Technical Report

on

Dynamic Traffic Light Management System Using SUMO

Course: Edge AI and Robotics: RL and Conversational AI (UCS760)

Submitted by

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CERTIFICATE

This is to certify that the Report titled "**Dynamic Traffic Light Management System Using SUMO**" embodies the original work done by Stuti Wadhwa (102197024) and Navtegh Singh Gill (102053004) students of Thapar Institute of Engineering and Technology, Batch 2024 under my supervision.

Date: 9th November, 2023

Place: Patiala   Name of Supervisor: Dr. Jyoti Maggu

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ABSTRACT

Traffic congestion and inefficient traffic signal management are critical issues in urban transportation systems, leading to increased travel times, fuel consumption, and environmental pollution. To address these challenges, this project presents a Dynamic Traffic Light Management System (DTLMS) utilizing SUMO (Simulation of Urban MObility) simulation software. The DTLMS aims to optimize traffic signal operations in real-time by integrating advanced algorithms and traffic data analysis.

This project begins by establishing a virtual urban road network using SUMO, encompassing various intersections and road segments. A crucial component of the DTLMS is the collection of real-time traffic data, such as vehicle counts, speeds, and congestion levels. These data are continuously fed into the system, allowing it to make informed decisions.

The core of the DTLMS is an intelligent traffic signal control algorithm that utilizes reinforcement learning to adapt signal timings based on current traffic conditions. The system aims to reduce traffic congestion, minimize travel times, and enhance overall traffic flow, leading to a more efficient and environmentally friendly urban transportation system.

In this project, the DTLMS is evaluated and validated through extensive simulations in SUMO. The results demonstrate its effectiveness in reducing traffic congestion, improving traffic flow, and minimizing environmental impact. Additionally, the study highlights the potential for real-world implementation, showcasing the benefits of integrating intelligent traffic management systems into urban transportation infrastructure.

By leveraging the power of SUMO simulation and innovative traffic signal control strategies, this project contributes to the development of smarter and more efficient traffic management systems, which are essential for addressing the challenges of urban transportation in the 21st century.

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1. INTRODUCTION

In today's rapidly urbanizing world, traffic congestion has become an everyday ordeal for commuters in metropolitan areas. The interplay of vehicles, complex road networks, and limited resources necessitates innovative solutions to mitigate the time and energy lost at traffic signals. Traditional, rule-based traffic light management systems are often inefficient and incapable of dynamically adapting to real-time traffic conditions. To address this challenge, we embark on a groundbreaking project – the development of a Dynamic Traffic Light Management System using the SUMO (Simulation of Urban Mobility) platform, bolstered by the power of reinforcement learning.

Our primary goal is to significantly reduce the waiting time experienced by drivers at traffic signals, and we aim to achieve this using cutting-edge machine learning techniques. In this venture, we turn to reinforcement learning, a subset of artificial intelligence that has proven to be immensely effective in optimizing decision-making processes in dynamic environments.

The heart of our project lies in creating a simulated urban environment that closely mimics the complexities of a real city. Within this simulated cityscape, we intend to train a reinforcement learning model to make intelligent traffic light management decisions. The model's objective is simple yet transformative: to earn rewards by minimizing travel time for vehicles passing through the intersections it controls.

One of the distinguishing features of our system is its reliance on minimal input data. The model operates with knowledge solely about the number of vehicles present at each intersection. This minimalist approach mirrors the limitations faced by real-world traffic light controllers, which often lack comprehensive information about traffic conditions.

Traditional, manually-operated traffic light management systems are inherently flawed. They can lead to traffic jams, extended waiting times, and unnecessary fuel consumption, even when roads are devoid of vehicles. In contrast, our system aspires to be a beacon of efficiency, capable of analyzing the prevailing traffic conditions in real time and making split-second decisions that ensure a smoother, more expedient flow of traffic.

In the pages that follow, we will delve deeper into the technical details of our project, exploring the integration of SUMO simulation and reinforcement learning algorithms, while also elucidating how our system adapts and evolves to effectively reduce traffic congestion. With the advent of our Dynamic Traffic Light Management System, we hope to pave the way for more intelligent and responsive urban transportation infrastructure, ultimately enhancing the quality of life for countless city dwellers.

