



NexGen Smart Traffic Controller System with Emergency Response

A Secure, Role-Based, Software-Only Intelligent Transportation Framework

Sandesh Rathod¹, Vivek Khedekar², Pushkar Avhale³, Abdul Wajid⁴, Samyak Meshram⁵, Komal Tiwari⁶, Sushama Telrandhe⁷

^{1 2 3 4 5} Department of Artificial Intelligence, Guru Nanak Institute of Engineering and Technology, Kalmeshwar Road, Dahegaon, Nagpur, Maharashtra, India.

⁶ Assistance Professor Department of Artificial Intelligence, Guru Nanak Institute of Engineering and Technology

⁷ Associate Professor Department of Artificial Intelligence, Guru Nanak Institute of Engineering and Technology

How to Cite this Article:

Rathod, S., Khedekar, V., Avhale, P., Wajid, A. & Tiwari, K. (2026). NexGen Smart Traffic Controller System with Emergency Response. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(10), 1-9.
<https://doi.org/10.55041/ijcope.v2i10.019>

License:

This article is published under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

© The Author(s). Published by International Journal of Creative and Open Research in Engineering and Management.



<https://doi.org/10.55041/ijcope.v2i10.019>

Abstract — Urban traffic congestion imposes a severe and measurable cost on emergency response, delaying ambulances, fire trucks, and police vehicles at precisely the moments when minutes determine patient outcomes. Existing traffic-signal infrastructure is predominantly static or locally reactive and provides no mechanism for city-scale, real-time emergency prioritization, hospital pre-arrival awareness, or verifiable, role-based control over who may exercise such priority. This paper presents the design of NexGen, a software-only intelligent transportation system that combines real-time GPS tracking, machine-learning-assisted route optimization, and dynamic, temporary-corridor traffic-signal control across three coordinated interfaces — an emergency-vehicle application, a hospital dashboard, and a traffic-control-center dashboard with a dedicated field-officer mode. The design places particular emphasis on the identity-and-access layer: a shared, accessible, light-themed UI spans login, role-specific registration, verification, and a formal administrator account-approval workflow with step-up re-authentication and multi-factor authentication for high-privilege roles, ensuring that emergency-priority capability is granted only to verified, auditable accounts. Every external dependency required by this interface layer is selected from free-tier or key-less providers, preserving a zero-recurring-cost, software-only architecture suitable for academic and municipal pilot deployment alike. Design targets include a 30-40% reduction in ambulance response time, GPS-tracking accuracy within 5-10 meters, and signal-priority activation within 2-3 seconds of vehicle detection, to be validated through simulation and structured testing.

Keywords — Intelligent Transportation Systems; Emergency Vehicle Priority; Dynamic Traffic Signal Control; GPS Tracking; Machine Learning; Route Optimization; Role-Based Access Control; Account-Approval Workflow; Multi-Factor Authentication; Accessible UI/UX Design; Hospital Integration.

I. INTRODUCTION

Urban traffic congestion has become one of the most persistent challenges faced by rapidly growing cities. As vehicle density increases and road infrastructure struggles to scale proportionally, average travel times across city corridors continue to rise. While this congestion is an inconvenience for ordinary commuters, its impact becomes critical when it delays emergency vehicles such as ambulances, fire trucks, and police vehicles. Every additional minute an ambulance spends stuck in traffic can materially affect patient survival outcomes, particularly in cases of cardiac arrest, stroke, trauma, or other time-sensitive medical emergencies.

Most traffic-signal infrastructure deployed today relies on fixed-time cycles or, at best, basic vehicle-actuated detection, with no inherent capability to recognize an approaching emergency vehicle or dynamically reprioritize signal timing



along its route. Emergency-corridor clearance today depends heavily on manual intervention by traffic police, siren-based driver compliance, or informal coordination, all of which are slow, inconsistent, and difficult to scale across a city. Hospitals typically have no visibility into an incoming ambulance's location or expected arrival time, preventing advance preparation of medical staff and resources, and VIP or other authorized-priority transport is often managed through ad-hoc, non-transparent interventions.

