AI-BASED ADAPTIVE TRAFFIC COORDINATION SYSTEM

Addressing the Limitations of Existing Smart Traffic Systems

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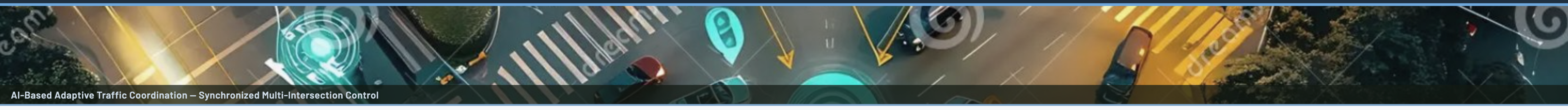


INTRODUCTION

Traffic congestion is a growing challenge in modern cities. Fixed-time traffic signals cannot adapt dynamically to real conditions, causing wasted fuel, increased emissions, and delayed emergency response.

Modern adaptive systems like SCOOT, SCATS, InSync, Miovision, and NoTraffic use AI and real-time sensors to improve signal timing. According to FHWA, adaptive systems improve flow by **10%+ on average**, with up to **50%** gains in poorly-timed environments. Yet large-scale deployment still faces critical limitations in communication, fairness, and explainability.

Fixed-time signals cause unnecessary queuing and delays

PROBLEM STATEMENT

Despite proven performance gains, widespread deployment of adaptive systems reveals consistent and critical failures. Communication and synchronization breakdowns between intersections remain the most documented failure mode, causing cascading traffic imbalance. Deployment costs ranging from $6,000 to over $115,000 per intersection restrict adoption to well-funded cities, while existing AI algorithms operate without providing human-readable justification for signal decisions. Fairness imbalances emerge as algorithms repeatedly prioritize arterial routes over minor approaches and pedestrians. Centralized architectures create single points of failure, and the absence of standardized fail-safe protocols leaves intersections fully vulnerable

RESEARCH OBJECTIVES

This research systematically analyzes the limitations of existing adaptive traffic control systems, focusing on documented real-world deployment failures and structural weaknesses. The study investigates unresolved gaps in fairness, transparency, and fail-safe coordination, then proposes a decentralized, explainable AI-based traffic coordination architecture. Key objectives include designing a low-cost scalable multi-intersection prototype and validating its performance through simulation against existing commercial benchmarks.

EXISTING SYSTEMS

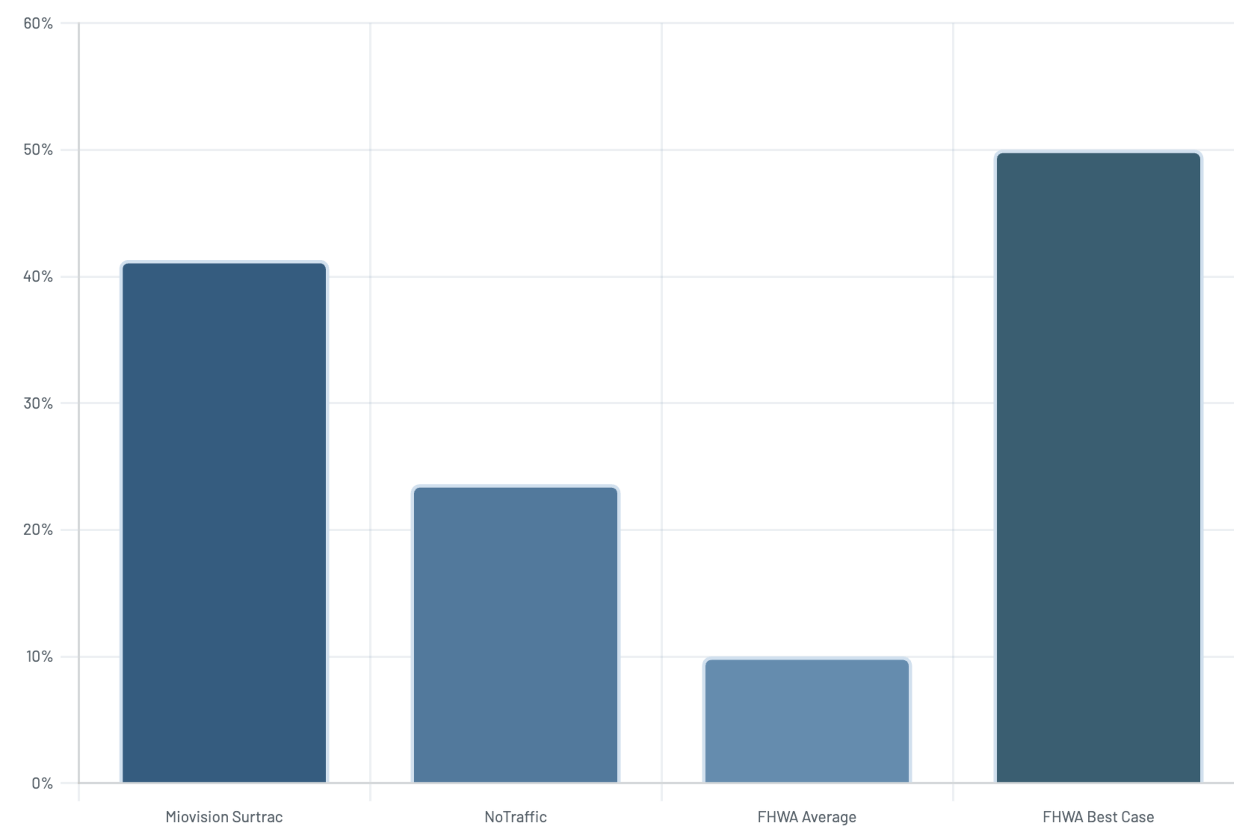
System	Technology	Limitation
SCOOT	Split-cycle offset	High cost, slow
SCATS	Real-time adaptation	Centralized
InSync	AI synchronization	Low explainability
Miovision	Predictive timing	Expensive scaling
NoTraffic	AI intersection ctrl	Comm. reliance

