

An Empirical Review of Scenario-Aware Traffic Signal Control Models from A Statistical Perspective

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Abstract:-Traffic signal deployments have increased many folds due to an exponential increase in road-traffic in both urban and rural areas. Thus, modern-day town planning agencies focus primarily on using optimized-traffic-signal-control models that can assist in reducing congestions and maintaining smooth traffic flows. Researchers have discussed design of various machine-learning based traffic signal control models, and each of these models vary in terms of their operational & functional characteristics. Moreover, these models have highly variant efficiency levels, due to which it is difficult to select optimal models for scenario-aware use cases. Due to these variations, it is difficult for city planning agencies to identify optimal models for their contextual use cases. To reduce this difficulty in model selection, a survey of some of the recently proposed models for traffic signal control is discussed in this text. This discussion evaluates the reviewed models in terms of their application-specific nuances, functional advantages, deployment-specific limitations, and contextual future scopes. Based on this evaluation, it was observed that bioinspired models, pre-emptive analysis models, and non-linear processing models outperform others. After referring this discussion, researchers will be able to identify optimal traffic-signal-control models for their functional use cases. To further simplify the process of model selection, this text also compares the reviewed models in terms of their computational complexity, deployment cost, fairness of control, scalability, and congestion control efficiency levels. After referring to this comparison, researchers will be able to contextually identify traffic-signal-control models suited for their deployment-specific use cases. This text also combines these parameters in order to identify models that can be deployed with low cost, have low complexity, are capable of improving fairness of control, with high scalability and congestion control efficiency performance under high traffic scenarios.

Keywords: Traffic, Signal, Control, Bioinspired, Pre-emption, Non-Linear, Complexity, Scenarios

1. Introduction

The problem of traffic congestion and determining the most efficient strategy to deal with it is one of the most significant challenges faced by city administrators. Traffic congestion in major cities worsens daily as the number of vehicles on the road continues to increase at an alarming pace. As a consequence of this rise, intersections are becoming more crowded and backed up with moving automobile lines, causing commuters to face delays throughout the day's peak hours. The state's economy, environment, and public health are all badly affected by the state's persistent traffic difficulties. The bad quality of life brought on by traffic congestion is the result of a variety of reasons, including excessive fatigue, mental sickness, problems with the neurological and respiratory systems, and cardiovascular issues.

Automobile operating is accountable for a substantial quantity of environmental pollution [1, 2]. This pollution is the fundamental cause of several issues that impact both human health and the environment. Higher automobile traffic leads to increased air pollution and noise levels [3, 4]. Transport delays have a negative impact on the economy, and firms are compelled to pass these costs on to consumers via higher prices. These factors underscore the continuous need for a system capable of minimizing traffic congestion caused by the growing popularity of public transit in metropolitan areas [5]. [Bibliography required] Modifications to the timing of the signals aim, among other things, to make it simpler for individuals to move through a junction in a safe and efficient way. To accomplish this purpose, it is

required to create a system that prioritizes various users in order to handle a high number of users. Due to fluctuations in demand, the plan must be adaptable. Several distinct signal timing variables impact the functioning of the junction. Several factors come into play, including the length of the cycle, the length of the "green" period, the duration of the "transition" gap, and the order in which the phases occur. Adjusting the timing of the traffic lights is one of the easiest and least expensive methods to reduce congestion at the intersection and speed up traffic in metropolitan areas. It is necessary to modify the TSC system's timing in order to meet the present urban traffic condition [6-8]. Researchers have reviewed and experimented with a range of possible strategies for enhancing the TST. On the topic of TST or TSC settings, a number of excellent studies [9, 10] have been published before. are the two most recent overviews; both were released in 2015 and cover a wide range of methodological subfields used prior to 2014. Both articles appeared in print in 2015. Although [10] offered some insight on fuzzy logic and some of the important work of Q-learning and neural network techniques utilized in the TSC environment [5, 11, 12], [10] examined the work and focused on fuzzy logic approaches in particular. After [10], [10] was released, shedding information on fuzzy logic and some of the important work of Q-learning and neural network approaches used in the TSC environment. There are few review publications that address the topic of common CI-based techniques to traffic management in urban transportation networks. However, the period between 2015 and 2020 gives a substantial possibility for technological advancement. There are insufficient high-quality literature evaluations to effectively account for the profusion of fresh studies on TSC and TST. By distributing right-of-way in a manner that promotes speedy and risk-free passage across junctions, TST settings may achieve their main aim of enabling intersection crossings. Some of the parameters used to calculate TSTs should be flexible enough to accommodate changes in traffic demand, however this should rely on the agency responsible for traffic management. These are the command's parameters. "Green time" refers to the period of time at a signalized intersection