This paper proposes NexGen, a unified, software-only platform that integrates real-time emergency-vehicle tracking, predictive route optimization, dynamic multi-signal prioritization, hospital-side coordination, and — distinct from prior work in this space — a rigorously specified, secure, and accessible identity-and-access layer governing who may exercise emergency-priority capability at all. Section II reviews related work; Section III presents the system architecture; Section IV details the proposed methodology, including the authentication, registration, and administrator-approval workflow and the UI/UX design system; Section V presents the core signal-priority algorithm; Section VI lists the implementation tools; Section VII discusses expected results and evaluation metrics; and Section VIII concludes with future scope.

II. RELATED WORK

Research on Intelligent Transportation Systems (ITS) has consistently emphasized the limitations of static, fixed-time signal control in dynamic urban environments, motivating adaptive control strategies that respond to real-time conditions. Early emergency-vehicle preemption systems relied on line-of-sight technologies such as infrared or optical strobe detectors, which required direct visibility between vehicle and receiver and were unreliable in poor weather or non-line-of-sight approaches. Subsequent GPS- and radio-based preemption removed this constraint by transmitting the emergency vehicle's position to the intersection controller over a wireless link, improving arrival-time estimation and enabling coordination between multiple converging emergency vehicles at a shared intersection [1], [2].

A separate body of work addresses route optimization and traffic-flow prediction using machine learning. Comparative studies of Random Forest, regression, gradient-boosting, and decision-tree models for short-term traffic-flow prediction consistently show that ensemble tree-based methods outperform simple regression baselines on real-world sensor and loop-counter datasets, while remaining computationally light enough for near-real-time inference [3]–[6]. This motivates the use of a scikit-learn-based Random Forest or gradient-boosted model, rather than a heavier deep-learning architecture, as the initial route/traffic-prediction component of a system such as NexGen, where inference latency directly affects the accuracy of ETA and priority-timing decisions.

Clinical studies of prehospital notification consistently report that notifying the receiving hospital before an ambulance's arrival significantly shortens door-to-CT and related in-hospital response times compared with unannounced arrivals, and more recent retrospective work confirms similar time savings across broader stroke and trauma cohorts [7], [8]. These findings support the hospital pre-arrival notification and ETA feature proposed in this work, though the reviewed clinical literature focuses on communication protocol and outcome measurement rather than the software architecture required to deliver such notifications reliably at city scale.

Separately, established practice in secure multi-tenant web-platform design — token-based authentication via JWT, delegated authorization via OAuth 2.0/OpenID Connect, and server-side role-based access enforcement — is documented in systems-architecture literature such as the redesign of scientific-service authentication and authorization around OAuth2, OIDC, and JWT [9], though this is rarely discussed in conjunction with emergency-vehicle traffic-preemption systems. Across the reviewed literature, adaptive and learning-based traffic-control systems consistently outperform static, fixed-timing approaches; however, a clear integration gap remains: few existing systems combine real-time GPS-based tracking, ML-based route optimization, dynamic multi-signal control, hospital-side coordination, centralized and field-level traffic-control monitoring, and a rigorously secured, verifiable, accessible identity-and-access layer within a single platform [10]. NexGen is designed specifically to close this gap.



TABLE I. COMPARATIVE LITERATURE REVIEW (REFERENCE STUDIES INFORMING SYSTEM DESIGN)

Study	Focus	Contribution	Gap Addressed by NexGen
Kodire et al, 2016	GPS + ZigBee V2I emergency preemption	Removes line-of-sight dependency; multi-vehicle conflict handling	No hospital coordination, no citywide dashboard, no access control
Mannan et al, 2021	IoT/cloud signal scheduling via GPS + RFID	Dynamic, cloud-hosted scheduling across an ambulance's path	Signal-side only; no route optimization or RBAC/identity layer
Janković et al; Kažić et al	ML-based short-term traffic-flow prediction	Confirms RF/ensemble models are accurate and light for real-time use	Prediction only; not integrated with signal control or preemption
Wiley Ch; arXiv:2507.13112	Voting-classifier / RF traffic-flow prediction, ITS	Higher accuracy via ensemble/voting methods on live traffic data	General ITS prediction; no emergency-priority or hospital linkage
Hsieh et al, 2016; Kimbrell et al, 2025	Clinical impact of prehospital hospital notification	Quantifies reduced door-to-CT/needle time from pre-arrival notice	Communication-protocol study; no automated notification architecture
Zorba et al, 2020	OAuth2/OIDC/JWT service authentication redesign	Reference architecture for token-based, role-aware access control	General-purpose; not applied to safety-critical, real-time systems



III. SYSTEM ARCHITECTURE

NexGen follows a microservices architecture organized into six functional layers, described below and summarized in Fig. 1 (system architecture) and Table II (components and functions).

