PERFORMANCE ANALYSIS OF ROAD INTERSECTIONS AT HYDERABAD (INDIA) UNDER HETEROGENEOUS TRAFFIC CONDITIONS

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ABSTRACT

Urban intersections in rapidly growing cities experience significant congestion due to uneven traffic demand and the limitations of fixed-time signal control. Adaptive Traffic Signal Control (ATSC) provides a rule-based mechanism to dynamically allocate green time based on traffic demand; however, it lacks learning capability and long-term optimization. This paper presents a comparative study of conventional ATSC and Reinforcement Learning–based ATSC (RL-ATSC) for minimizing vehicle delay at a real-world urban intersection. A case study is conducted at the Jalvayu Vihar Intersection using field-collected traffic data. MATLAB-based implementations are developed for both ATSC and RL-ATSC, and performance is evaluated using delay as the primary metric. Results show that ATSC reduces average delay to 51 seconds compared to fixed-time control, while RL-ATSC further enhances performance through learning-based optimization. The findings demonstrate the suitability of RL-based signal control for intelligent transportation systems in heterogeneous urban traffic environments.

Adaptive Traffic Signal Control at Jalvayu Vihar intersection is modeled as a Reinforcement Learning problem, where the signal controller acts as an agent that dynamically adjusts green times based on real-time traffic states to minimize average vehicle delay. Conventional Adaptive Traffic Signal Control (ATSC) adjusts green times using predefined mathematical rules, such as proportional allocation based on traffic volume. Adaptive Traffic Signal Control reduces average intersection delay by dynamically allocating green time based on real-time traffic demand. At Jalvayu Vihar Intersection, proportional green allocation and queue-responsive control reduced the average delay to 51 seconds, demonstrating the effectiveness of ATSC over conventional fixed-time control.

Reinforcement Learning is a learning-by-interaction paradigm, where a control agent:

- *Observes traffic conditions*

- *Takes signal control actions*

- *Receives feedback (reward/penalty)*

- *Improves decisions over time*

    In traffic signal control, RL transforms the intersection into a self-learning system.

    Reinforcement Learning enhances Adaptive Traffic Signal Control by enabling the signal controller to learn optimal timing strategies from real-time traffic interactions. Using traffic data from Jalvayu Vihar Intersection, RL overcomes the static nature of conventional ATSC and achieves superior delay minimization by optimizing long-term traffic performance rather than single-cycle efficiency.

RL improves ATSC by learning optimal signal timings from traffic feedback, minimizing long-term delay instead of relying on fixed proportional rules.RL-based ATSC outperforms conventional ATSC by learning optimal signal timings from traffic feedback, reducing long-term delay beyond rule-based proportional control.

KEYWORDS: *Adaptive Traffic Signal Control, Reinforcement Learning, Intersection Delay, Intelligent Transportation Systems, MATLAB Simulation*

OBJECTIVE

The primary objective of this study is to optimize vehicle delay at an urban signalized intersection by developing and evaluating adaptive and learning-based traffic signal control strategies under real-world traffic conditions for minimizing vehicle delay under heterogeneous traffic conditions,and also to demonstrate that reinforcement learning can systematically outperform conventional adaptive traffic signal control by learning from recurring congestion patterns and adapting to uncertain traffic behaviour, thereby providing a more intelligent and sustainable solution for urban intersection management.

Specifically, the study aims to move beyond conventional fixed-time and rule-based adaptive control by investigating how learning mechanisms can enhance decision-making in traffic signal control. While Adaptive Traffic Signal Control (ATSC) dynamically allocates green time based on instantaneous traffic demand, it operates without memory and does not account for the temporal evolution of congestion. As a result, ATSC may perform sub-optimally under highly variable and stochastic traffic conditions commonly observed at urban intersections.

To address this limitation, the study introduces a Reinforcement Learning–based ATSC (RL-ATSC) framework, in which the traffic signal controller learns optimal signal timing policies through repeated interaction with traffic conditions. The primary objective is therefore not only to reduce average intersection delay but also to improve the stability and robustness of signal control decisions over time.

The specific objectives are as follows:

- *To analyze the traffic demand characteristics of the Jalvayu Vihar Intersection using field-collected traffic volume data from multiple approaches.*

- *To develop a rule-based Adaptive Traffic Signal Control (ATSC) model that dynamically allocates green time based on proportional traffic demand.*

- *To design and implement a Reinforcement Learning–based ATSC (RL-ATSC) framework capable of learning optimal signal timing policies through interaction with traffic conditions.*

- *To estimate and compare intersection delay under conventional ATSC and RL-ATSC using a consistent queue-based delay model.*

- *To evaluate the effectiveness of RL-ATSC in reducing average delay and delay variability under peak and off-peak traffic conditions.*

- *To assess the statistical significance and robustness of delay reduction achieved by RL-ATSC through hypothesis formulation, variability analysis, and confidence-interval–based interpretation.*

- *To demonstrate the practical applicability of learning-based traffic signal control using MATLAB-based implementation and real-world traffic data.*

- *To identify limitations of rule-based adaptive control and highlight the advantages of reinforcement learning for complex and time-varying urban traffic environments.*

The objectives of this study are to develop ATSC and RL-ATSC models, compare their delay performance using real traffic data from Jalvayu Vihar Intersection, and statistically evaluate the effectiveness of reinforcement learning in optimizing intersection delay.