during which a certain traffic movement is allowed to continue at a saturation flow rate. Cycle duration refers to the total amount of time required by a signal to complete one cycle. Phase sequence refers to the order in which phases of a signal occur within a signal cycle. This time period is also known as the clearing interval in some circles. In order to clear a junction prior to the onset of conflicting traffic movements, the timing of the traffic lights between phases is altered to alternate between yellow and red signals at regular intervals. A time offset is the relationship between two contemporaneous periods of time. By increasing the duration of the green phase for a given movement, it may be able to reduce the amount of time spent waiting as well as the number of cars that are delayed. Extending the duration of the green light for one traffic flow may decrease the amount of time spent waiting for that flow, but it often increases the number of vehicles that must wait at a stop. Due to this, an effective design for signal timing would use the available resources so as to enhance traffic flow and reduce the average amount of time spent waiting.

As a result, researchers have concentrated their efforts on the development of numerous machine learning-based traffic signal management models, each with its own set of operational and functional characteristics. Due to the wide range of efficiency levels provided by these models, it may be difficult to determine which models are best suited for scenario-aware applications. Due to these differences, it may be difficult for municipal planning authorities to select the models best suited to meet their needs. In an effort to make the selection of a suitable model simpler, the following section of this book provides a concise summary of several of the recently proposed models for traffic signal management. In the following section, we will compare these models to a number of analyzed criteria in order to assist readers in selecting the models that will perform best for their particular needs. Contextual reflections on the evaluated models and suggestions for enhancing their applicability in real-world situations are presented in the paper's conclusion for different use cases.

Empirical review of different processing techniques

A large number of models are proposed for analysis of traffic signals and their control under real-time use cases. According to professionals in the field of traffic signal control, [1] the Webster optimal cycle time formula could previously only determine the optimal cycle based on historical data for fixed-time traffic signal control. This limitation meant that the formula could not be used to determine the optimal cycle for variable-time traffic signal control. In this paper, we investigate the application of fuzzy logic, Webster's formulas, and a modified version of Webster's formulas in the process of developing an adaptive traffic signal control. These formulas, which take into account the anticipated volume of traffic during the subsequent cycle, are used to calculate the cycle time that is optimal for the situation. In order to compensate for this irregularity, the fuzzy logic system monitors the differences in traffic conditions that occur between cycles and provides a response to these variations. On the basis of the optimal cycle time, an adaptive calculation is performed to determine either the effective phase green times or the maximum permitted extension limit of the green phase in the following cycle. Using the SUMO traffic simulator, comparisons are made between fuzzy logic-based traffic control, fixed-time Webster traffic control, and modified Webster traffic control with the proposed adaptive control methods. One intersection serves as the testing ground for the suggested procedures. This study evaluates the effectiveness of the suggested approaches using data gathered from three-, four-, and five-way intersections in Kilis, Turkey. The data were collected in real life. SUMO creates arbitrary requirements for a four-approach intersection in order to further evaluate the effectiveness of the proposed methods under heavy demands. The results of the simulation show that the proposed methods are superior to those based on fixed time and fuzzy logic when it comes to the overall delay, speed, and travel time for vehicles.

According to [2], traffic signal control is necessary at intersections to ensure both the efficiency of daily operations and the safety of those present.

