International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 12 | Dec - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Smart Road Sync for Dynamic Traffic Management

Mrs. Shruthi T V , Abhishree N , Banashree D N , Chandana P O , Likhitha T S

[1,2,3,4,5]Associate Professor, Dept of ISE, East West Institute Of Technology, Bengaluru Student, Dept of ISE, East West Institute Of Technology, Bengaluru

---***---

Abstract - Smart Road Sync is an intelligent traffic management system that enables real-time communication between vehicles and traffic signals. It adjusts signal timings based on traffic density to reduce congestion and waiting time at intersections. The system also monitors carbon emissions to encourage eco-friendly travel and improve air quality. Additionally, it provides priority pathways for emergency vehicles to reduce response time. By optimizing traffic flow and minimizing fuel wastage, Smart Road Sync supports safer, faster, and more sustainable urban transportation.

Key Words: Smart Road Sync, V2I Communication, Traffic Optimization, Dynamic Signal Control, Emergency Vehicle Priority, Carbon Emission Monitoring, Smart City Transportation.

1. INTRODUCTION

Smart Road Sync is an intelligent traffic management system that enhances traffic flow and road safety through real-time communication between vehicles and traffic signals. The system monitors traffic density, vehicle movement, and environmental conditions to adjust signal timings dynamically. This reduces unnecessary waiting at intersections, lowers congestion, and minimizes fuel consumption. It also prioritizes emergency vehicles by creating a clear passage during critical situations, improving response time. Additionally, the system tracks carbon emissions and reduces idle time, supporting cleaner and more sustainable urban mobility. Overall, Smart Road Sync provides a smarter, safer, and more efficient approach to modern traffic management. Its adaptive decision-making ensures the system performs effectively even under rapidly changing traffic conditions.

2. METHODOLGY

The system collects real-time traffic data through sensors and simulated inputs to accurately assess vehicle density and traffic flow patterns at intersections. This information is processed using adaptive algorithms that automatically adjust signal timings based on current conditions, ensuring smoother movement and reduced congestion. An emergency vehicle detection mechanism is integrated to identify ambulances or fire trucks and prioritize signal changes, creating an immediate clear route for safe and rapid passage. Carbon emissions are estimated by analyzing vehicle idle time at signals, allowing the system to track and reduce environmental impact. Finally, the complete model is tested through simulations to evaluate improvements in traffic flow, waiting time, and overall system efficiency.

2.1 System Architecture

The Smart Road Sync system loads the dataset, trains a Linear Regression model, and sets up traffic signals. Vehicles are generated and moved in a loop, and emergency vehicles get priority with extended green time. When there’s no emergency, the system counts vehicles and predicts green signal duration using machine learning. Pygame updates visuals like vehicle movement, signals, waiting time, and emissions. The cycle repeats to ensure smooth, adaptive traffic flow, reducing congestion and improving overall efficiency. This makes the system more reliable and responsive in real-time traffic situations.

The system integrates key components— Real-time Traffic Control, Machine Learning Signal Timing, Emergency Vehicle Priority, Vehicle Detection, Pygame Simulation, Carbon Emission Monitoring, Smart Transportation System.

