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The Evolution of Traffic Lights: A Comprehensive Analysis of Traffic Management Systems in Shanghai

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Abstract: This paper comprehensively analyzes the evolution of traffic light systems in Shanghai, highlighting the technological advancements and their impact on traffic management and safety. Starting from the historical context of the first traffic light in London in 1868 to the modern automated systems, the study explores the complexity and adaptability of traffic lights in Shanghai. Through field surveys and interviews with traffic engineers, the paper debunks common misconceptions about traffic light operation, revealing a sophisticated network that responds to real-time traffic dynamics using software like the Sydney Coordinated Adaptive Traffic System (SCATS) 6. The study also discusses the importance of pedestrian safety, suggesting future enhancements such as Global Positioning System (GPS) based emergency systems and accommodations for color-blind individuals. The paper further delves into the potential of Artificial Intelligence (AI) and Vehicle-to-Infrastructure (V21) technology in revolutionizing traffic light systems, emphasizing their role in improving traffic flow and safety. The findings underscore Shanghai's progressive approach to traffic management, showcasing the city's commitment to optimizing traffic control solutions for the benefit of both vehicles and pedestrians.

Keywords: Traffic management; Traffic light; Traffic network; Smart city; V2I (vehicle-to-infrastructure)

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1. Introduction

Traffic lights are indispensable tools that govern traffic flow and ensure the safety of pedestrians and motorists. The functionality of traffic lights goes beyond simple control signals: they embody a sophisticated network that coordinates vehicular and pedestrian movements by using a combination of red and green signals.

This study on traffic lights originated from a frustration with long wait times. However, through a multifaceted approach—including field surveys and interviews with esteemed traffic engineers from the Shanghai Traffic Management Authority—the complexity of traffic light systems and their significant development over the past 150 years became evident. This article aims to unravel the intricacies of traffic light systems in China, providing insights into their current operation, common public misconceptions, and future advancements.

2. The interesting history of traffic lights

To understand how traffic lights work and the journey behind them, we first need to look at the history of traffic lights, and their background information. The first traffic light was invented in December 1868 in London, England, by a railway engineer named J.P. Knight. This early traffic signal was installed outside the House of Parliament and was intended to control the flow of horse-drawn carriages and pedestrians. The traffic lights at that time were manually operated with gas-lit signals. It featured two semaphore arms and a gas light. The arms were used during the day and the gas light was used at night. During the day, the semaphore arms would be raised or lowered to signal "Stop" and "Go." At night, the gas light would show red to signal "Stop" and green to signal "Caution" (not exactly "Go"). The system was manually operated by a police officer. The signals helped to regulate the flow of horse-drawn carriages, reducing congestion at busy intersections. This was particularly important in bustling areas like the vicinity of the House of Parliament in London. Also, it improved the safety of the horse-drawn carriages as the signals can reduce collisions and maintain a safe distance between the carriages.

Figure 1. The first traffic light invention in London, England (Source: Knight, J.P. (1868) [1])

Unfortunately, this early traffic light had a significant drawback. On January 2, 1869, just a few weeks after it was installed, the gas light exploded, injuring the policeman operating it. This incident halted further development of traffic lights until the early 20th century.

The modern electric traffic light was later invented in 1912 by Lester Wire, a policeman in Salt Lake City, Utah, United States of America (USA), and the first electric traffic light was installed in Cleveland, Ohio, in 1914. This version used red and green lights and was manually operated from a nearby booth [2].

Figure 2. One of the first traffic cops in Detroit [3]

3. The misconception of modern traffic light systems

A common frustration among students is the prolonged waiting time at traffic lights. Since controlling traffic signals to reduce wait times is not feasible, identifying patterns in their operation can provide valuable insights. Additionally, such research may contribute to improving pedestrian safety, particularly for students.

This study investigates the timing and patterns of traffic lights in Shanghai, beginning with the development of a structured methodology to determine optimal observation periods. The selected time for analysis was 3:30 PM, coinciding with the end of the school day when many students rushed home, anticipating the light to turn green.

Initial data collection focused on establishing a baseline for the hypothesis. Observations revealed that green lights lasted approximately 20 seconds, whereas red lights lasted about 90 seconds—4.5 times longer. To determine the traffic light status at 3:30 PM, it was necessary to calculate the total cycle time and assess how many complete cycles occurred within the timeframe from an assumed starting point of 3:00 PM to 3:30 PM.

