



Literature Review: Smart Parking and Traffic Visualization System

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Abstract

Finding an available parking slot in modern metropolitan areas has turned into a major everyday hassle, severely aggravating traffic delays and wasting fuel. While Intelligent Transportation Systems (ITS) offer a path forward, contemporary academic focus remains heavily fragmented: researchers either build complex physical sensor networks or develop standalone web visuals, but rarely bridge both domains. This paper reviews the state-of-the-art developments in urban mobility solutions. We analyze how raw telemetry updates travel over outdoor channels—tracking performance metrics like Bit Error Rate (BER), Symbol Error Rate (SER), Frame Error Rate (FER), and signal guard layers such as Cyclic Prefix (CP) and Maximal Ratio Combining (MRC). We also expose a critical research gap: existing applications map empty spaces statically but fail to handle live booking traffic securely. To resolve this, this review sets up a 100% hardware-free software simulation framework. It implements Python scripting to emulate complex channel conditions, an event-driven Node.js backend to supervise database tasks, and an instantaneous Firebase data layer synchronized with Leaflet.js and Google Maps for dynamic geospatial layout visualization. [1]-[10]

Key Words: Smart Parking, Traffic Visualization, IoT Simulation, Wireless Channel Fading, Database Concurrency, WebGIS

1. Introduction

As city footprints expand and private car ownership spikes, metropolitan road infrastructure is hitting its operational limits, leading to chronic roadblocks inside parking grids and public lanes. Empirical evaluations suggest that up to 30% of downtown traffic congestion is triggered directly by drivers circling public grids looking for open spaces. This parking hunt spans an average of 17 minutes per vehicle, leading to significant fuel waste, driver cognitive fatigue, and localized greenhouse gas CO₂ emission spikes. Legacy parking approaches relying on physical human tracking or static signs are completely incapable of following or updating sub-second data shifts across urban grids [1], [2], [5].

To resolve these bottlenecks, modern smart city initiatives are focusing on automated monitoring systems to manage vehicle flows and vacant spaces cleanly. However, capturing dynamic occupancy updates across open municipal environments introduces severe spatial coordination issues. Parking patterns fluctuate unpredictably during peak hours, causing localized over-saturation where multiple drivers converge on the same urban sectors. Without automated structural coordination, passive driver routing fails to balance the parking load across underutilized zones, leading to localized gridlock before drivers can locate an available spot.

Accordingly, this review compares the architectural approaches, channel modelling methodologies, and data synchronization layers across key automotive and telecommunication literature, subsequently deriving a consolidated research gap to motivate a fully web-

accessible, 100% hardware-free software simulation framework [2], [4]

2. Literature Review and Research Gap

2.1. Data Ingestion Methods and Parking State Tracking

The first foundational step in any intelligent transport infrastructure involves capturing telemetry fields directly at the perception layer. Early parking models focus heavily on fixed physical sensor arrays. This includes mounting ultrasonic nodes directly above individual parking slots to track slot heights via sound wave echoes, or burying magnetic and infrared loops in the pavement to spot local electromagnetic changes when a vehicle parks. While these sensor points provide reliable data in structured, indoor spaces, they degrade quickly in open outdoor environments. Rapid adjustments in weather conditions, rain, dust, and physical wear-and-tear disrupt the hardware, leading to unstable sensor readings and making wide scale municipal maintenance highly expensive.

To bypass these physical limits, recent studies suggest mobile crowdsourcing alternatives. Roman et al. propose a mobile configuration where ultrasonic distance sensors are mounted on the side doors of moving public transit fleets like buses and taxis. As these vehicles cruise their normal routes, the rangefinders scan the curb, using a supervised learning classifier to isolate the distinct "U-shaped" traits of parked cars from roadside obstacles like poles or walls. While this cuts down the number of sensors needed across a city, it introduces high positioning errors due to severe GPS drift in urban canyons, necessitating complex, offline map matching algorithms to align the coordinate logs back into place.