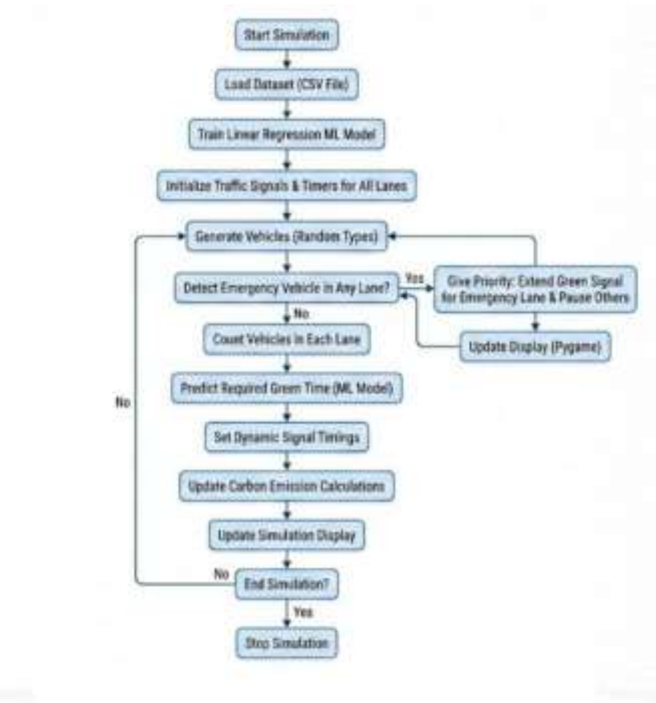

Fig.1 System Architecture

2.2 Dynamic Routing

Dynamic routing is a technique used to guide vehicles through the most efficient path based on real-time traffic conditions. The system continuously collects data such as vehicle density, speed, and road status at various intersections. Using this information, it identifies congested routes and suggests alternative paths that reduce travel time. Machine learning models help predict future traffic flow, ensuring routing decisions are accurate and timely. When an unexpected event like an accident or road blockage occurs, the system recalculates and updates the route instantly. Emergency vehicles are given priority routing, where traffic signals are adjusted to create a clear passage. This reduces response time and increases safety during critical situations. The system also focuses on lowering fuel consumption and carbon emissions by minimizing vehicle idle time and stop-and-go movement. Real-time route updates are continuously provided as conditions change. By adapting to traffic variations, dynamic routing improves travel efficiency and supports smoother traffic flow across the network. Overall, it enhances road safety, reduces congestion, and promotes eco-friendly urban mobility.

Fig.2 Dynamic Routing

2.3 Carbon Emission

Vehicle emissions significantly contribute to urban air pollution and global greenhouse gases. In traditional traffic, frequent stopping, idling, and accelerating at busy intersections increase fuel consumption and CO_2 output. The **Smart Road Sync** system solves this by using adaptive signal control to smooth traffic flow and reduce idling.By adjusting signal timing based on real-time traffic density, the system prevents unnecessary stop-and-go driving, which lowers fuel use. It also monitors emission levels to identify highly polluted areas and reroute traffic accordingly. Additionally, prioritizing emergency vehicles prevents sudden traffic jams that cause emission spikes. Tests show that optimizing signal timing reduces the carbon footprint and improves air quality, making Smart Road Sync a key tool for sustainable urban mobility.

Fig.3 Carbon Emission

2.3.1 Proactive & Predictive Control

The system's core is a Linear Regression Machine Learning (ML) Model trained on historical and real-time flow data. This model is designed for proactive control, meaning it anticipates congestion 2-5 minutes in advance, allowing it to adjust signal phases *before* traffic builds up.

The model calculates the optimal Green Phase duration (T_G) for each lane using learned weights (W) applied to the current vehicle count (N). The primary objective of this calculation is to minimize the delay time (D) experienced by vehicles, which directly reduces excess emissions.

1.VehicleClassification: The system uses Computer Vision (via cameras or integrated sensors) to classify approaching vehicles into precise categories: Heavy Vehicles (trucks/buses), Light Vehicles (cars/SUVs), and Two-Wheelers. This granular classification allows the system to apply a unique Emission Factor to each vehicle type, resulting in a far more accurate environmental impact assessment than simple vehicle counting.

2.3.2 Monitoring and Data Integration

The Smart Road Sync system integrates several layers of data for comprehensive environmental awareness:

1.IoT Sensor Feedback: The system maintains a continuous feedback loop by integrating real-time data from distributed Air Quality Index (AQI) sensors. When high pollutant concentrations are detected in a specific zone, the system can override the standard signal cycle, potentially triggering temporary traffic restrictions or rerouting suggestions.

b.Visual Analytics: For traffic authorities, the dashboard provides sophisticated geospatial visualizations and real-time congestion scores (often displayed as Heat Maps). This enables tracking of critical Key Performance Indicators (KPIs) such as Average Vehicle Speed (V_{avg}), Total Idle Time (T_{idle}), and Pollutant Exposure Index (PEI) per corridor.