2. OBJECTIVES

The objectives for the project "Dynamic Traffic Light Management System Using SUMO Simulation with Reinforcement Learning" can be outlined as follows:

1. **Simulation Development**: Create a realistic simulation environment using the Simulation of Urban MObility (SUMO) platform to replicate a typical city traffic network, including various intersections and road segments.
2. **Data Collection and Integration**: Collect and integrate real-world traffic data into the simulation to ensure the model operates in a contextually accurate environment.
3. **Reinforcement Learning Model Implementation**: Develop and implement a reinforcement learning algorithm to control traffic signal lights within the simulation. The model should learn how to optimize signal timing for minimizing waiting times based on the current traffic conditions.
4. **Reward System Design**: Design a reward system that provides positive reinforcement to the reinforcement learning model for actions that lead to reduced waiting times and smoother traffic flow.
5. **Data Pre-processing**: Pre-process the data, including the number of cars present on every intersection, to ensure it is in a suitable format for input to the reinforcement learning model.
6. **Model Training and Tuning**: Train the reinforcement learning model on the simulation environment, fine-tuning its parameters and hyperparameters to optimize traffic signal control.
7. **Performance Evaluation**: Assess the performance of the reinforcement learning model by measuring key metrics such as average waiting times, traffic flow efficiency, and reduction
8. in traffic congestion.
9. **Comparison with Manual Management**: Compare the performance of the reinforcement learning-based traffic light management system with traditional manual management methods, highlighting the improvements achieved.
10. **Real-time Adaptation**: Implement a real-time adaptation mechanism that allows the system to respond to dynamic changes in traffic conditions and adjust traffic signal timings accordingly.

11. **User Interface Development**: Create a user-friendly interface that provides visualizations of the traffic simulation, real-time traffic information, and insights into the decision-making process of the reinforcement learning model.
12. **Scalability Assessment**: Evaluate the scalability of the system to handle larger and more complex urban traffic networks, ensuring that it remains effective as the size of the simulated city grows.
13. **Cost-Benefit Analysis**: Conduct a cost-benefit analysis to determine the economic and environmental advantages of the dynamic traffic light management system, including potential savings in fuel consumption and reduction in greenhouse gas emissions.
14. **Documentation and Knowledge Transfer**: Prepare comprehensive documentation, including technical manuals and guides, to facilitate the transfer of knowledge and the potential deployment of the system in real-world urban settings.
15. **Future Enhancement Recommendations**: Provide recommendations for future enhancements and improvements to further optimize traffic management and reduce waiting times in urban areas.

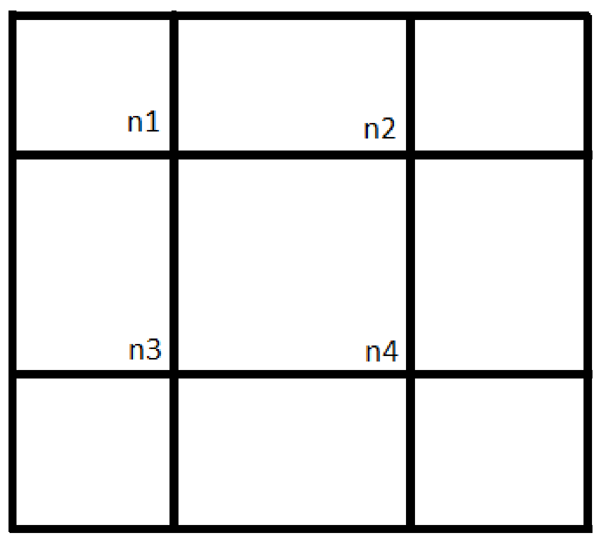
By addressing these objectives, the project aims to develop an intelligent traffic management system that leverages reinforcement learning to dynamically control traffic signal lights, resulting in reduced congestion, shorter waiting times, and more efficient traffic flow within a simulated urban environment

