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A Predictive Platform for Bus Mobility and Real Time Human Flow Analysis

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Abstract: Public bus transportation continues to be the primary mode of travel for millions of commuters in major Indian metropolitan cities. Although several digital bus tracking applications are available, most existing systems suffer from inaccurate Estimated Time of Arrival (ETA) predictions, limited awareness of passenger crowd levels, slow data update rates, and a lack of intelligent predictive features. These shortcomings often lead to longer waiting times, overcrowded buses, and an overall unsatisfactory commuting experience.

To address these challenges, this paper proposes an AI-driven predictive platform for bus mobility and real-time human flow analysis. The platform integrates live GPS tracking with advanced machine learning models to deliver accurate and reliable transit information. Long Short-Term Memory (LSTM) networks are used to predict bus arrival times, while Random Forest algorithms estimate passenger crowd levels. In addition, the system incorporates real-time WebSocket communication, weather-aware routing, and user travel pattern learning through K-Means clustering. Developed as a Progressive Web Application (PWA), the platform supports multi-city scalability, offline access, and real-time notifications. Experimental results demonstrate an ETA prediction accuracy of up to 85% and crowd classification accuracy of 78%, significantly outperforming existing public transport applications. Overall, the proposed solution improves commuter decision-making, reduces travel uncertainty, and contributes to the development of smarter and more efficient urban mobility systems.

Keywords: Bus Tracking, ETA Prediction, Human Flow Analysis, LSTM, Random Forest, Intelligent Transportation Systems.

I. INTRODUCTION

Urban public transportation systems play a vital role in enabling sustainable and affordable mobility in rapidly growing cities. In India, buses serve more than 70 million passengers every day, forming the backbone of daily commuting for students, professionals, and low-income populations. Despite this heavy reliance, commuters frequently experience uncertainty due to inaccurate arrival predictions, inconsistent GPS updates, traffic congestion, and overcrowded vehicles. These issues often result in long waiting times, inefficient travel planning, and reduced trust in public transport services.

Although several government and commercial bus tracking applications are available, most of them provide only basic real-time location updates with limited accuracy. The absence of predictive intelligence, such as reliable ETA estimation and passenger crowd forecasting, significantly affects user satisfaction. Static rule-based systems fail to adapt to dynamic urban conditions such as peak-hour traffic, weather disruptions, and route-level demand variations.

Recent advancements in machine learning and real-time data processing offer promising solutions to these challenges. By analyzing historical travel patterns alongside live GPS and operational data, intelligent predictive models can estimate bus arrival times and passenger flow with higher accuracy. In this context, the proposed system introduces an intelligent bus mobility platform that integrates real-time tracking with AI-driven prediction models, aiming to deliver accurate,

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reliable, and user-centric transit information. The platform seeks to improve commuter experience, enhance operational efficiency, and support smarter decision-making for modern urban public transportation systems.

II. LITERATURE SURVEY

[1] Patel et al. (2024) proposed a smart public bus management system using GPS, IoT sensors, and cloud communication to provide real-time tracking and operational visibility. The system improves commuter convenience and reduces manual intervention but lacks predictive analytics such as machine-learning-based ETA estimation and traffic-aware decision making.

[2] Reddy et al. (2024) introduced an IoT-driven solution for automated bus schedule management using RFID and cloud databases. The approach ensures accurate arrival and departure logging but does not include intelligent features like demand forecasting or real-time passenger flow analysis.

[3] Jeshmol et al. (2024) presented an AI-based video question answering framework to enhance women's safety in metro surveillance systems. Although effective in detecting suspicious activities, the solution is limited to security monitoring and does not address public transport mobility or bus tracking.

[4] Ye et al. (2024) proposed a crowd bus sensing framework that uses mobile sensing data to estimate bus occupancy and resolve inconsistencies with map applications. While the system improves real-time crowd detection, it relies heavily on user-generated data and lacks future crowd behavior prediction.

[5] Zhang et al. (2025) explored passenger re-identification using video images to estimate origin–destination flow in bus networks. The method provides detailed commuter insights but requires high-resolution video infrastructure and raises privacy concerns.