2.3.3 Future Readiness & Scalability

The system's modular design is fundamental to its long-term viability, ensuring the core signal logic can evolve independently of the sensing technology.

1.EV Network Interface: The architecture includes an Application Programming Interface (API) that allows it to share optimal routing data directly with connected Electric Vehicle (EV) and Hybrid networks. This capability facilitates eco-routing, where the suggested path minimizes the number of stops to reduce battery drain and optimize energy usage rather than just minimizing distance.

2.Autonomous Vehicle (AV) Compatibility: The system is V2X communication-ready, allowing it to receive and process direct inputs from AVs. This enables the system to provide preemptive signal information to self-driving cars, helping them minimize hard braking and maximize regenerative energy recovery.

2.4 Emergency Routing

Emergency routing is the critical function of ensuring fast, safe, and unobstructed passage for emergency vehicles (ambulances, fire trucks, police) through congested urban areas. Unlike traditional systems where these vehicles face delays from normal congestion and inflexible signal timing, Smart Road Sync employs a proactive, dynamic prioritization strategy.

2.4.1 Mechanism of Priority Clearance

When an emergency vehicle is detected, the system immediately executes a sequence of overrides:

1.Real-Time Detection: The system uses V2I (Vehicle-to-Infrastructure) communication and vehicle classification sensors to identify the emergency vehicle and anticipate its arrival at the intersection.

2.Green Corridor Creation: The system overrides the normal signal cycle to immediately display a green light for the approaching emergency lane.

3.Conflicting Traffic Halt: Traffic from all conflicting directions (perpendicular and opposing) is simultaneously halted, often turning signals to red or flashing yellow, to clear the intersection.

4. **Civilian Alerts:** Alerts can be broadcast to nearby civilian vehicles (via connected apps or V2V communication) to encourage lane clearance and yielding.

5. **Restoration:** Once the emergency vehicle has successfully passed the intersection, the system gradually restores normal signal patterns to prevent a sudden buildup of traffic congestion. This restoration involves a calculated transition, often cycling through the queued lanes based on the longest waiting time, to smooth the re-entry into the adaptive control loop.

2.4.2 Advanced Integration and Benefits

The system's architecture supports advanced features that enhance its reliability and efficiency:

1. **Multi-Intersection Coordination:** The architecture can interface with centralized traffic control centers to clear a continuous green corridor across multiple intersections for long-distance routes.

2. **Safety and Response Time:** This proactive, dynamic adjustment significantly shortens emergency response times and reduces the risk of accidents typically caused by vehicles trying to maneuver around emergency vehicles in chaotic conditions.

3. **ML Optimization:** Future integration with machine learning models will allow the system to analyze traffic behavior and optimize the priority routing algorithm based on real-world performance data.

By combining real-time sensing, adaptive control, and coordinated prioritization, Smart Road Sync ensures that emergency services can operate efficiently, enhancing public safety and supporting a more resilient transportation network.

By using V2I detection to dynamically override traffic signals, the Smart Road Sync system establishes an immediate priority green corridor for emergency vehicles, drastically improving response times and public safety.

Fig.4 Emergency Routing

2.4 Key Components

The system combines hardware simulation, dynamic control, and machine learning to optimize traffic flow and minimize its environmental impact.

2.5.1 Traffic Management & Control:

1. **Traffic Signal Controller:** This component dictates the signal timing (Red, Yellow, Green). It primarily uses dynamic timing based on real-time traffic density, ensuring that signals rotate automatically. Normal rotation is only suspended when the Emergency Routing Module is active.

2. **Emergency Vehicle Detection System:** This system continuously scans all lanes for emergency vehicles. It operates using a parallel thread to ensure that the main simulation execution is not interrupted. Its sole purpose is to trigger the emergency routing sequence upon detection of an ambulance or fire truck.

