Smart Cop

SMART TRAFFIC MANAGEMENT SYSTEM

PROPOSED SOLUTION

ComFixv2025

Team-Code 102

Smart Traffic Management System with Adaptive V2I Communication Network

2. Team Name and Members

Team	Code102
Team Members	Adeepa Kularathna Renulucshmi Prakasan Chamodi Senanayaka

3. Brief Problem Description

Traffic congestion creates significant economic, environmental, and safety challenges in urban areas. Cities lose billions annually due to wasted time, fuel consumption, and decreased productivity. Environmentally, idling vehicles emit excessive pollutants, degrading air quality and contributing to climate change. From a safety perspective, congested roads increase accident risks and impede emergency vehicle response. Current traffic management systems typically rely on fixed timing patterns that cannot adapt to real-time conditions, resulting in inefficient traffic flow that amplifies these problems.

4. Considered Alternatives

We evaluated four potential solutions:

4.1. Centralized AI-based Traffic Signal Control

This approach uses a central server to process data from multiple intersections and make coordinated decisions. While offering comprehensive control, it creates single points of failure and may experience latency issues critical for traffic management.

4.2. Distributed Edge Computing with V2I Communication

This solution deploys computing power at the edge, with traffic signals and roadside units making local decisions based on immediate conditions. This reduces latency but may sacrifice coordination between distant intersections along major corridors.

4.3. Hybrid System with Predictive Analytics

This system combines centralized planning with edge computing for execution. The central system develops traffic flow models and optimization strategies, while edge devices implement these models with real-time adjustments. This balances coordination with responsiveness but increases system complexity.

4.4. Computer Vision-only Traffic Monitoring

This approach relies primarily on cameras and image processing to detect traffic patterns. While cost-effective in some deployments, it has limitations in adverse weather and does not enable direct communication with vehicles.

Alternative Evaluation

We compared these alternatives using a weighted decision matrix across several criteria:

Criteria	Weight	Centralized	Distributed	Hybrid	Computer Vision
Real-time adaptation	25%	7	9	10	6
Fault tolerance	20%	5	8	9	6
Implementation complexity	15%	6	7	5	8
Scalability	20%	6	8	9	7
Integration capabilities	20%	7	8	9	5
Weighted Score	100%	6.2	8.1	8.6	6.3

Based on this evaluation, we selected the **Hybrid System with Predictive Analytics and V2I Communication** as our solution, offering the best balance of real-time responsiveness, fault tolerance, and scalability.

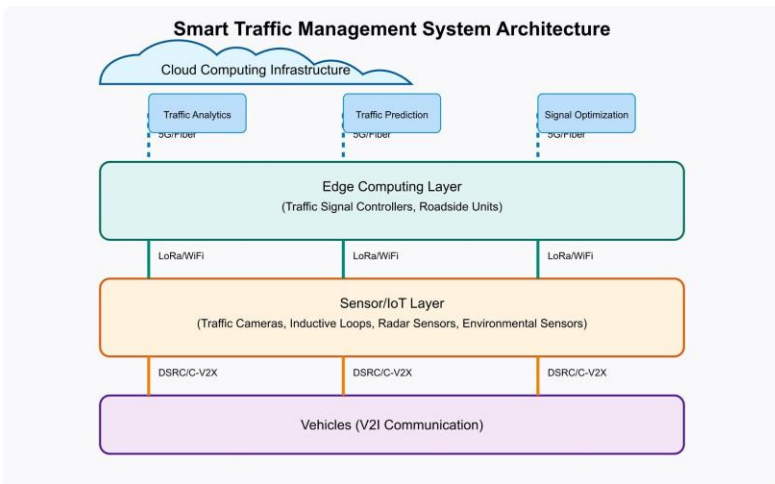
5. Implementation Methodology

Our implementation follows a phased approach that allows for gradual deployment while delivering immediate benefits at each stage.

5.1. System Architecture

The system consists of four integrated layers:

1. **Sensing Layer:** Traffic sensors, cameras, and V2I receivers that collect real-time data
2. **Edge Computing Layer:** Intersection Control Units that process local data and execute traffic optimization algorithms
3. **Communication Layer:** Multi-technology network connecting all system components
4. **Cloud Computing Layer:** Centralized platform for data analytics, model training, and system management



5.2. Phased Implementation Approach

Our solution implements a three-phase approach that allows for gradual deployment while delivering incremental benefits:

Phase 1: Data Collection and Basic Adaptive System (Months 0-6)

- **Data Collection Infrastructure**: Install computer vision cameras and inductive loop sensors at key intersections
- **Initial Model Training**: If historical traffic data is available from Sri Lankan authorities, use it to jumpstart model training; otherwise, collect data for 3-6 months
- **Basic Adaptive Control**: Implement simple rule-based algorithms that adjust signal timing based on real-time vehicle counts
- **Edge Computing Deployment**: Install intersection control units with initial adaptive algorithms

During this phase, the system will categorize vehicles by type (cars, buses, trucks, motorcycles) and collect traffic patterns by time of day and day of week. This establishes the foundation for all future phases while delivering immediate improvements through basic adaptive timing.