A. User Layer

Four user-facing surfaces share a single, light-themed, accessible design system: the ambulance/emergency-vehicle application, the hospital dashboard, the traffic-control-center dashboard (with a dedicated field-officer mode for on-ground personnel), and the shared login, registration, verification, and administrator account-approval screens.

B. API and Security Layer

An API gateway performs JWT authentication, OAuth 2.0 authorization, multi-factor authentication challenge issuance for high-privilege roles, rate limiting, and request routing to downstream services.

C. Core Services Layer

A route-optimization service, a real-time GPS/data-processing service, a traffic-signal-management service, and a notification service coordinate the core emergency-priority workflow.

D. Data Layer

PostgreSQL stores structured/relational data; Redis provides low-latency caching of real-time vehicle and signal state; Supabase provides cloud-hosted data access and object storage for registration-verification documents.

E. External Integrations

GPS-tracking feeds, traffic-signal controllers, and notification-delivery channels (transactional email and browser push) integrate with the platform, each sourced from free-tier or key-less providers as detailed in Section VI.

F. Processing and Output Layer

An ML pipeline for route/traffic prediction, a decision engine for signal-priority timing, and a logging/audit subsystem covering both emergency-priority events and account-access decisions together produce the system's outputs: updated vehicle routes, signal-timing changes, and real-time alerts to hospitals, traffic-control authorities, and field officers.

