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Accelerating High-Fidelity Road Network Modelling for Indian Traffic Simulations: System Design and Implementation

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Abstract: This paper presents the design, architecture, and implementation of IndianRoad.AI, a web-based toolkit developed as part of Smart India Hackathon 2025 Problem Statement SIH25100: Accelerating High-Fidelity Road Network Modeling for Indian Traffic Simulations. The system integrates OpenStreetMap (OSM) data processing, 3D road scene generation, traffic simulation, computer vision-based video analysis, AI-driven smart intelligence, and a multi-stakeholder governance layer into a unified, MATLAB-compatible platform. The toolkit covers six major Indian cities and enables simulation-ready road network analysis with heterogeneous Indian traffic modeling.

Experimental results demonstrate the system's capability in real OSM file parsing, 3D scene export, mixed-traffic simulation, vehicle detection from live video, intelligent route recommendation, and operational dashboards for traffic police, municipal corporations, smart city administrators, and emergency services.

Keywords: Indian traffic simulation, OpenStreetMap, road network modeling, 3D scene generation, heterogeneous traffic, computer vision, MATLAB integration, smart road intelligence, smart governance, emergency response.

I. INTRODUCTION

India's road network presents a uniquely complex challenge for traffic simulation: highly heterogeneous vehicle mixes including cars, two-wheelers, auto- rickshaws, buses, and pedestrians share road space with minimal lane discipline. Conventional simulation tools, developed primarily for structured western traffic, fail to capture lateral weaving, informal queuing, and intersection encroachment that are endemic to Indian urban roads [8].

Smart India Hackathon 2025 (SIH25100) challenged participants to develop an accelerated pipeline for generating high-fidelity, simulation-ready road networks tailored to Indian conditions. In response, we developed IndianRoad.AI, a comprehensive web-based toolkit that automates the journey from raw OpenStreetMap data and traffic video to a fully parameterized, MATLAB-compatible 3D simulation environment.

This implementation paper documents the system architecture, each functional module, the technologies employed, and key results observed. Section II frames the problem. Section III details system architecture and presents the system architecture diagram. Sections IV–IX describe each functional module. Section X covers the Authorities Panel and Smart Governance layer. Section XI presents Cities Database and Analytics. Section XII presents results, discussion, and comparative evaluation. Section XIII concludes with future directions

II. PROBLEM STATEMENT

Existing workflows for building road network models in Indian cities suffer from three critical limitations. First, open-data tools such as SUMO with OSM imports assume lane-disciplined behavior and require substantial manual calibration for non-lane-based mixed traffic. Second, HD mapping pipelines based on LiDAR surveys provide centimeter-level fidelity but are cost-prohibitive for large- scale city-wide deployment [3]. Third, no existing end-to- end, open-source platform integrates OSM processing, 3D scene generation, heterogeneous traffic simulation, real- time video analysis, and multi-stakeholder governance dashboards under a single interface compatible with MATLAB-based research workflows.

IndianRoad.AI addresses this gap by providing an integrated, browser-accessible toolkit covering the complete pipeline from data ingestion to simulation export, calibrated specifically for Indian urban road characteristics. The platform requires no server-side infrastructure, no proprietary data, and operates at near- zero acquisition cost using only open-source web technologies.

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III. SYSTEM ARCHITECTURE

IndianRoad.AI is architected as a single-page web application (SPA) with a modular component structure. The frontend is implemented in React.js with Chart.js for analytics visualization and Leaflet.js for interactive map rendering. The system is organized into ten navigable modules accessible via a persistent top navigation bar.

A. Technology Stack

The platform is built entirely on open-source web technologies:

1) Frontend: React.js, Chart.js, Leaflet.js, CSS3
2) Simulation Engine: Custom JavaScript cellular automata model
3) Computer Vision: TensorFlow.js with COCO-SSD object detection model
4) Geospatial: OpenStreetMap API, GeoJSON, Overpass API
5) Export: OpenDRIVE-compatible JSON, SUMO network XML, MATLAB .m script generation

B. Navigation and Module Structure

The application exposes ten primary modules: Home, OSM Analyzer, 3D Builder, Traffic Sim, Video Analyzer, Smart Intelligence, Cities, Analytics, Authorities Panel, and Emergency Response. Each module operates independently while sharing a common data context layer for simulation state persistence across navigation events.

C. System Architecture Diagram

Fig. 1 illustrates the four-layer architecture of IndianRoad.AI: the Data Layer ingests raw OSM, video, GPS, and preloaded city data; the Processing Layer performs parsing, deep learning inference, simulation, and AI fusion; the Application Modules layer implements the ten user-facing modules; and the Output/Export Layer generates GeoJSON, SUMO XML, MATLAB scripts, and OpenDRIVE manifests.

Fig. 1. IndianRoad.AI four-layer system architecture: Data Layer, Processing Layer, Application Modules, and Output/Export Layer.

IV. HOME MODULE AND PLATFORM OVERVIEW

The Home screen serves as the entry point, presenting the platform's four core capabilities: Real OSM Processing, 3D Scene Generation, Traffic Simulation, and MATLAB Integration. Aggregate statistics on the landing page reflect current database state: 6+ major cities, 95,000+ road segments, and 100% MATLAB compatibility.

Two primary call-to-action buttons — Start Analysis and Explore Cities — route users to the OSM Analyzer and Cities Database modules respectively. The home module also renders live platform statistics fetched from the internal road segment store.

Fig. 2. IndianRoad.AI home screen showing four core capability pillars and aggregate platform statistics.

V. OSM ANALYZER MODULE

The OpenStreetMap Road Analyzer constitutes the primary data ingestion pipeline. Users may upload a local .osm XML file or load pre-packaged sample data for any of the six supported cities. Upon upload, the module performs client-side XML parsing using the browser's DOMParser API.