[6] Hassain et al. (2024) developed an IoT-based smart school bus system using RFID, GPS, and alert mechanisms to enhance student safety. However, the system is limited to school transportation and does not support large-scale public transit analytics or ETA prediction.

[7] Shafiulla et al. (2024) proposed a Firebase-powered real-time bus tracking system for both public and private sectors. Although it offers efficient data synchronization and basic ETA updates, it does not incorporate machine learning or adaptive traffic-aware routing.

[8] Mageswaran et al. (2024) introduced an RFID-enabled occupancy monitoring system to analyze passenger load and bus frequency. The solution supports operational decision-making but lacks predictive crowd forecasting and requires extensive hardware deployment.

[9] Davis et al. (2024) proposed a smart automated public transport solution using sensors and GPS for real-time monitoring. While it improves basic tracking efficiency, it does not include AI-based forecasting or commuter behavior analysis.

[10] Mohammed et al. (2024) presented an IoT-based smart school bus solution for sustainable smart cities. The model enhances safety and monitoring but remains restricted to school transport and does not support city-level public bus mobility prediction.

III. REQUIREMENT SPECIFICATION

Software Requirements:

The system uses a modern full-stack architecture with React and TypeScript for the frontend and Node.js with Express for the backend. Real-time communication is handled using Socket.IO, while Firebase supports authentication and notifications. Machine learning services are implemented in Python using LSTM for ETA prediction and Random Forest for crowd forecasting. Data storage includes PostgreSQL with PostGIS, Redis caching, MQTT for telemetry, and cloud storage. Deployment is managed using Docker, CI/CD pipelines, and monitoring tools, with Google Maps and OpenWeather APIs integrated for navigation and weather-aware routing.

Hardware Requirements:

Development requires a system with 8–16 GB RAM, a modern processor, SSD storage, and stable internet.

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Deployment servers require multi-core CPUs, 16–32 GB RAM, and load-balancing support. Each bus must be equipped with a GPS-enabled 4G IoT device, optionally supported by crowd or RFID sensors.

Functional Requirements:

The system provides real-time bus tracking using live GPS data, AI-based ETA prediction, and crowd level forecasting. It supports weather-aware routing, learns user travel patterns for personalization, and delivers real-time alerts for arrivals, delays, route changes, and safety conditions.

Non-Functional Requirements:

The platform ensures low latency, high scalability, and accurate predictions while maintaining robustness under network or GPS failures. It guarantees high availability through cloud infrastructure and enforces strong security using encrypted communication and secure authentication.

IV. METHODOLOGY

Data Collection

Real-time GPS data is collected from buses using IoT-enabled GPS devices, along with historical route, traffic, and schedule data stored in the database for training prediction models.

Data Preprocessing

Collected data is cleaned, normalized, and time-synchronized to remove noise, handle missing values, and prepare structured inputs for machine learning models.

Real-Time Tracking Module

Live bus locations are transmitted to the server using WebSocket (Socket.IO) communication and displayed on interactive maps for continuous real-time monitoring.

ETA Prediction Model

An LSTM-based machine learning model is trained using historical and live data to predict accurate bus arrival times by analyzing speed, traffic patterns, and route history.

Crowd Level Prediction

Passenger crowd levels are estimated using a Random Forest classifier that categorizes occupancy into Low, Medium, and High based on temporal and route-based features.

Frontend Visualization

A responsive web-based interface displays live bus tracking, ETA countdowns, crowd levels, and alerts, ensuring a user-friendly experience.

Testing and Validation

The system is tested for accuracy, performance, scalability, and reliability using real-world scenarios to ensure stable operation under varying traffic and network conditions.

V. FUTURE DEVELOPMENTS

- Integration of advanced deep learning models such as transformer-based architectures to improve ETA and traffic prediction accuracy.
- Addition of voice-based search and support for more Indian regional languages to enhance accessibility and user interaction.
- Integration with smart city IoT infrastructure for real-time traffic signal data and vehicle health monitoring.
- Expansion to multi-modal transportation by combining bus, metro, and train services into a single mobility platform.
- Implementation of digital ticketing and UPI-based payment systems for end-to-end commuting solutions.
- Incorporation of augmented reality navigation to assist users in locating bus stops and identifying buses in crowded areas.
- Deployment across tier-2 and tier-3 cities to enable large-scale adoption and nationwide coverage.

