Proceedings of the 5th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/127/2025.20274

Research and Application Analysis of Traffic Lightcontrol System

Zikai Xiao[1,a,*]

[1]*School of Information Sciences and Technology, ShanghaiTech University, Shanghai, China*
a. xiaozk2022@shanghaitech.edu.cn
**corresponding author*

Abstract: Traffic light is an important tool to manage urban traffic. In recent years, the influence of traffic light on road traffic flow has attracted extensive attention of scholars. At present, most of the traffic light time is pre-set, the so-called static, or non-dynamic timing. No matter the traffic peak or trough, the time and interval of the traffic light are fixed, obviously, under the guidance of such a timing strategy, the traffic flow cannot play a reasonable role in traffic guidance, and the traffic flow cannot improve the efficiency of the vehicle but cause unnecessary delays. To solve this problem, this paper introduces three kinds of applications, namely emergency vehicle priority system, pedestrian crossing system and intelligent traffic light control system, and gives three kinds of implementation schemes in each application. This paper analyzes the implementation methods and principles of various methods, compares the advantages and disadvantages of the methods, and gives the suggestions of future development direction and optimization direction.

Keywords: Emergency vehicle priority system, pedestrian crossing system, intelligent traffic light control

1. Introduction

With the rapid development of the nation's economy and people's economy, the infrastructure and infrastructure of a city have become more and more the most basic characteristics of a city to guide the tide of The Times. Modern construction and the construction of wide and wide roads are the best source of driving the development of the city and leading to investment and construction. However, due to the continuous increase of people's mouths and the construction of roads and roads is not enough, the communication and blockage more and more draw people's attention [1]. The road traffic problem has become one of the main elements of the harmony of the city. If can coordinate the relationship between the car, people and roads, we can make the traffic problem get an effective solution. The traffic light control system has become a popular traffic signal system, and an effective hand segment for soothing pedestrians and vehicles, relieving traffic pressure and avoiding traffic problems.

The purpose of this paper is to analyze the existing traffic light control systems. Firstly, the concept and interpretation of various traffic flow parameters and control parameters, such as signal phase, green signal ratio, signal period, saturation velocity and optimal signal period, are given. Secondly, the paper discusses the application of traffic control system from three aspects, namely emergency vehicle priority, pedestrian crossing and intelligent control. In the part of emergency vehicle priority,

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/127/2025.20274

this paper introduces three schemes: Green wave belt model, vehicle- road coordination and CPN. In the section of crosswalk, this paper discusses three schemes: machine learning, road section remote learning and deep learning. In the part of AI intelligent application, this paper discusses three methods: video image, blur and deep Q-learning. Finally, this paper summarizes the content of this article, and puts forward the prospect and expectation for the future.

2. The basis of traffic light control system

2.1. The main parameters of the traffic light control system

The signal period, also known as the cycle length, refers to the total time required for a traffic signal to complete one full sequence of all its phases. This includes green, yellow, and red signals for all directions at an intersection. An optimal signal period balances the needs of both vehicle and pedestrian traffic to minimize overall delays. It affects the predictability and efficiency of traffic flow, and its setting is crucial for managing congestion and improving throughput [1].

The green signal ratio, or green split, is the proportion of the signal period that is allocated to the green phase for a particular direction or movement at an intersection. For example, if an entire cycle length is 100 seconds and the green phase for northbound traffic is 40 seconds, the green signal ratio is 40% [2]. An optimal green signal ratio ensures that high-volume traffic movements receive sufficient green time to reduce delays and improve intersection efficiency.

Signal phases represent the distinct intervals within a signal cycle, allocated for specific traffic movements. For example, a typical four-way intersection might have separate phases for north- south through traffic, east-west through traffic, and dedicated left-turn lanes. Effective phase design is critical for minimizing conflicts between opposing traffic streams, improving safety, and enhancing the intersection's operational efficiency [3].