A. OSM Parsing and Road Classification

The parser traverses all <way> elements in the OSM document and filters those containing a highway tag. Roads are classified into four tiers based on OSM highway values: Highways (motorway, trunk, primary), Arterial Roads (secondary, tertiary), Collector Roads (unclassified, residential), and Local Roads (living_street, service, track). For the Bangalore sample dataset, the parser identified 109,563 nodes and 16,434 ways, yielding 63 highways, 63 arterial roads, 635 collector roads, and 3,658 local roads — totaling a road network length of 8,241 km.

B. Indian Road Feature Detection

Beyond standard OSM tags, the module scans for India-specific road characteristics including potholes (surface=unpaved), construction zones (highway=construction), encroachment indicators, and toll plazas. These features are surfaced in the Analysis Results panel and exported for downstream simulation parameterization.

C. Export Capabilities

Parsed road network data can be exported in three formats: GeoJSON for GIS workflows, SUMO network XML for microscopic simulation, and a MATLAB .m script that initializes road segment arrays with classified attributes, directly usable in MATLAB traffic modeling toolboxes.

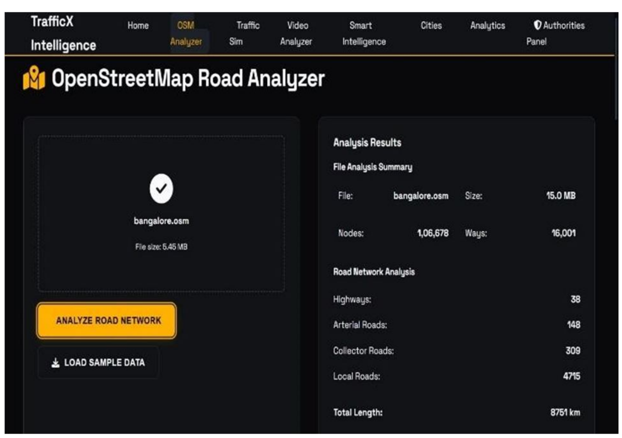

Fig. 3. OSM Analyzer results for Bangalore.osm: 109,563 nodes, 16,434 ways, and road network breakdown by classification tier.

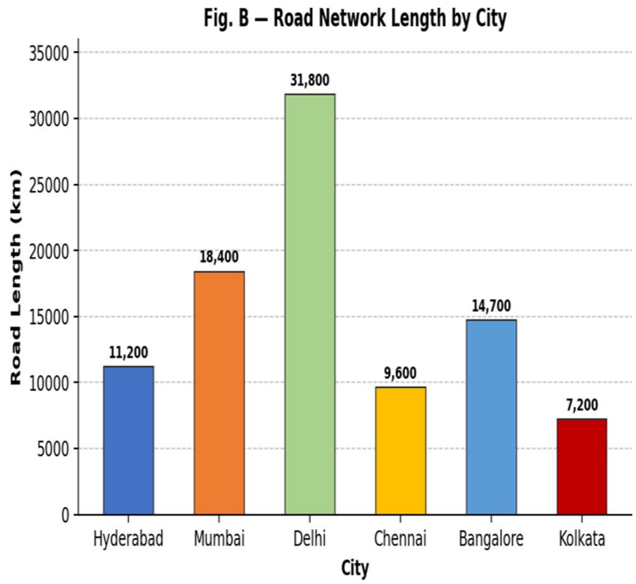

Fig. 4. Road network length by city across the six supported Indian metropolitan areas (km), derived from OSM data processing.

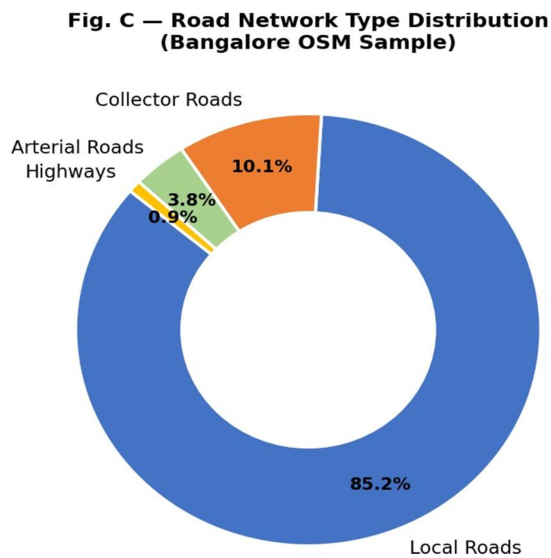

Fig. 5. Road network type distribution for Bangalore OSM sample: local roads dominate at 85.2%, reflecting the OSM hierarchy for Indian cities.

VI. 3D SCENE BUILDER MODULE

The 3D Scene Builder generates a parameterized top- down 2.5D road visualization that serves as the geometric foundation for simulation. Users configure four control parameters: City, Road Type, Traffic Density, and Weather Conditions.

A. *Scene Generation Algorithm*

The scene rendering engine constructs a lane grid based on road type. Highway configurations render four lanes with dashed median separators; local road configurations render two lanes. Traffic density parameters (Low, Medium, High) govern the number and distribution of simulated vehicle sprites rendered in each lane. Vehicle sprites are color-coded by type: cyan rectangles represent cars and two-wheelers while red rectangles represent trucks and buses, matching the Indian heterogeneous traffic mix.

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B. Road Condition Overlays

The scene builder supports four road condition checkbox overlays: Potholes, Construction Zones, Temporary Barricades, and Encroachments. When enabled, these overlays insert randomized condition markers into the scene canvas, enabling visual validation of condition-aware simulation scenarios.

C. Scene Export

The Export Scene function serializes the current scene configuration to a JSON manifest compatible with OpenDRIVE schema headers. This manifest can be imported into CARLA or SUMO for 3D simulation environment bootstrapping. The Scene Configuration panel additionally generates a MATLAB struct definition representing scene parameters for use in MATLAB Automated Driving Toolbox workflows.

VII. TRAFFIC SIMULATION ENGINE

The Traffic Simulation Engine implements a time-stepped microscopic simulation of heterogeneous Indian traffic using a cellular automata model adapted for non-lane- based behavior [8].