KEY PERFORMANCE DATA

41.3%	23.6%	37%	50%
Miovision Delay ↓	NoTraffic Delay ↓	Pedestrian Delay ↓	FHWA Best Case

Sources: Miovision Surtrac (Peterborough), NoTraffic (Tucson), FHWA Adaptive Signal Control

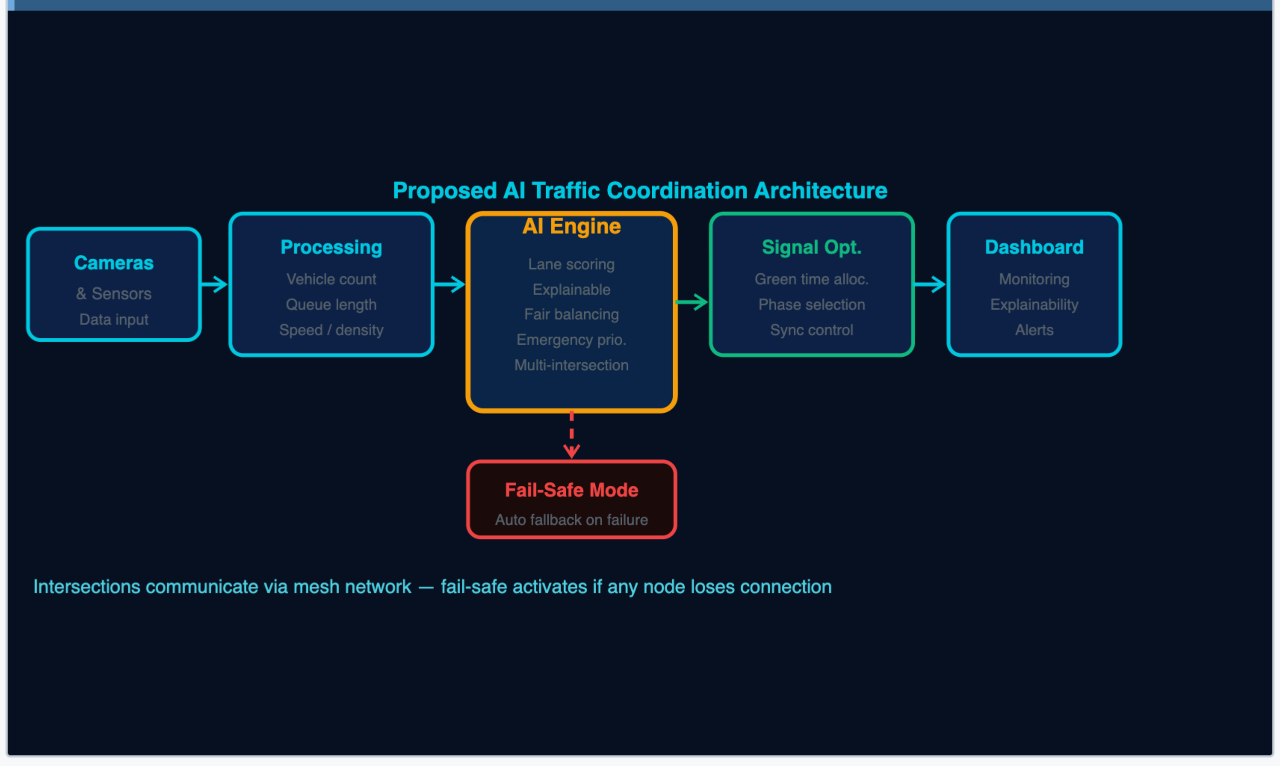
PERFORMANCE COMPARISON



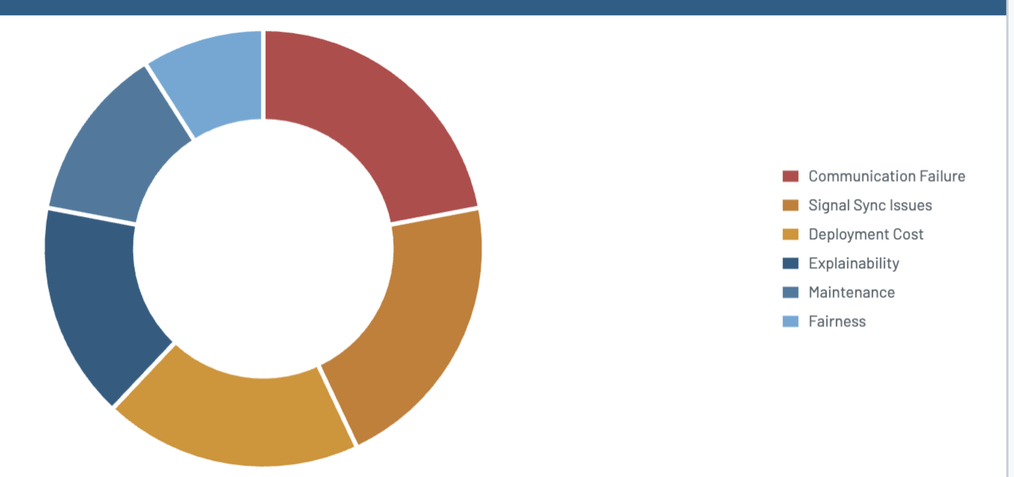
Infrastructure cost and synchronization issues remain major limitations in existing adaptive traffic systems.

AI-based coordination demonstrates improved adaptive efficiency compared to traditional fixed-timer systems, especially during peak traffic periods.

SYSTEM ARCHITECTURE



LIMITATION SHARE BY CATEGORY



** Visual estimate based on common deployment challenges; grouped to show relative limitation share.*

LANE SCORING FORMULA

AI DECISION ENGINE — SIGNAL PRIORITY SCORE