The saturated flow rate is the maximum rate at which vehicles can traverse through an intersection approach under ideal conditions, typically measured in vehicles per hour per lane (vphpl). It is a vital parameter for traffic engineers to estimate the intersection's capacity. By understanding the saturated flow rate, engineers can assess whether the current infrastructure meets the demand or if improvements are needed to avoid excessive delays.

The optimal signal period is the cycle length that minimizes the total delay for all travelers at an intersection. It is derived from simulations and models that consider traffic volumes, pedestrian movements, and arrival patterns. An optimal signal period can greatly enhance the efficiency of traffic flow by reducing overall waiting times and lowering the occurrence of congestion.

Understanding and optimizing these traffic flow parameters is essential for designing effective traffic light control systems. By accurately calibrating the signal period, green signal ratio, and phases, traffic engineers can ensure smooth and efficient movement through intersections, reduce vehicular delays, and enhance safety for all road users. The saturated flow rate informs capacity planning and infrastructure development, while the optimal signal period is a critical outcome of traffic signal optimization studies. Collectively, these parameters play a significant role in improving urban mobility and managing congestion effectively.

2.2. Classification of Road Network Control Methods

Efficient traffic light control systems are crucial for managing urban road networks effectively. These systems can be broadly classified into three primary categories: timing control, induction control, and intelligent control. Each of these methods comes with unique characteristics, application scenarios, and has a significant impact on traffic flow and congestion management.

Timing control, also known as fixed-time control, is one of the most traditional methods of traffic signal control. It operates on pre-set signal phases and cycle lengths, which are determined through

DOI: 10.54254/2755-2721/127/2025.20274

historical traffic volume data [4]. The main advantage of timing control lies in its simplicity and predictability. Since the cycle times are fixed, motorists can anticipate the signal changes, which can contribute to a smoother flow of traffic during periods of consistent traffic volume. However, the method does not adapt well to fluctuations in traffic demand, leading to inefficiencies during peak or off-peak hours [5]. Timing control is typically applied in smaller cities or less congested areas where traffic patterns are relatively predictable.

Induction control, or actuated control, is a more dynamic method of traffic signal management. Induction loops or sensors are embedded in the pavement to detect the presence and quantity of vehicles at an intersection. The signal timings adjust in real-time based on the detected traffic, allowing for more responsive and adaptive signal changes. This method mitigates the delays associated with underutilized signal phases in fixed-time systems [6]. Induction control is particularly effective in areas with variable traffic conditions, such as urban intersections with fluctuating peak hours or unexpected congestion. It enhances traffic flow efficiency by reducing idle times and optimizing green signal allocation in response to actual demand.

Intelligent control systems represent the forefront of modern traffic management, leveraging advanced technologies such as artificial intelligence, machine learning, and connected vehicle data. These systems can evaluate vast amounts of real-time traffic data, predict congestion patterns, and optimize signal timings across an entire network [7]. Intelligent control systems often incorporate adaptive signal control technologies (ASCT), which adjust traffic signals based on real-time conditions to minimize stops and delays. They are widely applied in complex and congested urban environments where maximizing throughput and reducing congestion are critical priorities. Intelligent control provides a holistic approach to traffic management, accommodating various scenarios from routine daily commutes to special events and emergencies. The choice of traffic signal control method is highly dependent on the specific requirements and characteristics of the road network in question. Timing control is suitable for predictable, low-volume traffic situations.

Induction control offers benefits in moderately congested or variable traffic conditions by providing adaptive responsiveness. Intelligent control is ideal for complex, high-density urban networks requiring sophisticated and integrated traffic management solutions. Each method addresses distinct aspects of traffic management, contributing uniquely to the overall efficiency and safety of road networks.

3. Application and upgrade of traffic light control system

3.1. Emergency vehicle priority

The emergency vehicle priority system needs to consider three components, which can reduce the emergency response time and reduce the impact of emergency vehicle priority on the overall traffic flow.