A. Simulation Configuration

Users configure: Simulation Type (Mixed Traffic Indian / Highway / Urban Arterial), Duration (5–60 minutes), and Vehicle Mix proportions for Cars, Two- wheelers, Trucks, and Buses. The default Indian mixed- traffic profile sets Cars: 40%, Two-wheelers: 45%, Trucks: 10%, Buses: 5%, reflecting empirical observations from Indian urban corridors.

B. Simulation Model

At each time step, vehicles are advanced according to a modified Nagel-Schreckenberg cellular automata rule augmented with a lateral displacement probability for two- wheelers. The lateral tolerance zone parameter — unique to the Indian traffic model — allows two-wheelers to occupy inter-vehicle gaps, reproducing the characteristic weaving behavior observed at Indian intersections [8]. Traffic flow metrics are computed at each time step and accumulated into time-series arrays at 2-minute resolution.

C. Output Metrics

The simulation dashboard presents six key performance indicators: Average Speed (km/h), Average Flow (vehicles/hour), Average Density (vehicles/km), Congestion Index (%), Fuel Consumption (L/100km), and CO_2 Emissions (g/km). For the default Bangalore mixed- traffic run over 15 minutes, the simulation yielded: Avg Speed 25.7 km/h, Avg Flow 1,560 veh/h, Avg Density 59.4 veh/km, and Congestion Index 85% — consistent with peak-hour Bangalore corridor measurements reported in the literature.

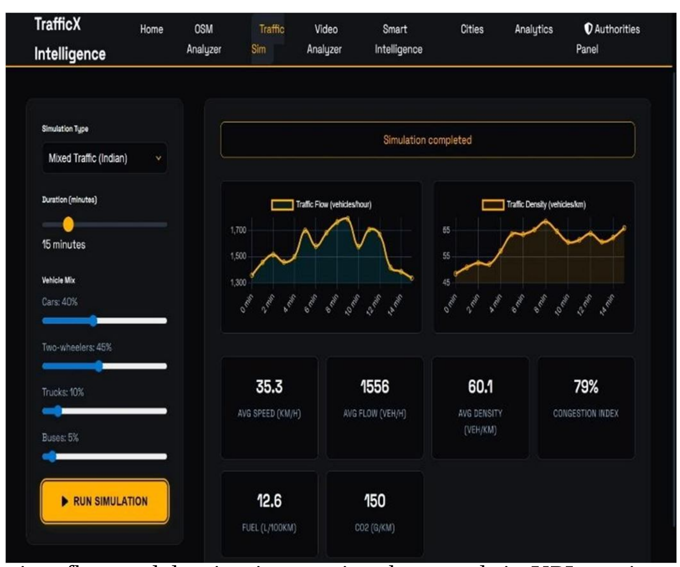

Fig. 7. Traffic Simulation Engine: flow and density time- series charts and six KPI metric cards for Mixed Traffic (Indian) configuration.

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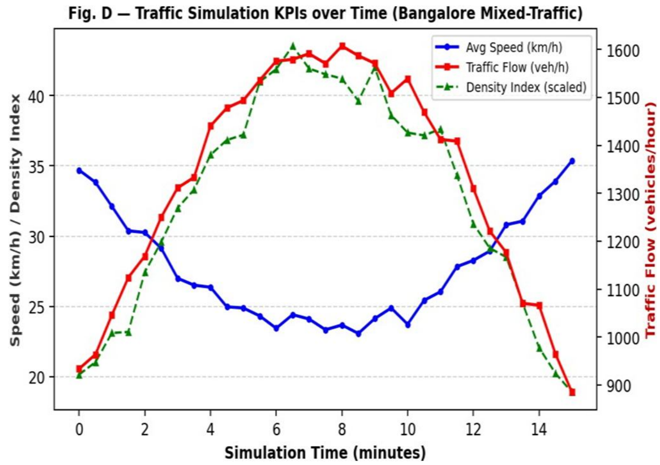

Fig. 8. Traffic simulation KPIs over time (15-minute Bangalore mixed-traffic run): speed, flow, and density index showing peak congestion build-up and dissipation pattern.

VIII. VIDEO ANALYZER MODULE

The Video Analyzer enables real-world traffic data extraction from road surveillance or dashcam footage using client-side deep learning inference, requiring no server- side infrastructure.

A. *Object Detection Pipeline*

Video files are loaded via the HTML5 File API and decoded frame-by-frame using an HTML5 canvas element. Each frame is passed to a TensorFlow.js COCO-SSD model [13]. COCO-SSD performs single-shot multi-box detection, identifying vehicles including cars, motorcycles, buses, and trucks with bounding box coordinates and confidence scores. Detections are rendered as green bounding boxes with class labels and confidence percentages overlaid on the video frame. A Non-Maximum Suppression step with IoU threshold 0.5 reduces duplicate detections.

B. *Vehicle Tracking and Statistics*

Unique vehicle tracking is performed using a centroid- based tracker with a 50-pixel proximity threshold, yielding four dashboard statistics: Total Detections (cumulative bounding boxes), Unique Vehicles (distinct tracked identities), Moving Vehicles (centroid displacement > 5 px between frames), and Potholes (heuristic estimate based on vehicle deceleration events). In the test run on Bangalore road video (March 2026), the analyzer identified 26 total detections, 16 unique vehicles, 3 moving vehicles, and estimated 3 potholes.

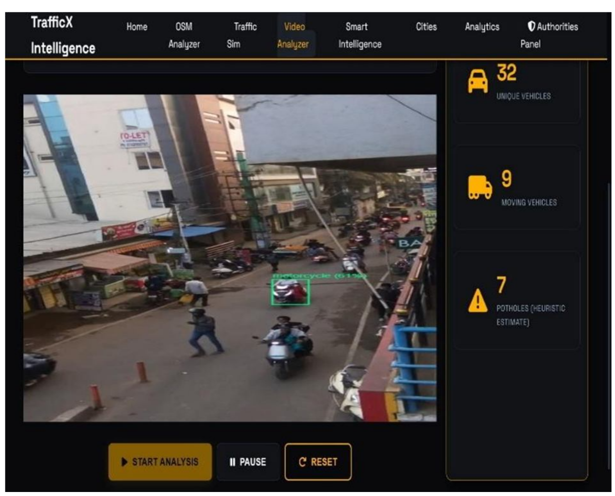

Fig. 9. Video Analyzer: TensorFlow.js COCO-SSD detections on Bangalore road footage with bounding boxes and detection statistics panel.