The majority of traffic light management strategies, on the other hand, are developed for particular intersections or lanes. Even though adaptive control systems do exist, it can be difficult to determine how effective they are because the methods they use are frequently kept secret. The purpose of this study is to propose an adaptive multi-input and multi-output traffic signal control method. This method has the potential to improve network-wide traffic operations by reducing the amount of time that traffic is delayed and the amount of energy that is consumed, while also being computationally more feasible than current centralized signal control methods. A linear dynamic traffic system model was developed and then adaptively updated in order to simulate the interactions that take place between intersections. This model illustrates how the input of signal control at each intersection can affect the overall travel delay across the network. Using the system model, an adaptive linear-quadratic regulator (LQR) was developed in order to reduce the number of traffic delays as well as the number of minor adjustments made to the control input. The effectiveness of the proposed method of traffic control was evaluated across a network of 35 intersections by using the microtraffic simulation environment that is located in Bellevue City, Washington. The results of the simulations showed that the proposed method was superior to max-pressure, self-organizing traffic lights, and independent deep Q networks when it came to reducing the average amount of time that it took for network traffic to move.

In [3], professionals in the field of traffic signal control investigate the issue of oversaturated intersections and the spillover of vehicles in lines, both of which are caused by unpredictable fluctuations in the flow of traffic. In order to achieve real-time adaptive control of the length of each phase of a traffic signal, a model for self-organizing control is developed with the constraints of road capacity and the minimum expected traffic flow delay as the objective. The local intersection and the intersections that are immediately adjacent to it serve as the fundamental unit of traffic signal control, and it is at this level that the fundamental equations of

traffic signal control are established. The equations establish an online method for determining the optimal phase duration of a traffic signal, which leads to the development of a rule-based real-time traffic signal control model, which is essential for the efficient allocation of intersection space resources. The method can be accessed through the Internet. Through the interaction of neighboring intersections, the rate of traffic entering an oversaturated phase is automatically restricted, which helps to mitigate the problem of queueing spillover. When the boundary inflow conditions are held constant, the results of the simulation demonstrate that the control effect is significantly superior to that provided by SCATS. The rule-based real-time traffic signal control model addresses the issue of vehicle queueing spillover caused by fluctuations in traffic flow more effectively than the traditional centralized coordinated control model does. This is because the rule-based model uses real-time data.

[4] suggests a new adaptive traffic signal control scheme in order to deal with the unpredictable traffic flows that occur at intersections. A deep neural network, also known as a long short-term memory network (LSTM), is used to make decisions regarding look-ahead signal control. These decisions are based on the anticipated long-term feedback from a particular traffic state. The network was constructed with the specific intention of achieving the goal of rapidly and accurately determining the complex traffic patterns that are present at any particular intersection. We collect data from multiple interactions that take place between a simulated environment and the corresponding adaptive traffic signal controller with the assistance of the actor-critic algorithm, which is one of the algorithms that are based on reinforcement learning. This allows us to determine the essential parameters of the LSTM deep neural network. The numerical experiments used a realistic model environment with a 24-hour time-varying traffic demand, including rush hour and non-rush hour scenarios, as the basis for traffic generation. This was done in order to verify the efficacy of the proposed scheme by generating traffic in accordance with the conditions of the

environment. The findings of these tests indicate that the proposed plan, when compared to an optimized fixed-time plan (Synchro), has the potential to drastically cut intersection wait times by as much as fifty percent. In addition, the proposed plan has the potential to reduce fuel consumption, emissions, line lengths, and vehicle delays while simultaneously increasing average speeds.