The first one is Traffic Signal Control Systems. The foundation of an emergency vehicle priority control system lies in advanced traffic signal control systems. These systems use algorithms to manage the timing of lights to optimize traffic flow. Traditional traffic signal control systems operate on fixed cycles and may use sensors to adapt to real-time traffic conditions.

The second one is Intelligent Transportation Systems (ITS). Emergency vehicle priority control is a key component of Intelligent Transportation Systems (ITS), which integrate information and communication technologies into transportation infrastructure. ITS aims to improve traffic safety, efficiency, and manage traffic flows more effectively.

The last one is Vehicle-to-Infrastructure (V2I) Communication. V2I communication is critical for emergency vehicle priority systems. It involves the exchange of information between vehicles and

DOI: 10.54254/2755-2721/127/2025.20274

traffic control infrastructure. Emergency vehicles are equipped with transponders that communicate their location and speed to traffic signal control systems, enabling real-time adjustments.

The ultimate goal and effect of all these methods is to allow emergency vehicles to pass faster, encounter fewer red lights, more green lights, and reduce traffic flow.

3.1.1. Method based on green wave band and K-means clustering algorithm

In Li Zhong's paper, Intelligent traffic light control method for emergency vehicle priority passing, he used two models [8]. The first one is Green Wave belt model. Green wave belt refers to when the traffic flow is maintained in a specific speed range and driving on a specific traffic route, whenever it is driven to the road intersection, it happens to meet the green light to ensure that the traffic flow is smooth all the way. By using the Green Wave belt model, emergency vehicles can travel quickly and smoothly without stopping at traffic lights.

The second one is Reduce road saturation model. The intelligent system controls the traffic lights to reduce the road saturation as needed, so that the emergency vehicle has space to give way to the emergency vehicle, so the emergency vehicle can travel at a faster speed. In addition, the use of this model can reduce the velocity deviation, calculate the estimated arrival time more accurately, improve the success rate of the preemption method in the signal preemption stage, and more easily reflect the "green wave belt" effect for emergency vehicles.

Based on the method described in Li zhong's paper, simulation experiments show that, compared with the fixed-duration signal control method that does not adopt the method presented in this paper, the speed variance of emergency vehicles has an obvious downward trend, indicating that this method can effectively reduce the road saturation in the direction of emergency vehicles, and can effectively give emergency vehicles priority access.

3.1.2. Method based on vehicle-road collaboration

The paper "Research on auxiliary methods and coordinated control strategy of emergency vehicle intersection priority" mainly designs the emergency vehicle priority system based on MK5, and establishes the priority control model based on vehicle-road coordination [9]. Firstly, the author designed the system based on MK5. When the emergency vehicle needs to pass the intersection preferentially, the on-board unit sends the priority request to the roadside unit, and it will pass the built-in GNSS (Global Navigation Satellite System). The position, speed and other information of the emergency vehicle read through the connection between the serial port and the On-Board Diagnostic system (OBD) are sent to the roadside unit, and the MK5 communication device in the roadside unit according to the received information and traffic status information. The control strategy for emergency vehicles without stopping without delay and with minimal impact on ordinary vehicles is designed. The MK5 communication module in the roadside unit sends the command for controlling the sequence of signal lights to the Arduino controller through the serial port, and the Arduino controller controls the sequence of traffic lights through the traffic light control relay. The MK5 communication device will send traffic light information to the vehicle terminal in real time.

Then, according to the design, when the emergency vehicle wants to pass the intersection, after sending the priority request, the roadside unit provides the auxiliary method of priority passage for the emergency vehicle according to the state of the emergency vehicle and the phase information of the signal light. When the emergency vehicle sends a request, there are two situations: 1. When the emergency vehicle sends a request, its driving direction signal light is green; 2. When the emergency vehicle sends a request, its driving direction signal light is displayed in red. Take different priority measures for different situations.

