COMPARISON OF FIXED-TIME VS. ACTUATED TRAFFIC SIGNALS: EFFICIENCY AND CHALLENGES

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ABSTRACT
Urban traffic congestion is a growing concern worldwide, particularly in developing countries like India. Traffic signal control strategies play a vital role in regulating vehicular flow at intersections. This paper presents a comprehensive review of fixed-time and actuated traffic signal control systems, comparing their efficiency, implementation, and adaptability. It evaluates signal timing techniques, performance indicators, and real-world applications. Challenges and opportunities associated with each system are discussed, supported by Indian and global case studies. The paper concludes with recommendations for future research and policy integration in smart traffic systems.

Keywords:
Fixed-time signals, Actuated signals, Traffic management, Signal efficiency, Urban congestion

INTRODUCTION

Traffic signals play a vital role in maintaining road safety and regulating the movement of vehicles. Fixed-time signals function based on set time intervals without considering the real-time traffic situation, which can lead to inefficiencies during varying traffic conditions. On the other hand, actuated traffic signals rely on sensors and real-time traffic data to adjust signal timings according to demand. The overall performance of either system depends on factors like traffic density, the quality of supporting infrastructure, and the level of available technology [1].

FIXED-TIME TRAFFIC SIGNALS

Fixed-time signals are widely used due to their simplicity and low maintenance. Their operation is based on preset timing plans developed from traffic studies. These signals are especially suitable for intersections with stable, predictable traffic patterns [2].

Advantages

- Cost-effective and easy to install: Fixed-time systems are relatively inexpensive compared to smart or actuated systems and have straightforward installation procedures, making them ideal for municipalities with limited budgets.
- Suitable for areas with consistent traffic flow: These signals work well in locations where traffic patterns are predictable throughout the day, ensuring steady control without frequent adjustments.
- Minimal technological infrastructure required: They do not rely on vehicle detection systems or advanced software, which simplifies maintenance and reduces technical dependency.

Limitations

- Cannot adapt to traffic fluctuations: Since timings are pre-set, the system cannot respond to real-time changes in traffic volume, causing inefficiencies during unexpected congestion or clear roads.
- Leads to unnecessary delays during off-peak hours: Vehicles may be forced to stop even when no cross traffic is present, resulting in wasted time and frustration for drivers.
- Increases fuel consumption and emissions due to idling: Unnecessary stopping and waiting leads to prolonged engine idling, contributing to higher fuel use and more emissions.

ACTUATED TRAFFIC SIGNALS

Actuated traffic signal systems rely on sensors embedded in the road or placed nearby—such as inductive loops, cameras, or infrared detectors—to monitor vehicle presence in real time. When a vehicle is detected, the system processes this data and adjusts the signal timings accordingly. This dynamic adjustment helps optimize traffic flow by minimizing wait times and responding more effectively to current traffic conditions. [4].

Types of Actuation

- **Semi-Actuated Control**:
  Semi-actuated control uses detection only for the minor movements at an intersection. The phases associated with the major-road through movements are operated as "non-actuated." That is, these phases are not provided detection information. In this type of operation, the controller is programmed to dwell in the non-actuated phase and, thereby, sustain a green indication for the highest flow movements (normally the major street through movement). Minor movement phases are serviced after a call for their service is received

- **Fully Actuated Control**:
  Fully-actuated control uses detectors for all traffic movements, making it ideal for intersections with changing traffic patterns. It adjusts signals in real-time and is often used at isolated or low-volume intersections. During off-peak hours, even coordinated systems can switch to this mode for better efficiency. It's also effective at key arterial intersections to optimize green time.

Advantages:

- Reduces vehicle delays and queue lengths: Actuated signals adjust timings based on real-time traffic flow, helping minimize waiting times and preventing long queues at intersections.
- Improves efficiency during non-peak hours: During times of low traffic, these systems can give immediate green signals to approaching vehicles, ensuring smoother and quicker movement.
- More responsive to dynamic traffic changes: These systems detect changes in traffic volume instantly and adjust accordingly, making them highly adaptable to unpredictable traffic patterns.