3. METHODOLOGY

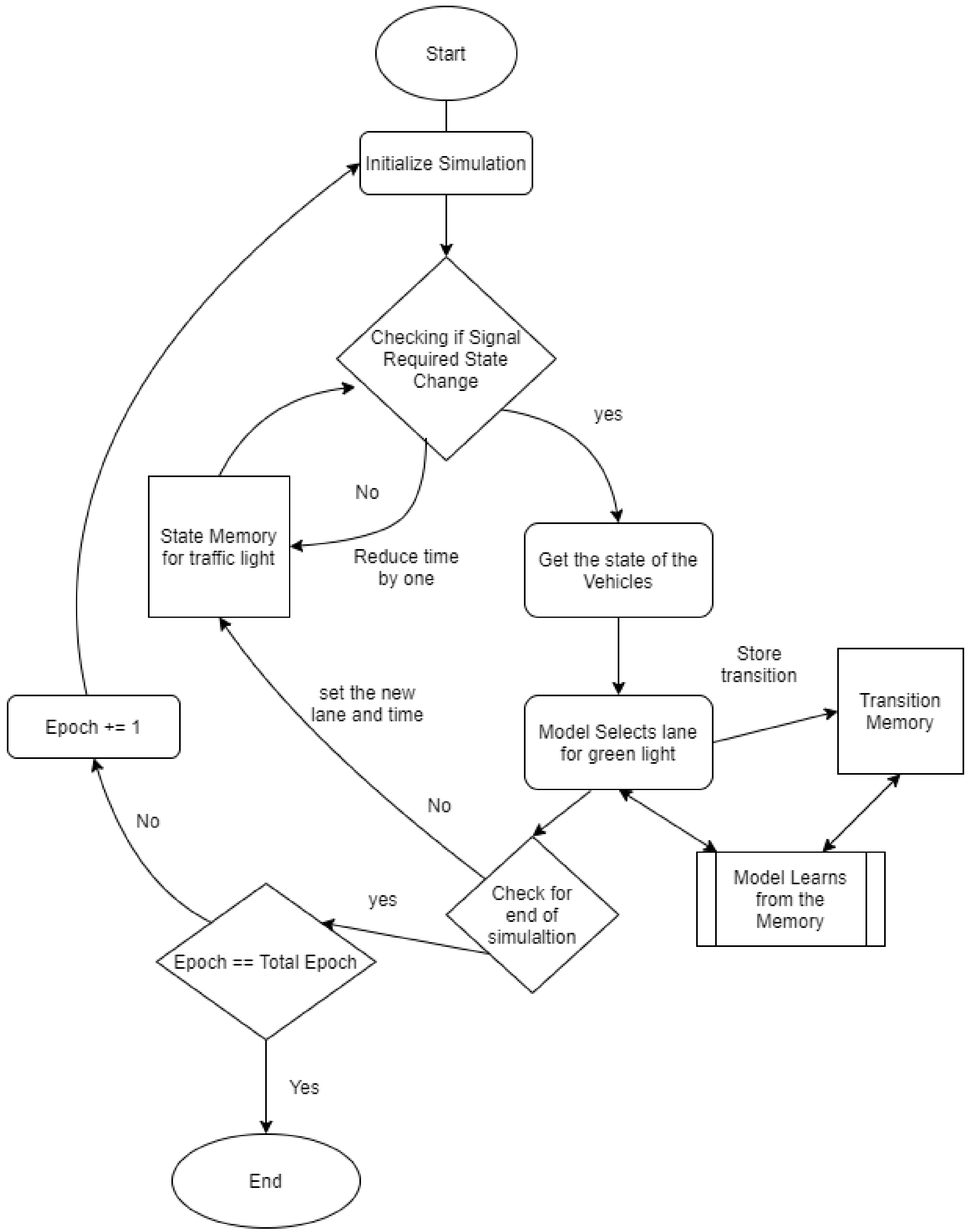
3.1 Basic Idea

Suppose we have a city grid as shown above with 4 traffic light nodes n1, n2, n3, and n4.
So, our model makes 4 decisions (one for each node) for which side to select for the green signal we have to select a minimum time (for ex 30s) that our model cannot select a green light time below that limit. Our task is to minimize the amount of time vehicles have to wait on the traffic signal.