$$Score = w_1(Density) + w_2(WaitTime) + w_3(QueueLength) + w_4(Priority)$$

w_1–w_4 = adaptive weights | Priority = 1 for emergency vehicles, 0 otherwise

This scoring runs each signal cycle, making the AI's green-time decision transparent and human-readable — directly addressing the explainability gap found in existing systems.

RESEARCH FINDINGS

1. Communication Dependency: Adaptive systems rely on IoT sensors, cameras, and centralized cloud networks. Communication failure causes desynchronization and emergency coordination breakdown.

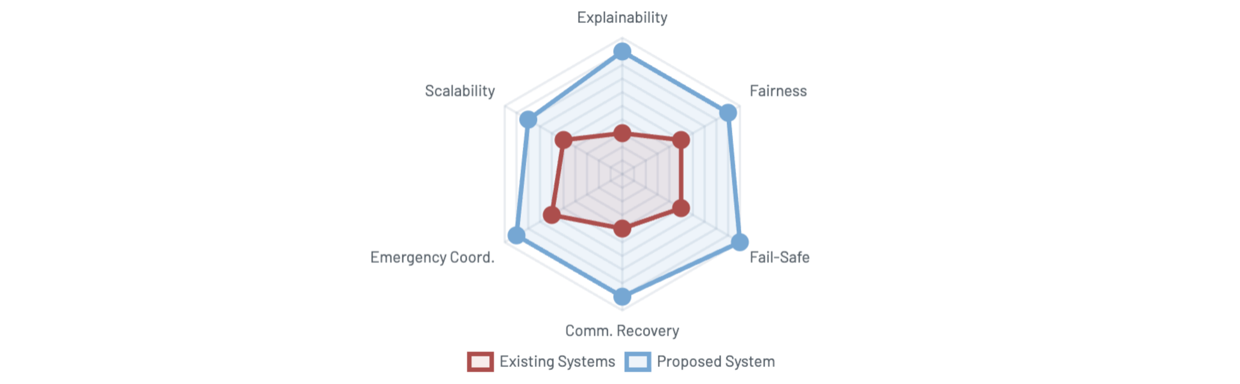
2. Real-World Failure (Nagpur, India): A smart traffic pilot experienced synchronization failures and malfunctioning intersections — only a fraction became fully operational.