An innovative adaptive traffic signal control scheme is the solution that experts in the field of traffic signal control claim is the answer to the problem of a hybrid manual-automated traffic scenario at a remote intersection [5]. Within a structure that accounts for the various speeds and states that vehicles can be in, the amount of time it takes for each one to cross is minimized. The control strategy ensures the safety of pedestrians and vehicles driven by humans by retaining the most essential components of conventional signal management systems. The optimal times for signal changes are communicated to automated vehicles one cycle in advance, which allows the vehicles to adjust their speed accordingly. The framework optimizes the amount of time that each signal is green by maximizing the amount of time that it does not directly take into account the cycle-split concept. A microtraffic simulation is used to evaluate how effective the proposed signal control strategy is after taking into account the percentage of the intersection's traffic that is turning, as well as the number of autonomous vehicles currently on the road. It has been observed that the shortest possible green time for each signal can be achieved through optimization. This is accomplished without a reduction in the capacity of the intersection, even when there is a high volume of traffic. Because of the adaptively shortened signal cycle, the flow of traffic has become more organized, and there are fewer cars that are idling in the roadway. Because of this, the surrounding area enjoys increased fuel economy as well as decreased levels of carbon dioxide emissions. The results are analyzed and compared to those that were obtained through the use of tried-and-true methods such as fixed-time control and signal-actuated control. The proposed system will see an improvement in the flow of traffic as

the number of vehicles capable of driving themselves increases in circulation.

According to research carried out by experts in the field of traffic signal control and published in [6], we are on the cusp of a paradigm shift toward agile and adaptive traffic signal control in Intelligent Transportation Systems. This shift will be made possible by the meteoric rise of technologies such as Big Data and the Internet of Things (IoT). An adaptive signal control system typically makes use of data gathered from real-time traffic detection in order to adjust the signal timing parameters based on control hyperparameters that have been pre-defined. After the traffic pattern has been altered, these hyperparameters, such as the maximum and minimum green times, will need to be modified so that they are compatible with the rapid shift in the traffic dynamics. The majority of the time, these adjustments are made by traffic engineers who are both knowledgeable and experienced. In this paper, we present a parallel learning framework that incorporates human input and is used to develop a holistic recommendation system that simulates and improves upon the in-field actions of signal control engineers. This framework is used to develop a holistic recommendation system that simulates and improves upon the in-field actions of signal control engineers. Adjustments to the system's signal control hyperparameters are recommended by experts in Hangzhou, China, where the system has been operational for some time. These recommendations are based on large multidimensional traffic datasets. The results of our experimental analyses indicate that the implementation of our signal recommendation system results in a discernible improvement in the flow of traffic.

According to [7], experts in the field of traffic signal control agree that enhancing VFE is essential to the process of finding a solution to the problem of energy shortages brought on by the growing global demand for power. VFE suffers tremendously as a result of the constant stopping and starting as well as the waiting at intersections. When the flow of traffic is managed by faulty traffic signal control, these negative effects are amplified. Deep reinforcement learning, also known as DRL, is a technique that has been

utilized in the past with great success to improve traffic light control. To the best of our knowledge, only a very small number of studies have concentrated on eco-driving strategies for the control of traffic signals for VFE. We suggest using DRLs as the basis for a fuel-efficient traffic signal control in order to reduce the gap and improve fuel economy in vehicles. The DRL technique is essentially what we use to develop an agent that is able to manage traffic signals based on real-time traffic data at intersections and adjust speed profiles for approaching vehicles in order to enhance traffic flow. This is done in order to improve the flow of traffic. We evaluated the efficacy of our approach using both simulated and actual traffic datasets that were obtained from surveillance cameras in Toronto. Extensive testing demonstrates that in comparison to traditional methods of eco-driving and traditional methods of traffic signal control, our approach not only significantly reduces the amount of fuel that is used, but it also significantly increases the effectiveness of traffic signal control.