The amount of waiting time for a given traffic signal is equal to the total car present on the signal x number of seconds. Each traffic signal will have 4 waiting time counter for each side of the road. So based on that our model will decide which side to select for the green signal.



3.1.2 Training Loop



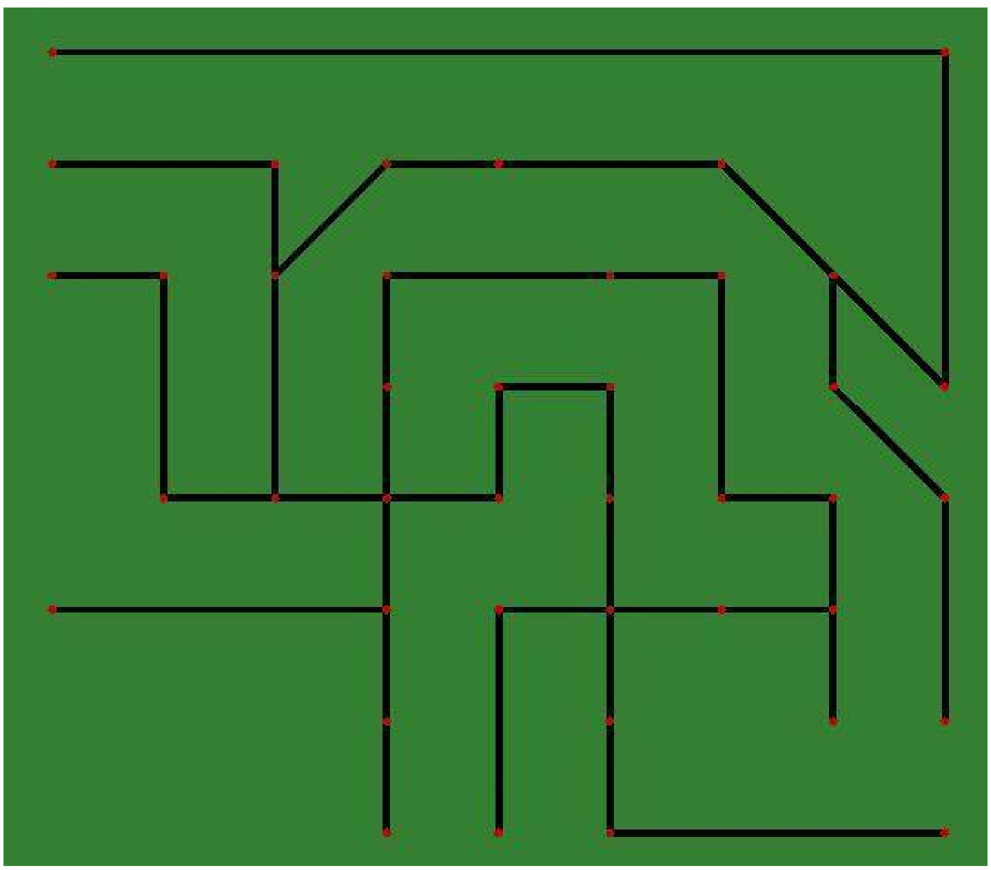
3.2 Training Process

We have trained our model on a number of events. Event is defined as a fixed motion where vehicles will pass through nodes in a fixed (pseudo-random manner). The reason for keeping the event fixed is that using a random event every time will give a random result. We will use many such fixed events to train our model so our model can handle different situations. The only input our model will receive is the number of vehicles present on 4 sides of each traffic node and our model will output 4 sides one for each node.The number of nodes depends on the size of the grid.