4. Steps and formula

4.1. Determine the total cycle time

(1) Green light duration: $G = 20$ seconds

(2) Red light duration: $R = 90$ seconds

(3) Total cycle time (T): $T = G + R = 20 + 90 = 110$ seconds

4.2. Calculate the total time in seconds from a starting point

(1) Starting point: 3:00 PM

(2) Observation time: 3:30 PM

(3) Total time from 3:00 PM to 3:30 PM (t): $t = 30$ minutes × 60 seconds/minute = 1,800 seconds

4.3. Determine the number of full cycles passed by 3:30 PM

(1) Number of full cycles (N): $N = t/T = 1{,}800/110 = 16$ cycles

4.4. Calculate the time elapsed into the current cycle

(1) Time elapsed in full cycles (E): $E = N \times T = 16 \times 110 = 1{,}760$ seconds

(2) Time into the current cycle (C): $C = t - E = 1{,}800 - 1{,}760 = 40$ seconds

4.5. Determine the status of the traffic light

(1) If $C \leq R$: the light is red

(2) If $C > R$: The light is green

Based on the above steps, the light will be red at 3:30 PM because 40 seconds is less than the duration of the red light (90 seconds).

4.6. Simpler formula

(1) Calculate the elapsed time into the current cycle: $C = t \times T$

(2) Determine the light status:

(i) If $C \leq R$: the light is red

(ii) If $C > R$: The light is green

Since 40 seconds is less than the duration of the red light (90 seconds), the light will be red at 3:30 PM. This hypothesis was tested through observations conducted at different times of the day over three days: Thursday, Friday, and Saturday. These days were selected based on expected pedestrian traffic patterns—higher volumes on Thursdays and Fridays and lower volumes on Saturdays. However, the results were unexpected. While the hypothesis was validated for Thursday and Friday, it did not hold true for Saturday.

4.7. Explanation of results

To analyze and understand the unexpected results, interviews were conducted with engineers from the Shanghai Municipal Traffic Management Bureau. Their insights provided a deeper understanding of the complexity of Shanghai's traffic light system, which, contrary to popular belief, is not purely time-based.

A key limitation of the initial survey was its reliance on timing as the sole variable. In reality, multiple factors influence traffic light operation. The system is controlled by advanced automated mechanisms that dynamically adjust signal timings in response to real-time traffic conditions. Software such as SCATS 6 enables engineers to fine-tune these timings to optimize traffic flow and safety.

This explains the observed discrepancies in the survey results: on Thursdays and Fridays, the traffic lights operate under high-traffic conditions, while on Saturdays, with significantly lower pedestrian flow, the intervals between green lights become longer.

Shanghai has already abandoned the time-based system since 1982. It is a perfect symbol of China's technological advancement. Notably, pedestrian safety emerges as a paramount concern in traffic light design. Suggestions for future enhancements, such as the integration of GPS-based emergency systems (to detect abnormal driving behavior) and accommodations for color-blind individuals, underscore the commitment to optimizing traffic light safety.

As pedestrian safety is improving, a problem slowly emerges as sometimes, pedestrians do not want to wait that long, causing some people to complain to the Shanghai Municipal Traffic Management Bureau. This issue can be improved by integrating solutions from other countries. One solution to this issue is by looking at Singapore's interesting policy dedicated to senior citizens. How this works is that people with a specific card (Senior Citizen Public Transport Concession Card) can tap the traffic light, therefore extending the time for crossing to an extra 20 seconds. What Shanghai can do is add more variation of cards, maintaining safety, and making the experience of pedestrians better.

5. Comparison of old and new traffic light systems

The evolution of traffic lights from the early gas-lit manually operated signals to the sophisticated, automated systems we see today highlights the significant advancements in traffic management technology.

5.1. Old traffic light systems

(1) Manual operation: Early traffic lights required a human operator, often a police officer, to manually change the signals.

(2) Gas light: The initial systems used gas lamps, which were prone to accidents, such as the explosion of the first traffic light in London.

(3) Simple timers: Later, electric traffic lights used simple timers to change signals at fixed intervals, without considering real-time traffic conditions.

(4) Limited adaptability: These systems could not adapt to varying traffic conditions and relied on fixed schedules, leading to inefficiencies during non-peak hours.

5.2. New traffic light systems

(1) Automated control: Modern systems are automated and use advanced algorithms to control signal timings.

(2) Real-time traffic data: They incorporate real-time traffic data through sensors and cameras to adjust signal timings dynamically.

(3) Software integration: Advanced software like the Sydney Coordinated Adaptive Traffic System (SCATS) is used to optimize traffic flow based on current conditions [4].

(4) Pedestrian safety features: Modern systems include features like extended crossing times for senior citizens, detection of abnormal driving behaviors, and accommodations for color-blind individuals.

(5) Integration with Al and V21: The future of traffic lights includes Al integration for better traffic management and Vehicle-to-Infrastructure (V2I) technology, allowing vehicles to communicate with traffic signals for enhanced safety and efficiency.