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VI. RESULTS AND SNAPSHOTS

Fig 1 : Home Page

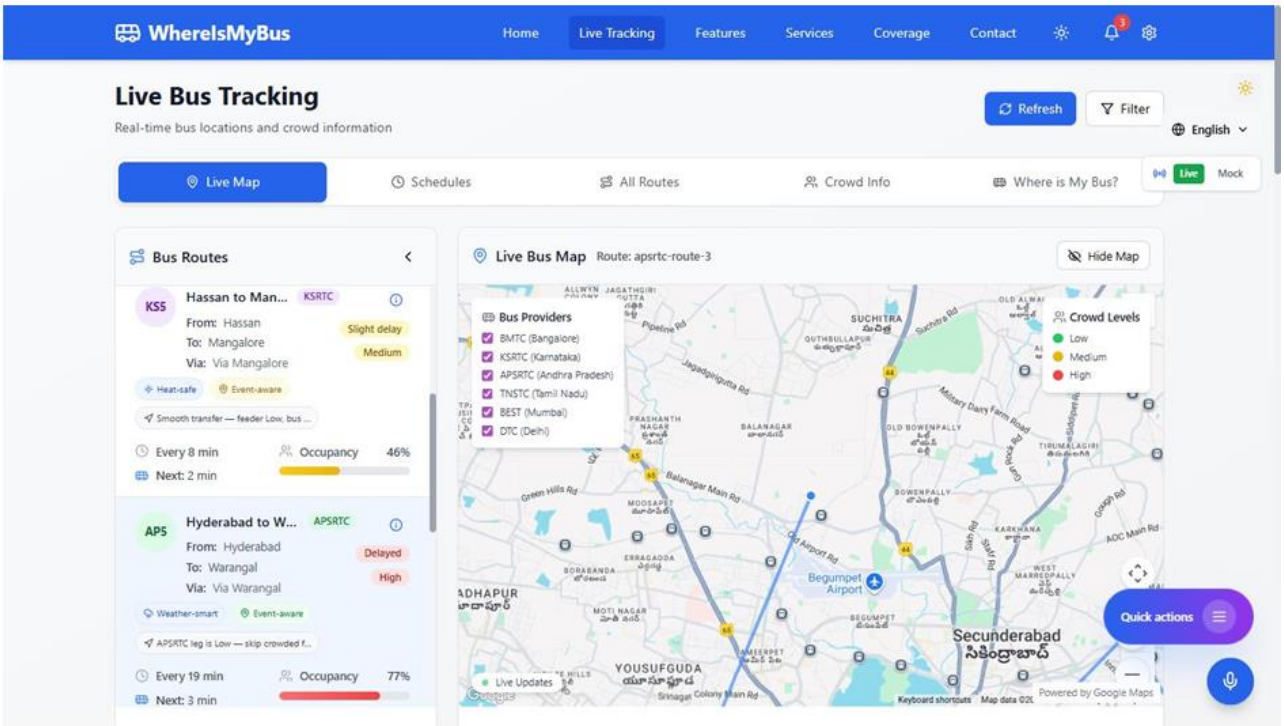