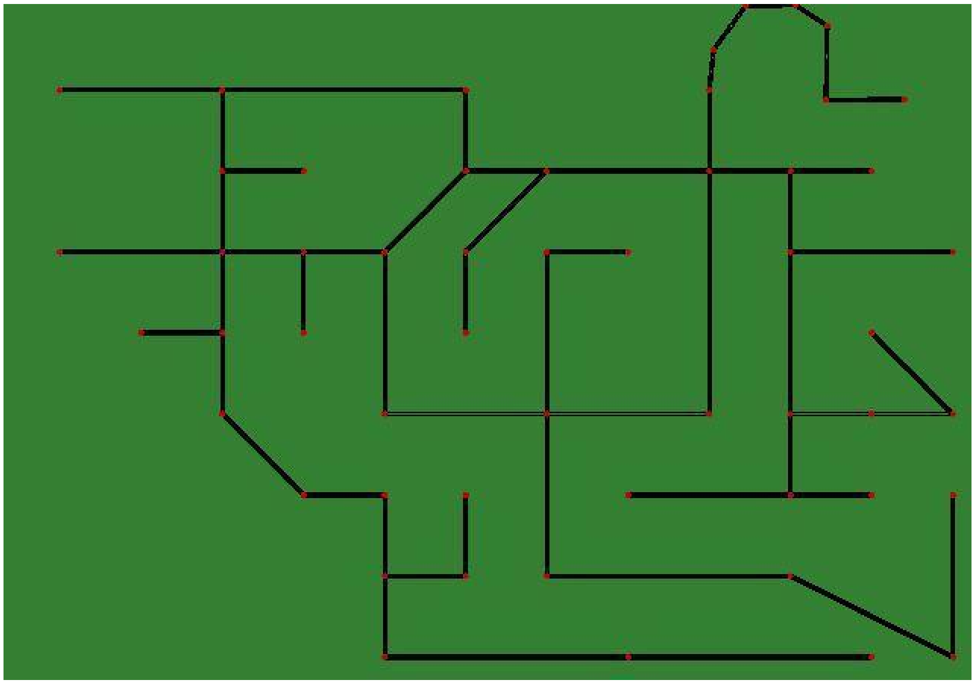
3.3 Sumo for Simulation

We used SUMO open-source software to make maps and generate simulations to train our model. Here are examples of some of the maps used to train the model.

Map 1



Map 2



The final phase of the project involved refining both the simulation environment and the RL-based algorithm:

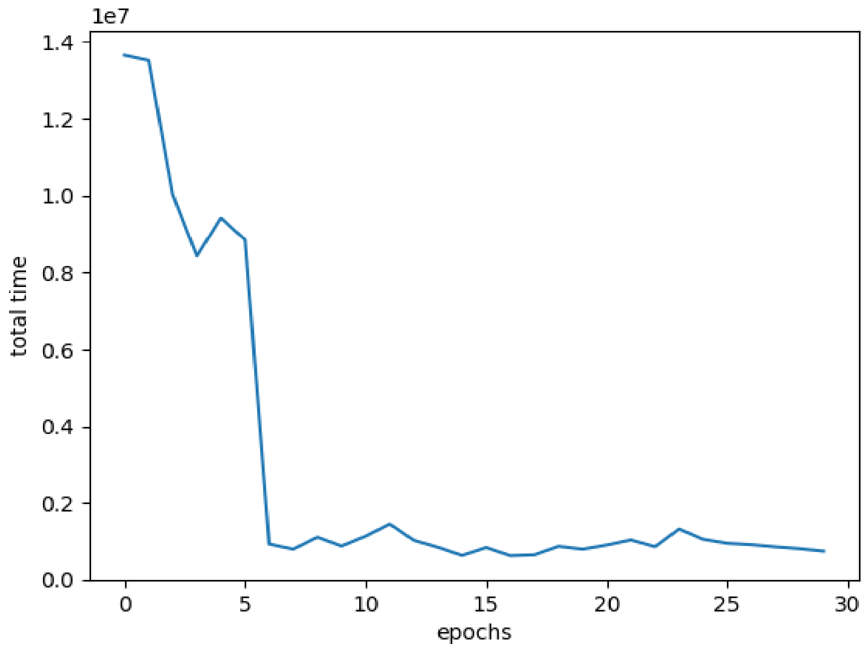
1. **Expanded City Simulation**: A larger, more comprehensive city simulation was created to better represent real-world traffic scenarios.