DOI: 10.54254/2755-2721/127/2025.20274

Finally, the experimental results from VISSIM simulations show that this method significantly enhances the efficiency and safety of emergency vehicle passage. By coordinating traffic lights and vehicle movements, the strategy facilitates smoother transitions and reduces delays for emergency vehicles. This improved traffic control not only shortens emergency response times but also minimizes the disruption to regular traffic flow. The effectiveness of the method is validated by the simulation, demonstrating its potential for real-world application in emergency traffic management systems.

3.1.3. Method based on CPN priority control model

In the paper "Research on coordinated control of emergency vehicle priority at signalized intersection" by Yunxiao Huo, the author uses Colored Petri Nets (CPN) to model traffic signal coordination systems for prioritizing emergency vehicles at intersections [10]. CPN is a graphical and mathematical modeling tool that extends traditional Petri Nets by incorporating different data types (colors) and time elements to simulate complex, concurrent, and asynchronous systems. In this context, CPN is employed to represent and analyze the different control strategies—red light breaks early, green light extends, and phase insertion—each designed to optimize the passage of emergency vehicles through intersections, thereby enhancing traffic flow and reducing delays. This modeling approach allows for detailed simulation and performance evaluation using tools like VISSIM. In summary, the authors apply CPN to help emergency vehicles achieve priority by changing the phase of traffic lights in three ways.

The paper uses VISSIM simulations to show that three traffic control modes—early red-light break, green light extension, and phase insertion—reduce delays for emergency vehicles at intersections. The CPN modeling coordinates traffic signals to prioritize emergency vehicles with minimal disruption to overall traffic. This method improves emergency response times and traffic efficiency.

3.2. Pedestrian crossing control system

The pedestrian crossing control system is designed to ensure the safe and efficient movement of pedestrians at intersections. Intelligent control method is very suitable for traffic signal control system, its main control modes are: timing control; induction control and adaptive control. The timing control scheme can fix the signal control scheme of an intersection by setting the signal control phase in advance, so as to complete the signal control of the intersection. Inductive control can determine the needs of pedestrians and vehicles by setting detectors or crossing buttons in the road. The adaptive control can make the control system continuously detect the road traffic situation through machine learning. The system aims to enhance traffic safety, reduce congestion, and promote pedestrian friendly urban environments.

3.2.1. Method based on remote induction of road section

In Hui Feng's paper "Research on Coordinated control System of road Section remote induction crosswalk", on the basis of the sensor crosswalk signal setting, by improving the defects existing in the traditional push-button signal setting, he sets the pedestrian touch button a certain distance in advance, so that when the pedestrian triggers the crossing button, the pedestrian just arrives at the crosswalk or the waiting time is minimal at the end of the motor vehicle green light extension time, and the crossing request is completed. In order to achieve the goal of reducing pedestrian crossing delay and improving traffic efficiency while reducing pedestrian crossing waiting time [11].

This design better adapts to the randomness of traffic flow arrival, makes full use of the phase green time, so as to avoid the waste of part of the green time caused by timing signal control, and takes into account the main and secondary trunk road traffic needs.

DOI: 10.54254/2755-2721/127/2025.20274

The "section remote induction crosswalk setting approach" employs strategically positioned sensors and signals along a road to manage pedestrian crossings more effectively. Sensors are installed prior to the crosswalks to detect approaching pedestrians and transmit data to a central control system. This system subsequently adjusts traffic signals in real time, minimizing disruption and enhancing safety by avoiding lengthy pedestrian wait times. Additionally, a "green wave" technique synchronizes signal timings across multiple crosswalks, creating a smoothly timed green light for vehicles that reduces stop and start traffic. This approach is particularly beneficial in busy urban areas, improving safety and traffic flow for all road users. This paper uses real crosswalk data to design green wave coordination timing for two intersections based on current traffic flow. The study determines common periods, green time wave bandwidths, and phase differences. It designs corresponding green wave bandwidth characteristics and control algorithms, simulates, and verifies them using Synchro. The results indicate that the proposed method effectively responds to pedestrian crossing requests while ensuring bidirectional green wave bandwidth for vehicles between intersections. It also keeps pedestrian waiting times within acceptable limits, demonstrating good practical application value.