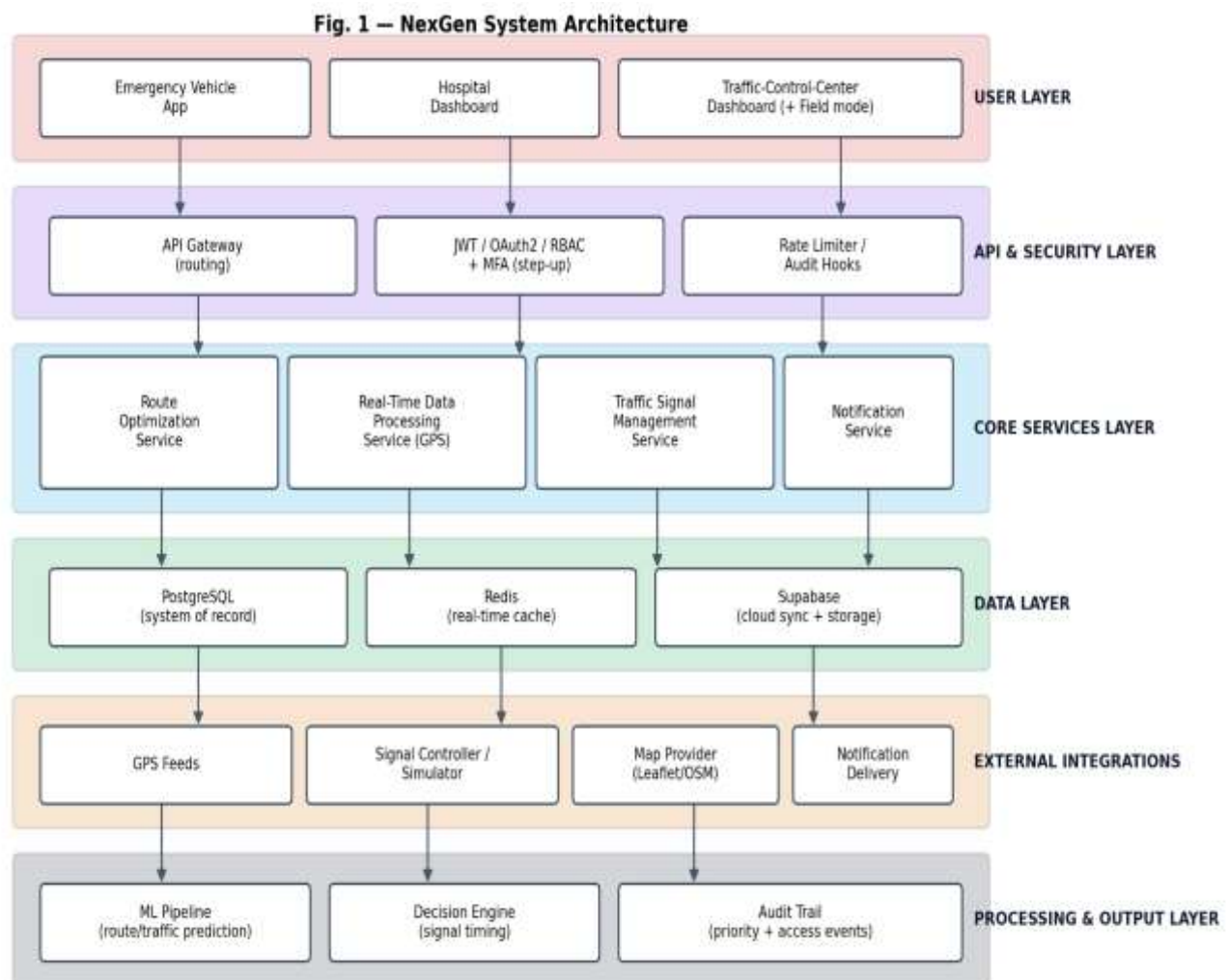


Fig. 1. System architecture of the NexGen Smart Traffic Controller System.

IV. PROPOSED METHODOLOGY

A. Authentication, Registration, and Account-Approval Workflow

The system distinguishes five roles: Emergency Vehicle User, Hospital Staff, Traffic-Control Operator (control-room and field modes), System Administrator, and Authorized Priority User (fire, police, VIP/military convoy). New accounts register through a role-specific form collecting role-appropriate fields and a supporting verification document, and enter a pending state until a System Administrator reviews the submission through a dedicated approval console. The console logs every document view as an auditable event, requires a non-empty justification for any rejection, and enforces step-up re-authentication before an approval or rejection is finalized if the administrator's session has been idle beyond a configured threshold. Approved accounts complete email/phone verification before first login; System Administrator and Traffic-Control-Operator accounts additionally require TOTP-based multi-factor authentication before becoming fully active. Access tokens are short-lived and held in memory; refresh tokens are stored in httpOnly, Secure, SameSite-strict cookies, mitigating both cross-site-scripting token theft and cross-site request forgery.

B. Real-Time GPS Tracking

Emergency vehicles transmit location to a central server at approximately one-second intervals, targeting positional accuracy within 5-10 meters, enabling near-real-time route and signal-priority decisions.

C. Route Optimization

Route optimization is assisted by data-driven and machine-learning methods analyzing historical and live traffic patterns. Candidate techniques include scikit-learn-based regression/classification models and Random Forest-based traffic-pattern classification, consistent with the comparative performance of ensemble methods reported in Section II; the specific algorithm(s) will be finalized during development based on accuracy and inference-latency testing.



D. Dynamic Signal Control and Field-Officer Interface

Upon confirming priority eligibility within a configured 100-200 meter detection range, the traffic-signal-management service activates a green-priority phase or otherwise adjusts signal timing to create a temporary emergency corridor, restoring normal operation once the vehicle has passed. A mobile-first field-officer interface extends the traffic-control-center dashboard for on-ground personnel: a GPS-sorted list of nearby signals, a single-signal manual-override control protected by step-up re-authentication and automatically disabled while an emergency corridor is active on that signal, and an incident-reporting form, all governed by the same role-based and audit rules as the control-room dashboard so that no override path is less scrutinized than another.