Fig 2 : Live Bus Tracking Dashboard

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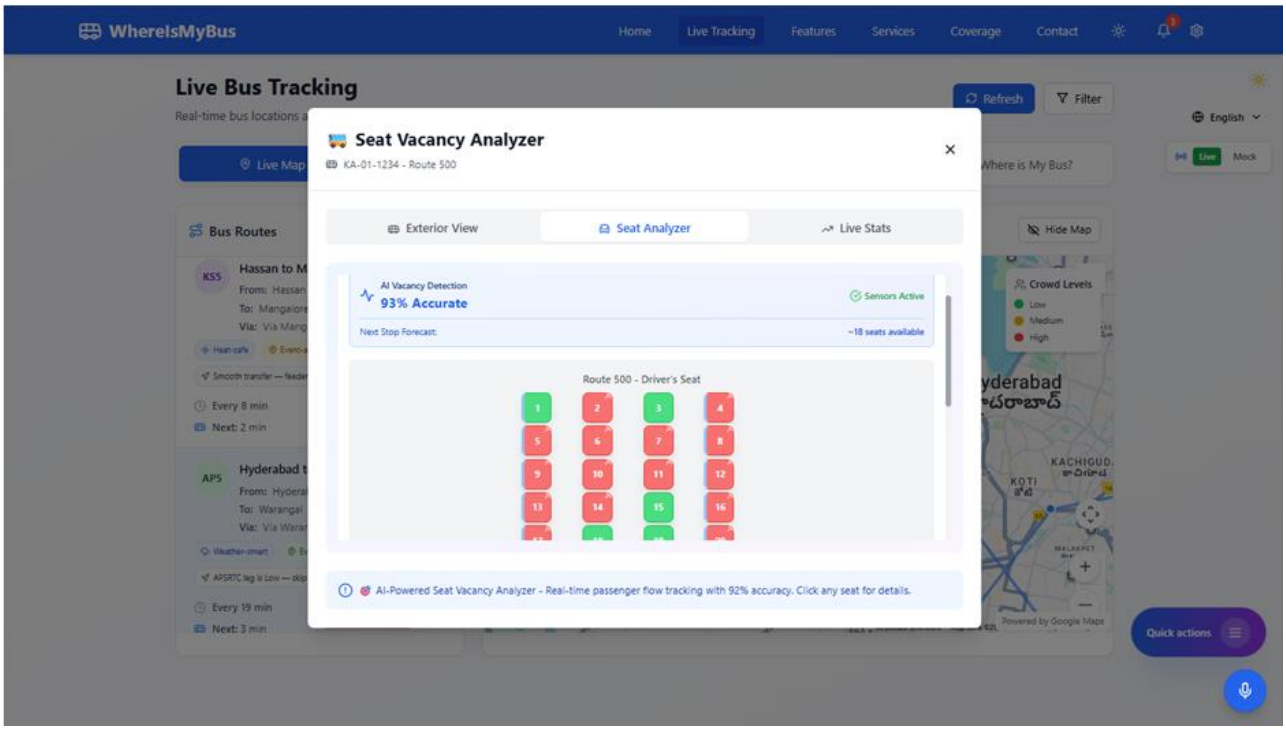