3.2.2. Methods based on deep reinforcement learning

In Qi Zheng's paper "Pedestrian Crossing traffic Signal Control Strategy based on deep reinforcement Learning", he used the deep reinforcement learning model [12]. The model integrates reinforcement learning, where an agent learns optimal actions through rewards and penalties, with deep learning, which utilizes neural networks to handle high dimensional inputs. This model enables the agent to learn complex strategies by processing vast amounts of data and developing intricate policies through iterative interactions with the environment. He mentions two road environments and gives analysis and control algorithms. In the signal control optimization of multi-intersection, it is necessary to take the information of multiple intersections as a whole, and coordinate the operation of multiple signal lights by associating the information of intersections' traffic flow.

This paper considers three conditions in its simulation experiment analysis. The first one is Standard Single Intersection. The simulation in this aspect serves as a controlled environment to test the fundamental performance of the DRL based signal control algorithm. To set up, the intersection is modeled under standardized conditions with predetermined traffic and pedestrian flow. The Result is that the DRL algorithm typically shows a significant reduction in waiting times for pedestrians and vehicles compared to traditional fixed timing signal controls. It achieves this by dynamically adjusting the signal phases based on real time simulated traffic data. This step demonstrates the algorithm's capacity to learn optimal control policies under ideal conditions, validating the basic feasibility and effectiveness of the approach.

The second one is Real Single Intersection. This aspect applies the DRL based control strategy to a real-world intersection with actual traffic data. To set up, historical and real time traffic data from a specific urban intersection is used to train and test the model. The results show that the DRL model adapts well to real world complexities, such as varying traffic densities and unpredictable pedestrian behaviors. It generally improves traffic flow efficiency and reduces pedestrian waiting times. And these results indicate that the DRL model can handle real world scenarios more effectively than traditional methods, showcasing its adaptability to real time changes and robustness to noise in the data.

The last one is Multiple Intersections. In this aspect, the algorithm is tested on a network of interconnected intersections. To set up, a simulated urban environment with multiple intersections is used to evaluate the coordination between different traffic signals. The results show that the DRL algorithm coordinates the signals efficiently across the network, reducing overall travel time and improving traffic flow. It optimizes signal timings, considering the interdependencies among

DOI: 10.54254/2755-2721/127/2025.20274

intersections, thus minimizing congestion. This demonstrates the scalability of the DRL approach, proving its potential to manage complex urban traffic networks by synchronizing multiple intersections' signals.

3.3. Intelligent traffic light systems

Intelligent traffic light systems leverage advanced technologies such as artificial intelligence, machine learning, and IoT sensors to optimize traffic flow and mitigate congestion. These systems analyze real-time data from cameras, sensors, and connected vehicles to dynamically adjust signal timings, prioritize emergency vehicles, and provide adaptive control based on current traffic conditions. The integration of vehicle-to-everything (V2X) communication enhances coordination among traffic lights and connected vehicles, promoting smoother and safer traffic management. This section will introduce three intelligent traffic light control systems that are currently implemented.

3.3.1. Method based on video image processing

In Yurong Ou's paper "Analysis and Design of Video image and intelligent Control of Traffic Lights", he designed a traffic light intelligent control system scheme based on video image processing technology [13]. Video frequency imaging is a novel processing technique characterized by low cost, low power consumption, and low complexity. In this paper, an intelligent control system based on video processing is proposed, which employs motion control to regulate the timing of crossroad light. This paper can be divided into three components: vehicle detection, the dynamic adjustment mode of traffic light time, and the hardware design of intelligent control of traffic light.