E. Hospital Integration

The hospital dashboard receives live updates on incoming ambulances, including estimated time of arrival, enabling pre-alert of medical teams and advance resource allocation, consistent with the reduction in in-hospital response time reported for prehospital notification in Section II.

F. Notification System

A dedicated notification service delivers real-time alerts to hospitals, traffic-control authorities, field officers, and emergency teams regarding vehicle status, signal changes, and corridor activity.

G. UI/UX Design and Accessibility

Every screen in the platform — authentication, registration, dashboards, and the administrator console — shares one light-themed design system: a light neutral background with role-specific accent colors, a defined type scale, an 8-pixel spacing grid, and standard interaction states for loading, empty, error, and RBAC-disabled conditions, implemented with React/Next.js, Tailwind CSS, and the shadcn/ui component library. All text/background pairs meet WCAG 2.1 AA contrast, icon-only controls carry descriptive labels, and live-updating views use polite live-region announcements. Every client-side restriction (hidden menu items, disabled controls, route guards) is treated strictly as a usability affordance; the authoritative access decision is re-validated server-side on every request.

H. Data Storage, Audit, and Free-Service Strategy

PostgreSQL, Redis, and Supabase form the data layer, with all priority-access events, account-approval decisions, and manual overrides recorded in an audit log. To preserve a zero-recurring-cost, software-only character, every external dependency of the interface layer is selected from free-tier or key-less providers: OpenStreetMap tiles and Nominatim geocoding (key-less), OpenRouteService (free-tier key), Resend/Brevo transactional email (free-tier key), self-generated VAPID browser push, and Google reCAPTCHA v3 (free-tier key). Paid-only alternatives such as the Google Maps JavaScript API and commercial SMS-OTP gateways are deliberately excluded from the default design.

V. ALGORITHM: EMERGENCY VEHICLE PRIORITY HANDLING

- 1) Receive authenticated emergency-vehicle GPS coordinates via the emergency-vehicle application.
- 2) Determine current location and intended destination.
- 3) Collect real-time traffic-state information along candidate routes.
- 4) Calculate candidate routes and estimate travel cost/time for each.
- 5) Select the optimal route using the route-optimization service.
- 6) Continuously update vehicle position at the configured GPS update frequency.
- 7) Identify upcoming traffic signals along the selected route.
- 8) Determine the vehicle's distance from the next signal.
- 9) If the vehicle enters the configured priority-detection zone (approx. 100-200 m), evaluate signal-priority activation.
- 10) Activate the green-priority phase or otherwise modify signal timing to establish the emergency corridor.
- 11) Notify the hospital dashboard, traffic-control dashboard, and nearby field-officer devices in real time.
- 12) Monitor the vehicle as it crosses the signal.



- 13) Restore normal signal timing after the vehicle has passed, unless a field officer has independently placed the signal into manual mode.
- 14) Store trip and event data in the audit log.
- 15) Repeat for each subsequent signal until the destination is reached.