3. **Emergency Routing Module:** This module takes immediate control upon detection, executing an override of the normal signal cycle. It turns all conflicting signals RED and sets the emergency lane signal to GREEN, guaranteeing safe and fast passage. It is also responsible for smoothly resuming the normal signal cycle after the emergency vehicle has cleared the intersection.

4. **Machine Learning Predictor (Traffic Flow Analysis):** This component is the brain of the adaptive timing system. It uses a Linear Regression model trained on historical traffic data (from data_new.csv) to predict future vehicle density for each direction. Based on these predictions, it dynamically allocates the optimal green signal time to minimize queuing.

2.5.2 Simulation & Environmental Tracking

1. Vehicle Generator: Responsible for adding vehicles to the simulation. It randomly generates various vehicle types: Car, Bike, Bus, Truck, Rickshaw, and Emergency Vehicle. Emergency vehicles are generated with a low probability (e.g., 5%) to simulate real-world rarity.

2. Carbon EmissionCalculator: This environmental tracker assigns a specific emission rate to each vehicle type. It actively calculates and adds the values generated when vehicles are waiting at red signals. It also simulates realistic engine ON/OFF behavior for waiting vehicles to model emission reduction efforts. The total carbon emission is displayed in real time.

3. Simulation Environment (Pygame UI): The system's user interface (UI) provides real-time visualization of the traffic environment, showing moving vehicles, signal status, the emergency priority indicator, and the live carbon emission count.

4. Data Logger: This critical component ensures data integrity for ongoing analysis and future model training. It records key metrics for every cycle, including:Vehicle count per direction,Total waiting time,Signal duration allocated,Total emission produced,This data is stored in a **CSV format** for analysis and future ML training.

3. Advantages

The system delivers significant benefits across traffic efficiency, safety, and environmental sustainability:

2.6.1 Traffic & Safety Improvements

1. Reduces Traffic Congestion: It dynamically adjusts signal timings based on real-time conditions, improving traffic flow and throughput.

2. Enhances Emergency Response: It provides faster and safer emergency vehicle movement through immediate priority routing.

3. Improves Road Safety: It maintains organized and predictable vehicle flow at intersections, reducing the likelihood of accidents.

3.1 Environmental & Urban Benefits

1. Minimizes Emissions: Fuel consumption and carbon emissions are minimized by reducing unnecessary vehicle idling and abrupt stop-and-go patterns.

2. Supports Smart City Development: It enables scalable and intelligent traffic management, providing a foundational element for a modern, efficient urban environment.

4. Results and Analysis

The testing of the Smart Road Sync system under varying traffic densities demonstrated clear performance improvements across efficiency, safety, and sustainability metrics:

1. Efficiency and Flow

- The system achieved a noticeable reduction in average waiting time at intersections when compared to traditional fixed-time signal systems.
- This outcome confirms that the adaptive signal control approach successfully improves overall traffic flow and efficiency.

2. Safety and Response

- Emergency vehicle priority routing was highly effective, significantly decreasing emergency response time by providing an uninterrupted travel corridor.

3. Environmental Impact

- The system demonstrated a clear reduction in fuel consumption and estimated carbon emissions. This benefit is directly attributed to the minimized idle duration and the reduction of unnecessary stop-and-go patterns.

Overall, the analysis strongly indicates that the Smart Road Sync system successfully achieves its goals, simultaneously enhancing safety and supporting sustainable urban mobility.

5. CONCLUSIONS

The Smart Road Sync system provides an efficient and intelligent approach to traffic management by adapting signal timing based on real-time vehicle density and prioritizing emergency vehicles. This integrated system successfully reduces congestion, minimizes fuel wastage, and helps lower carbon emissions, contributing to a cleaner urban environment. Crucially, the emergency routing capability ensures faster and safer passage for lifesaving services, thereby improving overall public safety. The simulation results consistently demonstrate improved traffic flow, reduced waiting time, and better resource utilization, confirming that Smart Road Sync effectively supports the development of sustainable, safe, and smart transportation infrastructure for modern cities.