As stated in [8,] the claims made by experts in the field that streamlining the control of traffic signals is effective at reducing congestion at signalized intersections are not entirely clear. Recent studies have focused on implementing RL techniques for cooperative traffic signal control in a road network in order to effectively manage traffic throughout the entire system. This is being done in order to improve safety and efficiency. When it comes to exchanging data about traffic flow in the modern day, approaches that are based on collaboration frequently ignore the effects that transmission delay has on the system as a whole. The vast majority of reports take it as a given that it is possible for signal controllers to perform real-time data collection that is comprehensive across all vehicle characteristics. An RL-based cooperative traffic signal control strategy is what we suggest should be implemented in a traffic road network in order to address the problem of data transmission delay. We propose a traffic state prediction method to address the issue of data transmission delay by closing the gap between real-time and delayed traffic conditions. Additionally, we use a performance metric to evaluate how well our proposed work performs in

both synthetic and real-world scenarios. The findings demonstrate that by reducing the amount of time spent waiting for data transmission, our method is superior to max-pressure-based traffic signal control strategies that have been used in the past.

According to research that was carried out by authorities in the field of traffic signal control and published in [9], traffic signal control is an essential method that must be utilized in order to guarantee an effective flow of traffic in metropolitan areas all over the world. A significant amount of research has been conducted on the topic of developing optimal signal timing strategies. The signal plan is determined by optimization models that have static parameters in the overwhelming majority of cases within these analyses. RL is a model-free method that overcomes the limitations of traditional approaches. This is accomplished by gradually learning the optimal control strategy through the learning process. In recent years, deep RL approaches have become increasingly popular due to the scalable learning capability of deep neural networks under the complex real-world traffic conditions they are trained to analyze. In this article, we develop a complete actor-critic method for the efficient design of traffic signals. A novel deep neural network model is used to analyze a time-stamped series of images of the area in order to get a better understanding of the current traffic situation at an intersection than could be gleaned from static data such as queue length alone. This is done so that the situation can be understood more thoroughly. The actor-critic model and the deep neural network model are able to circumvent the problems that are inherent in the value-based and policy-based alternatives when used in conjunction with one another. Simulation experiments show that the deep actor-critic approach achieves higher performance than the conventional model-based approach as well as several other deep reinforcement learning strategies. Metrics used in the experiments include queue length, average delay time, and throughput.

Those who are knowledgeable in the field of traffic signal control are in agreement that increasing traffic densities in urban areas present difficulties

in terms of optimizing networks in terms of delay and capacity. However, the integration of connected vehicles into intelligent transportation systems presents novel opportunities for improving urban mobility and reducing delays. In this paper, Multi-mode Adaptive Traffic Signals are suggested as a solution for the distributed management of traffic lights at urban intersections (MATS). MATS is created by combining information on the locations of connected vehicles with plans for inductive loops and signal timing. The MATS algorithm, in contrast to other traffic signal control strategies for networked environments, is adaptable to scenarios with a restricted number of connected vehicles. This makes it possible for the algorithm to scale. Because a test bed is provided, connected traffic signal controllers in Birmingham, which is located in the United Kingdom, can be put through their paces on the city's extensive urban road network. In this experiment, we compare the performance of the MATS algorithm to that of MOVA using a calibrated TRANSYT plan and a single intersection by using the testing framework that was just proposed. When compared to MOVA, the MATS algorithm has the potential to reduce the mean delay by up to 28%; when compared to TRANSYT, it can reduce the mean delay by up to 96% and by up to 33%, respectively; this applies to networks with 0-100% connected vehicles. It is also demonstrated that the reliability of the MATS algorithm is maintained despite the fact that there is a high traffic demand on the road network and communication channel conditions that are less than ideal.

Adaptive traffic light signal control (ATSC) is a promising paradigm for alleviating traffic congestion in intelligent transportation systems, as stated in [11], which cites professionals working in the field of traffic signal control. [11] cites professionals in the field of traffic signal control. Current approaches to achieving collaborative ATSC rely on frequent exchanges of traffic data between neighboring intersections. This may not be possible in practice due to bandwidth restrictions in communication links, but it is a method that can be used to achieve collaborative ATSC. We design a decentralized ATSC framework for multi-intersection traffic networks that

