT and ICT-based electronic circuit for traffic light control is being developed by Oliveira et al. [32], with the goal of communicating with other network traffic lights, exchanging system information over a wireless network and thus providing an improvement over current traffic control system. This electronic circuit will control and monitor each lamp. In [24], each intersection in this study was monitored in real-time by probe cars, which are able to predict traffic conditions in advance and manage their spread. At saturation point, the flow of traffic is virtually unaffected. Queue length and sustainable traffic development can't be detected using current detection technologies like ultra-sonic sensors. To put it another way, current technologies are unable to identify traffic after saturation. Probing vehicles are a new method of detecting anomalies in the environment. Those cars that are equipped with this technology can get information about traffic from the moving car in front of them. This information includes things such as trip times and waits times. Using the probe car to identify the traffic states and adaptively control the signal control algorithms.

2.6 Artificial-Intelligence-Based Traffic Control Method Methods

The following are some articles in which researchers use Artificial-intelligence-based approach to optimize TSC and TST setting. For the purpose of resolving the TST puzzle, the papers [4, 12] make use of an artificial learning method. Machine learning algorithms such as Neural Networks, Adaptive Neuro-Fuzzy Inference Systems, Q-Learning, fuzzy logic, and Deep Reinforcement Learning have been incorporated into these studies. In these studies, several objectives were utilized, including minimizing average delay [4, 41], total travel time [5, 28], average queue length [39], optimization of the TST plan [19], and maximizing flow rate [12].

3 Discussion

Traffic delays, traffic safety, trip quality, and pollution emissions are the key objectives of TSC technology research. In metropolitan regions, vehicular traffic grows much faster than roads infrastructure, which has led to a rise in traffic congestion. Pre-timed traffic signals at road intersections exacerbate the issue by increasing travel time, fuel consumption, and pollution. The status of the traffic light at a crossroad causes traffic delays that ripple out to other junctions, resulting in a chain reaction. Traditional traffic systems don't take into consideration catastrophes, road closures, or vehicle breakdowns, which might cause travel delays. Moreover, emergency vehicles with increased needs, such as ambulances, fire brigades, police, and VIPs, must be able to travel through crossing points seamlessly. A more efficient and safer transportation network is therefore required, as is an improvement in the current traffic system to reduce traffic congestion and wait times, and travel times while also increasing economic advantages. The bulk of traffic monitoring technologies at intersections rely on expensive cameras and sensors that are difficult to install and maintain. Outdated traditional traffic signal control systems are employed at road junctions. Because of this, better real-time signal control techniques at road crossings are required to reduce traffic congestion on the route. As a major shortcoming, previous techniques do not sync traffic signals in a region.

4 Conclusion

Intelligent traffic signal control (TSC) is a revolutionary, innovative technology with exceptional potential in intelligent transportation systems. This paper provides a comprehensive survey on traffic light control techniques for intelligent and adaptive TSC. First of all, this paper outlines the traditional traffic light control technologies used for congestion control at intersections in urban cities. Then, recent studies within the last 8 years of intelligent and adaptive traffic signals are discussed. Following, this paper summarizes the development status of traffic signals for intelligent vehicles by surveying all the research work on traffic signal control. In addition, we discuss many emerging and potential directions for the future of traffic light control systems. This study will provide researchers with the basis for more understanding and investigation of intelligent traffic lights for intelligent and non-intelligent vehicles. The following table is a brief description of the articles reviewed in this paper.

Table 1: Brief Articles Description

Reference Number	Name	Author	year	Strategies Used	Data Gathering Method
[21]	Vehicle Detection and Tracking Techniques: A Concise Review. Signal Image Process	Hadi RA	2014	Feature-based techniques and Neural networks	Camera
[15]	Video based adaptive road traffic signaling	Indu S	2019	Fair weight and optimal weight	Camera
[2]	Traffic timer synchronization based on congestion. In: Proceedings of the 2016 International Conference on Computation System and Information Technology for Sustainable Solutions	Amogh AS	2015	OpenCV	Camera
[18]	Intelligent traffic light control system based on real time traffic flows	Li Z	2016	Traffic control theory	Sensor
[1]	Video-based Road traffic monitoring and prediction using dynamic Bayesian networks	Chaudhary S	2018	Bayesian networks and Gaussian mixture model (GMM)	Camera
[23]	Accurate freeway travel time prediction with state-space neural networks under missing data	Lint J	2018	Feature-based techniques and Neural networks	Camera
[8]	Application of Deep Reinforcement Learning in Traffic Signal Control: An Overview and Impact of Open Traffic Data	Gregurić M	2020	Machine learning (ML)	Previous Data
[14]	Adaptive Optimization of Traffic Signal Timing via Deep Reinforcement Learning	Ma Z	2021	Machine learning (ML)	Camera
[27]	The Design and Simulation of Intelligent Traffic Signal Control System Based on Fuzzy Logic	Lin Y	2018	Fuzzy Logic	Detector
[10]	Removing traffic congestion at traffic lights using GPS technology	Tanwar R	2016	XX	on-board GPS
[37]	Big Data Technology and Its Analysis of Application in Urban Intelligent Transportation System	Liu Y	2018	Big Data	on-board GPS
[26]	Novel Embedded Vehicle Terminal for Intelligent Transportation	Liping X	2014	System on chip (SOC)	on-board GPS GSM/GPRS
[25]	Applying floating car data in traffic monitoring	Tiedong W	2014	Applying floating car data (FCD)	Sensor
[38]	Multiagent Approach to Autonomous Intersection Management	Dresner K	2019	Multiagent Systems (MAS)	Sensor
[42]	Smart Traffic Light Controller System	Oliveira LFP	2019	Internet of Things (IoT)	IoT Sensor
[32]	Adaptive traffic signal control algorithms based on probe vehicle data	Lian F	2021	Iterative signal control algorithm Optimized signal control algorithm	Sensor
[24]	Intelligent cuckoo search optimized traffic signal controllers for multi-intersection network	Araghi S	2015	Neural Network (NN) Adaptive NeuroFuzzy Inference System (ANFIS)	Previous Data
[4]	Deep Reinforcement Learning for Autonomous Traffic Light Control	Garg D	2018	Machine learning (ML)	Camera
[12]	IntelliLight: a Reinforcement Learning Approach for Intelligent Traffic Light Control	Wei H	2018	Machine learning (ML) Deep reinforcement learning	Previous Data
[41]	Influence of meta-heuristic optimization on the performance of adaptive interval type2-fuzzy traffic signal controllers	Araghi S	2017	Genetic Algorithm	Previous Data
[5]	Comparison of Two Approaches for Preemptive Traffic Light Control	Miletic M	2018	Fuzzy Logic	Previous Data
[28]	Improving Traffic Light Control by Means of Fuzzy Logic	Vogel A	2018	Fuzzy Logic	Previous Data
[39]	An intelligent control system for traffic lights with simulation-based evaluation	Jin J	2017	Fuzzy Intelligent Traffic Signal (FITS) Fuzzy Logic	Previous Data

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