3. High Deployment Cost: Range from $6,000 (ACS-Lite) to $115,810 per intersection for AI-driven solutions — making rollout unaffordable for smaller cities.

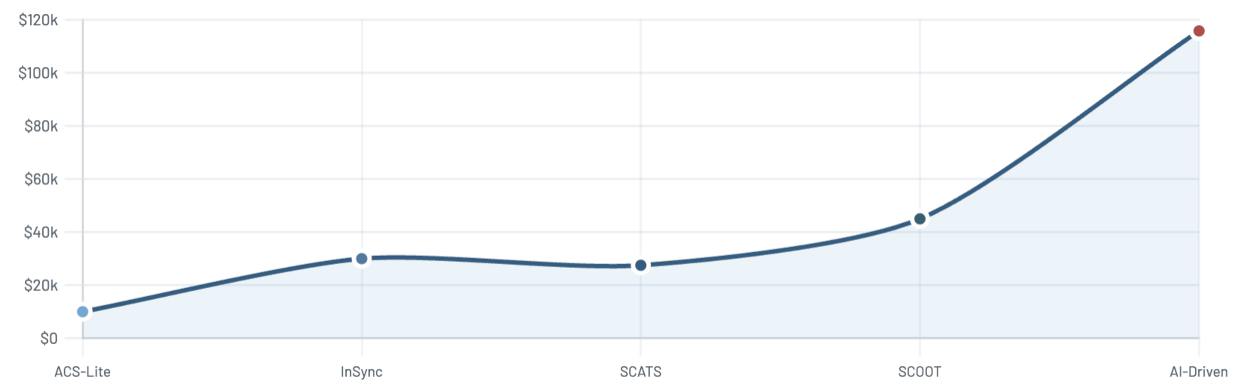
4. Lack of Explainability: Systems optimize automatically but cannot explain why signals changed — reducing transparency and public trust.

5. Fairness Imbalance: Main routes are repeatedly prioritized while smaller lanes and pedestrians experience long neglect periods.

EXISTING VS. PROPOSED SYSTEM



DEPLOYMENT COST TREND



RESEARCH GAP

Existing adaptive systems focus almost exclusively on maximizing traffic throughput efficiency. A comprehensive review of current literature reveals five critical challenges that remain unresolved in both academic research and commercial deployments: no current commercial platform provides human-readable per-cycle justification for signal decisions; no standardized equity mechanism ensures balanced green-time distribution across all lane approaches; no universal fail-safe standard exists for communication infrastructure failure; centralized server dependency creates systemic fragility unaddressed by current architectures; and no affordable commodity-hardware-compatible design exists for smaller municipalities and developing regions.

PROPOSED SYSTEM FEATURES

The proposed system incorporates eight core features targeting the identified gaps. An **Explainable AI engine** logs every signal decision with human-readable factor scores. A **fairness-weighted algorithm** ensures all lane approaches receive proportionate service. **Emergency vehicle priority** clears automatic green corridors for ambulances and fire apparatus. A **communication recovery protocol** allows graceful degradation on network loss, while a **per-node fail-safe module** activates fixed-time fallback automatically on fault detection. **Decentralized mesh coordination** eliminates central server dependency. A **live dashboard** provides real-time XAI logs and analytics, and the entire system targets a **low-cost commodity hardware** deployment of $500–$2,000 per

CONCLUSION

Existing adaptive systems improve traffic flow significantly. However, real-world deployments still face major challenges in communication reliability, fairness-aware optimization, explainable AI, and fail-safe operation.

This research proposes a transparent, fair, and fail-safe AI-based traffic coordination architecture — solving the unresolved limitations of current systems to make smart traffic technology more trustworthy and accessible.

SYSTEM ARCHITECTURE & WORKFLOW

Step 1 Data Acquisition — Cameras & sensors → **Step 2** Data Processing — Clean & extract → **Step 3** AI Decision Engine — Score & compute → **Step 4** Signal Optimization — Phase & timing → **Step 5** Traffic Controller — Send to signals → **Step 6** Dashboard Monitor — Analytics & XAI → **Step 7** Fail-Safe Mode — Auto-switch

ACKNOWLEDGMENTS

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Graphic data references: FHWA congestion reports, NHTSA crash statistics, TTI Urban Mobility Report.