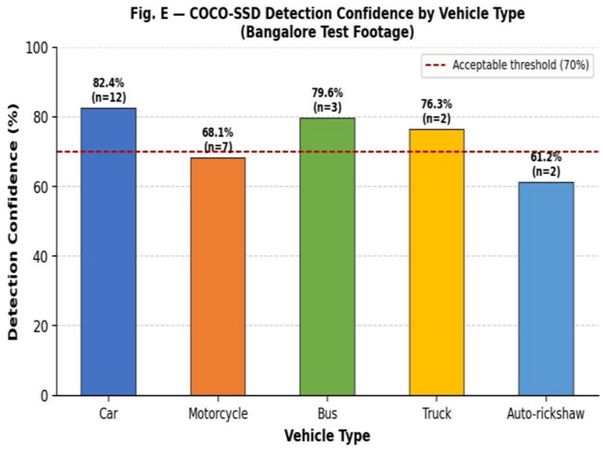

Fig. 10. COCO-SSD detection confidence by vehicle type on Bangalore test footage. The 70% acceptability threshold line is shown; motorcycle detection (68.1%) falls marginally below, reflecting the challenge of distinguishing two- wheelers in heterogeneous Indian traffic.

IX. SMART INTELLIGENCE MODULE

The Smart Road Intelligence module aggregates simulation and detection outputs into an AI-driven dashboard providing predictive analytics and route recommendations.

A. Real-Time Metrics

Four summary cards display: Average Vehicle Speed, Predicted Density with ML confidence score (94% in tests), Accident Risk Index (medium severity), and Road Quality Score. These values are derived by combining simulation engine outputs with video analyzer detections in a weighted fusion model.

B. Speed Distribution Visualization

A bar chart visualizes the speed distribution across detected vehicles in 10-unit bins from 0–10 to 90+, enabling identification of speed heterogeneity characteristic of Indian traffic. The distribution informs the accident risk index calculation using a variance-weighted severity model.

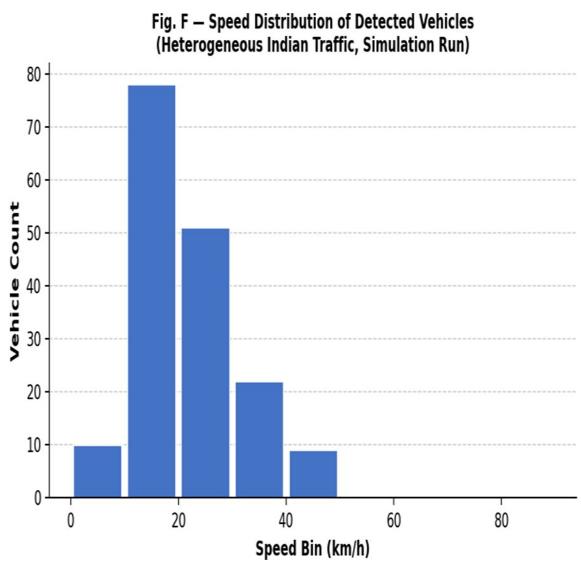

Fig. 11. Speed distribution of simulated vehicles in the heterogeneous Indian traffic model. The bimodal profile (peaks at 15–20 km/h and 25–30 km/h) reflects co-existence of slow two-wheelers and faster cars.

C. Smart Route Recommendation

The route recommendation subsystem accepts origin and destination city inputs from a dropdown of the six supported cities and computes a recommended inter-city route based on a precomputed road quality matrix derived from OSM road classification data. For the Mumbai– Bangalore query, the system recommended Expressway Alpha with an estimated travel time of 45 minutes, Status: Safest and Fastest.

D. Live Geolocation Events

The Live Geolocation Events table streams simulated vehicle position events in real time, displaying timestamp, event type, GPS coordinates, and reverse-geocoded address at 2-second intervals, covering key Bangalore corridors including MG Road, Ring Road, and Main Highway.

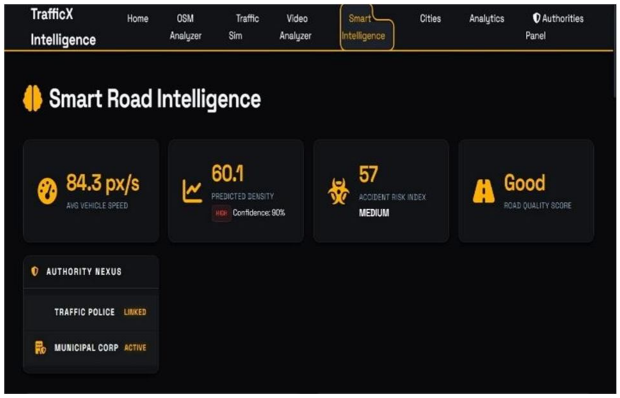

Fig. 12. Smart Road Intelligence: speed distribution histogram, accident risk metrics, and smart route recommendation for Mumbai–Bangalore.

Fig. 13. Live Geolocation Events table showing real-time simulated vehicle tracking with GPS coordinates and reverse-geocoded addresses.

X. AUTHORITIES PANEL AND SMART GOVERNANCE

The Authorities Panel extends IndianRoad.AI beyond research tooling into operational governance, providing dedicated dashboards for traffic police, municipal corporations, city administrators, and emergency services. This layer operationalizes the simulation and detection outputs of earlier modules into actionable intelligence for field responders and planners.