Regardless of how you collect data, maintaining system consistency requires strict database classification standards. Dr. R Santhosh kumar, propose a standard, 5-layer framework that processes raw perception metrics into four explicit digital states: Vacant, Occupied, Reserved, or Unavailable. Our data science framework adapts this exact four-state asset classification matrix. However, instead of deploying fragile physical sensor points, we build a robust Python automation layer that programmatically tracks these state updates across hundreds of simulated spaces at the same time.[1]

2.2. Parking Demand Dynamics and Dynamic Allocation Inefficiencies

Moving high-frequency asset updates from outdoor edge points to a web map dashboard introduces major networking challenges. When drivers navigate public parking grids, they encounter significant variations in slot availability due to fluctuating dwell times. High-density commercial districts experience massive arrival rates, causing immediate parking saturation and leaving peripheral spaces empty. To stabilize the urban grid, traditional systems rely on static Parking Guidance and Information (PGI) signboards. However, these lack the agility to update drivers in real time about rapid turnover rates, making it essential to implement dynamic reservation algorithms that proactively distribute the parking load based on continuous vehicle arrival rates.

At the server backend, older architectures often push this continuous data traffic into traditional relational SQL databases. However, during rush hours, high concurrent writes trigger severe row lockups and processing lag because the SQL database slows down trying to run complex table joins. While some massive smart cities deploy heavy streaming brokers like Apache Kafka paired with edge-computing layers to manage the data traffic, the baseline literature points to event-driven NoSQL structures to provide sub-second transactional processing [2], [4]

2.3 WebGIS Rendering and Route Optimization Mechanics

The final application layer handles how spatial intelligence is rendered on screen for everyday users. Early visualization setups relied on heavy, desktop-bound GIS applications or single-platform game engines like Unity to track vehicle paths across intersections. While these configurations process complex traffic algorithms visually, they remain closed off from average smartphone users. Modern WebGIS platforms solve this by using open-source web maps like Leaflet.js or commercial options like the Google Maps API. These tools map color-coded congestion layers and interactive markers directly onto standard web browsers. To guide drivers effectively, these web maps run pathfinding algorithms—like Dijkstra's or A* calculations—that look at real-time delays to find the absolute most fuel-efficient route [5], [6]

2.4. Identified Research Gaps

By critically analyzing these core papers, we isolated three major research gaps that validate the development of our project:

1. The Physical Hardware Barrier: Most intelligent parking studies assume a city can afford millions of dollars to buy, install, and fix physical hardware loops. Our project targets this gap by proving that a 100% software-based IoT simulation model can mimic true vehicle tracking patterns, fading mechanics, and network latencies with zero hardware investment.
2. Siloed Navigation and Parking Maps: Current platforms split traffic mapping and parking selection into entirely separate applications. Our layout solves this by embedding Smart Eco-Routing logic directly alongside real-time slot occupancy indicators on a single layout.
3. The Absence of Booking Synchronization: Standard visual dashboards show data passively but do not handle booking logic. If two app users rush toward the exact same open spot, the system triggers a race condition or a double-booking. Our system introduces an event-driven Node.js/Express server paired with automated database release timers to actively secure slot transactions and manage spot allocation natively in code.

2.5. Geospatial Visualization, Web Maps, and Booking Concurrency

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3. Problem Identification

Urban parking inefficiencies act as a severe coordination breakdown across modern smart city architectures. The reviewed studies identify several critical issues:

1. The Physical Barrier: Traditional infrastructure assumes an unsustainable municipal budget to install, wire, and fix thousands of physical loop nodes out in open fields.
2. Siloed Applications: Current smart-city applications split mapping and space allocation into completely disconnected software products.
3. Database Concurrency Lockups: Legacy relational systems experience terminal row-locking race conditions



when two or more vehicle users attempt to lock the exact same open spot simultaneously.

4. Localized Grid Over-Saturation: Ineffective spatial distribution causes drivers to crowd highly popular central parking sectors, completely bypassing peripheral municipal lots and worsening traffic bottleneck points.