Fig. 2 – Emergency Vehicle Priority & Dynamic Signal Control Workflow

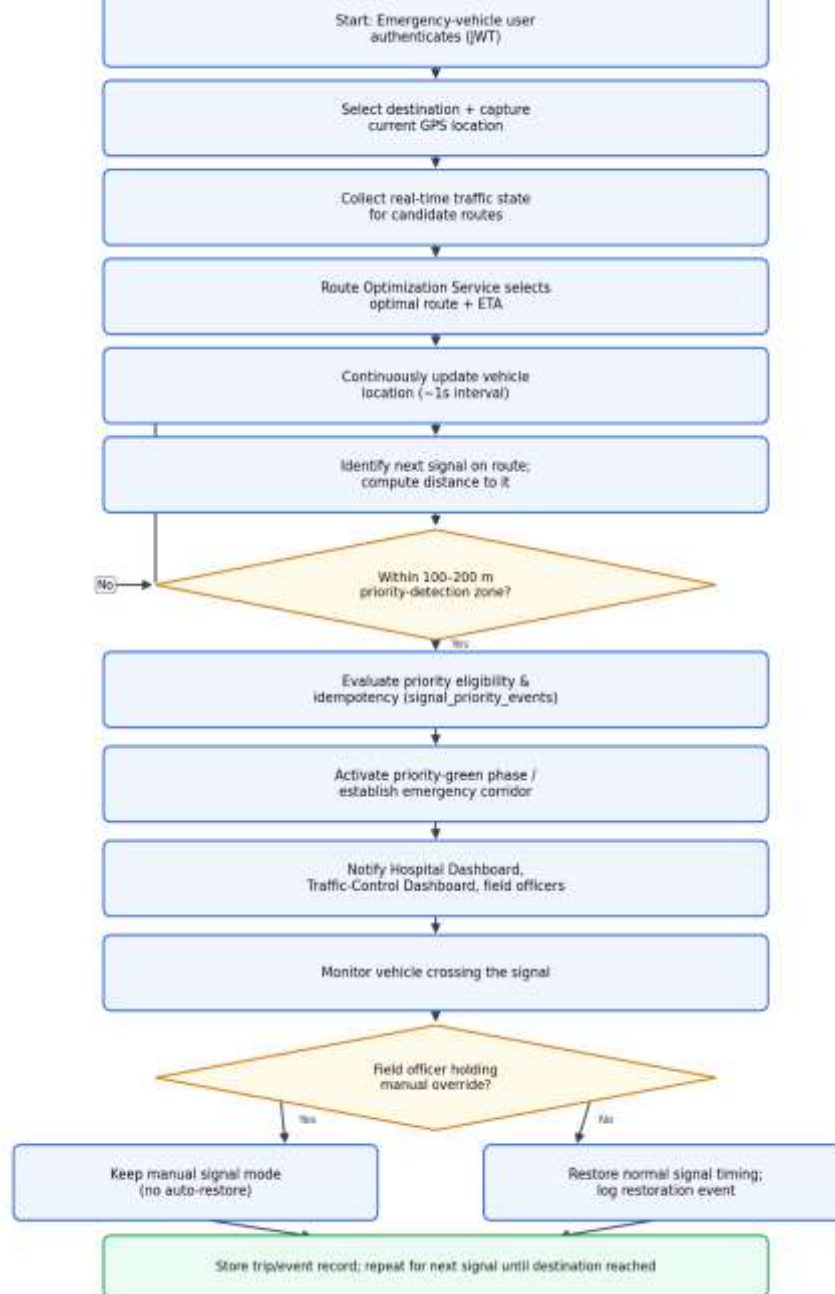


Fig. 2. Emergency vehicle priority and dynamic signal control workflow.

VI. IMPLEMENTATION TOOLS AND TECHNOLOGIES

TABLE II. TOOLS AND TECHNOLOGIES BY CATEGORY

Category	Tools / Technologies
Frontend	Next.js (React), Tailwind CSS, shadcn/ui, react-hook-form + zod, recharts, react-leaflet / OpenStreetMap
Backend	FastAPI (Python), Fastify/TypeScript
Database & Storage	PostgreSQL, Supabase, Redis
Machine Learning	scikit-learn, Random Forest, TensorFlow/Keras



Category	Tools / Technologies
Security & Auth	JWT, OAuth 2.0, AES-256, TOTP MFA, reCAPTCHA v3
Notifications	Resend / Brevo (email), self-generated VAPID (browser push)
Mapping & Routing	OpenStreetMap, Nominatim, OpenRouteService
DevOps	Docker, Kubernetes, GitHub Actions / GitLab CI

VII. EXPECTED RESULTS AND EVALUATION METRICS

As this work is presented at the design and proposal stage, no field-measured results are reported here. System performance is proposed to be evaluated through simulation and structured testing against the design targets summarized in Table III: a 30-40% reduction in emergency-vehicle response time relative to conventional routing; GPS-tracking positional accuracy within 5-10 meters at an update frequency of approximately one second; signal-priority activation within 2-3 seconds of vehicle detection at a configured 100-200 meter detection range; minimal measurable disruption to cross-traffic at signals along an active corridor; and account-approval turnaround time, tracked as an operational metric of the identity-and-access subsystem introduced in Section IV-A. Actual quantitative results will be reported following implementation and testing.