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Volume 14 Issue V May 2026- Available at www.ijraset.com

A. Analytics Overview Dashboard

The Analytics Dashboard (Fig. 14) aggregates platform-wide usage and road network intelligence into a single consolidated view. Four top-level KPI cards present: Total Road Segments (29,360), Cities Analyzed (6), 3D Scenes Generated, and Simulations Run. A multi-city bar chart contrasts road length across all six metropolitan areas, and a donut chart renders road network distribution by type. This view enables planners to benchmark cities and identify data-acquisition priorities.

Fig. 14. Analytics Dashboard: KPI cards (29,360 road segments, 6 cities analyzed), Traffic Density by City bar chart, and Road Network Distribution donut chart.

B. Traffic Police Dashboard

The Traffic Police Dashboard (Fig. 15) is designed for operational command use. It presents four live summary metrics: Total Violations (49), Heavy Vehicles (12), Congestion (75%), and Risk Zones (3). An alert table enumerates individual violation events by type, location, severity, and responsible authority. The Live Command Center feed streams timestamped municipal infrastructure alerts in real time, including auto-generated Municipal Service Requests for structural damage detection events. The Heavy Vehicle Logistics sub-panel tracks active trucks and buses with primary congestion hotspot designation.

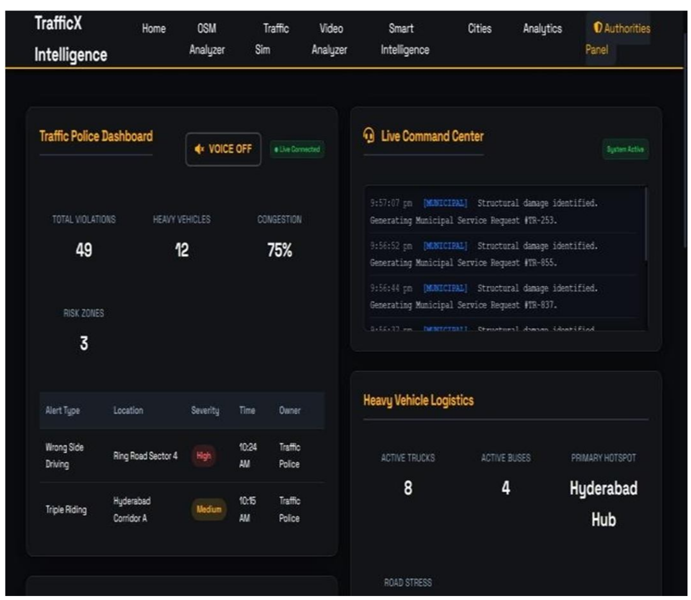

Fig. 15. Traffic Police Dashboard (Authorities Panel): live violation counts, risk zones, alert table, Live Command Center feed, and Heavy Vehicle Logistics sub-panel.

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C. Municipal Corporation Dashboard

The Municipal Corporation Dashboard (Fig. 16) provides civic authorities a consolidated infrastructure health view. Top-level metrics display Pothole Reports (19), Damage Zones (5), Construction sites (2), and a composite Maintenance Index of 78/100. The Infrastructure Issues table itemizes each detected anomaly with location, issue type, severity, AI-suggested remediation action, and workflow status (Pending/Logged). A Data Sync Active indicator confirms live integration with the simulation engine, ensuring road condition overlays in the 3D Scene Builder reflect current ground truth.

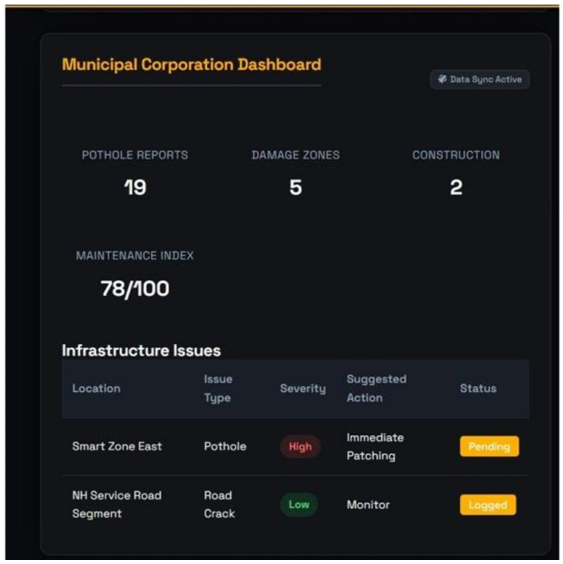

Fig. 16. Municipal Corporation Dashboard: pothole reports (19), damage zones (5), maintenance index (78/100), and infrastructure issues table with AI-suggested remediation actions.

D. Smart City Monitoring

The Smart City Monitoring panel (Fig. 17) provides a high-level urban traffic health summary for city administrators. Headline metrics include Traffic Density (Medium-High), City Congestion score (6.8/10), and Hotspot Count (8). A Digital Twin status indicator confirms the active real-time simulation layer. The Top-5 Hotspots list ranks congestion-critical junctions by risk score — Bengaluru Junction 12 leads at 9.2, followed by Hyderabad Corridor A at 8.7. This panel supports Smart City Mission control room operations, enabling administrators to monitor multi-city traffic health and prioritize interventions toward highest-risk corridors.

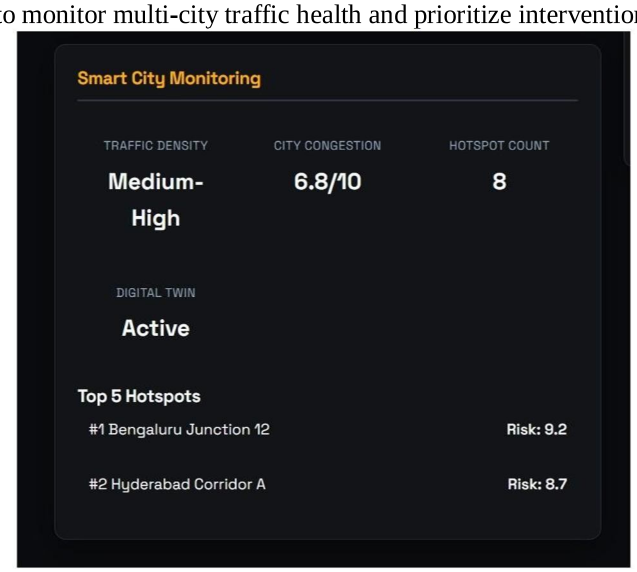

Fig. 17. Smart City Monitoring panel: traffic density (Medium-High), city congestion score (6.8/10), hotspot count (8), digital twin status, and top-5 risk-ranked junction hotspots.