minimizes wasted communication by allowing only neighboring intersections to share traffic data. This framework is intended to be used in traffic networks with multiple intersections. The proposed framework is comprised of an algorithm for the recovery of data through the use of GAN and an algorithm for the improvement of efficiency through the utilization of multi-agent deep reinforcement learning (DRL). Value decomposition is a technique that establishes a nonlinear mapping between local state-action values and the global reward. This allows each intersection to make its own decision about the timing of its traffic lights based on its own traffic data while still cooperating with neighboring intersections. Thanks to this technique, each intersection is able to make its own decision about the timing of its traffic lights. The decentralized ATSC framework that we have proposed makes use of environmental interactions in order to be resistant to changes in the flow of traffic and scalable to extremely large traffic networks. Simulations have shown that our proposed algorithm can significantly reduce the amount of time it takes for vehicles to complete their journeys while maintaining a high and stable level of traffic throughput.

According to the findings of their research that was published in [12], professionals in the field of traffic light management believe that electric vehicles (EVs) are essential to the delivery of care that can save lives. The amount of time it takes for electric vehicles to respond to an emergency call is one of the most telling indicators of how the emergency service process works. This survey investigates the most recent strategies for the management of traffic with the objective of accelerating the responses to electric vehicles. To begin, we put in place a number of different methods for controlling traffic, such as reserving lanes, ignoring signals, and a combination of the two. Following that, we will investigate the research that surrounds the various approaches to traffic management that make use of various kinds of algorithms. In addition, objective criteria are utilized in the categorization process by these surveys. The total also takes into account other objective metrics in addition to response time. In conclusion, this study offers an insightful analysis

of the shortcomings that are present in the practices that are currently used to direct emergency traffic. After that, it outlines the primary concerns and suggests possible future avenues of investigation for further research.

[13] Traffic signal control specialists advise the use of a parallel recommendation engine known as PRECOM for traffic control operations. This is recommended in order to lessen the amount of gridlock that occurs in the metropolitan area. Engineers who are tasked with manually calibrating traffic signal plans can receive effective and optimal control plans in real-time from the recommendation engine in the event that a road network is experiencing heavy congestion as a result of disruptive events. A computational experiment module, a parallel execution module, and an artificial system model make up the three primary components that make up the PRECOM system. The cycle of operations is going to benefit from having specialist understanding incorporated into it. A graph-based candidate generator, a spatiotemporal ranker, and a context-aware re-ranker are the three essential algorithmic steps that have recently been implemented in the recommendation engine. Testing of the PRECOM system was conducted both offline and online before it was finally put into operation in the city of Hangzhou in China. The findings of the experiments indicate that the recommendation system is compatible with the existing human-centric traffic management, operation, and control scheme.

Signalized intersections are the solution to the problems of transportation efficiency and vehicle fuel economy that are prevalent in urban areas, according to authorities on traffic signal control that were cited in [14]. As connected and autonomous vehicles (CAVs) continue to advance in capability, the mixed traffic environment, which comprises participants in the traffic flow with varying degrees of intelligence, will develop into an essential component of the intelligent transportation system. In this paper, a Coupled Vehicle-Signal Control (CVSC) approach to optimizing the timing of traffic signals and the driving trajectories of CAVs simultaneously is proposed. The goals of improving traffic efficiency and reducing energy consumption are the driving

forces behind the development of this approach. We should hopefully be able to reduce the total amount of time spent waiting at the intersection with the assistance of continuous signal timing optimization. The arrival time of the signal and the time the vehicle was sent the signal are both factored into the planning of eco-driving trajectories that are developed by conveyance-based vehicles, also known as CAVs, in an effort to reduce the amount of fuel that is consumed. In the end, simulation experiments were carried out in order to validate the proposed CVSC's ability to exert a controlling influence. In the first step of this process, we analyzed and discussed how changing key optimization parameters affected our findings. The proposed CVSC method was evaluated alongside the more traditional CACC control as well as the eco-driving model developed by GlidePath. It would appear from the findings of the study that the CVSC technique has the potential to successfully improve the functionality of signalized intersections. When more than 40% of vehicles on the road are CAVs, this strategy has the potential to reduce the amount of fuel consumed by 6%-14% and the average speed by 1%-5%.