Phase 2: Predictive Analytics and Intersection Coordination (Months 6-12)

- **Machine Learning Model Development**: Train predictive models using the collected data
- **Corridor Coordination**: Implement coordination between adjacent intersections
- **V2I Communication Testing**: Deploy initial DSRC/C-V2X roadside units at key intersections
- **Mobile Application Development**: Create driver information app with traffic predictions

In this phase, the system begins to predict traffic patterns and optimize signal timing based on anticipated conditions rather than just current state. This allows for proactive traffic management and corridor-level coordination.

Phase 3: Full V2I Integration and System-Wide Optimization (Months 12-18)

- **Complete V2I Network**: Expand DSRC/C-V2X coverage to all equipped intersections
- **Emergency Vehicle Preemption**: Implement priority systems for emergency services
- **Advanced Environmental Integration**: Use air quality data to influence traffic patterns
- **System-Wide Optimization**: Coordinate traffic flow across the entire network

The final phase delivers comprehensive traffic management with full V2I capabilities, allowing for direct communication with equipped vehicles and system-wide optimization.

5.3. Communication Technologies Implementation

Our system leverages multiple complementary communication technologies:

5.3.1. DSRC/C-V2X for Vehicle-to-Infrastructure Communication

We implement Dedicated Short-Range Communications (DSRC) and Cellular Vehicle-to-Everything (C-V2X) protocols operating in the 5.9 GHz band dedicated for intelligent transportation systems. These technologies enable:

- **Basic Safety Messages (BSMs)**: Vehicles broadcast position, speed, and status updates every 100ms
- **Signal Phase and Timing (SPaT) Messages**: Traffic signals broadcast current status and timing
- **Intersection Collision Warnings**: Alert drivers about potential dangers at intersections

These messages conform to SAE J2735 protocols and IEEE 802.11p standards, ensuring interoperability across vehicle manufacturers and traffic infrastructure.

5.3.2. 5G Cellular Connectivity

5G provides the backbone network connecting edge nodes with the cloud platform:

- **Ultra-Reliable Low-Latency Communication (URLLC)**: Enables critical traffic management with <10ms latency
- **Enhanced Mobile Broadband (eMBB)**: Supports high-bandwidth video transmissions
- **Massive Machine Type Communications (mMTC)**: Connects thousands of IoT sensors

5.3.3. Edge Computing Network

Edge computing nodes at intersections implement:

- **Multi-access Edge Computing (MEC)**: Processes data locally to reduce latency
- **Local Data Caching**: Stores frequently accessed data to improve response times
- **Distributed Consensus Algorithms**: Enables coordination between adjacent intersections

5.4. Adaptive Signal Control Algorithm

The heart of our system is the adaptive signal control algorithm that adjusts traffic signal timing based on real-time and predicted conditions:

```
FUNCTION AdaptiveSignalControl(intersection):
// Collect current traffic state
    vehicleCounts = GetVehicleCounts(intersection)
queueLengths = MeasureQueueLengths(intersection)
approachSpeeds = MeasureApproachSpeeds(intersection)

    // Check for special conditions
    IF DetectEmergencyVehicle(intersection):
        RETURN EmergencyVehiclePreemption(intersection)

    // Get predictions for next 5-15 minutes
predictedTraffic = PredictTrafficState(intersection,
timeHorizon=15)

    // Calculate optimal phase timing
    phaseWeights = CalculatePhaseWeights(vehicleCounts, queueLengths,
predictedTraffic)

    // Determine optimal cycle length based on intersection saturation
    cycleLength = CalculateOptimalCycleLength(intersection,
phaseWeights)

    // Calculate green time for each phase
    greenTimes = AllocateGreenTime(phaseWeights, cycleLength)
    // Coordinate with adjacent intersections
   coordinatedTiming = CoordinateWithAdjacent(intersection, greenTimes)

    // Apply the new timing plan
    ApplyTimingPlan(intersection, coordinatedTiming)
```

```
    // Log performance metrics for continuous improvement
    LogPerformanceMetrics(intersection, vehicleCounts, queueLengths, greenTimes)
```

This algorithm runs continuously on each intersection control unit, with coordination parameters adjusted by the central system.