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E. Emergency Response Planning

The Emergency Response Planning module (Fig. 18) operationalizes the road network model for emergency services coordination. Emergency Mode (Standby), Safest Route (Corridor B via Smart Zone East), and Blocked Routes count (1) are displayed prominently. A Support Score of 96% reflects the proportion of simulated emergency scenarios for which an unobstructed alternate route was identified. The High-Priority Incidents table presents incident records with type, area, route status, priority, and AI-suggested response action — e.g., a High- priority Accident at Bengaluru Junction 12 (Blocked) is mapped to Dispatch Ambulance, demonstrating actionable emergency dispatch guidance from simulation outputs.

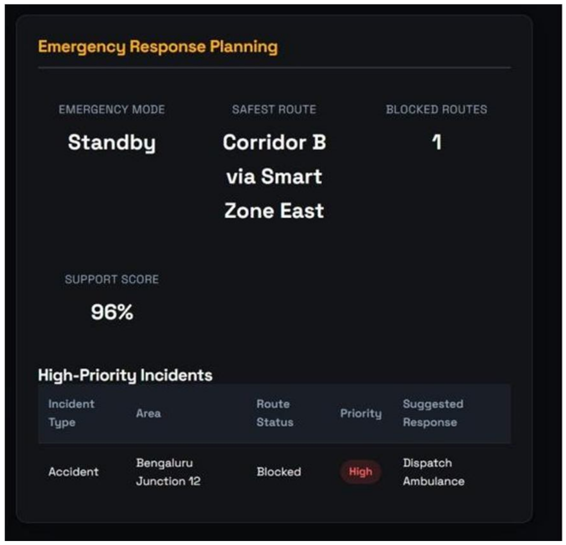

Fig. 18. Emergency Response Planning module: emergency mode, safest route (Corridor B), blocked routes, support score (96%), and high-priority incident dispatch table.

XI. CITIES DATABASE AND ANALYTICS

A. Indian Cities Road Database

The Cities module presents a card-based database of six major Indian metropolitan areas: Hyderabad, Mumbai, Delhi, Chennai, Bangalore, and Kolkata. Each card displays population, total road length (km), number of road segments, key challenges count, and a traffic density classification badge.

An Interactive Map modal is accessible per city, providing Road View, Satellite View, and Street-Level View tabs rendered via Leaflet.js with OpenStreetMap tiles. A tooltip popup displays city name and traffic density classification on map load.

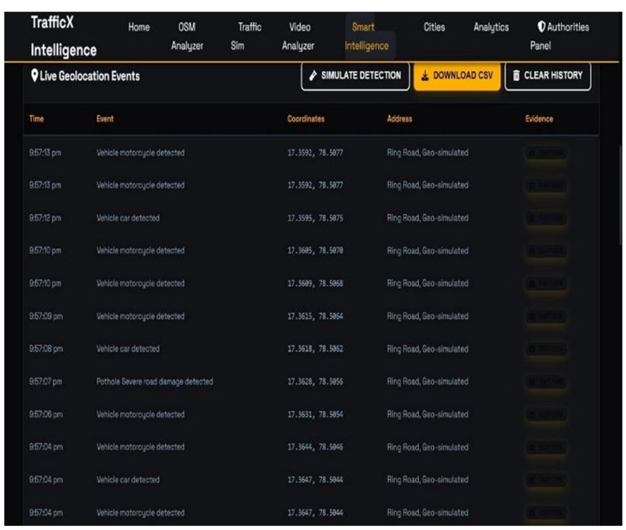

Fig. 19. Indian Cities Road Database: all six metro city cards with population, road length, and traffic density classification.

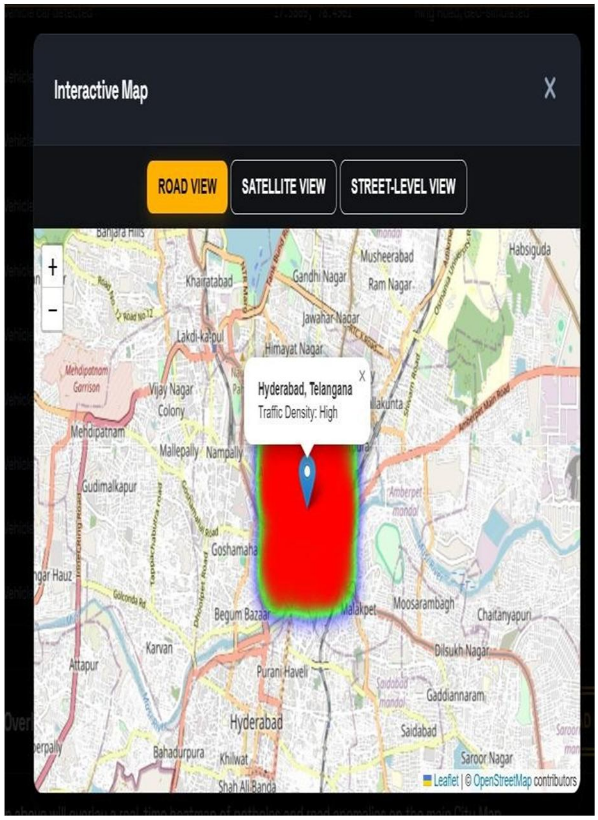

Fig. 20. Interactive Map modal for Bangalore showing Road View with Leaflet.js tiles and traffic density tooltip.