[15] presents the findings of researchers working in the field of traffic signal control, who come to the conclusion that effective traffic signal control strategies are essential for the management of urban traffic networks. The length of the update time interval is typically determined by a trade-off between computational efficiency and control performance, and the existing optimization-based methods for urban traffic control update the traffic signal at fixed intervals. In most cases, the length of the update time interval is determined by the trade-off. Because it can avoid redundant optimization while still exhibiting a behavior that is satisfactory, we use an ETC scheme to control the traffic lights because it enables more versatile and effective control than traditional time-triggered control by triggering the control action based on events. In addition, we use it because it can avoid redundant optimization. The use of a distributed paradigm helps to reduce the computational complexity of the optimization process, which is beneficial because traffic networks are spread out across the globe. We propose a distributed

threshold-based event-triggered control strategy as a solution to this problem. According to this approach, agents are independently triggered, which results in asynchronous updates to the traffic signals that are used by the system. The agent will then work through the solution of a linear mixed-integer programming problem in order to modify the timing of the traffic lights. After being put through its paces in a number of different simulated traffic scenarios, it was determined that the proposed method offered the optimal balance between the ease of control it offered and the amount of computation it required. The proposed approach is evaluated under various traffic demands by simulation, and is shown to yield the best trade-off between control performance and computational complexity compared to other control strategies. Thus, it can be observed that a wide variety of models are proposed for traffic signal analysis, and each of them have different efficiency levels. But, in terms of cost Fuzzy Logic [1], LQR [2] and DRL [7] outperform other models, while SCATS [3] & LSTM [4] have low complexity, in terms of fairness of control work in cycle splits [5], and Reinforcement Learning [9] provide better fairness of control, in terms of scalability ATSC with GAN & LSTM [11], and CVSC [14] have better performance and congestion control efficiency of LSTM [4] and LQR [2] have better performance thus can be used for large-scale scenarios.

2. Conclusion And Future Scope

This article examines several models of traffic signal control and makes comparisons between them. It is clear that numerous models have been proposed for the purpose of traffic signal analysis, and that each of these models achieves varying degrees of success. Fuzzy Logic [1], LQR [2], and DRL [7] outperform other models in terms of cost, while SCATS [3] & LSTM [4] have low complexity, in terms of fairness of control work in cycle splits [5], and Reinforcement Learning [9] provide better fairness of control, in terms of scalability. However, in terms of scalability, Reinforcement Learning [9] provides better fairness of control. LSTM [4,] and LQR [2] have better performance and congestion control efficiency of ATSC with GAN & LSTM [11], and CVSC [14] have better

performance and can therefore be used for large-scale scenarios. In the future, these models will need to be validated on larger datasets. Additionally, they can be improved by integrating low-complexity Q-Learning based methods, which help the model perform better in real-time scenarios. Improving this performance for large-scale use cases can also be accomplished through the application of models that make use of computing techniques inspired by biological behaviours for real-time scenarios.