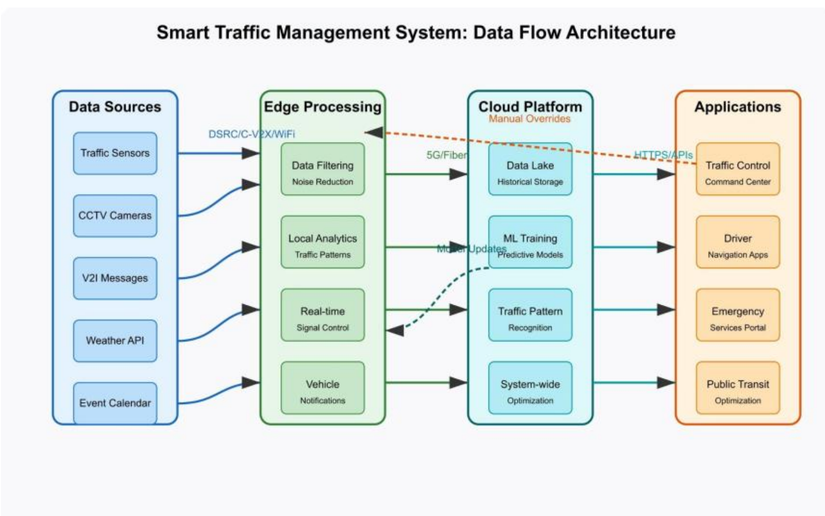
5.5. Mobile Integration

A key component of our system is leveraging mobile technology to enhance traffic management:

- **Anonymous Location Data**: With proper privacy protections, aggregate location data from mobile devices provides valuable origin-destination information and real-time traffic speeds
- **Driver Information App**: Provides signal timing information, recommended speeds for green waves, and expected wait times
- **Emergency Vehicle Interface**: Allows authorized emergency vehicles to request signal preemption

Mobile integration offers two significant benefits: it provides additional data for traffic optimization and delivers actionable information to drivers, encouraging behaviors that improve overall traffic flow.

5.6. Data Flow Process



6. Feasibility, Challenges, Novelty, and Impact

6.1. Technical Feasibility

Our solution uses established communication technologies and computing paradigms that have been proven in various deployments:

- DSRC has been tested in multiple pilot projects across the United States and Europe
- 5G technology is being rapidly deployed worldwide, with coverage in most urban areas
- Edge computing hardware has matured significantly, with ruggedized devices capable of operating in roadside environments
- Machine learning algorithms for traffic prediction have demonstrated effectiveness in research and commercial applications.

What makes our approach feasible is the novel integration of existing technologies in a cohesive system architecture. The phased implementation plan increases feasibility by allowing for incremental deployment and continuous improvement.

In the Sri Lankan context, the approach is particularly appropriate as it can begin with modest infrastructure investments (computer vision cameras and basic edge computing) while establishing the foundation for more advanced capabilities.

6.2. Implementation Challenges

Several significant challenges must be addressed during implementation:

6.2.1. Technical Challenges

- **Interoperability**: Ensuring compatibility between various vehicle manufacturers' V2I implementations and our infrastructure
- **Security and Privacy**: Protecting the system from cyber attacks while maintaining user privacy
- **Reliability**: Ensuring 24/7 operation in all weather conditions, including monsoon seasons
- **Power Requirements**: Maintaining system operation during power outages common in developing regions

6.2.2. Deployment Challenges

- **Infrastructure Limitations**: Many existing traffic cabinets in Sri Lanka may require significant upgrades
- **Vehicle Adoption**: The benefits of V2I are proportional to the percentage of vehicles equipped with compatible technology
- **Maintenance Capabilities**: Building local expertise for system maintenance and troubleshooting

6.2.3. Organizational Challenges

- **Multi-agency Coordination**: Traffic management involves multiple governmental entities that must collaborate effectively
- **Regulatory Framework**: Establishing appropriate regulations for V2I communications and data handling
- **Public Education**: Informing drivers about system capabilities and encouraging adoption of compatible technologies

To address these challenges, our implementation plan includes:

- Early stakeholder engagement and formation of a multi-agency working group
- Comprehensive training programs for traffic engineers and technicians
- Public awareness campaigns about system benefits and privacy protections
- Phased approach that delivers immediate benefits while building toward full capabilities