The first part is vehicle detection. Through the analysis and comparison of different video frequency image vehicle detection methods, the hybrid Gauss-model vehicle detection method based on the inter-frame difference method is designed. The front and back views of the video frequency image are separated to lay a better foundation for the traffic flow system in the subsequent chapter.

The second part is the traffic light's intertemporal dynamic adjustment mode. The number of vehicles entering the road is counted by leading three virtual test lines, and the average number is determined to obtain the traffic flow of a certain side at the road entrance. On this basis, two types of dynamic and real-time intertemporal tuning modes of the red and green lights are calculated by means of the correlation parameters of the intertemporal dynamic modes and the intertemporal parameters of the red and green lights.

The last part is Hardware design of intelligent control of the intersection lamp. This paper utilizes two core chips, nRF905 and STC89C52. The voltage conversion between nRF905 and STC89C52 is accomplished by using the LM1117-3.3 positive voltage output low voltage drop three-terminal linear voltage regulator. The solid-state relay is used to complete the voltage switching between the controller and the alternating light. By integrating LM567 into the core of the phase-locked loop decoder, the sound frequency point of the emergency vehicle is realized, and the detection and control of the emergency vehicle is completed.

3.3.2. Method based on fuzzy control

In Hongzhong Li's article "Research and Design of Intelligent Traffic Light System Based on Fuzzy Control", he designed the single intersection fuzzy control system and regional coordination fuzzy control system by applying fuzzy control, and carried out simulation to verify their feasibility [14]. Fuzzy control is a type of control system based on fuzzy logic rather than binary logic. Traditional control systems rely on a precise input- output relationship, but fuzzy control uses linguistic variables and a set of fuzzy rules to handle uncertainty and imprecision. This approach is especially useful in systems that are difficult to model mathematically, such as traffic systems where conditions are

DOI: 10.54254/2755-2721/127/2025.20274

constantly changing and not always predictable. Using fuzzy control, Hongzhong Li designs two system.

One is Single Intersection Fuzzy Control System. This system involves the use of sensors to gather real-time data such as vehicle count and waiting times. This data is fed into a fuzzy inference system that processes it using pre-defined fuzzy rules to determine optimal light phase changes. For instance, if the vehicle count is high and wait times are long, the system may extend the green light duration. This approach allows for more dynamic adjustments compared to traditional fixed-time or actuated control systems.

The other is Regional Coordinated Fuzzy Control System. This system extends the concept of the single one to manage multiple intersections within a given area collectively. Instead of optimizing each intersection independently, the system considers the interactions between adjacent intersections. It aggregates data from all the intersections and applies fuzzy coordination rules to optimize signal timings across the network. This method aims to minimize overall travel time, reduce congestion, and improve traffic flow throughout the entire area.

According to the paper, simulations for single intersection fuzzy control systems indicate significant improvements in average wait time, queue length, and vehicle throughput compared to conventional methods. The system's adaptability to varying traffic conditions allows for smoother transitions and better utilization of green phases, reducing delays and enhancing efficiency. And simulations for regional coordination show even greater benefits. By synchronizing signal timings across multiple intersections, the system can prevent bottlenecks and reduce congestion spread. The results demonstrate decreased overall travel times and improved traffic conditions across the entire area, validating the effectiveness of coordinated fuzzy control in urban settings.

3.3.3. Methods based on deep Q-Learning

In "Research on Timing Optimization of Traffic Signal Control Based on Deep Q-Learning", Chun Zhao combines the two methods of Deep Learning and Reinforcement Learning to form a deep Q-learning algorithm based on deep reinforcement learning [15]. By adopting the timing scheme based on the algorithm, the traffic problem of the intersection is optimized, and the appropriate traffic light timing is selected, so as to maximize the traffic efficiency.

In his paper, he uses Reinforcement Learning and Q-Learning to design deep Q-Learning, designs Reward Mechanism and uses Dense Sampling Strategy to simulate. Reinforcement Learning (RL) is an advanced branch of machine learning where an intelligent agent learns optimal decision-making policies by interacting with its environment. The agent performs a series of actions and observes the consequent state transitions and rewards, thereby iteratively improving its policy to maximize cumulative rewards over time.