2. **Development of Dummy Simulation**: To expedite model training, a dummy simulation with the same dimensions as the real simulation was developed.

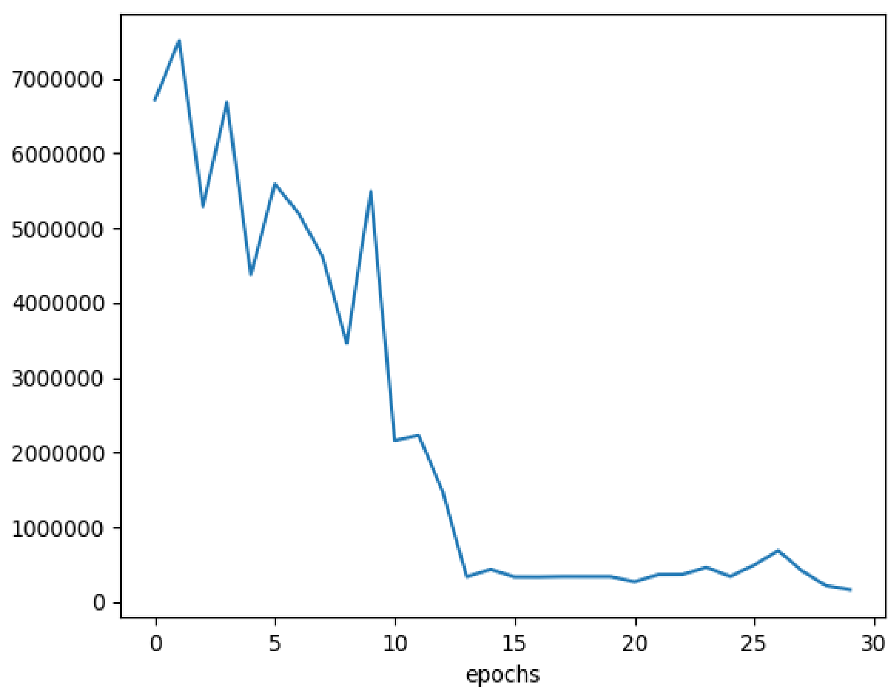
3. **Reward Function Definition**: A reward function suitable for the RL algorithm was defined, allowing the algorithm to be tested within the real simulation environment, thereby fine-tuning its performance and decision-making capabilities.

4. RESULTS AND DISCUSSION

4.1.1 Epoch Vs Time for Map1



4.1.2 Epoch Vs Time for Map2



ADVANTAGES

Implementing a Dynamic Traffic Light Management System using SUMO simulation with reinforcement learning offers numerous advantages, including:

1. **Reduced Waiting Times**: The primary goal of the system is to minimize waiting times at traffic signals. By using reinforcement learning, the system can adapt in real-time to optimize traffic flow, resulting in reduced waiting times for commuters.

2. **Improved Traffic Flow**: Unlike manual traffic light management, which can be inefficient and lead to traffic congestion, this system assesses the current traffic situation and makes decisions based on real-time data. This leads to smoother traffic flow, reducing the likelihood of traffic jams.

3. **Enhanced Safety**: By reducing waiting times and congestion, the system can improve road safety. Shorter waiting times at intersections can reduce the risk of accidents and increase overall road safety.

4. **Energy Efficiency**: Dynamic traffic light management can help reduce energy consumption by minimizing unnecessary idling and acceleration, which is common in congested traffic situations. This is not only environmentally friendly but also cost-effective in the long run.

5. **Adaptability**: The reinforcement learning model can adapt to changing traffic conditions, making it suitable for various scenarios, such as rush hours, special events, or accidents. It ensures that traffic lights are responsive to real-time data.

6. **Resource Optimization**: The system helps optimize the allocation of resources, such as traffic signals and road infrastructure, to accommodate the current traffic demands efficiently. This can lead to cost savings in the long term.

7. **User Satisfaction**: Reduced waiting times and improved traffic flow contribute to a better overall commuting experience for drivers and pedestrians. This can result in higher user satisfaction and reduced frustration with traffic congestion.