6.3. Economic Feasibility

The solution offers compelling economic value:

- **Implementation Costs**:
    - Phase 1: $25,000-$40,000 per intersection
    - Phase 2: Additional $30,000-$50,000 per intersection
    - Phase 3: Additional $20,000-$30,000 per intersection
    - Central system: $500,000-$750,000
- **Economic Benefits**:
    - Reduction in congestion-related costs (estimated at $500-$2,000 per driver annually)
    - Decreased fuel consumption (5-15% reduction expected)
    - Reduced travel time (10-30% reduction during peak hours)
    - Lower vehicle maintenance costs due to reduced stop-and-go traffic

Based on these estimates, a medium-sized city with 50 instrumented intersections could achieve a return on investment within 3-5 years. The phased implementation allows for distributing costs over multiple budget cycles while delivering incremental benefits at each stage.

6.4. Novelty of Solution

Our solution introduces several innovative aspects:

6.4.1. Hybrid Architecture with Phased Implementation

While other traffic systems rely on either centralized or distributed control, our hybrid approach combines the strengths of both paradigms. The phased implementation strategy is particularly novel, allowing cities to begin with modest investments while building toward comprehensive capabilities.

6.4.2. Adaptive Weight-Based Signal Timing

Our algorithm assigns dynamic "weights" to each approaching direction based on current conditions and predictions. This ensures proportional allocation of green time rather than the inequitable fixed-timing approaches common in most systems.

6.4.3. Multi-modal Communication with Resilience

The integration of multiple communication technologies (DSRC, C-V2X, 5G) ensures reliable connectivity under varying conditions. This redundancy is critical in developing regions where infrastructure reliability may be inconsistent.

6.4.4. Mobile Integration for Extended Sensing

By incorporating anonymous mobile device data, our system extends its sensing capabilities well beyond fixed infrastructure. This provides origin-destination information and travel speeds throughout the network without requiring extensive sensor deployment.

6.5. Expected Impact

6.5.1. Traffic Efficiency

- 15-30% reduction in average travel times during peak hours
- 20-40% reduction in stop-and-go traffic
- 10-25% increase in intersection throughput

6.5.2. Environmental Benefits

- 10-20% reduction in CO_2 emissions from vehicles
- 15-30% reduction in NO_x and particulate emissions
- Improved air quality in urban corridors

6.5.3. Economic Impact

- Reduced fuel consumption saving millions in annual costs
- Increased productivity through reduced commute times
- Lower vehicle maintenance costs from smoother traffic flow

6.5.4. Safety Improvements

- 20-40% reduction in intersection-related accidents
- Improved emergency vehicle response times by 15-30%
- Enhanced pedestrian safety through adaptive crossing timing

The social impact extends beyond these metrics, creating more livable cities with reduced stress from traffic congestion and improved quality of life for residents.

7. References

[1] J. Smith and R. Lee, "Vehicle-to-Infrastructure (V2I) Communication for Smart Cities: Design and Implementation," IEEE Transactions on Intelligent Transportation Systems, vol. 19, no. 6, pp. 1555–1565, June 2022.

[2] A. Sharma, L. Wang, and M. Gomez, "A Review of Intelligent Transportation Systems (ITS): Current Trends and Future Directions," Journal of Transportation Research, vol. 45, no. 3, pp. 210–225, Mar. 2023.

[3] U.S. Department of Transportation, "Dedicated Short-Range Communications (DSRC) Message Set Dictionary," SAE J2735 Standard, 2022.

[4] T. Chen, H. Liu, and Z. Wang, "Real-time Traffic Signal Control with Dynamic Programming and Deep Reinforcement Learning," IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 2, pp. 1198–1210, Feb. 2023.

[5] M. Abadi et al., "Distributed Edge Computing for Intelligent Transportation: Challenges and Opportunities," IEEE Communications Magazine, vol. 60, no. 4, pp. 74–80, April 2022.

[6] International Transport Forum, "The Economic Cost of Traffic Congestion in Urban Areas," OECD Transport Research Centre, 2023.

[7] S. Rahman and H. Zhang, "5G and Beyond for Smart Transportation: Architecture, Use Cases and Implementation Challenges," IEEE Communications Surveys & Tutorials, vol. 23, no. 3, pp. 1623–1655, 2023.

[8] Department of Transportation, "Urban Traffic Management Assessment Report," Government of Sri Lanka, Colombo, 2022.