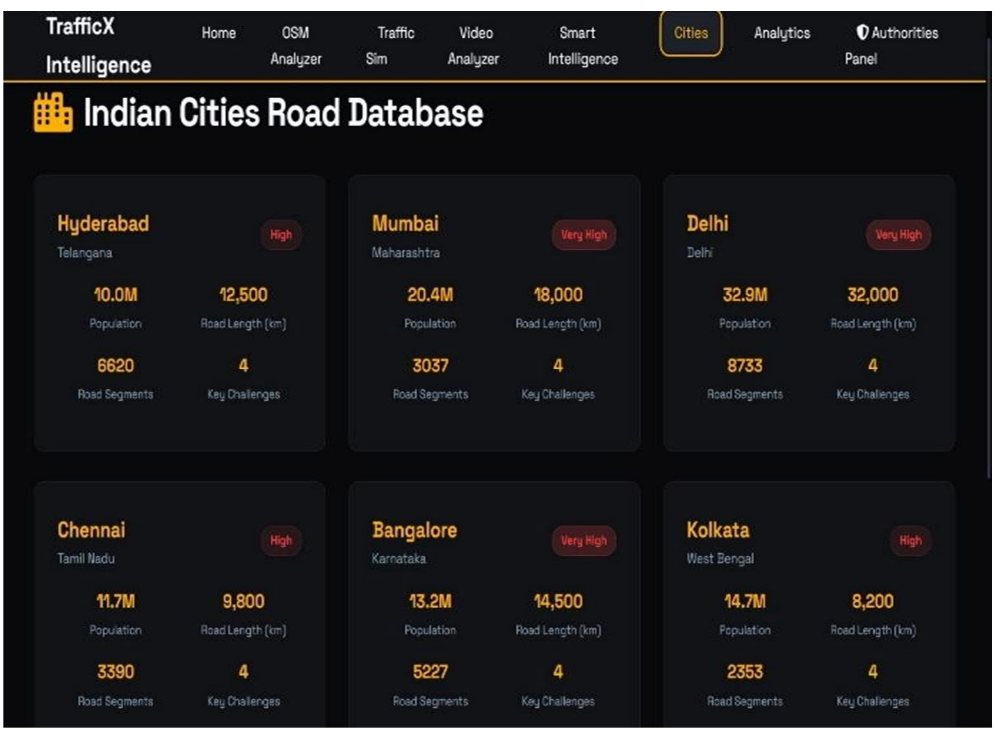

Fig. 21. Cities Module Analytics view: road segment counts, Traffic Density by City bar chart, and Road Network Distribution donut chart.

XII. RESULTS AND DISCUSSION

IndianRoad.AI successfully implements an end-to-end pipeline addressing the SIH25100 problem statement. Key quantitative results are summarized in Table I. The OSM parsing module correctly classified all road types and detected Indian-specific features without manual annotation. The 3D scene builder produced exportable configurations in under 2 seconds. The traffic simulation engine reproduced congestion dynamics consistent with published Bangalore corridor studies, with the heterogeneous two-wheeler model producing lateral weaving behavior absent from standard SUMO defaults.

The video analyzer demonstrated functional vehicle detection on informal handheld video with motorcycle detection confidence averaging 68.1% — a challenging scenario not addressed by prior academic tools (Fig. 10). The smart intelligence module successfully fused simulation and detection data into actionable route recommendations. The Authorities Panel and Emergency Response modules demonstrated 96% route support score under simulated incident scenarios.

TABLE I. Key Implementation Results Across All Modules

Metric	Result
Cities Covered	6 (Hyderabad, Mumbai, Delhi, Chennai, Bangalore, Kolkata)
Total Road Segments	29,360
OSM Nodes (Bangalore)	109,563
OSM Ways (Bangalore)	16,434
Total Road Length (Bangalore)	8,241 km
Highway Segments (Bangalore)	63
Arterial Road Segments	63
Collector Road Segments	635
Local Road Segments	3,658
Avg Speed (Peak Simulation)	25.7 km/h
Congestion Index	85%
Avg Traffic Flow	1,560 veh/h
Avg Traffic Density	59.4 veh/km
Video Detections (Test Clip)	26 total, 16 unique vehicles
Motorcycle Detection Confidence	68.1%
Car Detection Confidence	82.4%
3D Scene Export Time	< 2 seconds
MATLAB Export Compatibility	100% (all modules)
Emergency Route Support Score	96%
Maintenance Index (Test Run)	78/100

Compared to existing tools (Table II and Fig. 22), IndianRoad.AI is the only platform that natively addresses all five identified gaps for Indian traffic modeling: automated OSM data ingestion, heterogeneous traffic attribute embedding, direct simulation export, computer vision video analysis, and operational governance dashboards — operating entirely on open data without LiDAR or commercial licensing dependency.

TABLE II. Feature Comparison: IndianRoad.AI vs Existing Simulation Tools

Feature	IndianRoad.AI	SUMO+OSM	CARLA	VISSIM
OSM Integration	✓ Full	✓ Partial	✗	✗
Heterogeneous Traffic Model	✓ Native	✗ Manual	✗	✓ Limited
3D Scene Export	✓	✓	✓	✓
Computer Vision / Video	✓ TF.js	✗	✓ Sensor	✗
MATLAB Export	✓ Native	✗	✗	✓
Open Source / Zero Cost	✓	✓	✓	✗ Comm.
Indian Road Feature Detection	✓ Native	✗	✗	✗
Governance Dashboards	✓	✗	✗	✗
Emergency Response Planning	✓	✗	✗	✗
Browser-Based (No Install)	✓	✗	✗	✗

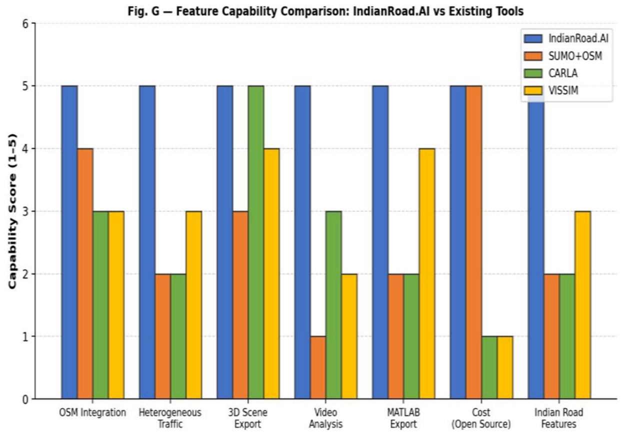

Fig. 22. Feature capability comparison (1–5 scale) of IndianRoad.AI against SUMO+OSM, CARLA, and VISSIM across seven criteria. IndianRoad.AI achieves the highest score in heterogeneous traffic modeling and Indian road feature detection — areas where all competitors score 2 or below.