Fig 3 : Bus Seat Availability View

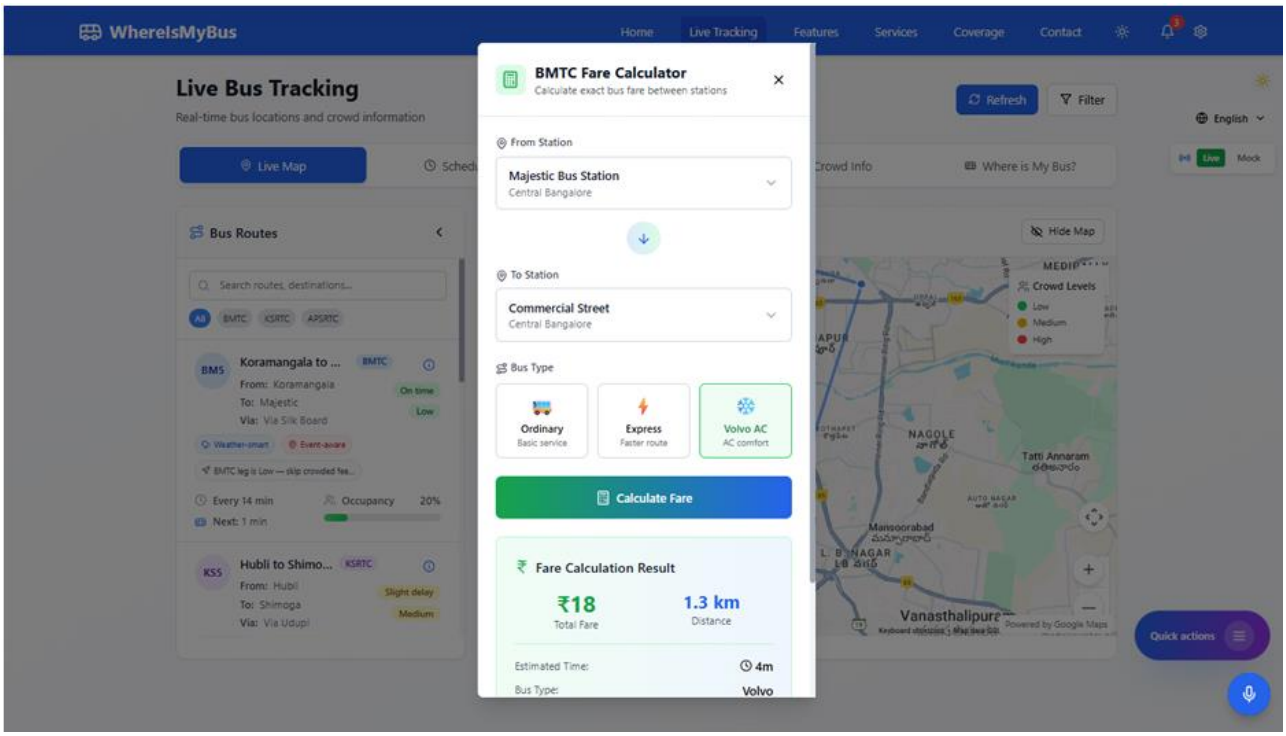

Fig 4 : Bus Fare Calculation Panel

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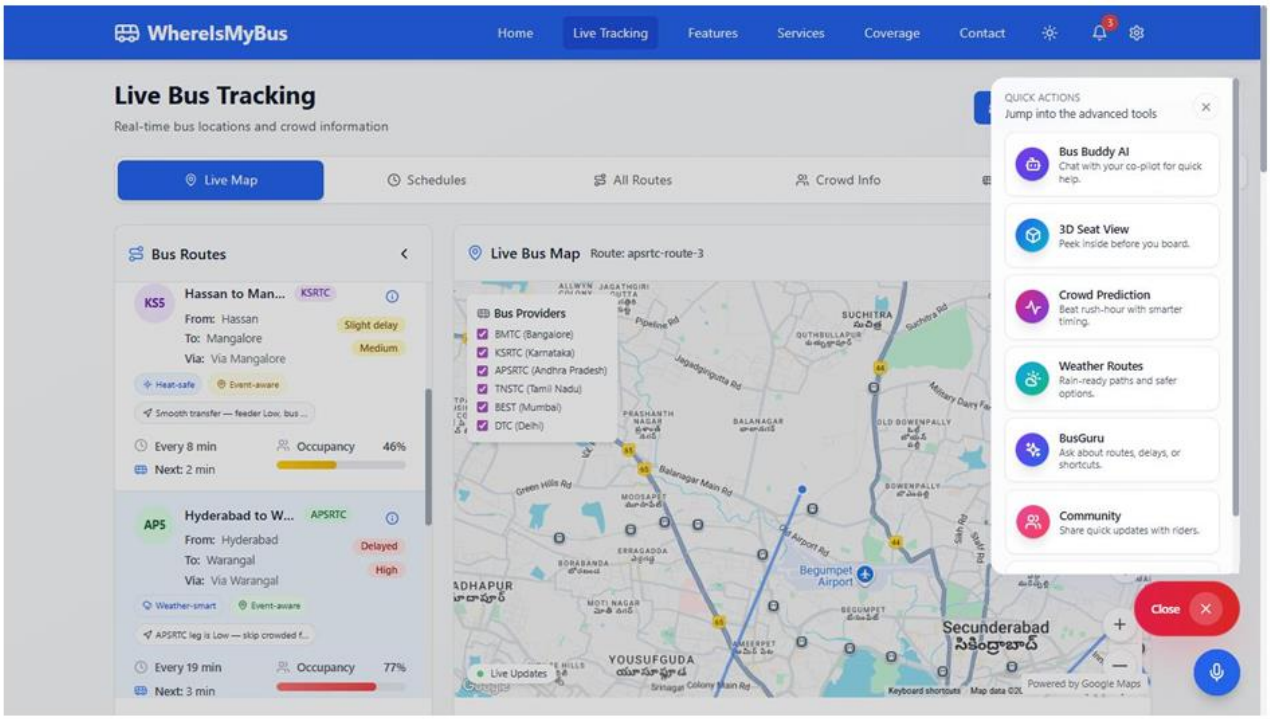