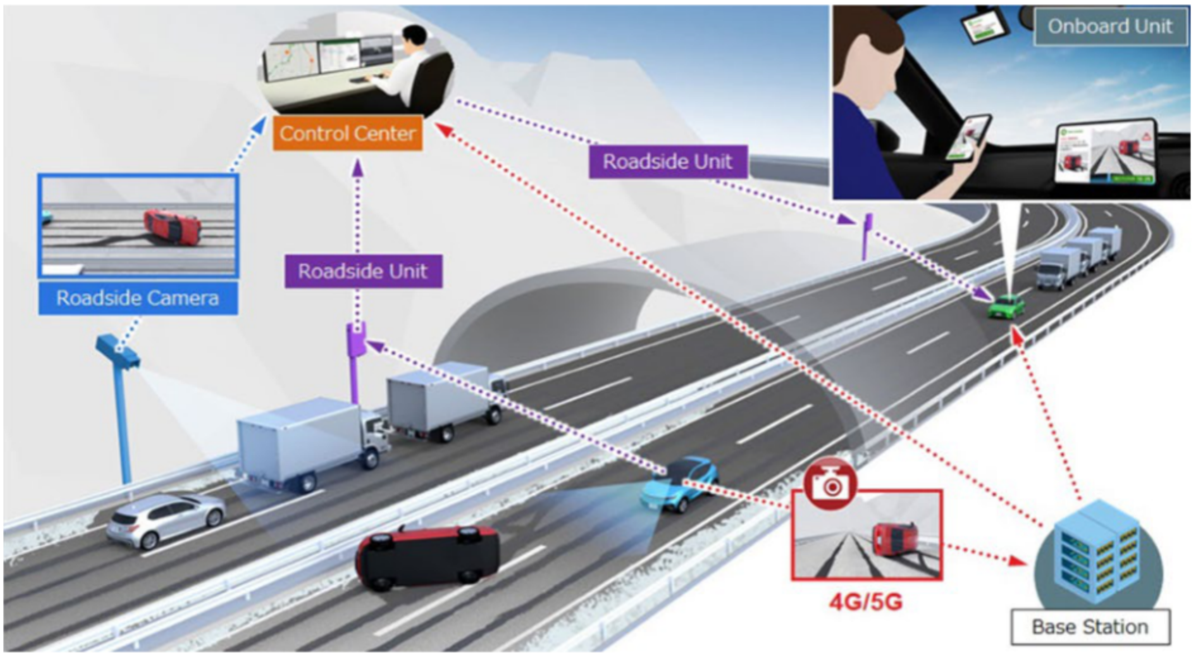

Figure 3. Conceptual image

Information in the forward direction undetectable by the onboard unit of an autonomous vehicle following another vehicle is transmitted to the rearward vehicle by V2I [5].

6. The future: a traffic light system without lights

Artificial Intelligence (AI) has already been integrated into traffic light systems. Although it may seem like a distant development for some, similar technologies have already been implemented and are expected to expand globally.

The primary advantage of AI in traffic management is its ability to optimize signal timing and coordination more efficiently and logically. As AI continuously learns and improves, it can analyze and recognize traffic flow patterns, adapting to changing conditions in real-time. Moreover, AI can assess overall traffic conditions, providing valuable insights to law enforcement for identifying the causes of traffic incidents and enhancing road safety for both vehicles and pedestrians.

Besides Al technology, a more revolutionary change is also on the horizon: Vehicle-to-Infrastructure (V2I) technology. Vehicles can communicate with traffic lights and other infrastructure. The goal of V21 is to improve traffic management, enhance road safety, and support the development of autonomous and connected vehicles. V21 relies on several key components and technologies to facilitate communication:

(1) Onboard Units (OBUs): These are installed in vehicles and are responsible for sending and receiving data. OBUs can communicate with other vehicles (V2V) and infrastructure (V21).

(2) Roadside Units (RSUs): These are installed along the roadway and in traffic infrastructure (traffic lights, road signs). RSUs collect data from vehicles and send relevant information back to them.

(3) Communication protocols: V2I communication uses dedicated short-range communications (DSRC) or cellular networks (C-V2X). DSRC operates in the 5.9 GHz band and is specifically designed for

automotive use, providing low latency and high reliability.

(4) Sensors and cameras: These are integrated into the infrastructure to gather data on traffic conditions, weather, road hazards, and more.

(5) Central management systems: These systems aggregate data from multiple sources, analyze it, and make decisions to optimize traffic flow and safety.

This futuristic technology can provide crucial data for the efficient operation of the transportation system. More importantly, it can create better safety for vehicles, pedestrians, and bikes.

7. Conclusion

Through a nuanced exploration of traffic light operations in Shanghai, a holistic perspective emerges, revealing the intricate interplay between technology, safety, and efficiency. The adaptive nature of these systems, coupled with an unwavering focus on pedestrian welfare, underscores a progressive approach to traffic management. This study serves as a small beacon illuminating the ongoing advancements in traffic light systems and the enduring quest for optimized traffic control solutions in Shanghai, also helping individuals who are interested in this topic understand the importance of traffic lights in our everyday lives.

Disclosure statement

The author declares no conflict of interest.

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