Challenges:

- High installation and maintenance costs: Setting up actuated systems requires advanced sensors and technology, which can be expensive to install and maintain.
- Requires continuous calibration and monitoring: To ensure accuracy and responsiveness, these systems must be regularly checked and fine-tuned by trained personnel.
- Sensor malfunction can affect system reliability: If a sensor fails or gives inaccurate readings, the entire signal operation can be disrupted, leading to inefficiencies or traffic issues.

Parameter	Fixed-Time Signals	Actuated Signals
Adaptability	Low	High
Installation Cost	Low	High
Maintenance Needs	Low	High
Efficiency during low flow	Low	High
Sensor Requirement	No	Yes

Table 1: Comparison between Fixed-Time and Actuated Signal Systems

PERFORMANCE INDICATORS

Evaluating signal control strategies involves analyzing indicators such as:

- **Average Delay per Vehicle**: Measures how long, on average, each vehicle is delayed at an intersection. Lower delays indicate more efficient signal control.
- **Queue Length**: Refers to the number of vehicles lined up at a signal. Shorter queues suggest smoother traffic flow.

- **Throughput/Capacity**: Indicates the number of vehicles passing through an intersection in a given time. Higher values reflect better handling of traffic volume.
- **Fuel Consumption and Emissions**: Analyzes the environmental impact of traffic signals. Efficient systems reduce idling time, saving fuel and lowering emissions.

Simulation tools like VISSIM, TRANSYT, and Synchro help traffic engineers model and compare these performance metrics under different traffic signal strategies. [5]

CASE STUDIES

Delhi, India – Ring Road Corridor Study

An IIT Delhi study compared fixed-time vs. actuated signals using VISSIM simulation. Results showed:

- 21% reduction in average delay
- 18% improvement in vehicle throughput
- 15% decrease in CO_2 emissions

when using actuated signals [6].

Toronto, Canada – Smart Traffic Control

The Toronto Transport Commission implemented fully actuated signals at major intersections. Key outcomes included:

- 25% reduction in wait time
- Increased pedestrian safety

Cost recovered within 3 years through fuel savings [7]

IMPLEMENTATION CHALLENGES

While actuated signals offer superior performance, their deployment faces several barriers:

- **Sensor Reliability**: Detectors installed at intersections are often exposed to harsh weather conditions such as rain, dust, and extreme temperatures, which can degrade their performance over time. Additionally, acts of vandalism or accidental damage can impair their sensitivity and accuracy, leading to unreliable traffic signal responses.
- **Power Supply**: For traffic signal systems to function without interruption, a stable and consistent electricity supply is essential. Any power outages or fluctuations can disrupt signal timing, leading to traffic delays, safety risks, and system malfunctions, especially in areas lacking backup power solutions.
- **Training & Expertise**: Designing and maintaining advanced traffic signal systems requires specialized knowledge and technical skills. However, there is often a shortage of trained professionals in this field, which can lead to improper installation, delayed maintenance, and inefficient system performance, particularly in smaller cities or developing regions.
- **Integration with ITS**: Actuated signals work best when connected to a larger intelligent traffic system. This allows better coordination, real-time adjustments, and improved traffic flow across multiple intersections. Without integration, their effectiveness remains limited.

CONCLUSION

The comparison shows that fixed-time signals are more affordable and easier to implement in smaller cities with limited traffic variation. However, actuated signal systems, which adjust timings based on real-time traffic flow, provide better long-term performance by reducing delays and adapting to changing conditions. For cities planning to switch to actuated systems, it is advisable to start with a phased approach—beginning with pilot projects in selected areas—along with a detailed cost-benefit analysis to ensure the transition is both practical and effective.

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