3. References

- [1] M. E. M. Ali, A. Durdu, S. A. Celtek and A. Yilmaz, "An Adaptive Method for Traffic Signal Control Based on Fuzzy Logic With Webster and Modified Webster Formula Using SUMO Traffic Simulator," in *IEEE Access*, vol. 9, pp. 102985-102997, 2021, doi: 10.1109/ACCESS.2021.3094270.
- [2] H. Wang, M. Zhu, W. Hong, C. Wang, G. Tao and Y. Wang, "Optimizing Signal Timing Control for Large Urban Traffic Networks Using an Adaptive Linear Quadratic Regulator Control Strategy," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 1, pp. 333-343, Jan. 2022, doi: 10.1109/TITS.2020.3010725.
- [3] G. Long, A. Wang and T. Jiang, "Traffic Signal Self-Organizing Control With Road Capacity Constraints," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 10, pp. 18502-18511, Oct. 2022, doi: 10.1109/TITS.2022.3152060.
- [4] S. Li, C. Wei, X. Yan, L. Ma, D. Chen and Y. Wang, "A Deep Adaptive Traffic Signal Controller With Long-Term Planning Horizon and Spatial-Temporal State Definition Under Dynamic Traffic Fluctuations," in *IEEE Access*, vol. 8, pp. 37087-37104, 2020, doi: 10.1109/ACCESS.2020.2974885.
- [5] M. A. S. Kamal, T. Hayakawa and J. -i. Imura, "Development and Evaluation of an Adaptive Traffic Signal Control Scheme Under a Mixed-Automated Traffic Scenario," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 21, no. 2, pp. 590-602, Feb. 2020, doi: 10.1109/TITS.2019.2896943.
- [6] J. Jin, H. Guo, J. Xu, X. Wang and F. -Y. Wang, "An End-to-End Recommendation System for Urban Traffic Controls and Management Under a Parallel Learning Framework," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 22, no. 3, pp. 1616-1626, March 2021, doi: 10.1109/TITS.2020.2973736.
- [7] A. Boukerche, D. Zhong and P. Sun, "FECO: An Efficient Deep Reinforcement Learning-Based Fuel-Economic Traffic Signal Control Scheme," in *IEEE Transactions on Sustainable Computing*, vol. 7, no. 1, pp. 144-156, 1 Jan.-March 2022, doi: 10.1109/TSUSC.2021.3138926.
- [8] A. Boukerche, D. Zhong and P. Sun, "A Novel Reinforcement Learning-Based Cooperative Traffic Signal System Through Max-Pressure Control," in *IEEE Transactions on Vehicular Technology*, vol. 71, no. 2, pp. 1187-1198, Feb. 2022, doi: 10.1109/TVT.2021.3069921.
- [9] D. Ma, B. Zhou, X. Song and H. Dai, "A Deep Reinforcement Learning Approach to Traffic Signal Control With Temporal Traffic Pattern Mining," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 8, pp. 11789-11800, Aug. 2022, doi: 10.1109/TITS.2021.3107258.
- [10] C. B. Rafter, B. Anvari, S. Box and T. Cherrett, "Augmenting Traffic Signal Control Systems for Urban Road Networks With Connected Vehicles," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 21, no. 4, pp. 1728-1740, April 2020, doi: 10.1109/TITS.2020.2971540.
- [11] Z. Wang, H. Zhu, M. He, Y. Zhou, X. Luo and N. Zhang, "GAN and Multi-Agent DRL Based Decentralized Traffic Light Signal Control," in *IEEE Transactions on Vehicular Technology*, vol. 71, no. 2, pp. 1333-1348, Feb. 2022, doi: 10.1109/TVT.2021.3134329.
- [12] W. Yu, W. Bai, W. Luan and L. Qi, "State-of-the-Art Review on Traffic Control Strategies for Emergency Vehicles," in *IEEE Access*, vol. 10, pp. 109729-109742, 2022, doi: 10.1109/ACCESS.2022.3213798.
- [13] J. Jin et al., "PRECOM: A Parallel Recommendation Engine for Control, Operations, and Management on Congested

Urban Traffic Networks," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 7, pp. 7332-7342, July 2022, doi: 10.1109/TITS.2021.3068874.

- [14] Y. Du, W. ShangGuan and L. Chai, "A Coupled Vehicle-Signal Control Method at Signalized Intersections in Mixed Traffic Environment," in IEEE Transactions on Vehicular Technology, vol. 70, no. 3, pp. 2089-2100, March 2021, doi: 10.1109/TVT.2021.3056457.
- [15] N. Wu, D. Li, Y. Xi and B. de Schutter, "Distributed Event-Triggered Model Predictive Control for Urban Traffic Lights," in IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 8, pp. 4975-4985, Aug. 2021, doi: 10.1109/TITS.2020.2981381.