6. ACKNOWLEDGEMENT

We wish to express our profound appreciation and sincere gratitude to our project guide Mrs. Shruthi T V for their unwavering continuous support, invaluable guidance, and constant encouragement throughout the entire development process of the Smart Road Sync system.

We also extend our sincere thanks to the faculty members and the entire Dept of ISE,EWIT department for providing us with the necessary technical resources and a stimulating learning environment.

Furthermore, we are deeply thankful to our dedicated teammates for their exceptional cooperation, commitment, and strong sense of teamwork, which were instrumental to the project's successful completion.

Finally, we recognize and appreciate the unwavering motivation and support provided by our families and friends at every stage of this endeavor.

7. REFERENCES

[1]. K.S. Rekha , Sivapriyaa S. M., Tanmayee M. D., and Shree Raghav L. B. in their paper “Dynamic Traffic Management System” (ICIPTM 2023) proposed an intelligent system to control and manage traffic flow efficiently.

[2]. Changhao Fan, Chunxiao Li, and Chunyan Qi in their paper “A Dynamic Traffic Lights Controlling Combined with Vehicle Routes Planning Solution for Alleviating Traffic Congestion” (ICTC 2023) presented an integrated approach to reduce urban traffic congestion.

[3]. Mohammed Rehaman Pasha, S. Latha, R. Usha, V. Bini Marin, M. V. Ishwarya, and M. Muthulekshmi in their paper “Dynamic Lane Management with IoT for Real time Lane Configuration and Traffic Flow” (IC4 2024) proposed an IoT-based system for optimizing lane usage and improving traffic movement.

[4]. Rajeshwari B. S., Vinay Y., Venu Gopal V., Tauksik Anil Kumar, and Viraj Chowdarapu in their paper “Emergency Response Optimization System with Dynamic Traffic Signal Control (Life Saver)” (ICoICI 2024) introduced an intelligent system to prioritize emergency vehicles in traffic management.

[5]. Md. Humayun Kabir and Md. Saiful Islam in their paper “Enhancing Traffic Flow and Reducing Congestion: A Smart City Approach with an IoT-based Intelligent Traffic Management System” (ICISET 2024).

[6]. A. Boukerche and J. Wang, “Machine Learning-based traffic prediction models for Intelligent Transportation Systems”,*Computer Communications*, vol. 182, pp. 195-207, 2022.Comprehensive review on using ML, specifically for traffic prediction and control in ITS.

[7]. M. R. Nulyn Punitha, N. Saravanaselva, M. Viswam, and M. Pandikannan, "Real-Time Traffic Density Monitoring and Adaptive Signal Control Using YOLOv8 and Arduino-Based LED System" Uses real-time computer vision (YOLO) for vehicle density monitoring and dynamic signal adjustment, directly supporting your simulation's approach.

[8]. O. Ryzhanskyi, V. Pavlyshyn, I. Krak, and V. Zhumashev, "AI-Driven Traffic Signal Control System to Reduce Emissions," presented at the *International Conference on Information Technology*, 2023. Proposes an AI system that utilizes Deep Reinforcement Learning (DRL) specifically to reduce cumulative CO_2 emissions at intersections, supporting your environmental claims.

Volume: 09 Issue: 12 | Dec - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

[9].Z. Wang, L. Xu, and J. Ma, "Carbon Dioxide Emission Reduction-Oriented Optimal Control of Traffic Signals in Mixed Traffic Flow Based on Deep Reinforcement Learning," Focuses on using advanced ML techniques with emissions as the key optimization criterion, providing technical backing for your carbon calculator module.

[10]. L. Bieker-Walz and M. Behrisch, "Queue discharge-based emergency vehicle traffic signal preemption to minimize disruption," presented at the **SUMO User Day 2019**.An evolution of the prior Bieker paper, detailing the **Restoration Phase** of emergency routing—how the system calculates the impact of the green corridor and manages the subsequent signal phase to minimize disruption to normal traffic flow.