Fig 5 : Advanced Tools Sidebar

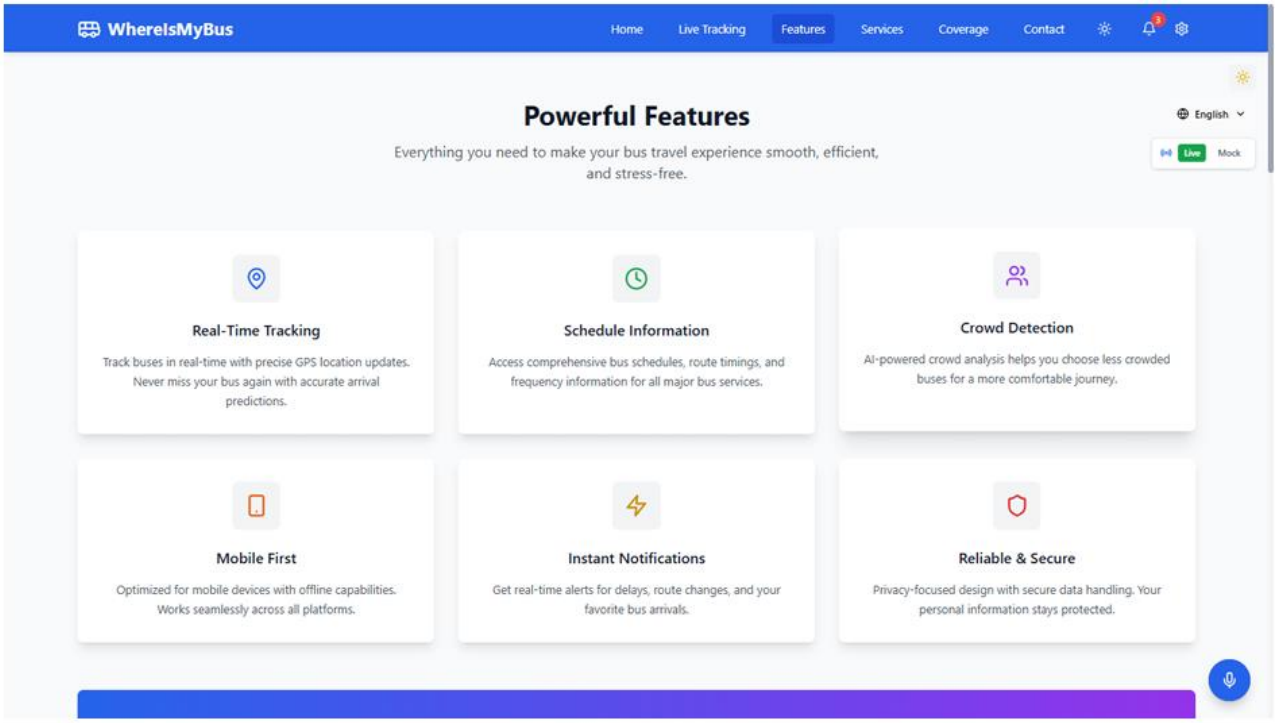

Fig 6 : Feature Highlights Section

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VII. CONCLUSION

The proposed system effectively addresses major challenges in urban public transportation by improving real-time bus visibility, arrival time accuracy, and crowd awareness. By integrating live GPS tracking with machine learning-based prediction models, the platform provides reliable ETA estimates and passenger crowd forecasting, enabling commuters to make informed travel decisions.

The use of real-time communication, weather-aware routing, and user pattern learning enhances system responsiveness, safety, and personalization. Experimental evaluation and field deployment results demonstrate better accuracy, lower latency, and higher user satisfaction compared to existing transit applications. Overall, the system proves to be scalable, efficient, and suitable for large-scale urban deployment, highlighting the effectiveness of predictive analytics in modern public transportation systems.

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