TABLE III. DESIGN TARGETS FOR SIMULATION-BASED EVALUATION

Metric	Design Target	Method
Ambulance response-time reduction	30-40%	Simulation vs. baseline routing
GPS-tracking accuracy	5-10 m	Field/simulated GPS logs
GPS update frequency	~1 second	Streaming pipeline benchmark
Signal-priority activation latency	2-3 seconds	Event-timestamp analysis
Detection range	100-200 m	Configurable geofence testing
Cross-traffic disruption	Minimized (measured, not assumed)	Before/after simulation comparison

VIII. CONCLUSION AND FUTURE SCOPE

This paper has presented the design of NexGen, a software-only, microservices-based intelligent transportation system that integrates real-time GPS tracking, machine-learning-assisted route optimization, and dynamic traffic-signal prioritization to reduce emergency-vehicle response times while limiting disruption to regular traffic. Distinct from prior emergency-preemption literature, this design gives equal weight to the identity-and-access layer that governs the system itself: a shared, accessible, light-themed UI spanning login, role-specific registration, and a formal, auditable administrator account-approval workflow with multi-factor authentication for high-privilege roles, plus a dedicated field-officer interface extending citywide traffic-control monitoring down to individual intersections. Every external service required by this design is sourced from free-tier or key-less providers, keeping the platform software-only and free of recurring licensing cost — a property intended to make the design directly replicable for academic evaluation and small-scale municipal pilots alike.

Future work includes finalizing and benchmarking the specific machine-learning route-optimization model against the candidate approaches identified in Section IV-C, extending the platform to political-leader and military-convoy priority classes as previously scoped, conducting structured simulation and, where feasible, controlled field testing against the metrics in Table III, and exploring a native mobile application for the emergency-vehicle and field-officer interfaces using the same underlying API and security layer.



REFERENCES

- [1] V. Kodire, S. Bhaskaran, and H. Vishwas, "GPS and ZigBee based traffic signal preemption for emergency vehicles," in Proc. IEEE Int. Conf. on Emerging Trends, 2016.
- [2] J. Mannar Mannan, J. Karthick Myilvahanan, R. Mohemmed Yousuf, K. Sindhanai Selvan, and T. Parameswaran, "Smart scheduling on cloud for traffic signal to emergency vehicle using IoT," Int. J. Cloud Computing, vol. 10, no. 4, 2021.
- [3] S. Janković, D. Mladenović, S. Mladenović, and S. Zdravković, "Traffic flow prediction using machine learning," in Proc. 3rd Int. Conf. Transport for Today's Society (TTS), 2021.
- [4] B. Kažić, D. Mladenović, and A. Košmerlj, "Traffic flow prediction from loop counter sensor data using machine learning methods," in Proc. Int. Conf. Vehicle Technology and Intelligent Transport Systems (VEHITS), 2015.
- [5] "Voting classifier-based machine learning technique for the prediction of traffic flow for the intelligent transportation system," in Digital Convergence in Intelligent Mobility Systems, Wiley, 2025, pp. 347-362.
- [6] "Prediction of highway traffic flow based on artificial intelligence algorithms using California traffic data," arXiv:2507.13112, 2025.
- [7] M.-J. Hsieh, S.-C. Tang, W.-C. Chiang, L.-K. Tsai, J.-S. Jeng, and M. H.-M. Ma, "Effect of prehospital notification on acute stroke care: a multicenter study," Scand. J. Trauma Resusc. Emerg. Med., vol. 24, p. 57, 2016.
- [8] J. Kimbrell, A. C. Shekhar, J. Stebel, D. Poke, J. Geldner, J. Kreinbrook, A. Hasan, J. Vega, B. Mac Grory, and R. J. Robitsek, "Prehospital notification in acute stroke: a retrospective cohort study," Proc. (Bayl. Univ. Med. Cent.), 2025.
- [9] S. Zorba, F. Tinarelli, C. Knapic, R. Butora, G. Taffoni, and B. Major, "Rebuilding services A&A architecture using OAuth2, OIDC and JWT," INAF Technical Report 37, 2020.
- [10] F. Ahmad and A. Kumar, "Prediction of data traffic flow using machine learning approach," AIJR Proceedings, 2023.