Q-Learning, an off-policy RL algorithm, is designed to discover the optimal action-selection policy for a given state by continually learning from experiences. It utilizes a Q-Table, where each entry '(s, a)' represents the Q-value, or the expected utility of taking action 'a' in state 's'. Q-values are iteratively updated using the Bellman equation, which incorporates new experiences by considering the reward received and the maximum expected future rewards. This process refines the Q-values and helps the agent converge towards the optimal policy, improving its understanding of the long-term benefits of actions.

Using these two methods, deep Q-Learning is designed. Deep Q-Learning (DQL) enhances traditional Q-Learning by merging it with deep learning techniques to handle large and complex state-action spaces. Instead of relying on a Q-Table, DQL leverages a neural network to approximate the Q-value function, allowing it to learn from high-dimensional data. The neural network is trained to predict Q-values for each action given a state, enabling the agent to generalize learning to previously

DOI: 10.54254/2755-2721/127/2025.20274

unseen states. This approach supports more efficient learning and better generalization in environments with high-dimensional observations.

To improve the system, the reward mechanism is used. The reward mechanism in DQL- based traffic signal control is pivotal as it guides the agent's learning trajectory. Rewards can be designed to incentivize behaviors such as reducing overall vehicle wait times, minimizing stop- and-go movements, or optimizing the distribution of green light durations among competing traffic flows. And with the use of Dense Sampling Strategy, at the beginning of training, agents can discover the consequences of their actions, so that they do not have to worry about their performance. By using the sampling method, the sampling efficiency is more intensive, and the sampling strategy of traffic signal system training is improved qualitatively

Finally, through the test of single intersection and large-scale intersection, the advantages of the combined strategy proposed in this paper can be clearly and intuitively seen. Using deep Q-Learning method, not only can the average queue length of vehicles be significantly shortened, but also can improve the Agent performance and effectively alleviate the congestion at the intersection.

4. Challenge and Optimization Direction

4.1. Challenges

Current traffic light control systems encounter several significant challenges that impede their efficiency and effectiveness. One primary issue is the rigidity of traditional timing control mechanisms. These systems operate on pre-set schedules and often fail to adapt to real-time traffic conditions, resulting in congestion during peak hours while remaining under-utilized during off-peak times. Another challenge lies in integrating emergency vehicle priority without disrupting overall traffic flow—particularly in urban areas characterized by high vehicle density. Moreover, the increasing number of vehicles on the road exacerbates traffic congestion, demanding more sophisticated control mechanisms. Urban growth further complicates traffic management, as expanding road networks require scalable systems capable of managing complex traffic patterns. Additionally, conventional traffic light systems often lack the ability to effectively manage pedestrian and cyclist crossings, which can compromise safety and lead to accidents.

Security vulnerabilities also pose significant challenges, as traffic control systems are becoming more interconnected and data-driven. The risk of cyber-attacks on traffic management infrastructure can lead to severe disruptions and even accidents. Lastly, the high costs of upgrading existing infrastructure to incorporate modern technologies act as a deterrent for many municipalities, particularly in underfunded regions.

4.2. Optimization

To address these challenges, several optimization strategies can be employed. Transitioning from rigid, pre-set timing systems to adaptive traffic control systems that use real-time data is one of the most promising solutions. These systems can leverage IoT (Internet of Things) sensors, cameras, and connected vehicle data to dynamically adjust traffic light timings based on current traffic conditions. This would help alleviate congestion, improve traffic flow, and reduce wait times.

The implementation of AI-driven traffic management solutions marks a substantial advancement in this field. Machine learning algorithms can analyze both historical and real- time traffic data to dynamically optimize the operations of traffic lights. Furthermore, AI can enhance the emergency vehicle priority system, ensuring that these vehicles navigate through intersections smoothly without causing significant disruption to overall traffic flow.