8. **Data-Driven Decision Making**: The system relies on data about the number of cars at each intersection to make decisions. This data-driven approach ensures that traffic lights are adjusted based on actual traffic conditions, rather than relying on predetermined schedules.

9. **Scalability**: The system can be scaled to cover larger areas and even entire cities, making it a versatile solution for improving traffic management in urban environments.

10. **Long-Term Sustainability**: As traffic patterns evolve and technology advances, the system can continue to adapt and improve over time, ensuring its long-term sustainability and relevance.

In summary, a Dynamic Traffic Light Management System utilizing SUMO simulation with reinforcement learning offers a range of benefits, from reducing waiting times and congestion to enhancing safety and sustainability in urban traffic management.

5. CONCLUSIONS

In conclusion, our project on the "Dynamic Traffic Light Management System Using SUMO simulation with reinforcement learning" presents a promising and innovative approach to address the challenges posed by conventional traffic light management systems. By harnessing the power of reinforcement learning and leveraging simulation technologies like SUMO, we aim to optimize traffic flow in urban areas, ultimately reducing waiting times and congestion.

The traditional manual management of traffic lights has proven to be inadequate in efficiently handling the ever-evolving dynamics of urban traffic. This project offers a solution that takes into account real-time data, specifically the number of vehicles at intersections, to make intelligent decisions regarding traffic light control. By providing rewards to the reinforcement learning model for time-saving actions, we can create a self-adaptive system that learns and adapts to the current traffic situation, thereby potentially minimizing traffic jams and long waiting times.

Our project underscores the importance of leveraging cutting-edge technology and artificial intelligence to improve the quality of life in urban environments. By introducing a dynamic traffic light management system, we move one step closer to smarter, more efficient, and sustainable urban transportation. With further development and implementation, this approach holds the potential to significantly enhance the overall traffic management and, consequently, the daily lives of people in urban areas.

6. FUTURE WORK

The future work in the realm of our "Dynamic Traffic Light Management System Using SUMO simulation with reinforcement learning" holds exciting possibilities for further enhancing urban traffic management. Here are some key areas of development:

1. **Integration with Self-Driving Cars**: As self-driving cars become more prevalent, there's a great potential to establish direct communication between traffic management systems and these autonomous vehicles. This communication can be utilized to inform self-driving cars of optimal speeds and routes, reducing the need for sudden braking and resulting in fuel savings. This integration can also facilitate smoother traffic flow and enhanced safety on the road.

2. **Predictive Traffic Management**: With advancements in predictive analytics and data collection, future iterations of our system can gain insights into the destinations of vehicles. By considering this information, traffic lights can be adjusted in real-time to create green waves that favor routes toward the most common destinations. This proactive approach can significantly reduce travel time and congestion while improving overall traffic efficiency.

3. **Enhanced Priority for Emergency Vehicles**: To improve road safety and response times, the system can be further developed to provide higher priority to emergency vehicles. Real-time tracking and immediate adjustments to traffic lights can help clear the path for ambulances, firetrucks, and police vehicles, ensuring they reach their destinations quickly and efficiently.

4. **Energy Efficiency and Sustainability**: Future work can focus on incorporating sustainability and energy efficiency measures into the traffic management system. This might involve optimizing traffic light schedules to reduce idling time, promote the use of electric vehicles, and explore innovative ways to minimize energy consumption while maintaining efficient traffic flow.

5. **Scalability and Real-World Implementation**: The project can be expanded to simulate larger and more complex urban environments, taking into account the diverse range of traffic scenarios and conditions. Real-world implementation of the system, in collaboration with city authorities and transportation agencies, would be a crucial step toward testing and validating its practical viability.

In summary, the future work for the Dynamic Traffic Light Management System includes not only technological advancements but also a deeper integration of smart transportation solutions into the fabric of urban infrastructure. This integration can lead to more efficient, sustainable, and safe transportation systems, ensuring a better quality of life for urban dwellers and contributing to a greener, smarter future.

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