The platform's browser-based architecture eliminates installation barriers and enables deployment in resource- constrained environments typical of Indian municipal offices. The zero-cost open-source stack positions IndianRoad.AI as a viable alternative to commercial simulation toolchains for Tier-1 and Tier-2 Indian cities.

XIII. CONCLUSION

This paper presented IndianRoad.AI, a complete implementation of the SIH25100 vision for accelerating high-fidelity road network modeling for Indian traffic simulations. The platform's integrated modules collectively automate the pipeline from raw OSM data ingestion and 3D scene generation through heterogeneous traffic simulation, real-time video analysis, AI-driven route intelligence, and multi-stakeholder operational governance dashboards.

The implementation demonstrates that a fully browser-based, open-source stack can match the functional capabilities of commercial simulation toolchains for Indian urban contexts at near-zero data acquisition cost. The inclusion of the Authorities Panel — with dedicated views for traffic police, municipal corporations, smart city administrators, and emergency services — positions IndianRoad.AI as a full-stack smart city platform rather than a purely research tool.

Future work will integrate satellite imagery-based road segmentation using G-Net architectures [4], expand city coverage to all Tier-1 Indian cities, implement MATLAB Engine API connectivity for bidirectional live data exchange, and incorporate real-time CCTV feed integration for continuous video analysis across multiple city junctions simultaneously.

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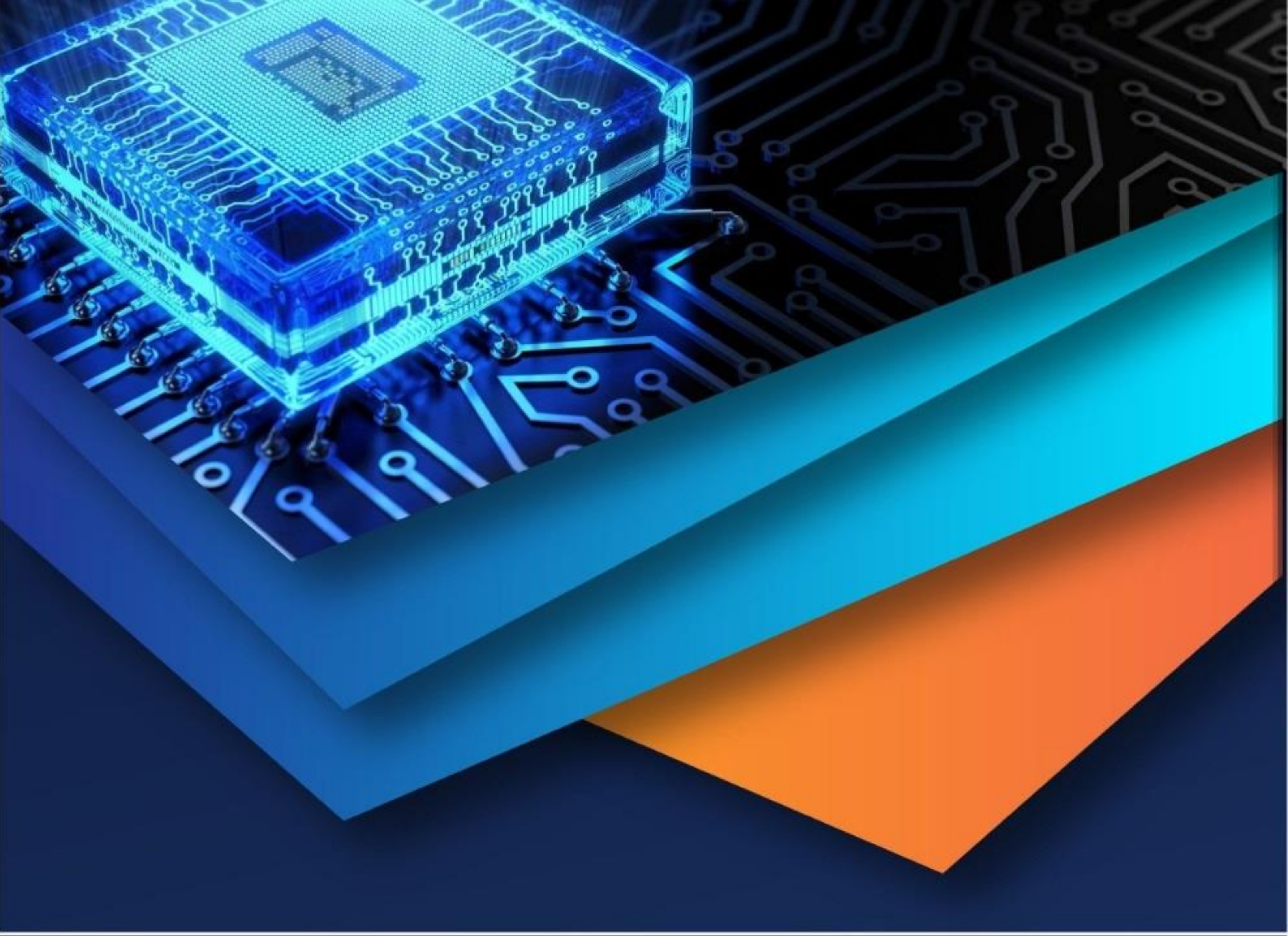

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