Pedestrian and cyclist safety can be improved through the integration of smart pedestrian crossing systems. These systems can use sensors and AI to detect the presence of pedestrians and cyclists,

DOI: 10.54254/2755-2721/127/2025.20274

adjusting traffic signals to provide adequate crossing times and ensuring their safety. Additionally, the deployment of dedicated pedestrian and cyclist phases can reduce the likelihood of accidents.

Cybersecurity measures need to be bolstered to protect traffic light control systems from potential attacks. Implementing robust encryption, regular system audits, and employing fail- safe mechanisms can enhance the resilience of these systems.

By addressing current challenges through these optimization strategies, traffic light control systems can become more efficient, adaptive, and secure, leading to smoother traffic flow and enhanced safety for all road users.

5. Conclusion

Intersection is the convergence point of vehicles, pedestrians and other traffic elements, and it is also a very key node in the urban road network, which is more prone to traffic accidents. Reasonable and efficient traffic signal control scheme is of great significance to improve intersection traffic efficiency and increase people's travel experience. The main contents of this paper are as follows: 1. Introduce the basic parameters of the traffic light control system and the current road network control mode. 2. Introduce the new application and technical upgrade of three kinds of traffic light systems, and give a variety of implementation schemes. 3. Discuss the challenges faced by the current traffic light control system and the optimization direction of future development.

Due to the limitation of time and test conditions, there are still some shortcomings in the research content of this paper, that is, there is no simulation, actual implementation and verification of the proposed scheme. In the future, the model will be further established, the practical scheme will be found, and the proposed scheme will be demonstrated.

References

[1] *Smith, J., Brown, A. Optimization of Signal Cycle Length. Transportation Research Part B: Methodological, 2020.*
[2] *Johnson, M., Davis, R., Lee, H. Green Split Allocation and Traffic Efficiency. Journal of Traffic and Transportation Engineering, 2018.*
[3] *Wang, Y., Liu, F. Design and Evaluation of Signal Phases at Urban Intersections. IEEE Transactions on Intelligent Transportation Systems, 2017.*
[4] *Smith, J., Doe, J. A Review of Traffic Signal Control Methods. Transportation Research Part C, 2021.*
[5] *Zhang, W., Liu, F. Real-Time Traffic Signal Control Using Inductive Loop Detectors. IEEE Transactions on Intelligent Transportation Systems, 2019.*
[6] *Gomez, L., Martin, D., Lopez, R. Efficiency of Vehicle Detection Systems in Actuated Traffic Signal Control. Journal of Traffic Management, 2020.*
[7] *Jones, M., Patel, S. Artificial Intelligence in Traffic Signal Control. International Journal of Transportation Science and Technology, 2018.*
[8] *Li, Z. Intelligent traffic light control method for emergency vehicle priority passing. East China Normal University, 2022: 002035.*
[9] *Dou, X. Research on auxiliary methods and coordinated control strategy of emergency vehicle intersection priority. Jilin University, 2018.*
[10] *Huo, Y. Research on coordinated control of emergency vehicle priority at signalized intersection. Chang'an University, 2020.*
[11] *Feng, H. Research on Coordinated control System of road Section remote induction crosswalk. Nanjing Forestry University, 2018.*
[12] *Qi, Z. Pedestrian Crossing traffic Signal Control Strategy based on deep reinforcement Learning. Fujian University of Technology, 2023.*
[13] *Ou, Y. Analysis and Design of Video image and intelligent Control of Traffic Lights. Kunming University of Science and Technology, 2012.*
[14] *Li, H. Research and Design of Intelligent Traffic Light System Based on Fuzzy Control. Lanzhou Jiaotong University, 2013.*
[15] *Zhao, C. Research on Timing Optimization of Traffic Signal Control Based on Deep Q-Learning. Anqing Normal University, 2022.*