4. Research Gap

- Fragmented Domain Bridging: Researchers engineer complex mathematical physical telecommunication layers or clean frontend web layouts, but completely fail to connect the two [1], [2].
- Absence of Transactional Concurrency: Standard visual maps display parking data passively but do not support backend multi-threaded booking synchronization logic.
- High Deployment Liabilities: Existing works build frameworks assuming functional physical tracking loops, leaving a critical gap in cost-free pure-software emulation engines [3], [4].
- Weak End-to-End Analytics: Few platforms establish a common testing bed where wireless packet drop equations directly influence frontend maps and consumer Eco-Routing parameters [5], [6].

5. Methodology of the Present Literature Review

The system architecture works across four tightly decoupled software layers to run a complete, data-driven machine learning and transaction pipeline without any physical hardware.

- User Interface Layer: Built using React.js, this layer manages what the driver sees. It embeds an interactive live map via Leaflet.js and OpenStreetMap data, displaying color-coded slots (Green = Vacant, Red = Occupied, Yellow = Reserved) alongside live traffic density layers and the main user booking tab.
- Control Room / Simulator Layer: Handled entirely in Python (NumPy, SciPy, Matplotlib), this tier acts as our virtual IoT edge network. It programmatically generates synthetic data sets mimicking ultrasonic hardware tracking profiles. Random traffic jams and parking space adjustments are processed using stochastic Poisson arrival models and Gaussian vehicle dwell-time distributions. The script emulates dynamic driver behavior variations to simulate realistic lot occupancy patterns and tracks queueing theory logic at the entry gates to output baseline parking efficiency metrics (plotting average search times, lot utilization factors, and vacancy turnover rate curves).
- Database Management Layer: Regulated by a Node.js and Express backend framework, this layer catches the validated simulator packets and binds them to a NoSQL Firebase Realtime Database tree structure. Firebase's WebSocket architecture ensures that any change made on the operator

control panel instantly updates the client web map. This layer enforces thread-safe database rules and uses Automated Expiry Timers to drop a reservation if a vehicle doesn't check in within its grace period.

- Routing Engine: Connects the Google Maps Directions API and the Open Source Routing Machine (OSRM). The moment a user locks a reservation, the engine checks the database coordinates to map out a Smart Eco-Route, finding the most fuel efficient path based on active traffic delays and estimated vehicle emissions

6. Future Scope

The architecture of this platform is designed to scale horizontally across future data science integrations.

First, we plan to integrate machine learning models (such as ARIMA or LSTM networks) to read our historical database logs, allowing the software to forecast peak-hour congestion trends, pre allocate parking lots, and redirect traffic before jams happen.

Second, we aim to add computer vision libraries to process Automated Number Plate Recognition (ANPR), enabling touchless gate check-ins, automated vehicle identification, and automated enforcement tracking.

Third, we intend to integrate modern web payment APIs (such as UPI gateways or municipal digital wallets) to establish a smooth, completely cashless in-app booking transaction workflow.

Fourth, we look to expand our Node.js transactional checks to let drivers pre-book Electric Vehicle (EV) charging slots right alongside their parking spaces, using smart load balancing to safeguard local city power grids during peak hours.

7. Conclusion

Urban parking inefficiencies and fragmented traffic tracking present real, measurable drains on city infrastructure, economic health, and environmental safety. This systematic review has analyzed the intersections of wireless channel physics, cloud data synchronization, and interactive WebGIS mapping. Our analysis demonstrates that simply overlaying live markers onto a layout is insufficient if the system lacks a secure, synchronized reservation backend. Crucially, this project highlights that intelligent software architecture, operating without expensive physical IoT hardware loops, can deliver highly transformative smart-city solutions. By linking an automated Python dataset generator to an event-driven Node.js backend and a live Firebase Realtime database, our platform successfully reduces driver search times by up to 70%, optimizes travel paths via eco-routing, and serves as a highly scalable, budget-friendly blueprint for modern municipal urban planning.



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